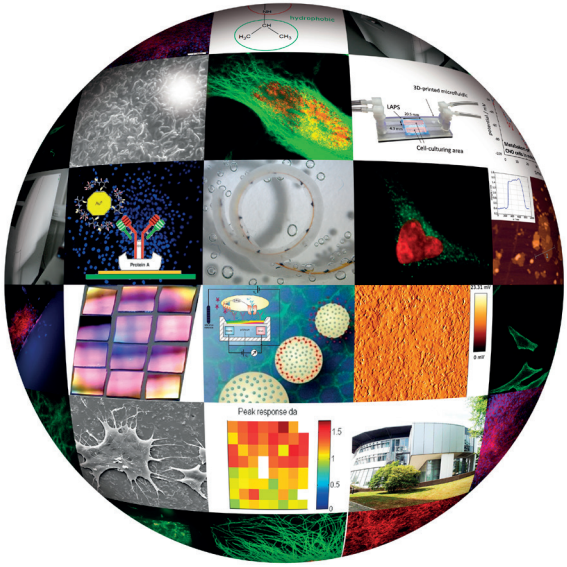
EnFI 2015

Engineering of Functional Interfaces



July 6 & 7, 2015

Hannover Medical School

enfi-2015.eu

HNO Förderverein

MHH Medizinische Hochschule Hannover

GMM VDE/VDI-GESELLSCHAFT MIKROELEKTRONIK, MIKROSYSTEM- UND FEINWERKTECHNIK

For more informationen scan this QR-Code with your smartphone:

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Participants 120

Modern medicine, engineering and information technology have one fact in common: They all rely on materials interfaces that provide additional functionalities. This holds not only for ceramic hip joints but equally well for biochemical sensors in bioreactors or nanoelectronic processors - just to name a few examples. However, each scientific discipline has its own sight on these interfaces, emphasizes one property more than others and, not at last, its own scientific language and theoretical models. For young scientists who are working in these interdisciplinary, overlapping fields such as active prostheses, biochemical sensors or brain-computer interfaces this "Babylonic language confusion" is an extra burden to overcome.

The EnFI conference series has exactly this point in mind. EnFI serves with an exchange of perspectives where young researchers present their work in short oral presentations in the elds of sensors, medical implants, biocatalysis as well as technology and surface analytics. This way, they become familiar with a broad range of concepts, experimental methodologies and theoretical models. Ample time is reserved for the discussions at the posters markets, which will be stimulated by a competition for prestigious awards. As a framework for this, also carefully selected and internationally renowned speakers will deliver keynote lectures as solid introductions to their fields.

Prof. Dr. rer. Nat. Joachim Knoch from the Institue Rheinisch-Westfälische Technische Hochschule Aachen will introduce Nanoelectronics

Prof. Dr. Ing. Antja Spieß also from the Institue Rheinisch-Westfälische Technische Hochschule Aachen will talk about Enzymes and Catalysis on Interfaces

Dr. Davide Ricci from the Istituto Italiano di Tecnologia will present Brain Computer Interfaces – Potential and Challenges

Prof. Dr. med. Michael Tiemann from the University of Paderborn will give an overview about Nanoporous Materials and their Applications

Dr. Martin Dienwiebel from the Karlsruher Institut für Technologie will give us some information of Nanotribology for Engineering

The Hannover Medical School, in cooperation with Leibniz University and the Veterinary School are proud to host EnFI in 2015, which is now running already in its 8th consecutive year.

The organizers invite you for this interdisciplinary exchange of ideas amongst PhD students and post-doctoral researchers aside of the established conferences. Furthermore, EnFI is a workshop of excellence, as routinely more than 35% of the contributions result directly in peer-reviewed journal publications. Moreover, the conference series has always rewarding elements which make EnFI a memorable event for all participants. Hannover will continue this tradition with both an excellent selection of contributions and tutorials as well as a lively city to experience with its historic sites, leisure places and exciting social events.

Prof. Dr. Theodor Doll

Prof. Prof. h. c. Dr. med. Thomas Lenarz

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Venue:

Hannover Medical School
Carl-Neuberg-Str. 1, 30625 Hannover
Lecture Hall R - Building J6

Discover Hannover

Welcome to one of the most important international trade fair locations in the world and a modern pulsating city with lots to discover! A modern state capital with groundbreaking architecture and a model infrastructure, surrounded by idyllic little towns and villages – this is the Hannover location with all its delightful contrasts.

Hannover's strengths as a business location are its innovative companies, ist international flagship fairs and its economic stability. The academic world, business and government pool their resources to put pep into the economy of the city that was home to the all-round genius Leibniz. The "Germany 2020" study by the Zukunftsinstitut, a Frankfurt-based institute for prognostics, presents Hannover as "soundly based and future-driven", with "creative entrepreneurs, excellent conditions for education and research and a talent for keeping up with decisive trends". Museums such as the Wilhelm Busch Museum, home to Max and Moritz, theatres where world-famous stars appear and a celebrated State Opera offer outstanding cultural experiences. Equally attractive are the Herrenhausen Gardens, the maritime atmosphere of the Maschsee Lake, the great diversity of sporting events and open-air concerts, and the many fairs and popular festivals. Passers-by linger in the picturesque Old Town, and the exotic landscapes of the Adventure Zoo enchant the whole family. Keen shoppers can roam through one of Germany's largest pedestrian zones or enjoy the idyllic atmosphere of the Region's half-timbered towns. All round the city, recreational areas such as Lake Steinhude or the Deister Hills offer a wide diversity of leisure activities.

„Red Thread" Hannover

The Red Thread is painted on the pavement, is 4200 metres long, and weaves its way through the inner city joining up 36 prime attractions. This is a floorline visitors' guide of a different kind. All you have to do is follow the Red Thread! This „do it yourself" city tour is accompanied by an informative brochure which describes all of the interesting buildings and monuments you meet along the way, and is also full of interesting historical background. Furthermore the brochure describes an „ExtraTour" which is a 45 minutes refreshing detour to the banks of Lake Maschsee.

Useful numbers

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We wish to thank all sponsors of EnFI 2015 cordially for their financial, organizational and logistic support:

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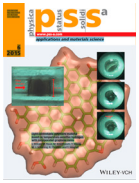
Call for papers – Invitation to authors
Special Issue in physica status solidi (a)

Guest Editors
Torsten Wagner, Patrick Wagner, Michael J. Schöning, and Theodor Doll



Submission Deadline
September 30, 2015
(Please confirm your contribution to the Guest Editors asap.)
www.editorialmanager.com/pssa-journal

Dear EnFI-2015 presenters,

Related to this year's workshop and in continuation of a long-standing tradition of the EnFI series it is planned to publish a regular special issue (no conference proceedings) with selected contributions on engineering of functional interfaces, as a reference to latest developments in the field, in pss (a) – *applications and materials science*. In collaboration between the Guest Editors and the pss Editorial Office we cordially invite you to contribute a **Feature Article** (topical review) or **Original Paper** manuscript based on your presentation. Further Contributed Articles may appear in pss (c) – *current topics in solid state physics.*

The physica status solidi journals are designed to reach a broad audience in the field of condensed matter and materials physics. pss is one of the largest and well-established publication platforms in solid state physics with more than 1500 articles per year – now over 50 years in business – and is widely accessible as part of many institutional site licenses, evidenced by close to one million article downloads annually.

All submitted manuscripts will undergo **peer review.** According to the editorial policy of pss, two positive recommendations by independent referees are a prerequisite of acceptance. Peer review and publication occur rapidly on individual manuscript basis. Published in Wiley Online Library **Early View** few weeks after acceptance, your article is citable immediately; hence there is **no waiting for the remainder of the contributions**. When all articles are complete, the topical section will be assembled in a regular monthly issue of pss (a). The clustering of related articles raises the visibility of these articles significantly, and once again we are confident that this will become a quality publication reflected by high article access and citation numbers.

Please refer to the author instructions available on our homepage www.pss-a.com ⇨ **Author Guidelines** (including optional Word template and

LaTeX style files and the link to online submission through Editorial Manager - please **mention** that this is a submission to the **EnFI-2015** special issue in your cover letter and select the appropriate section/category Engineering of Functional Interfaces to expedite handling).

We look forward to receiving your contributions!
Torsten Wagner, Patrick Wagner, Michael J. Schöning, Theodor Doll, Stefan Hildebrandt

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Information on submissions:

Feature Articles should provide an overview of a current topic in the format of a topical review of about 10–12 (max. 15) journal pages. Due to this length restriction, a complete bibliographic overview on the existing literature cannot be expected, but referencing should be well-balanced. The manuscript should represent a snapshot of most recent progress, the state of research and particularly relevant aspects, with focus on the highlights and possibly open or controversially discussed questions. They are intended to inform an audience not immediately familiar with the specific topic. Original, previously unpublished results may also be included to a certain extent. Feature Articles are considered with priority for cover picture publication.

Original Papers expose original and previously unpublished work of general interest to the community. Manu-scripts do not have a strict length limit (typical lengths vary from 6 to 10 journal pages). Articles must fulfil the standards and requirements of the journal. Acceptance of a contribution for presentation at the conference does not automatically include publication in the topical section. The main criteria for consideration by pss (a) are:

- The importance, relevance, and novelty of the results match those expected for a regular journal paper.
- The general quality of the manuscript and the amount of information provided is appropriate for an international journal. Serial or incremental, pure self-referential and lab-report-style work is discouraged.
- Main results have not yet been published (also not in conference proceedings) and are not under consideration for publication elsewhere.

pss (a) is focused on topics related to materials science, solid state physics and applications (including solid materials preparation and characterization,

electronic devices etc.). While we welcome interdisciplinary approaches (e.g., biosensing, inter-faces of biosystems with solid surfaces) please make sure that your contribution is sufficiently related to these aspects and within the journal's scope. Pure engineering (in the sense of non-scientific or technological work), biological or medical topics cannot be considered for inclusion in the issue and should better be submitted to a more appropriate different journal.

Online submission: www.pss-a.com ⇨ Submit an Article, www.editorialmanager.com/pssa-journal

Further **benefits** for pss authors include:

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- pss is indexed in ISI Web of Science and all other major abstracting databases.
- Promotion of selected content via web portals, e.g. materialsviews.com, newsletters, and press releases.

Special Issue: Phys. Status Solidi A 212(6), pp. 1183 ff. (2015) (DOI 10.1002/pssa.v212.6)
Including: From 2D to 1D functionalization: Steps towards a carbon nanotube based biomembrane sensor for curvature sensitive proteins, F. Ostermaier, L. Scharfenberg, K. Schneider, S. Hennig, K. Ostermann, J. Posseckardt, G. Rödel and M. Mertig, Phys. Status Solidi A 212, 1389 (2015) (DOI 10.1002/pssa.201431723)

Feature Article: Diamond-based DNA sensors: surface functionalization and read-out strategies, S. Wenmackers, V. Vermeeren, M. vandeVen, M. Ameloot, N. Bijnens, K. Haenen, L. Michiels, and P. Wagner, Phys. Status Solidi A 206, 391 (2009) (DOI 10.1002/pssa.200880486) (free-to-read)

Expert Opinion: Functional surfaces in heterogeneous catalysis: A short review, D. Rosenthal, Phys. Status Solidi A 208, 1217 (2011) (DOI 10.1002/pssa.201001207)

On-chip control of magnetic particles, P. Rinklin, H.-J. Krause, and B. Wolfrum, Phys. Status Solidi A 209, 871 (2012) (DOI 10.1002/pssa.201100529) (free-to-read)

Scientific Program

Sunday, July 5th, 2015

EnFI School

15:00	Pre-Registration
15:30 - 16:30	Student Courses 1
	Stimulation, Recording and Signal Analysis at several Functional Levels of Neural Tissue *Prof. Dr. Andrej Kral*
16:45 - 17:45	Student Courses 2
	Electrochemistry and Design Considerations of Electrodes *Prof. Dr. Jochem Rieger*
19:00	Beer Garden Gathering

Monday, July 6th, 2015

EnFI – First Day

08:00 - 9:00		Registration
09:00 - 09:15		Conference Opening
09:15 - 12:00		Session A
Tutorial Speaker		Prof. M Tiemann, Paderborn University
09:15 - 10:00	A.0	*Prof. M. Tiemann:* "Nanoporous Materials - Synthesis and Application"
10:00 - 10:03	A.1	*J. Oberländer:* "Study of interdigitated electrode array using experiments and FEM-models for evaluation of sterilisation processes"
10:03 - 10:06	A.2	*T. Bronder:* "Electrical detection of unlabelled DNA with polyelectrolyte modified EIS sensors: Comparison between ssDNA and dsDNA adsorption"
10:06 - 10:09	A.3	*S. C. Feifel:* "Modified graphene interfaces as novel photobioelectrodes with integrated photosystem I"
10:09 - 10:12	A.4	*B. Lim:* "Design and Fabrication of On-chip Square Wave Voltammetric Circuit for High Scan Speed of Two-dimensional Redox Imaging"
10:12 - 10:15	A.5	*S. Ebschke:* "Towards a nanoscale sensor system for intra-arterial simultaneous blood flow and pressure measurement"
10:15 - 10:18	A.6	*C. F. Werner:* "New LAPS driving method for better lateral resolutions"
10:18 - 10:21	A.7	*M. Alasel:* "Rapid and specific diagnostic pipette tip based on gold nanoparticles for diagnosis of borreliosis"
10:21 - 10:24	A.8	*P. Cornelis:* "Heat transfer resistance as a tool to quantify hybridization efficiency of DNA on a nanocrystalline diamond surface"

10:24 - 10:27	A.9	*C.S. Wu:* "Sensing of double-stranded DNA molecules by their intrinsic molecular charge using light-addressable potentiometric sensor"
10:27 - 10:30	A.10	*S. Takenaga:* "Long-term cell-cultivation system with a LAPS-based "lab-on-chip" to monitor cell activities under controlled conditions"
10:30 - 10:33	A.11	*S. Dantism:* "Determination of the extracellular acidification of Escherichia coli K12 with a multi-chamber-based LAPS System"
10:33 - 10:36	A.12	*S. Chunta:* "Low Density Lipoprotein Particle Sensor Based on Molecularly Imprinted Polymers"
10:36 - 10:39	A.13	*N.Dassinger:* "A new assay for detection of feline trypsin-like immunoreactivity in blood-serum using Surface Plasmon Resonance"
10:39 - 10:42	A.14	*D. Molinnus:* "Toward adrenaline biosensor based on an enzyme logic gate"
10:42 - 10:45	A.15	*L. Augel:* "Ge PIN photodetectors for possible integrated sensing applications"
10:45 - 10:48	A.16	*A.E.Strallhofer:* "Development of a novel platelets functional assay using QCM"
10:48 - 10:51	A.17	*M. Khorshid:* "Real-time monitoring of self-assembling monolayer formation using the heat-transfer method HTM"
10:51 - 10:54	A.18	*J. Pilas:* "Application of a bienzyme sensor setup for the amperometric detection of alcohols in biogas"
10:54 - 10:57	A.19	*D. Rani:* "Label free detection of prostate-specific antigens using Si-NW FETs"
10:57 - 11:00	A.20	*K. Miyamoto:* "Rapid prototyping of microfluidic devices for on-chip cell assay combined with a chemical imaging sensor"
11:00 - 12:00		Poster Session
11:45 - 12:45		Lunch

Monday, July 6th, 2015

EnFI – First Day

12:45 - 15:15	Session B	
Tutorial Speaker		Prof. A. Spieß, RWTH Aachen
12:45 - 13:30	B.0	*Prof. A. Spieß:* "Enzymes and Catalysis on Interfaces"
13:30 - 13:33	B.1	*I. Pötzelberger:* "Cu-Ni thin film combinatorial library for electrochemical oxidation of glucose"
13:33 - 13:36	B.2	*J.J. Velasco-Velez:* "On the activation and stability of electrodeposited fourth row transition metals onto Au studied by in situ XAS"
13:36 - 13:39	B.3	*C. D. Grill:* "Investigation of cobalt-nickel material libraries obtained from electrodeposition using different complexing agents"
13:39 - 13:42	B.4	*V. Scherbahn:* "Enzymatic biofuels cells based on direct enzyme-electrode contacts using modified carbon nanotube materials"
13:42 - 13:45	B.5	*S. C. Feifel:* "Supramolecular architectures of cellobiose dehydrogenase and cytochrome c on electrodes using artificial matrices"
13:45 - 13:48	B.6	*J. Posseckardt:* "Mobility of a supported lipid bilayer on dispersed single-walled carbon nanotubes"
13:48 - 13:51	B.7	*S. Schusser:* "Sensor system for in-situ and real-time monitoring of polymer (bio)degradation"
13:51 - 13:54	B.8	*G. Wackers:* "Detection of the peanut allergen Ara h1 by electrochemical impedance spectroscopy and the heat-transfer method"
13:54 - 13:57	B.9	*H.-C. Schwarz:* "Controlled transformations in transparent conducting films fabricated from highly stable hydrophilic dispersions of single wall nanotubes"
13:57 - 14:00	B.10	*A. Ibañez-Landeta:* "Electroadsorptive Effect on SnO2 Films"

14:00 - 14:03	B.11	*D. Nettelroth:* "Catalytic Graphitization of Mesoporous Carbon CMK-3 by Various Synthesis Approaches to Obtain Improved Electrode Materials"
14:03 - 14:06	B.12	*P. Cabello:* "Surface effects on the kinetic of the electro-chemical deposition of copper on graphite HOPG"
14:06 - 14:09	B.13	*J. Warmer:* "Catalytic conversion of triaceton triperoxide on different metal oxides"
14:09 - 14:12	B.14	*C. Huck:* "Chemical sensors based on the same transducer material of barium strontium titanate"
14:12 - 14:15	B.15	*K. Doll:* "Liquid-infused structured titanium as an innovative medically relevant material with antibiofilm properties"
14:15 - 15:15		Poster Session and Coffee Break
15:15 - 18:00	Session C	
Tutorial Speaker		Prof. D. Ricci, IIT, Genova
15:15 - 16:00	C.0	*Prof. D. Ricci:* "Human-centered brain interfaces"
16:00 - 16:03	C.1	*Y. Guo:* "LAPS-based optoelectronic device for mapping the brain activities in vivo"
16:03 - 16:06	C.2	*L. De Laporte:* "Light modulated hydrogel stiffness for mechanical stimulation of cells and nerves"
16:09 - 16:12	C.3	*S. D. Angelov:* "Electrophoretic deposition of ligand-free nanoparticles affected electrode impedance"
16:12 - 16:15	C.4	*D. Schurzig:* "Determination of Optimal Excitation Patterns for Intracochlear Inner Ear Stimulation Using a Physiologically-Based Model"
16:15 - 16:18	C.5	*N. Burblies:* "Carbon Nanotube Coatings for Neural Interface Electrodes: Cytocompatibility for Fibroblasts and Spiral Ganglion Neurons"
16:18 - 16:21	C.6	*I. Akhoun:* "Automated Classification of Electrically-Evoked Compound Action Potentials"

Monday, July 6th, 2015

EnFI – First Day

16:21 - 16:24	C.7	*K. D. Kreisköther:* "Surface Modification of Neural Electrodes by Nanoporous Platinum Coatings"
16:24 - 16:27	C.8	*K. Wissel:* "Kapton® with cell selective coatings to improve electrode-nerve interaction"
16:27 - 16:30	C.9	*D. Majaura:* "Evaluation of the bonding strength between a silicone rubber/ polyimide interface for cochlear implants"
16:30 - 16:33	C.10	*J. Stieghorst:* "Silicone rubber spreading during infrared curing for individually shaped neural implant fabrication"
16:33 - 16:36	C.11	*L. Guntenhöner:* "Neural interfacing via track etch membrane of cell model mediated by human growth factors"
16:36 - 16:39	C.12	*K. Tegtmeier:* "Investigation of silicone rubber removal from carbon nanotubes by means of wet and dry etching"
16:39 - 16:42	C.13	*J. Wang:* "High-resolution light-addressable potentiometric sensors (LAPS) based on an organic monolayer modified silicon on sapphire (SOS)"
16:42 - 16:45	C.14	*G. L. Quaß:* "Electric Stimulation of the Mouse Auditory Midbrain"
16:45 - 17:45		Poster Session
19:30		Conference Dinner

Tuesday, July 7th, 2015

EnFI – Second Day

09:00 - 11:45	Session D	
Tutorial Speaker		Prof. J. Knoch, RWTH Aachen
09:00 - 09:45	D.0	*Prof. J. Knoch:* Nanoelectronics: Vision and Reality
09:45 - 09:48	D.1	*G. Göbel:* "Point-of-care (POC) diagnostics in punctate liquids based on gold nanoparticles"
09:48 - 09:51	D.2	*L. Breuer:* "Light-controllable hydrogels with incorporated graphene oxide as actuators for lab-on-chip devices"
09:51 - 09:54	D.3	*M. Riedel:* "Coupling of biochemical reactions with Quantum Dots for light switchable electrodes"
09:54 - 09:57	D.4	*X.L. Li:* "Application of electroosmotic micropumps to a microfluidic system combined with a light-addressable potentiometric sensor"
09:57 - 10:00	D.5	*G. Vandevenne:* "Near-room temperature sintering of inkjet printed silver patterns"
10:00 - 10:03	D.6	*S. Nagels:* "Adaptation of silver-based screen pastes to achieve stretchable, conductive patterns"
10:03 - 10:06	D.7	*J. Zessin:* "Synthesis of a polythiophene-oligonucleotide-conjugate for site-specific integration into DNA origami"
10:06 - 10:09	D.8	*A. Herms:* "Design and construction of thermophoretic swimmers"
10:09 - 10:12	D.9	*A. Grimm:* "Room Temperature Photoluminescence of Strained Ge-layers"
10:12 - 10:15	D.10	*I. Verboven:* "Printing of organic light emitting diodes on textile"
10:15 - 10:18	D.11	*J. Schmidt:* "Strained Ge layers on virtual Si1-xGex(001) substrates"

Tuesday, July 7th, 2015

EnFI – Second Day

10:18 - 10:21	D.12	*F. Fischer:* "High-throughput structural characterization of DNA origami"
10:21 - 10:24	D.13	*R. R. Poloczek:* "Membrane Stiffness Tuning for Micro-machined Pressure Sensors"
10:24 - 10:27	D.14	*L.E. Delle:* "Miniaturization improves device performance of organic electrochemical transistors"
10:27 - 10:30	D.15	*A. Müller:* "Integration of FET-based biosensors into a Wheatstone bridge for purely resistive sensing"
10:30 - 10:33	D.16	*F. Hempel:* "Organic electrochemical thin-film transistors by spin coating fabrication"
10:33 - 10:36	D.17	*J.K.Y. Law:* "Optimization of reduced graphene oxide-based field-effect transistor for impedimetric immunoassays"
10:36 - 10:39	D.18	*R. F. van de Wijdeven:* "Optimization of organic electro-chemical transistors based on PEDOT:PSS for biological applications"
10:39 - 10:42	D.19	*W. Munief:* "Fabrication of graphene oxide field-effect transistor devices"
10:45 - 11:45		Poster Session
11:30 - 12:30		Lunch

12:30 - 15:15	Session E	
Tutorial Speaker		Prof. M. Dienwiebel, KIT, Karlsruhe
12:30 - 13:15	E.0	*Prof. M. Dienwiebel: "*Nanoscale characterization of tribological surfaces"
13:15 - 13:18	E.1	*F. Kratz:* "Influence of different ion composition on the protein film formation on dental materials"

13:21 - 13:24	E.2	*V. Rink:* "Self-assembly of tomato bushy stunt viruses (TBSV) investigated by scanning force and scanning electron microscopy"
13:24 - 13:27	E.3	*J. Gertje:* "Analysis of the adsorption behavior of carbohydrates on dental materials"
13:27 - 13:30	E.4	*N. Davoudi:* "Measurement of Lateral Strength for Bacterial Adhesion by Scanning Force Microscopy"
13:30 - 13:33	E.5	*C. Rösch:* "Role of carbohydrate-protein interaction in adsorption processes"
13:33 - 13:36	E.6	*F. AL Halabi:* "Coaxial electrospun scaffolds with piezoelectric effect for tissue regeneration"
13:36 - 13:39	E.7	*O. Akkermans:* "Long-Term Tracking of Bruxism during Day Time by Implementing Conducting Hollow-Sphere Polymers into a Splint"
13:39 - 13:42	E.8	*J. Stryckers:* "Optical properties and morphology of spray coated polystyrene nanoparticle layers"
13:42 - 13:45	E.9	*J. Arreola:* "Immobilization of bacterial spores on biosensor substrates with organosilanes"
13:45 - 13:48	E.10	*H. Requardt:* "Biocompatibility of Carbon Nanotubes for targeted Drug Delivery"
13:48 - 13:51	E.11	*T. Shopova:* "Detection and separation of the bacteria strain Escherichia coli BL21 (DE03) using surface modified polymer particles"
13:51 - 13:54	E.12	*D. Vornicescu:* "Investigation of fibroblast growth factor-binding protein anti-tumor effects using surface plasmon resonance"
13:54 - 13:57	E.13	*N. Schulz:* "Surface area enhancement of microchannels by vertically and horizontally aligned growth of multi-walled carbon nanotubes"
13:57 - 14:00	E.14	*R. Lanche:* "Wafer-scale dielectrophoretic deposition of graphene oxide for biosensing platforms"

Tuesday, July 7th, 2015

EnFI – Second Day

14:00 - 14:03	E.15	*P. Aliuos:* "Enhanced adhesion of NIH3T3 fibroblasts mediated by magnetic beads"
14:03 - 14:06	E.16	*D. Tanasic:* "Molybdenum oxides in efficient antibacterial coatings"
14:15 - 15:15		Poster Session and Coffee Break
15:15 - 15:30		Farewell and Best Poster
15:30		Vianna Lab Tour

Additional Programm: VIANNA Lab Tour

VIANNA - Institute of AudioNeurotechnology, Nanobiomaterials and Lasermedicine Hannover

VIANNA is the centre for translational research in the field of auditory prosthesis and nanomaterials. It well cooperates with NIFE and CROSSBIT, two other research institutions in the medical park. The institute has a dual leadership which reflects the close relationship between basic research headed by Prof. Andrej Kral (left) and translational research headed by Prof. Thomas Lenarz, chairman of the department of Otolaryngology. The research groups, approx. 30 scientists of different scientific fields such as engineering and natural sciences, and research groups of global leading companies in the field of auditory prosthesis focus on basic mechanisms of hearing and deafness, the researched design and development of auditory prosthesis and the translation into new products.
VIANNA is also home of parts of the collaborative research centre SFB 599 of the German Research Foundation (by medical engineering) and the Centre of Excellence Hearing4all.

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Session A

A

Session A - Tutorial
Nanoporous Materials - Synthesis and Application

Ordered, nanoporous materials possess unique properties that make them interesting for a large variety of applications, including as gas sensors, electrode materials, or magnetic devices. Their synthesis is typically accomplished by utilization of porogenic supramolecular entities or by the so-called nanocasting method. In the latter approach the pores of a solid structure matrix (e.g. silica) are filled with a precursor compound for the desired product (e.g. sucrose for porous carbon or metal nitrates for metal oxides), which is then converted in-situ, followed by selective removal of the matrix. As a result, mesoporous materials with uniform pores (few nanometers) and large surface-to-volume ratios (few hundred m2/g) are obtained. The tutorial lecture will introduce the general methods of synthesis and standard characterization techniques. In addition, the presentation will cover some examples, such as porous carbon materials as sorbents or electrodes in battery devices, porous metal oxides as gas/humidity sensors, and magnetic materials with interesting nanostructure-related properties.

Prof. Dr. M. Tiemann

A 0

1991-1997: studies of Chemistry (Dipl.-Chem.) at University of Hamburg
2001: PhD (summa cum laude) at University of Hamburg (Inorganic Chemistry; supervisor: Prof. Michael Fröba)
2001-2002: post-doc at Åbo Akademi University in Turku, Finland (Physical Chemistry; group of Prof. Mika Lindén)
2002-2009: group leader at University of Giessen
2009 habilitation/venia legendi
2008-2009 Adjunct Professor (Lehrstuhlvertretung) of Inorganic Chemistry
since 2009: Professor of Inorganic Chemistry at University of Paderborn
2009-2014 Regular Tenured Professor (W2)
since 2014 Full Professor (W3)
(2014 call to Technical University of Clausthal; declined)
Guest Professor at the Sino-German Technical Faculty (CDTF) at Qingdao University of Science and Technology (QUST) in Qingdao, China

Study of interdigitated electrode array using experiments and FEM-models for evaluation of sterilisation processes

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Abstract: In this work, a sensor to evaluate gaseous sterilisation processes has been investigated. The sensor set-up is based on planar interdigitated electrodes. Experimental, analytical and numerical methods have been applied to evaluate and study the sensor.

Keywords: sterilisation process monitoring, hydrogen peroxide (H_2O_2), impedimetric sensor, sensor modelling

A 1

Introduction

Hydrogen peroxide (H_2O_2) has become the main choice for sterilisation in aseptic food packaging systems. Gaseous hydrogen peroxide possesses germicidal and sporicidal properties due to strong oxidising effects [1]. Evaluation of the sterilisation efficiency is a time-consuming procedure. Therefore, an interdigitated electrode (IDE)-based sensor was developed to monitor sterilisation effects on test microorganisms (*B. atrophaeus* spores). In this work, various sensor measurements were conducted to prove sensor functionality. The results were verified and validated analytically and numerically.

Results and Discussion

One of the IDE sensor approaches was fabricated by means of thin-film technologies on a glass substrate base (Borofloat 33, Schott). The electrodes consist of vapour-deposited titanium and platinum layers with thicknesses of 10 nm and 100 nm, respectively. The IDE structure consists of 614 identical electrode fingers; 5 µm in width and separation, 3.25 mm in length, which covers a total sensing area of 20 mm2. A view of the developed sensor is shown in Fig. 1 a).

Sensor measurements with and without spore-free carrier solution were conducted (Fig. 1 b)). The measurements were verified by using an analytical approach based on first-order elliptical integral as described in [2]. A finite-element method (FEM) model was designed and simulated to validate the experimental findings. Due to the complexity of the sensor structure the full fidelity model was substituted by a 2D periodic approach, as depicted in Fig. 2. The results of above mentioned testing methods were comparable to each other and the sensor experiments. Based on the created FEM model, a thorough investigation toward the electrical properties of the spore samples can be established.

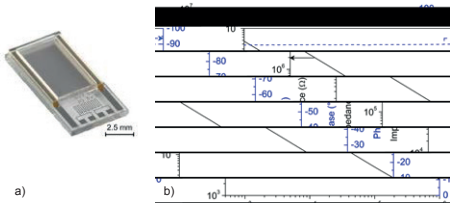

Figure 1: a) Photo of a glass substrate-based sensor; b) impedance spectrum of a bare sensor.

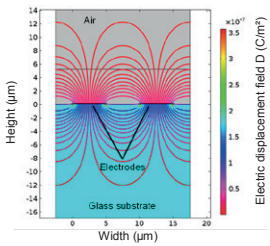

Figure 2: 2D-model output of FEM-studied bare sensor on glass substrate, streamlines showing electric displacement field.

Conclusions

An initial FEM-based model of the developed sensor has been simulated. The model has been verified and validated by analytical expressions and experiments.

References

[1] I. A. Ansari and A. K. Datta, *Food Bioprod. Process.* **81**, 57-65 (2003).

[2] B. Timmer, W. Sparreboom, *et al.*, *Lab Chip* **2**, 121-124 (2002).

Acknowledgements

This work has been financially supported by BMBF project "ImpediPack".

Electrical detection of unlabelled DNA with polyelectrolyte modified EIS sensors: Comparison between ssDNA and dsDNA adsorption

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Abstract: Charge-sensitive field-effect electrolyte-insulator-semiconductor sensors have been used to detect single- and double-stranded DNA adsorption onto the gate oxide of the sensor. It has been demonstrated that the amplitude of the sensor signal can be used as an indicator for evidencing a successful DNA hybridization.

Keywords: DNA detection, label-free detection, field-effect biosensor, layer-by-layer technique

Introduction

DNA biosensors have been proven to be a powerful tool in a wide range of applications. Particularly, field-effect electrolyte-insulator-semiconductor (EIS) sensors represent a favourable platform for the development of electrical and label-free DNA detection strategies. A simple method for adsorption of DNA is presented by the layer-by-layer technique resulting in a formation of a polyelectrolyte/DNA bilayer [1]. The measured signal amplitude during the adsorption corresponds with the amount of charge change occurred near the sensor surface. In field-effect devices an intrinsic molecular charge is used to detect DNA adsorption onto the EIS sensor surface. In this work, the possibility of electrical detection of single-stranded DNA (ssDNA) and double-stranded DNA (dsDNA) adsorption onto the surface of EIS sensors has been investigated. For adsorbed dsDNA, a doubled signal change can be expected compared to adsorbed ssDNA.

Results and Discussion

For the DNA adsorption experiments, the EIS sensors (consisting of an Al-p-Si-SiO_2 structure, with 30 nm gate oxide thickness) were modified with a positively charged polyelectrolyte (poly(allylamine hydrochloride), PAH). By exposing the PAH-modified sensor chip to solutions containing negatively charged DNA molecules, those molecules will attach to the surface and change the output signal. Fig. 1 shows the response of an EIS before and after exposing to a solution containing only probe ssDNA (a), and both probe ssDNA and complementary DNA sequences (b), which can hybridize in solution and adsorb onto the sensor surface as dsDNA. The observed signal change after adsorption of dsDNA was doubled. This can be used as an indicator for verifying the successful DNA hybridization process in solution.

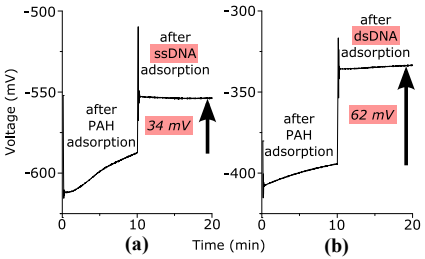

Figure 1: The graphs represent the sensor signal before and after the adsorption process of single-stranded (a) and double-stranded DNA (b).

Conclusions

The presented results demonstrate the potential of field-effect EIS sensors as a sensing platform for the detection of ssDNA and dsDNA adsorption. Moreover, EIS sensors are capable for distinguishing between the adsorption of ssDNA and dsDNA molecules and thus, they can be used for evidencing a successful DNA hybridization process in solution.

References

[1] C. Wu, T. Bronder, A. Poghossian, C.F. Werner and M.J. Schöning, *Nanoscale* **7** (14), 6143–6150 (2015).

Acknowledgements

The authors kindly acknowledge the support of this work by the Bundesministerium für Bildung und Forschung (BMBF), project no. 031A192D.

Modified graphene interfaces as novel photobioelectrodes with integrated photosystem I

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Abstract: Π-system modified graphene architectures exhibit the features for the direct assembly and electrical connection of proteins. Photosystem I is used as a functional building block for the efficient light-to-current conversion leading to very good photocurrent performances.

Keywords: graphene, photosystem I, π-systems, biophotocatalysis, artifical interface

Introduction

Artificial systems exploiting the features of natural photosynthesis are increasingly becoming a focus of current research. Particularly the two photosystems PSI and PSII of the oxygenic photosynthesis have attracted the attention of researchers to build up new solar energy-converting systems.[1,2] In such systems an efficient coupling of PSI with the electrode is essential. Besides the light-to-current conversion, PSI may also be used for light-driven redox and/or enzymatic reactions resulting in photobioelectrocatalysis. To date a couple of approaches for coupling PSI to gold surfaces have been previously described.[3,4] Such photo-bioelectrode systems lacks efficiency due to large electron tunneling distances between the reaction center and the electrode or because of insufficient orientation on the electrode surface.[5]

Results and Discussion

In this contention the focus has been on the unidirectional assembly of PSI on highly conductive graphene electrodes using different Π-systems as interface modifiers for a proper assembly of PSI. The carbon material used provides the advantage to adjust proper surface properties. The different Π-systems serve as an artificial scaffold harbouring functional groups which interplay with PSI for site-directed assembly. Particularly important is the hydrophilic-hydrophobic balance. After the assembly of PSI on these Π-system modified surface electrochemical experiments have been done, exploiting the functional features of these electrodes. In comparison of two groups of modifiers, anthracene and pyrene, the first one exhibits photocurrents in anodic and cathodic direction. It has been found that the pyrene modifiers shown higher photocurrents overall and display exclusively a unidirectional photocurrent in cathodic direction. This kind of electron pathway is demonstrated in Fig. 1.

In addition there have been assemblies along with a covalent and non-covalent approach for the fixation of the PSI. Hereby, demonstrating that in both cases the generation of a photocurrent and also the deposition of stable PSI assemblies is feasible. Hence, the covalent approach is the most effective one, exhibiting the highest photocurrent densities reaching 135 μA/cm^2.

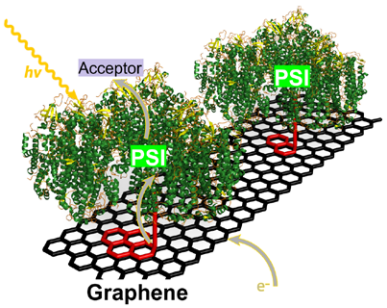

Figure 1: Scheme of the photobioelectrode consisting of graphene (black), two different π-systems basic compounds (anthracene and pyrene, red) and photosystem I (PSI).

Conclusions

Via the artificially modified graphene surface novel biohybrid systems with an improved unidirectional photocurrent output at the OCP have been developed.

References

[1] A. Badura et al, *Energy Environ. Sci.* **4**, 3263–3274 (2011).

[2] F. Wang, et al, *Adv. Mater.* **25,** 349–377 (2013).

[3] C. J. Faulkner et al, *Langmuir* **24,** 8409–8412 (2008).

[4] K. R. Stieger, S. C. Feifel, et al, *PCCP* **16**, 15667–15674 (2014).

[5] P. N. Ciesielski, et al, *ACS Nano* **2**, 2465–2472 (2008).

Acknowledgements

Financial support by BMBF, Germany, projects: 031A154A+B is kindly acknowledged.

A 3

Design and Fabrication of On-chip Square Wave Voltammetric Circuit for High Scan Speed of Two-dimensional Redox Imaging

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2) Core Research for Evolutional Science and Technology, Japan Science and Technology Agency, Tokyo, Japan.

Abstract: Integrated square wave voltammetric (SWV) pulse generator circuit has successfully designed and fabricated with Si Technology. This system can control frequency, a square wave amplitude, and a step increment which are three components of the SWV. The proposed sensor obtained the redox image of potassium ferricyanide from 8 x 8 array electrodes. Scan speed of each frame is 2 seconds under the condition of 200 Hz. With this sensor chip, SWV method could be used without an external bulky system with high scan speed.

Keywords: Square wave voltammetry, redox imaging, chemical imaging, microelectrode array

Introduction

Microelectrode array chip based on the electrochemical analysis using Si technology has attracted attention for miniaturization of the chip to conduct on-site monitoring [1]. Square wave voltammetry (SWV) is one of the pulse voltammetric method which has advantages in high scan speed measurement of biomaterials and small influence of capacitive current [2]. In this study, SWV pulse generator circuit using Si technology has been fabricated and it was integrated with an 8 x 8 microelectrode redox array for high scan speed and 2-dimensional redox imaging.

Results and Discussion

The SWV pulse generator circuit consists of a presetter, two counters, a selector, a D flip-flop, an R-2R ladder DAC, and a voltage shifter. Each counter makes stair-wave pulse. The counter can modulate the amplitude of the square wave and the step increment by controlling the presetter and the reference voltage of DAC, respectively. The square wave frequency is controlled by system clock.

Figure 1 shows an output voltage signal from the designed square wave pulse generator. Step increment is 4 mV by adjusting reference voltage of DAC which was 1.3 V. Square wave frequency is 25 Hz. This waveform is a good match with a general square wave pulse [2]. Figure 2 shows a two dimensional redox imaging of peak currents of 64 array pixels. To obtain this current signals, the potentiostat which is also integrated in this chip is used. The square wave from the figure 1 enters into the potentiostat. Potassium ferricyanide is used to measure which is widely used in electrochemical field. The concentration of material is 6 mM. Step increment is 4 mV, square wave amplitude is 50 mV, and square wave frequency is 20 Hz. The sensor was operated until 500 Hz of square wave frequency in the previous work [3]. This means that 150 ms/frame of scan speed can be possible using this sensor.

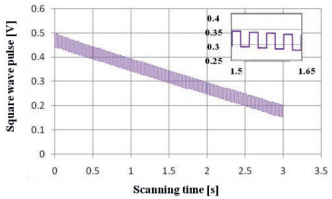

Figure 1: Output signal of square wave voltammetric pulse generator.

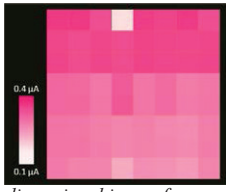

Figure 2: 2-dimensional image from array pixels.

Conclusions

Integrated SWV pulse generator circuit has successfully designed and fabricated, and 2-dimensional redox image has obtained using 8 x 8 array pixels. Using this chip, SWV method could be used without an external semiconductor analyzer system with high scan speed. The sensor has possibility of rapid chemical imaging at the study of living cells.

References

[1] R. A. Young, *Cell* **102**, 9-15 (2000).

[2] V. Mirceski, S. Komorsky-Lovric, and M. Lovric, Square-wave voltammetry: Theory and application, (Springer-Verlag Berlin Heidelberg, 2007), pp. 1-12.

[3] B. Lim, M. Futagawa, S. Takahashi, F. Dasai, M. Ishida, and K. Sawada, *Jpn. J. App. Phys.* **52**, 116502 1-4 (2013)

Towards a nanoscale sensor system for intra-arterial simultaneous blood flow and pressure measurement

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sven.ebschke@tu-dortmund.de

Intelligent Microsystems Institute, Faculty of Electrical Engineering and Information Technology, TU Dortmund University, Emil-Figge-Str. 68, 44227 Dortmund, Germany,

Abstract: The design and development of an innovative nanoscale sensor system for a simultaneous measurement of blood flow and pressure will be presented. It contains an ultrasensitive Thermal-Time-of-Flight (TToF) sensor for bidirectional measuring the fluid velocity and an absolute pressure sensor with a build-in pseudo-MOSFET read-out device for the blood pressure metering.

Keywords: blood flow sensor, blood pressure sensor, intra-arterial, MEMS, NEMS, microfluidic, TToF

Introduction

Over 31% of all global deaths have been caused by cardiovascular diseases (CVDs) in 2012 [1]. Hence, there is a huge demand for improved medical devices which can prevent or at least detect cardiac insufficiencies. The monitoring of parameters like blood pressure and blood flow are crucial information for detecting health risks and counteracting the CVDs. Therefore, a novel sensor system for the intra-arterial, simultaneous long-term measurement of these two parameters is desirable.

A 5

Results and Discussion

The initial development of a nanoscale Thermal-Time-of-Flight (TToF) sensor and its first characterization has been shown in recent publication (cf. [2]). The principle is displayed in Figure 1, where the filament, located in the middle, creates heat packages which are conveyed by the fluid and detected by the nanodiodes (d1 to d4). The heat packages are created by short current impulses and lead to bias deviation at the diodes.

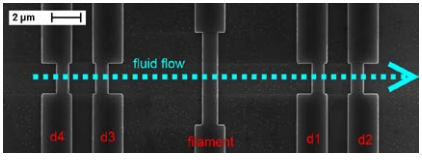

Figure 1: A nanoscale Thermal-Time-of-Flight sensor with a filament and four nanodiodes.

The velocity of the blood (v_{blood}) can simply be calculated by the equation:

$$v_{blood} = \frac{s_{d2} - s_{d1}}{t_{d2} - t_{d1}}$$

Where $s_{d1,\ d2}$ denote the location of diode one and two and $t_{d1,\ d2}$ the times of detection. The second pair of nanodiodes (d3, d4) is used for a bidirectional measurement of the pulsed blood stream. Furthermore, these diodes are used to compensate outside influence of external heat sources.

The second part of the sensor is an absolute pressure sensor with an integrated pseudo-MOSFET read-out device, which uses a membrane as channel of a transistor (cf. Fig. 2). Based on the pressure difference between the surrounding fluid and the sealed cavity, the membrane will deflect. This leads to a change of the resistivity in the channel of the MOSFET (cf. [3, 4]).

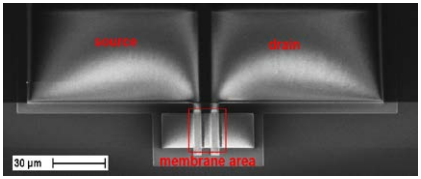

Figure 2: An absolute pressure sensor with an integrated pseudo-MOSFET read-out device.

Conclusions

First results for developing a new sensor system have been shown. More comprehensive results will be presented within the full contribution, i.e. the optimization by simulations, the process development and the full characterization of the sensors. Finally, the first results for the development of the sensor system will be featured.

References

[1] World Health Organization Fact Sheet **No 317**, updated January 2015.

[2] S. Ebschke, M. Wieker, J. Gerwinn, K. T. Kallis and H. L. Fiedler, Nanofair 2014, Paderborn.

[3] S. Ebschke, R. R. Poloczek, K. T. Kallis and H. L. Fiedler, IEEE Sensors 2013, Baltimore, Maryland, USA, 4.-6. November 2013.

[4] S. Ebschke, R. R. Poloczek, K. T. Kallis and H. L. Fiedler, *Journal of Nano Research* **Vol. 25**, 49-54 (2013).

New LAPS driving method for better lateral resolutions

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Abstract: To study chemical and biological processes, the spatially resolved determination of concentrations of one or more analyte species is of distinct interest. With a light-addressable potentiometric sensor (LAPS) chemical images can be created, which visualise the concentration distribution above the sensor chip. One important challenge is to achieve a good lateral resolution in order to detect events that take place in a small and limited region. This study proposes a new driving method of LAPS to achieve better lateral resolutions.

Keywords: light-addressable potentiometric sensor (LAPS), chemical imaging

Introduction

Light-addressable potentiometric sensors (LAPS) have the advantage to determine the concentrations of one or more analyte species in a spatially resolved manner. This allows to illustrate the concentration distribution, of e.g., local chemical reactions or diffusion processes, in chemical images [1]. Therefore, LAPS is interesting to monitor cellular activities or microfluidic channels. One important parameter for these applications is the lateral resolution. Typical lateral resolutions are in the range of 200 µm to 500 µm [2]. Some methods, described in literature achieve better lateral resolutions by thinning the silicon layer [2] or by the utilisation of amorphous silicon [3]. However, these methods come with several shortcomings, that is fragile LAPS chips and unwanted interface states that will influence the measurement quality and applications. To achieve better lateral resolutions and to overcome those disadvantages, a new type of LAPS system is proposed.

Results and Discussion

LAPS utilises a light spot to address the region of interest (see Fig. 1). This light is usually continuously modulated and generates charge carriers, which result in an externally measurable photocurrent to be correlated with the local concentration of the analyte. The size of the measurement spot depends not only on the light diameter, but also on the diffusion of the charge carriers inside the silicon.

Instead of utilising continuously modulated light, light pulses should be used and the resulting photocurrent should be sampled with a high temporal resolution. This signal would then consist of two parts: The first part depends on electron-hole pairs generated directly inside the space-charge region of the semiconductor and the second part depends on diffused charge carriers. The second part results in a poor lateral resolution, thus, only the first part is of interest.

Figure 2 depicts the photocurrent response of the proposed LAPS system and their dependency towards the applied bias voltages.

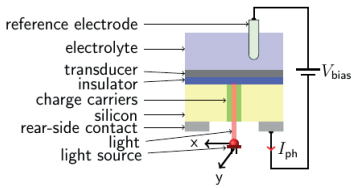

Figure 1: Schematic of the principle of LAPS utilising a continuously modulated light source.

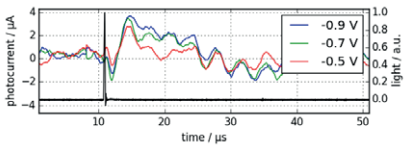

Figure 2: Photocurrent response to a 300 ns pulse.

Conclusions

Light pulses can be used to drive LAPS. The results of achieved lateral resolutions, the working principle and details of the LAPS system will be discussed at the conference.

References

[1] T. Yoshinobu, H. Iwasaki, Y. Ui, K. Furuichi, Y. Ermolenko, Y. Mourzina, T. Wagner, N. Näther, and M.J. Schöning, *Methods* **37**, 94-102 (2005).

[2] M. Nakao, S. Inoue, T. Yoshinobu, and H. Iwasaki, *Sensors and Actuators B* **34**, 234-238 (1996).

[3] W. Moritz, T. Yoshinobu, F. Finger, S. Krause, M. Martin-Fernandez, and M.J. Schöning, *Sensors and Actuators B* **103**, 436-441 (2004).

Acknowledgements

This work is financially supported by the Japan Society for the Promotion of Science (JSPS): grant number 26-04037 and international research fellow (C.F. Werner).

Rapid and specific diagnostic pipette tip based on gold nanoparticles for diagnosis of borreliosis

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Abstract: Gold nanoparticles modified with protein A was successfully used to improve sensitivity and selectivity of a diagnostic pipette tip based on 3D polyethylene sinter body packed in pipette tip for serological diagnosis of borreliosis. Utilizing the catalytic properties of gold nanoparticles for detection of antibody-antigen complex has been successfully introduced to the specific detection of *Borrelia* antibodies in blood serum.

Keywords: Gold nanoparticles, DiaTip, Serological diagnosis, Borreliosis, 3D polyethylene sinter body

Introduction

Selectivity and sensitivity of immunoassays are one of the main concerns when developing a new assay for serological diagnosis in a matter of decreasing the chance for false positive or false negative results. Labels are one of the important parameters that are considered when improving selectivity and sensitivity of the immunoassay. Gold nanoparticles exhibit a very intense red colour that can be visualised by scattered light in addition to suitable functionalization with bio-conjugates. This makes colloidal gold a good candidate for colorimetric immunoassays. The high solubility of gold nanoparticles in water that in turn would decrease the background could be utilized to improve the selectivity of the immunoassay [1]. The catalytic properties of gold nanoparticles could be used as well to increase the sensitivity of the immunoassay through deposition of metallic silver on the gold nanoparticle surface [2]. The signal obtained after silver deposition is amplified up to 5 times of magnitude. The amount of metallic silver can then be quantified colorimetry. In the presented work both characteristics of gold nanoparticles were used to improve sensitivity and selectivity of a diagnostic pipette tip based on 3D polyethylene sinter body packed in pipette tip for serological diagnosis of borreliosis.

Results and Discussion

Gold nanoparticles were synthesized followed by modification with protein A; it was then successfully used for the detection of antibody-antigen interaction on a 3D polyethylene sinter body packed inside a pipette tip. Firstly, *Borrelia*-antigen has been immobilized on the surface of the sinter bodies. Then, a serum containing *Borrelia* antibodies is exposed to the sinter body followed by the modified gold nanoparticles. The signal was amplified when using silver enhancer, which can be quantified using a photometer at 650 nm and 520 nm. Positive and negative sera were tested using the proposed assay; the assay showed a very specific interaction between antigen and sera samples (Figure 1). Time of analysis is about 10 min.

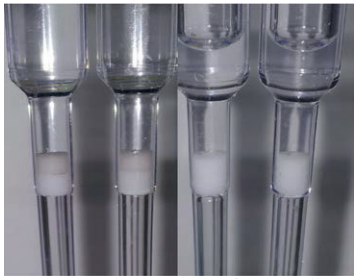

Figure 1: Borreliosis assay after metallic silver deposition on gold nanoparticles for testing positive serum (Left) and negative serum (Right).

Conclusions

Utilizing the catalytic properties of gold nanoparticles for detection of antibody-antigen complex has been successfully introduced to the specific detection of *Borrelia* antibodies in blood serum. The assay has been developed on a sinter body, which can be placed inside a pipette tip. The pipette tip showed a very good selectivity and very rapid time of analysis (10 min). The assay can be employed also with many other antigens.

References

[1] Y. Qi, F. Xiu and B. Li, *Anal. Biochem*. **449** (15), 1–8 (2014).

[2] Q. Yu, H. Li, C. Li, S. Zhang, J. Shen and Z. Wang *Food Control* (54) 347- 352 (2015).

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A 7

Heat transfer resistance as a tool to quantify hybridization efficiency of DNA on a nanocrystalline diamond surface

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Abstract: We report on a label-free real-time method based on heat transfer resistivity for thermal monitoring of DNA denaturation and its potential to quantify DNA fragments with a specific sequence of interest. Probe DNA was immobilized on a nanocrystalline diamond surface. Various concentrations of full matched target DNA fragments were hybridized with this probe DNA. We observed that the change in heat transfer resistance upon denaturation depends on the concentration of target DNA, which allowed to determine a dose response curve. These results illustrate the potential to quantify concentration and hybridization efficiency of DNA.

Keywords: CVD diamond, heat transfer resistance, DNA quantification, hybridization efficiency analysis

Introduction

Measuring the concentration of specific sequences of bacterial DNA can be used to determine the contamination level of a sample. This work reports on a label-free real-time method based on heat transfer resistivity for thermal monitoring of DNA denaturation and its potential to quantify DNA fragments with a specific sequence [1].

Results and Discussion

Four different concentrations of target DNA were hybridized onto the surface of the sensors. The initial heat transfer resistance (R_{th}) value of the measurement rises as the used concentration of target DNA is lowered. After denaturation, the R_{th} value is identical for all concentrations. Therefore, the change in R_{th} can be considered as being dependant on the concentration. These results allow for the determination of a dose-response curve (Figure 1).

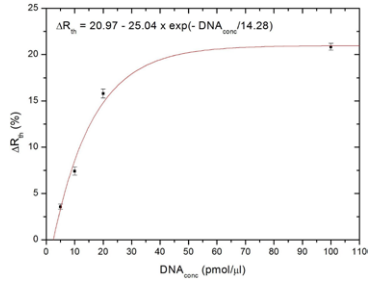

Figure 1: Dose-response curve. The solid line was calculated using an exponential fit algorithm.

The hybridization efficiency, which is a measure for the amount of target DNA that is effectively hybridized compared to the total amount that was exposed to the sensor surface, can also be calculated based on these results (Table 1). The low efficiency, around 8 %, indicates that optimizing this technique could further improve its performance.

Target concentration (pmol/µl)	100	20	10	5
# targets	3.61×10^{14}	7.23×10^{13}	3.61×10^{13}	1.81×10^{13}
# probes	8×10^{12}	8×10^{12}	8×10^{12}	8×10^{12}
target/probe ratio	45.17	9.03	4.52	2.26
Signal strength (%)	100	75.80 ± 2.71	35.57 ± 2.16	17.14 ± 1.43
ΔRth (%)	20.83 ± 0.37	15.79 ± 0.49	7.41 ± 0.43	3.57 ± 0.29
Efficiency (%)	2.21	8.39 ± 2.71	7.88 ± 2.16	7.59 ± 1.43

Table 1: Calculated hybridization efficiencies for the different concentrations of target DNA.

Conclusions

This study confirmed the possibility of using a method based on heat transfer resistivity to measure the concentration of a specific gene of interest. This illustrates the potential of this technique to be used as a user-friendly alternative to determine the level of contamination with bacterial pathogens in food and drinking water production as well as clinical diagnostics and environmental studies. Moreover, this technique enables the calculation of the hybridization efficiency of a target DNA fragment to the probes.

References

[1] P. Cornelis, T. Vandenryt, G. Wackers, E. Kellens, P. Losada-Pérez, *et al*. Diamond & Related Materials **48**, 32–36 (2014).

Acknowledgements

Financial support by the Life-Science Initiative of the Province of Limburg, the Research Foundation Flanders FWO (Project G.0829.09 and Project G.0B62.13 N) and the EU FP7 through Marie Curie ITN 420 “MATCON” (PITN-GA-2009-238201) is greatly appreciated.

† Authors contributed equally to this work

Sensing of double-stranded DNA molecules by their intrinsic molecular charge using light-addressable potentiometric sensor

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Abstract: A multi-spot light-addressable potentiometric sensor (LAPS) covered with a positively charged polyelectrolyte layer was used for label-free detection of negatively charged double-stranded deoxyribonucleic acids (dsDNA). Distinct signal changes have been observed in each spot after the layer-by-layer adsorption of polyelectrolyte/dsDNA bilayer. The mechanism of an electrostatic detection of dsDNA with the polyelectrolyte-modified LAPS is discussed.

Keywords: dsDNA, polyelectrolyte, LAPS, label-free detection

Introduction

In the recent decade, DNA biosensors have attracted more and more interest due to their promising prospects and potential applications in many fields from DNA diagnosis to gene analysis [1]. Especially, field-effect devices (FEDs) opened up an exciting realm for the development of a new generation of DNA biosensors due to their unique capability of label-free detection of charged molecules by their intrinsic molecular charge [2]. The vast majority of DNA-FEDs are developed for the detection of hybridization of probe single-stranded DNA (ssDNA) molecules (immobilized onto the sensor surface) with complementary target cDNA molecules. On the other hand, little is known about using of FEDs for the direct detection of dsDNA. In this work, a multi-spot (16 spots) light-addressable potentiometric sensor (LAPS) consisting of an Al-p-Si-SiO_2 structure covered with a positively charged polyelectrolyte layer of poly(allylamine hydrochloride) (PAH) was applied for a direct label-free electrostatic detection of negatively charged dsDNA molecules by their intrinsic molecular charge for the first time.

Results and Discussion

Fig. 1 shows the typical constant-photocurrent responses of the LAPS recorded in three spots before and after the layer-by-layer adsorption of the PAH/dsDNA bilayer. The mean signal changes for all 16 spots after the adsorption of PAH and dsDNA molecules were 35 mV and 30 mV, respectively. In contrast, the LAPS shows insignificant response after the exposing of the bare SiO_2 surface (without PAH coating) to dsDNA solution (data not shown). The underlying mechanism of a direct label-free electrostatic detection of dsDNA by the PAH-modified LAPS will be discussed.

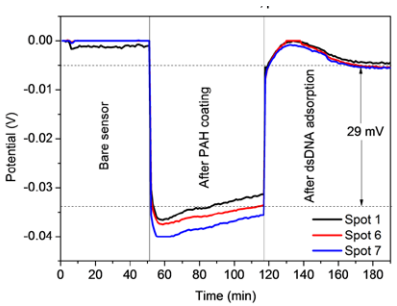

Figure 1: Typical constant-photocurrent responses in three spots of the LAPS recorded in a 10 mM phosphate buffer solution (pH 7.5) before and after the layer-by-layer adsorption of a PAH/dsDNA bilayer.

Conclusions

The obtained results demonstrate that the PAH-modified LAPS provides a convenient and rapid approach for the direct label-free electrical detection of dsDNA molecules.

References

[1] A. Sassolas, B.D. Leca-Bouvier and L.J. Blum, *Chem. Rev.* **108** (1), 109–139 (2008).

[2] C.S. Wu, T. Bronder, A. Poghossian, C.F. Werner, M. Bäcker and M.J. Schöning, *Physica Status Solidi (A)* **211** (6), 1423–1428 (2014).

Acknowledgements

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A 9

Long-term cell-cultivation system with a LAPS-based "lab-on-chip" to monitor cell activities under controlled conditions

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Abstract: Long-term cell-cultivation systems with controlled environmental conditions were fabricated to monitor cell activities with an integrated LAPS chip. The set-up consists of microfluidic channels combined with a LAPS chip to culture living cells, a pump system to provide flexible flow rates and an incubator to control the temperature and humidity during cell cultivation.

Keywords: Light-addressable potentiometric sensor, Chinese hamster ovary cells, microfluidics, lab-on-chip

Introduction

The light-addressable potentiometric sensor (LAPS) can detect spatially resolved the local hydrogen concentration on its sensor surface. The LAPS has been developed towards the label-free detection of the metabolic activity of living cells. In previous works, LAPS-based lab-on-chip devices were partially manufactured by a rapid prototyping process gaining the advantages of 3D-printing technologies. To detect signals from living cells accurately, the cultivation- and measurement system requires controlled conditions of e.g., temperature, humidity and flow rate. In this work, the cell-culturing progress in microfluidic channels on a LAPS chip under continuous flow was investigated.

Results and Discussion

Figure 1 depicts the pump system for the cultivation of living cells in a LAPS set-up with the attached microfluidic channels. The inlet of the microchannel was connected to the pump (FIALab) to supply new culture medium to the cells. The pump system generates 0.2 ml per minutes of flow rate. 80 µl Chinese hamster ovary (CHO) cell suspension (5×10^5 cells/ml) was filled into each channel. Caps were placed on the inlet and outlet to avoid evaporation and the entire system was incubated at 37 °C and 5% CO_2 for 3 hours to advance cell attachment. After that, one of the two microfluidic channels was connected to the pump system and incubated under the continuous flow over night. For comparison, cell culturing without pumping was conducted in the second channel, too. Figure 2a shows microscopic photographs after 24 hours culturing of CHO cells. Estimated by the cell density and morphology, the cell-growth progress for a continuous flow of culture medium reaches confluence much faster compared to the static culturing condition. Exemplarily, the metabolic activity, responding to addition of glucose (20 mM) was recorded utilizing a scanning LAPS set-up. It was observed that the acidification of the cell culturing under continuous flow was promoted faster and stronger, indicating a higher cell activity (Fig. 2b).

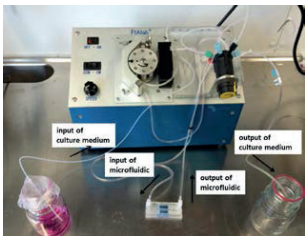
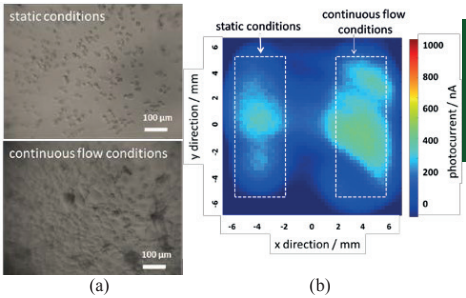


Figure 1: Pump system for the cell cultivation in a LAPS-based "lab-on-chip" system including microfluidic channels.



(a) (b)

Figure 2: Microscopic photographs of cultured CHO cells culturing overnight (a). Photocurrent-image of metabolic activity of CHO cells after adding glucose (b).

Conclusions

The long-term cultivation of CHO cells in a "lab-on-chip" device based on a LAPS and microfluidics was demonstrated. The new system can be used to observe culturing conditions under continuous or intermittent flow enabling a long-term cultivation by providing nutrition support and constant oxygenation. This allows more accurate detection of the metabolic activities in future.

Acknowledgement

This work was supported by the German Federal Ministry of Education and Research BMBF within the research frame of "Opto-switch" (13N12585).

A 10

Determination of the extracellular acidification of *Escherichia coli* K12 with a multi-chamber-based LAPS System

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Abstract: On-line monitoring of the metabolic activity of microorganisms involved in intermediate stages of biogas production plays a major role to avoid undesirable "down times" during the biogas process operation. In order to control the process and eliminate the external influences, like temperature fluctuations, sensor drift and external pH changes, an on-chip differential measuring system using 3D-printed multi-chambers fixed on a light-addressable potentiometric sensor (LAPS) can be deployed. *Escherichia coli* K12 has been used as a test organism to observe the metabolic activity.

Keywords: Light-addressable potentiometric sensor, extracellular acidification rate, *Escherichia coli* K12, 3D-printed multi-chamber, differential measurement

Introduction

In the recent years, light-addressable potentiometric sensors (LAPS) are commonly used sensor systems to determine the extracellular acidification [1]. LAPS provide a spatially resolved concentration detection of (bio)-chemical species on the sensor surface [1, 2]. In avoidance of external influences, a differential measuring set-up could be applied, as shown in Fig. 1 (left). Furthermore, the simultaneous measurement with different microorganisms in suspension on a single LAPS chip would be favourable. These challenges are handled by the combination of a LAPS chip with a new developed multi-chamber, 3D-printed polymer structure (PP-ABS), as it shown in the Fig. 1 (right).

Results and Discussion

200 µl of *E. coli* K12 bacteria (4.8×10^9 cell/ml) suspended in phosphate-buffered saline (PBS, pH 7.4) was pipetted into the left chamber of the differential set-up (Fig. 1). On the right side, as reference, only PBS buffer was added. After conditioning phase of the LAPS chip with *E. coli* for about 30 min., 100 µl of glucose solution (0.5 mM) was added to both chambers.

The potential change rate (slope of dropped potential in mV/min for 10 min) has been determined and the acidification rate (in pH/min) was calculated. The described measurement procedure was repeated for three more glucose concentrations (1 mM, 1.5 mM, and 5 mM). The absolute value of the potential change rate and the acidification rate increase by adding a higher glucose concentration into the cell suspension.

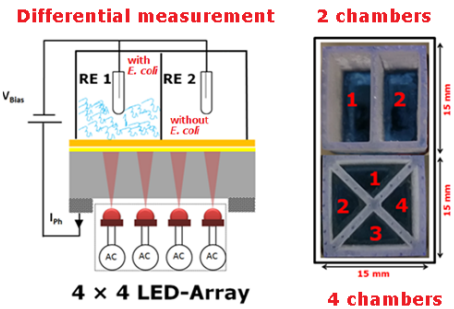

Figure 1: Differential set-up with two chambers (left), multi-chamber 3D-printed structures (right).

Conclusions

The combination of two established technologies (LAPS with 3D-printed structures) enables a promising time- and cost-effective analytical approach for the verification of extracellular acidification of microorganisms in the biogas process operation.

References

[1] J.C. Owicki and J. W. Parce, *Biosens. Bioelectron.* **7**(4), 255-272 (1992).

[2] T. Wagner, R. Molina and M. J Schöning, *Electrochemica Acta* **53**, 305-311 (2007).

Acknowledgements

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Low Density Lipoprotein Particle Sensor Based on Molecularly Imprinted Polymers

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Abstract: Novel Molecularly imprinted polymers (MIPs) were synthesized as biomimetic specific receptors to artificially detect low density lipoprotein (LDL). Functional monomer ratios of acrylic acid (AA), methacrylic acid (MAA) and N-vinylpyrrolidone (VP) were screened on 10 MHz dual-electrode quartz crystal microbalances (QCM). MAA and VP, ratio 3:2, revealed the highest response to LDL from 50 to 400 mg/dL in PBS without significant interference: human serum albumin (HSA) leads to 2 % of the LDL signal, high density lipoprotein (HDL) to 6%.

Keywords: molecularly imprinted polymer, low density lipoprotein, quartz crystal microbalance

Introduction

Low density lipoprotein (LDL) is a biomolecular complex consisting of triglyceride, cholesteryl ester, phospholipid, unesterified cholesterol and apolipoprotein. Higher concentration of serum LDL is the essential criterion for assessing coronary heart disease and monitoring its treatment [1]. Novel molecularly imprinted polymers (MIPs) were synthesized to detect LDL with biomimetic specific receptors that can bind directly to the LDL without tedious sample preparation. MIPs have been successfully applied as selective receptor materials for numerous bio-analytes, e.g. cells, proteins, bacteria, viruses, and yeasts [2]. Currently, no MIPs exist for these complex aggregates; this inherently opens up a novel field in the area of molecular imprinting. LDL on the one hand has negative surface potentials at -4.5 to -7.0 mV, and on the other hand contains both negatively and positively charged side chains. Therefore we tested variable ratios of acrylic acid (AA), methacrylic acid (MAA), and N-vinylpyrrolidone (VP) as monomers, because they complement positive and negative charges, respectively.

Results and Discussion

MAA and VP, ratio 3:2, N,N′-(1,2-dihydroxyethylene) bisacrylamide, 2,2′-azobis (isobutyronitrile, and dimethyl sulfoxide were screened as suitable functional monomers, cross-linker, initiator, and solvent for UV polymerization, respectively. Spin-coating those polymers as MIP and non-imprinted polymer (NIP), respectively, onto 10 MHz dual-electrode QCM, has led to sensors that can indeed quantify LDL in 10 mM PBS. The resulting sensor characteristic revealed linear response of the sensor towards LDL from 50 to 400 mg/dL as shown in Figure 1. Furthermore, the sensor signals did not show significant interference: human serum albumin leads to 2% of the LDL signal, HDL to 6%.

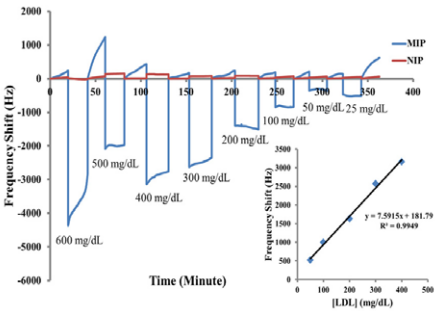

Figure 1: Dose–response curve of LDL assay using the LDL-MIPs QCM sensor.

Conclusions

LDL-MIPs were successfully synthesized with high specificity for directly LDL recognition. The sensitivity range covers clinically relevant concentrations including normal and abnormal levels. This setup thus constitutes the first step for a sensor in serum. Furthermore, this is the first MIPs-based artificial recognition material targeting a lipoprotein aggregate.

References

[1] M. Nauck, G.R. Warnick and N. Rifai, *Clin Chem* **48**, 236-254 (2002).

[2] M. Hussain, J. Wackerlig and P.A. Lieberzeit, *Biosensors* **3**, 89-107 (2013).

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A new assay for detection of *feline* trypsin-like immunoreactivity in blood-serum using Surface Plasmon Resonance

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Abstract: An improved assay for the detection of *feline* trypsin-like immunoreactivity (fTLI) based on Surface Plasmon Resonance (SPR) has been developed. A recombinant fusion protein was used as a linker for binding IgG proteins to the surface. Via this fusion protein, specific antibodies against fTLI were coupled onto the sensor chip and an assay for the detection of fTLI in serum samples was successfully established.

Keywords: fusion protein, ConcanavalinA (ConA), ProteinA (ProtA), *feline* trypsin-like immunoreactivity (fTLI), Surface Plasmon Resonance (SPR)

Introduction

To diagnose an exocrine pancreatic insufficiency or an acute pancreatitis it is important to analyze the serum proteins. The enzyme trypsinogen, which is produced by the pancreas, can react immunologically as fTLI in cats. There is a certain normal level of fTLI in the blood-serum, but during a dysfunction of the pancreas, the concentration of fTLI alters [1].

In order to bind the specific antibodies against fTLI on a sugar coated surface, a new fuison protein was developed. One moiety of the protein consists of the protein A (ProtA) sequence and the other is the lectine Concanavalin A (ConA). To avoid crosslinking of the fusion protein, only one binding domain of ProtA was chosen for cloning [2].

This linker protein is also able to attach multiple IgG antibodies to sugar coated surfaces, what makes it versatile in application.

Results and Discussion

The ConA-ProtA protein has been successfully expressed in *Escherichia coli*. After inclusion body purification and refolding of the protein, the functionality was tested on a mannan coated SPR-chip surface.

ConA-ProtA binds to the mannan-coated surface via the ConA part and the ProtA is able to bind the specific antibody against fTLI. To establish the assay, a purified sample of fTLI was applied. Due to the high concentration of glycerol in the fTLI protein sample, which is important for the protein stability, the binding-signal becomes unclear. Therefore a secondary detection antibody was applied to amplify the binding signal (see detail in fig. 1) of fTLI to the surface.

After establishing the assay, several serum samples were tested to detect the presence of fTLI. In control-experiments the specificity of the obtained signal was determined (shown on the poster).

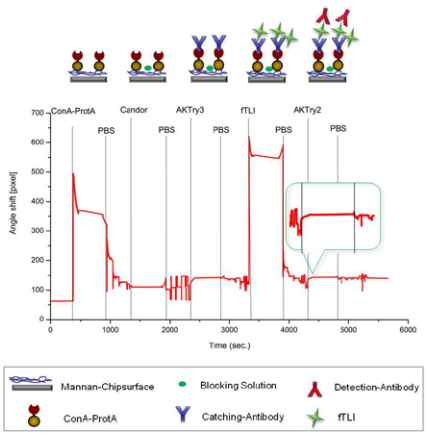

Figure 1: SPR Sensorgram. Mannan coated gold with injection of ConA-ProtA after baseline with PBS buffer. Application of Candor Blocking Solution and injection of purified fTLI sample. After application of detection antibodies an amplified signal occured (box).

Conclusions

A ConA-ProtA fusion protein could be sucessfully established. The fusion potein was tested for the detection of fTLI in serum samples via SPR.

The fusion protein is useful for further immunoassays.

References

[1] J.M. Steiner and D.A Williams, *J Vet Intern Med.* **14** (6), 627-629 (2000).

[2] T. Moks et al, *Eur. J. Biochem* ***156,***637-643 (1986).

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A 13

Toward adrenaline biosensor based on an enzyme logic gate

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Abstract: A novel concept for an adrenaline biosensor based on substrate recycling principle in combination with an enzyme logic gate is presented. A two-enzyme amperometric adrenaline sensor has been prepared by modification of an oxygen electrode with the enzyme laccase and a PQQ-dependent glucose dehydrogenase. The biocatalytic scheme employs adrenaline and glucose as biomarker inputs that mimics the functioning of a Boolean AND logic gate. A lower detection limit of 30 nM of adrenaline has been achieved in an optimal pH range of pH 7 – pH 8.

Keywords: molecular logic gate, adrenaline, laccase, glucose dehydrogenase, biosensor, substrate recycling

Introduction

During the last years, tremendous efforts have been directed toward the development of biosensors based on biomolecular logic gates [1]. Such biosensors are expected to be able to detect multiple biochemical input signals simultaneously and convert them into electrical output signals with logical operations, such as **OR**, **AND**, **NOR**, etc. In this study, a novel platform for an adrenaline biosensor based on substrate recycling and enzyme logic-gate principles is presented. Adrenaline is of rising interest in medical diagnostics. For instance, adrenaline can be used as biomarker for tumor localization by adrenal venous sampling procedure, since its concentration in adrenal veins is ten times higher in comparison to the periphery. This requires a fast adrenaline detection method with a high sensitivity and low detection limit in the nanomolar concentration range.

Results and Discussion

The schematic of the developed biocatalytic **AND** logic gate for the detection of adrenaline by using a substrate recycling principle is shown in Fig. 1. The two-enzyme amperometric adrenaline sensor has been designed by modification of an oxygen electrode with the enzyme laccase (from AB Enzymes) and a PQQ-dependent glucose dehydrogenase (GDH) from *Acinetobacter caloaceticus*. Two analytes, namely glucose and adrenaline were used as input A and input B, respectively, to mimic the Boolean **AND** logic gate. Adrenaline molecules are oxidized by laccase forming quinone species, while the oxygen consumption is measured with an oxygen sensor. In a second oxidation reaction, GDH transforms glucose into gluconic acid, while the quinone is reduced back to adrenaline [2]. The absence of the respective analytes is considered as the input signal **0**, while addition of analytes is used as the input signal **1**. If both input signals or either one of them is missing, the logic output signal is **0**. In the presence of both the adrenaline and glucose, the logic output signal switches to **1**.

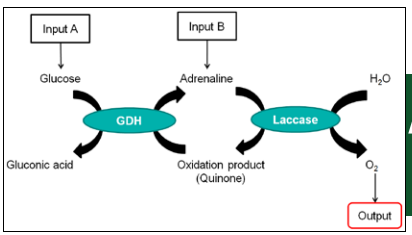

Figure 1: Schematic of the biocatalytic AND logic gate.

Conclusions

With the developed biosensor a lower detection limit of 30 nM of adrenaline has been achieved in an optimal pH range of pH 7 – pH 8. The possibility of an application of the developed biosensor for the adrenaline detection during the adrenal venous sampling procedure could open new prospects in medical diagnostics.

References

[1] F. Moseley, J. Halámek, F. Kramer, A. Poghossian, M.J. Schöning, E. Katz, Analyst **139** (8), 1839-1842 (2014).

[2] A.L. Gindilis, A. Makower, C.G. Bauer, F.F. Bier, F.W. Scheller, *Anal. Chim. Acta.* **304** (1), 25-31 (1994).

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Ge PIN photodetectors for possible integrated sensing applications

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Abstract: For around 50 years the field of information processing is driven by integrated circuits fabricated in Si-based technology. Photonic sensors based on surface plasmon resonances offer a way to integrate sensors into Si-based integrated circuits for a continuously monitoring in highly portable devices.

Keywords: Si-based technology, integration, monitoring

Introduction

Si-based technology sensor designs open the path to highly integrated sensor concepts. Integrating the sensor together with the evaluation and optional communication circuitry offers small and highly portable sensing devices for close-to user applications were measurements could be done in real-time and continuously. Applications would therefore be in measuring in saliva with devices which could be kept in the oral cavity or measuring in sweat with sensors integrated in smart watches where also environmental sensing applications would be possible.

Results and Discussion

Ge PIN photodetectors are due to their higher optical responsivity compared to Si detectors and their possible monolithically integration well suited for optical sensor concepts. The evaluation of analyte could then be established by using localized surface plasmon resonance (LSPR) on metallic nanoparticles located on top of the photodetector (Fig. 1) or extraordinary optical transmission (EOT) through perforated metallic layers. Since the LSPR and the EOT are highly sensitive to changes of the surrounding refractive index, sensing based on refractive index changes should be possible.

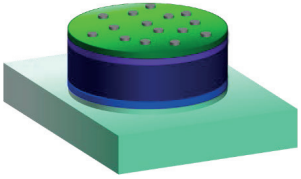

Figure 1: Ge PIN Photodetectors layer stack on Si substrate with disc-shaped Al NA.

On the Ge PIN photodetectors fabricated at the IHT Al nanoantennas (NA) with different shapes and diameters were created by using electron beam lithography for a lift-off mask and Al evaporation. The normalized photocurrent created in the device by stepping through a wavelength range from 1200 to 1750 nm was determined with a semiconductor tester. Opposed to the behaviour expected from LSPR the measurements reveal that the NA affect the absorption behaviour only at a specific wavelength. An increase and decrease in the normalized photocurrent at a specific wavelength range was observed with increasing disc diameter. This behaviour was observed for different samples and verified by simulations where the underlying Ge layers act as waveguide in which the incoming radiation can be trapped if LSPR and modes of the "waveguide" Ge layers are matching.

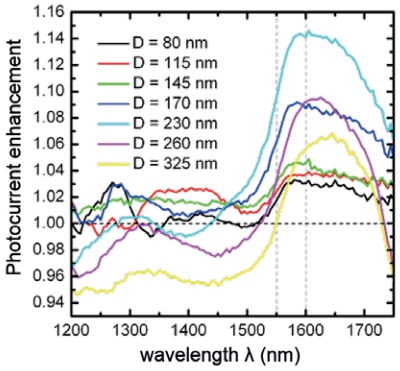

Figure 2: Photocurrent enhancement for a structure shown in Fig. 1.

A possible sensing application would make use of this behaviour by impinging light at a specific wavelength, e.g. 1550 nm. If the NA are now functionalized to establish a binding event only for a specific analyte, the change in refractive index could be measured as a change in the generated photocurrent.

Conclusions

We've shown how a possible sensor in Si-based technology could be realized using Al NA and how these interact with the underlying substrate by coupling the incoming light into the waveguide created by the Ge layers of the photodetector. Simulation of the setup have lead to a better understanding of the device.

Development of a novel platelets functional assay using QCM

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Abstract: Establishing a quick and precise method to differentiate between activated and inhibited platelets has always been a challenge in clinical practice. Yet, by immobilizing thrombin on the surface of a Quartz Crystal Microbalance (QCM) this challenge was fulfilled. The initial results are very promising: they showed persistent and reliable immobilization of thrombin even after several steps of washing and coagulation on the surface.

Keywords: Platelets, activatable and inhibited platelets, Thrombin, coagulation sensor

Introduction

Platelets play an important role in blood coagulation. Differentiating between activatable ("normal") and inhibited platelets using a quick method poses a challenge in clinical practice. The aim of this work is to develop a novel platelet function assay, to monitor the blood coagulation of human whole-blood samples in real time, using quartz crystal microbalance (QCM) biosensors [1] & surface plasmon resonance (SPR). This was achieved by immobilizing thrombin on the QCM surface. For that intension sensor surfaces are modified with 3-mercaptopropionic acid followed by attaching a functional group through EDC/NHS (1-ethyl-3(3-dimethylaminopropyl) carbodiimid / N-Hydroxysuccinimid) [3]. breyAfter successful immobilization of thrombin on the surface and generating a clot, we begun to develop molecularly imprinted polymers (MIP). Such sensor layers are expected to be highly selective and useful for detecting target species in complex environments [2].

Results and Discussion

Thrombin was successfully immobilized by the functionalization of 3-mercaptopropionic acid on QCM surface. Successful covalent binding of thrombin on the QCM surface (see Fig. 1; frequency shift of -120Hz) turned out highly stable, even after several times of washing with PBS buffer. As Fig. 1 also shows, that blood clots were able to be generated on the sensor surface by adding $CaCl_2$ (0,026 mM) (observed shift was 400 HZ). Changes were observed in frequency due to platelet activation (interaction with thrombin and $CaCl_2$). Such a frequency change could not be observed when the platelets were inhibited via the intake of Aspirin. Accordingly, the observed frequency change served as an indication of the difference between activatable (normal) and inhibited platelets.

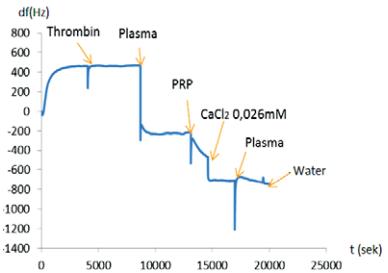

Figure 1: Change in frequency (400Hz) due to platelet activation (interaction with thrombin and $CaCl_2$).

Conclusions

In the early experiments, platelet functional state was successfully monitored the in real time and it was possible to differentiate between activatable vs. inhibited ones. Further investigation will address the following questions: Do various concentrations of thrombin, CaCl2 and aspirin play a significant role in the aggregation of platelets and which polymers are most suitable to generate MIPs? Using atomic force microscopy (AFM) would enable us to measure "surface structuring" of imprinted materials.

References

[1] G. Sauerbrey, *Zeitschrift für Physik* ***155***, 206 – 222 (1959).

[2]] F. L. Dickert, *Anal Bioanal Chem* ***377***, 540 – 549 (2003).

[3] S. Sinn, L. Müller, H.Drechsel, M.Wandel, H.Northoff, G.Ziemer, H.P.Wendel and F.K.Gehring, Analyst. **135** (11), 2931 (2010).

Real-time monitoring of self-assembling monolayer formation using the heat-transfer method HTM

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Abstract: This work reports on monitoring the formation of alkanethiol self-assembled monolayers at gold/ethanol interfaces by means of a recently developed surface-sensitive technique, the heat-transfer method HTM. Upon thiol adsorption and layer formation, the heat-transfer resistance increases considerably as compared to a blank gold/ethanol interface. The amplitude of the effect and the time constants for layer formation show a systematic dependence on the thiol concentration.

Keywords: alkanethiols, self-assembled monolayers, heat-transfer method, thin films

Introduction

Thiol self-assembled monolayers (SAMs) are molecular assemblies of organic constituents formed spontaneously by the adsorption process of molecules in liquid- or vapour phase on metal- or metal-oxide surfaces. Over the last decades, SAMs have become popular due to their utility for different applications ranging from biosensing platforms to nano- and microfabrication [1]. Therefore, real-time monitoring of SAMs, along with studying their kinetics and their thermal-transport characteristics is important. In this work the novel heat-transfer method is used, for which already a variety of applications is documented, in order to verify whether SAMs show a heat-blocking effect similar to *e.g.* DNA layers or adsorbed cells [2].

Results and Discussion

To investigate SAM formation on gold substrates, 11-mercaptoundecanoeic acid (a thiol) was selected. Its COOH terminal group makes it particularly useful for linker applications in biosensors. The results indicate that the presence of a SAM on the gold surface leads to a surprisingly strong increase of the interfacial heat transfer resistance R_{th}, given the fact that thiol molecules are only 1.5 nm in length. As shown in Figure 1, there is a jump in R_{th} for all concentrations and the jump height increases with increasing concentration. For concentrations below 0.5 mM, R_{th} displays a two-step evolution: First, the level of the R_{th} signal stays the same as with a blank gold substrate, secondly it increases gradually with time until reaching a stable plateau. This reflects the transition from a lying-down- to a standing-up conformation, which increases the thickness of the SAM layer, resulting finally in a time-independent plateau.

Complementarily, the layer formation was studied with the quartz crystal microbalance, Fourier-transform infrared spectroscopy, and atomic force microscopy, confirming that the pronounced heat-blocking effect is caused by thiol monolayers and not by multilayers.

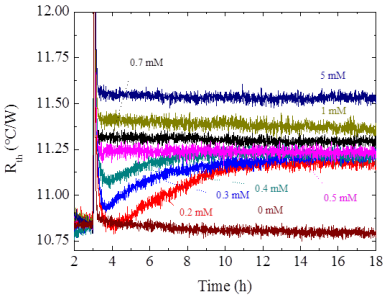

Figure 1: Heat-transfer resistance R_{th} as a function of time for all thiol concentrations under study.

Conclusions

The results demonstrate that a nanometer thin thiol 'carpet' causes an unexpectedly strong heat-blocking effect at gold/ethanol interfaces. The nominal thermal resistance of the layer is by orders of magnitude higher than in case of conventional thermal-insulator materials. This observation points to an interface effect, which can possibly be explained by the mismatch between the phonon frequencies of gold and the vibration frequencies of ethanol- and thiol molecules in the tera-Hz regime.

References

[1] C. Vericat, M.E. Vela, G. Benitez, P. Carro and R.C. Salvarezza, *Chem. Soc. Rev.* **39**, 1805 – 1834 (2010).

[2] B. van Grinsven, K. Eersels, M. Peeters, P. Losada-Pérez, T. Vandenryt, T.J. Cleij and P. Wagner, *ACS Applied Materials & Interfaces* **6** (16), 13309 – 13318 (2014).

Acknowledgements

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Application of a bienzyme sensor setup for the amperometric detection of alcohols in biogas processes

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Abstract: Biogas production relies on the anaerobic digestion of organic material by a multitude of microorganisms, which produce in a first step organic acids and alcohols. These compounds are the basis for the formation of methane. In order to get an improved understanding of the complex procedures inside biogas plants, comprehensive monitoring devices are required. In this regard, an amperometric biosensor is presented, which is based on an alcohol dehydrogenase in combination with a diaphorase from *Clostridium kluyveri*.

Keywords: alcohol, amperometric biosensor, bienzyme electrode, biogas, NADH

Introduction

The production of renewable biogas by anaerobic digestion of organic matter is an attractive alternative to fossil fuels. However, for an efficient conversion of biomass to energy the monitoring of biogas plants is crucial. In the last years, extensive efforts have been made to optimize the methane yield. In this regard, it has been shown recently that supplementation of sludge from biogas plants with acetate and ethanol, resulted in an increased formation of methane [1, 2]. In order to evaluate the effect on the biogas production, versatile monitoring devices are required.

Results and Discussion

Recently, a multi-parameter sensor array for the simultaneous detection of formate, D- and L-lactate has been presented, which is based on the application of specific NAD^+-dependent dehydrogenases [3]. The alcohol concentration in biogas plants is another important parameter for the process monitoring. Therefore, the extension of the multi-parameter sensor setup by implementation of an alcohol sensor is intended. Figure 1 shows the detection principle of the alcohol sensor based on an alcohol dehydrogenase (ADH) and diaphorase (DIA). The ADH converts alcohol to acetaldehyde and thereby, reduces the cofactor NAD^+ to NADH.

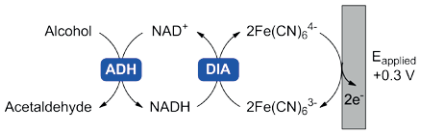

Figure 1: Schematic sensor layout for the detection of alcohols by an amperometric biosensor (ADH, alcohol dehydrogenase; DIA, diaphorase).

Afterwards, the released NADH is regenerated by the DIA. This enzyme reaction uses $Fe(CN)_6^{3-}$ as an electron acceptor, which is reduced to $Fe(CN)_6^{4-}$. The amperometric detection is based on the current, which is generated by oxidation of $Fe(CN)_6^{4-}$ at an applied potential of 0.3V *vs*. Ag/AgCl, depending on the alcohol concentration in the analyte.

Conclusions

Application of the proposed bienzyme alcohol biosensor provides an interesting approach for the analysis of fermentation processes. In order to provide a multi-parameter sensor setup, the DIA-based system can be combined with different NAD^+-dependent dehydrogenases. Thereby, besides alcohol also other substrates like formate and lactate can be monitored. Observation of different parameters enables an improved understanding of the complex fermentation processes inside a biogas plant.

References

[1] S. Refai, K. Wassmann, S. van Helmont, S. Berger and U. Deppenmeier, *Journal of Industrial Microbiology and Biotechnology* **41**, 1763-1772 (2014).

[2] A. Weiss, V. Jérôme, D. Burghardt, L. Likke, S. Peiffer, E.M. Hofstetter, R. Gabler and R. Freitag, *Applied Microbiology and Biotechnology* **84**, 987-1001 (2009).

[3] J. Pilas, H. Iken, T. Selmer, M. Keusgen and M.J. Schöning, *Physica Status Solidi (A)*, DOI: 10.1002/pssa.201431894 (2015).

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Label free detection of prostate-specific antigens using Si-NW FETs

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Abstract: A label-free, electrical biosensor platform based on silicon nanowire field-effect transistors (SiNW FETs) for the detection of Prostate Cancer (PCa) biomarkers namely the Prostate-Specific Antigen (PSA) is demonstrated. SiNW FETs fabricated by a newly developed nanoimprint lithography process and in a special dip-chip configuration were surface modified with PSA-specific receptors and deployed as field-effect based sensors. Using optimal chemistry on the surface of the Si NW, the sensors are able to translate the biomolecular interaction between PSA and PSA-specific aptamers in high ionic concentrations, and therefore establishing a reliable platform towards the development of a real diagnostics platform for early screening of PCa.

Keywords: Silicon nanowire field-effect transistor, prostate specific antigen

Introduction

Semiconducting one dimensional FETs are promising candidates for direct, label-free and real time electrical detection of biomarkers with high sensitivity and selectivity [1-2]. In this work SiNW FET sensor arrays are realized by a top down-process on silicon-on-insulator substrates [2]. The aim of this work is to design such a SiNW FET sensor array for simultaneous detection of multiple PCa biomarkers. The new sensor concept is designed such that electronic detection can be combined with optical detection.

Results and Discussion

The schematic for the SiNW FET sensor platform is shown in Fig. 1. The SiNW chip consists of 8 sets of four SiNWs (6 µm in length and 0.2 µm in width) with a common source and separated drains. The contact lines have equal resistance (with parts of contact lines metallic in order to minimize the resistance) and capacitance in order to have identical electrical characteristics for all the sensor positions on a chip. The NWs are arranged at one edge of the chip in order to allow for an easy testing of biomarkers just by dipping into the test solutions (dip-chip configuration). In the optimized fabrication process, the performance of SiNW devices is improved by boron doping of the source and drain contact lines to reduce the serial resistances, while retaining the high carrier mobility of the SiNWs channels [2]. The chips are passivated by a thick layer of SiO_2 (300 nm) in order to prevent the leakage current and to provide isolation from external environment in the contact line regions. A thin SiO_2 layer (6-8 nm) is used as gate dielectric for SiNWs. Each of the NW sets on a chip can be immobilized differently using a micro spotting technique and an electrical readout can be obtained for different biomarkers binding, simultaneously and without an overlap from neighbouring sets. The SiNW FETs are first deployed as PSA detectors and show high reproducibility and accuracy. Further, the SiNW FETs will be realized on transparent substrates in order to realize parallel optical detection complimenting the electrical assays and to investigate the sensing mechanisms. This opto-electronic method of detection will be implemented 'on chip' by a novel top-down nanoimprint lithography (NIL) SiNW fabrication process on transparent substrates like sapphire (Al_2O_3), etc.

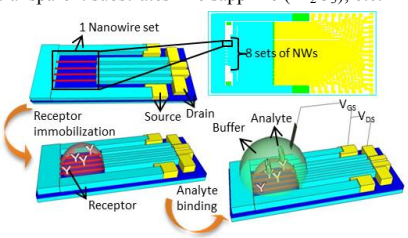

Figure 1: SiNW FET chip design and sensing mechanism.

Conclusions

Preliminary sensing experiments have been carried out on newly fabricated SiNW FETs. Furthermore sensing limit of these sensors will be evaluated in the next experiments.

References

[1] S. K. Arya, S. Sahab, J. E. Ramirez-Vick et al., *Analytica chimica Acta* **737** (1), 1-21 (2012).

[2] X. T. Vu, R. Stockmann, B. Wolfrum, et al., *Phys. Status Solidi A* **207** (4), 850-857 (2010).

Acknowledgements

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Rapid prototyping of microfluidic devices for on-chip cell assay combined with a chemical imaging sensor

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Abstract: 3D-printing of the channel structure is an effective approach to design and fabricate microfluidic devices. In this study, the 3D-printing technique was applied to rapid prototyping of microfluidic devices combined with a chemical imaging sensor. The developed device realizes visualization of chemical species inside the microfluidic channel, which is expected to be applicable to on-chip cell assay.

Keywords: microfluidic device, 3D printer, chemical imaging sensor

Introduction

Cell assay is an essential test in biology, medicine and pharmacology, in which the effect of chemicals are examined by measuring the response of cells. Although a cell assay based on a microfluidic device is promising for laboratory analysis and clinical applications, (a) pricey fabrication of microfluidic devices and (b) monitoring method inside the channel remain as challenges to be overcome. Here, it is proposed to develop on-chip cell assay devices with the help of rapid prototyping by 3D-printing and visualization by the chemical imaging sensor [1] based on the principle of the light-addressable potentiometric sensor [2].

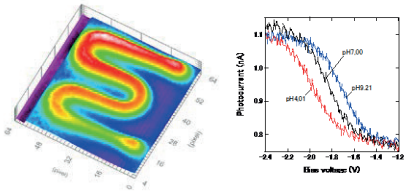
Results and Discussion

Figure 1a shows a design of the channel structure. The height and width of the channel were 1 mm and 1.5 mm, respectively. In Figure 1b, the channel was mounted on the sensor. The channel structure was printed by a resin-based 3D printer, and was bonded onto the sensing surface of the chemical imaging sensor.

(a) (b)

Figure 1: (a) Design of the channel structure for 3D-printing. (b) Implementation of the 3D-printed channel for chemical imaging.

Figure 2a presents an example of a chemical image, in which the whole area inside the channel was clearly observed. Figure 2b depicts the response of the photocurrent characteristics to pH changes, in which a potential shift was observed depending on the particular pH value. These results suggest the free addressability of measurement inside the channel.



(a) (b)

Figure 2: (a) Chemical image inside the channel and (b) response of photocurrent characteristics to pH change.

Conclusions

Combination of a chemical imaging sensor with a microchannel structure fabricated by a 3D printer was demonstrated. A PDMS channel fabricated with a 3D-printed mold is used for cell culture. Application of the device for wound-healing assay is also proposed.

References

[1] M. Nakao, T. Yoshinobu and H. Iwasaki, *Sensors and Actuators B* **20**, 119-123 (1994).

[2] D. G. Hafeman, J. W. Parce, H. M. McConnell, *Science* **27**, 1182-1185 (1988).

Acknowledgements

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Session B

B

Session B - Tutorial
Enzymes and Catalysis on Interfaces

Enzymes are the protein catalysts that nature uses in all metabolic processes for energy generation, storage and even defense purposes. Whenever we produce enzymes or apply them technologically, they interact with surfaces or interfaces. E.g. in downstream processing, enzymes adsorb to chromatographic resins, in a catalytic reactor they either interact with the vessel, membrane or liquid surface and finally, immobilised catalytic enzymes are hopefully beneficially bound non-/covalently to a carrier material. In order to identify suitable materials, we need to understand quantitatively, how the surface interaction changes the enzyme activity, selectivity, and stability. This tutorial lecture will cover the basics of enzyme kinetic analysis to yield information on activity, selectivity and stability. Concepts of coupled transport and reaction serve as a quantitative basis for the interfacial effects on enzymes. A range of examples covering kinetic analysis, enzyme immobilisation, degradation of biomass particles, and liquid/gas/solid interface effects will accompany the theoretical fundament.

Prof. Dr. A. Spieß

Antje C. Spiess has studied chemical engineering at Technical University Hamburg-Harburg and Pisa University, she did her PhD at TU Hamburg-Harburg and gained industry experience at Procter & Gamble before pursuing her habilitation research in Biochemical Engineering at RWTH Aachen University in the field of enzymes in non-conventional media and for biomass conversion. In 2010 Antje Spiess became professor for Enzyme Process Technology at Aachener Verfahrenstechnik, RWTH. One year later, she joined DWI's scientific board which became Leibniz-Institute in 2014. Her research focusses on biocatalytic and chemical engineering and modeling of reaction kinetics.

Cu-Ni thin film combinatorial library for electrochemical oxidation of glucose

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Abstract: The electrocatalytic oxidation of glucose was investigated on a wide range Cu-Ni combinatorial library in alkaline solution. A flow-type scanning droplet cell was used for electrochemical studies on Cu-Ni combinatorial thin films. Cyclic voltammetric measurements showed the occurrence of the glucose oxidation in a certain compositional spread (1.8 at.% Ni to 12.5 at.% Ni).

Keywords: glucose oxidation, thin combinatorial library, scanning flow cell microscopy

Introduction

Glucose sensors have attracted much attention due to their applications in biological systems, food analysis, clinical detections and environmental monitoring. Therefore, cheap, sensitive and non-enzymatic electrochemical glucose sensors are investigated. Ni based alloys have been investigated due to their electrocatalytic activities for oxidation reactions [1].

Results and Discussion

A Cu-Ni thin film combinatorial library was obtained from a co-deposition physical vapour process. Using scanning electron microscopy (SEM), X-ray fluorescence spectroscopy (XRF) and X-ray diffraction (XRD) microstructure, composition and crystallographic properties were investigated. The electrochemical properties of the glucose, formaldehyde and hydrazine oxidation were studied using a 3D-printed flow type scanning droplet cell microscope (FT-SDCM) for electrocatalytic screening along the Cu-Ni thin film combinatorial library. Cyclic voltammetric measurements were performed to show the occurrence of formaldehyde and hydrazine oxidation in a certain compositional spread (1.8-12.5 at.% Ni). Chronoamperometric measurements at different concentration of each component showed that the Cu-Ni thin film combinatorial library can perform as electrochemical sensor. Further, the Cu-Ni thin film alloy shows a good reproducibility and stability in electrocatalytic oxidation of glucose.

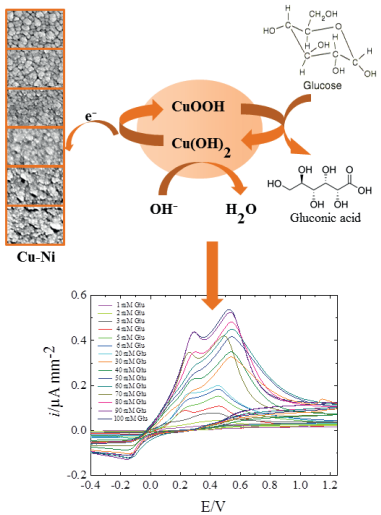

Figure 1: A suggested mechanism for the oxidation of Glucose (Glu) at Cu-Ni thin film library in alkaline solution.

Conclusions

In this study the electrochemical behaviour of Cu-Ni was characterized. Further, its influence on the electrocatalytic oxidation of glucose and its sensing properties can be determined. The sensor mechanism is directly linked to the electrocatalysis of the oxidation of glucose. Therefore the electrocatalytic activity of thermally evaporated copper nickel thin film combinatorial library was investigated in alkaline solution.

References

[1] R. L. Shervedani, M. Karevan and A. Amini, *Sensor Actuat B-Chemical* **204**, 783–790 (2014).

B 1

On the activation and stability of electrodeposited fourth row transition metals onto Au studied by in situ XAS

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Abstract: The activation of gold in catalytic reactions is a topic of intensive research yielding a good catalyst with excellent activity and selectivity. The electrochemical activation of Au by means of electrodeposited transition metals of fourth row was investigated. Their activity and chemical characterization was performed by means of *in situ* XAS-FY revealing aspects such as electronic structure under reaction conditions.

Keywords: Au activation, overpotential deposition, fourth row transition metals, in situ XAS

Introduction

Gold is by far the most noble and the least active electrocatalytic metal. Meanwhile bulk Au is a poor catalyst, the addition of other molecules has shown exceptional activity and selectivity [1]. Thus, nanoparticles exhibit unusual activity when they are dispersed onto oxide support. The variation in the electrochemical activity of electrochemically activated Au thin film with fourth row transition metals was investigated. Although it is of great importance the analytic techniques are still very limited, in most cases the electrochemists act blindly as they do not have the ability to accomplish electrochemical data with direct experimental characterization. Using a thin membrane of Si_3N_4 (100 nm thick) with a Au thin film electrode (20 nm) deposited on top of the membrane (see figure 1.a) the complex electrochemical reactions were monitored under working conditions [2].

Results and Discussion

Figure 1.b shows the CV (recorded at 20 mV/s) overpotential deposition of Cu onto Au electrode collected in our electrochemical *in situ* XAS cell with 1 mM $CuSO_4$, Pt counter and Ag reference electrodes. The voltammogram shows a cross-potential (V_C) at around -0.4 V indicating the equilibrium potential of the metal redox couple (Cu^{2+}/Cu^0). Peaks A, B, and C are associated with the dissolution of chemically deposited copper or with the oxidation of Cu rich in OH-groups. The electrodeposition was performed at V_d = -0.6 V. It was monitored by *in situ* XAS revealing an increase of the signal intensity of a Cu_2O (Cu^+) as the spectra show (see figure 1.c bottom curve). Further, it is possible to control the chemical state of the electrodeposited copper just by applying a potential as figure 1.c shows. Thus the application of a positive bias induces the formation of CuO (Cu^{2+}) species (red curve) [3]. This experiment proves the capabilities of this setup in order to monitored the chemical changes induces by the applied potential.

Conclusions

Using this approach the structure and the chemical activity of different electrodeposited fourth row transitions metals was revealed. These results will be widely discussed and presented at the conference.

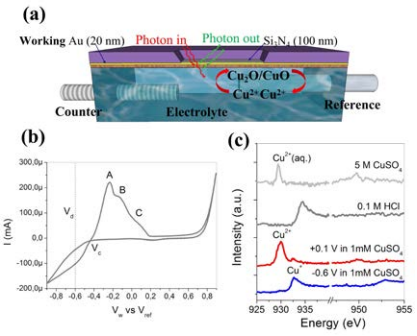

Figure 1: (a) Schematic of the in situ electrochemical XAS cell. (b) CV of overpotential deposition of Cu. (c) Chemical state of the electrodeposited Cu depending in different conditions such as bias and electrolyte.

References

[1] J.A. Rodriguez et al., *Accounts of chemical research* **47** (3), 773-782 (2013).

[2] J.J. Velasco-Velez et. al., *Science* **346** (6211), 831-834 (2014).

[3] P. Jiang et al., *Electrochemical communications* **12** (6), 820-822 (2010).

Acknowledgements

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Investigation of cobalt-nickel material libraries obtained from electrodeposition using different complexing agents

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Abstract: This work focuses on the fabrication of cobalt-nickel material libraries, exhibiting a wide spread composition gradient and the evaluation of different complexing agents added to the electroplating bath. As cobalt-nickel alloys show activity for non-enzymatic glucose sensing applications, glucose detection was performed using scanning droplet cell microscopy (SDCM).

Keywords: Co-Ni electrodeposition, material libraries, Hull cell, glucose sensing

Introduction

The cobalt-nickel electroplating system is under most conditions characterised by the peculiarity of anomalous codeposition, which is the enhanced tendency of a less noble metal to be deposited in the presence of a nobler one. Moreover, cobalt-nickel is usually electrodeposited from simple salt baths in the absence of complexing agents. Nevertheless the addition of complexing agents to the electroplating bath can lead to improved film properties [1]. By using a modified Hull cell and suitable electroplating conditions combinatorial alloy material libraries exhibiting a composition gradient can be fabricated [2]. Electrodeposition of cobalt-nickel material libraries from simple salt baths has already been studied extensively [3]. In this work the effect of several complexing agents added to the electroplating solution on the cobalt-nickel material libraries is evaluated. Furthermore, cobalt-nickel is a highly sensitive and promising material for non-enzymatic glucose sensing applications [4].

Results and Discussion

Different complexing agents (glycine, trisodium citrate, tetrasodium pyrophosphate, tartaric acid, malic acid) have been studied in terms of their effects on the composition and properties of cobalt-nickel material libraries.

It was found, that by addition of complexing agents the cobalt-nickel system can be tuned from anomalous towards normal codeposition behaviour. Furthermore, especially glycine and trisodium citrate have a positive influence on the appearance of the cobalt-nickel films and reduce surface defects in number as well as in size.

To identify the effect of the respective complexing agent cyclic voltammetry was performed. The composition of the cobalt-nickel material libraries was determined by scanning XRF. Further characterisation of the cobalt-nickel samples was carried out by SEM, to evaluate the surface morphology, and by XRD, giving information about the crystallographic structure.

Using SDCM the whole composition range on a material library can be studied concerning its sensitivity and activity for glucose sensing.

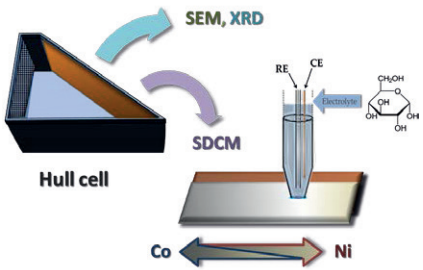

Figure 1: Electrodeposition of cobalt-nickel material libraries using a Hull cell and further characterisation.

Conclusions

Cobalt-nickel films have emerged as highly interesting material for glucose detection. In this context SDCM represents a powerful method for electrochemical investigation of combinatorial material libraries.

References

[1] A. Brenner, Electrodeposition of Alloys Vol. 1 (Academic Press, New York, 1963).

[2] S. D. Beattie and J. R. Dahn, *Journal of the Electrochemical Society* **152**, C542-C548 (2005).

[3] C. D. Grill, J. P. Kollender and A. W. Hassel, *Physica Status Solidi A* (2015), doi: 10.1002/pssa.201431715.

[4] L. Wang, X. Lu, Y. Ye, L. Sun and Y. Song, *Electrochimica Acta* **114**, 484–493 (2013).

B 3

Enzymatic biofuels cells based on direct enzyme-electrode contacts using modified carbon nanotube materials

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Abstract: Two types of carbon nanotubes bucky paper (BP) and vertically aligned carbon nanotubes (vaCNTs) materials are used for the development of glucose/oxygen enzymatic biofuel cells. After modification of these electrode materials the directly contacted enzymes pyrroloquinoline quinone dependent glucose dehydrogenase ((PQQ) GDH) and bilirubin oxidase (BOD) allow a maximum power density of 107 µW/cm^2 for the BP-based fuel cell and 122 µW/cm^2 for the vaCNT-based.

Keywords: biofuel cell, PQQ-dependent glucose dehydrogenase, bilirubin oxidase, bucky paper, vertically aligned carbon nanotubes

Introduction

A high power output of EBFC can only be achieved when an efficient communication between enzyme and electrode is established. The most efficient way is the direct electron transfer (DET) where current flow starts near the E^0 of the enzyme redox center. In addition a power output loss due to a compartmentalisation can be avoided by a membrane-less BFC. (PQQ) GDH is an interesting enzyme with this respect since it is insensitive towards oxygen - the terminal electron acceptor on the cathode. Poly(3-aminobenzoic acid-co-2-methoxyaniline-5-sulfonic acid (PABMSA) modified BP and vaCNTs are used for anode preparation with the glucose oxidising (PQQ) GDH. For the cathode the oxygen reducing BOD is covalently coupled to PQQ modified BP and vaCNTs electrodes. Both electrodes are characterized separately and in combination as BFC.

Results and Discussion

The examination of different anode preparations via linear sweep voltammetry shows that the modification of both carbon nanotube electrodes with an aniline-based polymer film (PABMSA) and covalent enzyme coupling allows a direct communication of the enzyme with the electrode. The influence of the polymer concentration and the buffer composition on the current density is investigated. A maximum current density of 1.3 µA/cm^2 can be achieved with vaCNTs in 10 mM glucose containing 100 mM citrate phosphate buffer applying 5 mg/ml PABMSA for modification (fig 1). Similar experiments are done for the cathode. The approach with PQQ as interface and a covalent attachment of the BOD to a BP based electrode shows the highest catalytic current under air saturation – about 1 mA/cm^2 at 0.1 V vs. Ag/AgCl. The vaCNT based electrode reveals a local maximum current of 1.3 mA/cm^2 and a steady-state catalytic current of 550 µA/cm^2 at +0.1 V vs. Ag/AgCl.

The resulting BP based EBFC achieves a power output of 107 µW/cm^2 and the vaCNTs based EBFC 122 µW/cm^2.

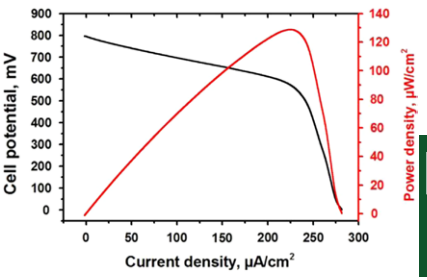

Figure 1: Performance curves of a vaCNTs based BFC with a (PQQ)GDH/PABMSA/vaCNT-anode and a BOD/PQQ/vaCNT-cathode.

Conclusions

The separate investigation of the anodes and cathodes shows a high suitability of vaCNTs as transducer material for the enzymes in BFCs. However both carbon materials result in rather similar performances.

Acknowledgements

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B
4

Supramolecular architectures of cellobiose dehydrogenase and cytochrome *c* on electrodes using artificial matrices

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Abstract: Supramolecular architectures open the potential for coupling enzymes at a high integration density on electrodes surfaces. DNA and SiNPs are used as a biocompatible matrix for the self-assembly of cytochrome *c*/cellobiose dehydrogenase adducts.

Keywords: layer-by-layer, biohybrid surfaces, bioelectrocatalysis, protein assembly, multilayer architectures

Introduction

The use of biological redox processes for the construction of sensors is a rather promising approach.[1] A spotlight here is the confinement of the catalytic reaction onto the electrode surface. Numerous attempts to arrange proteins as monolayers have been successful,[2,3] but there is a need to increase the density of biological functional units, i.e. going beyond the monolayer arrangement. A major advance was made by the use of the layer-by-layer self-assembly technique, leading to a significant increase in protein surface concentration. A number of protein multilayer designs have been reported which are stabilized by a polyelectrolyte or metallic nanoparticles. Such multilayer assemblies have been shown to allow incorporation of enzymes and establish communication to the electrode, thus allowing the construction of analytical signal chains.[4,5,6]

Results and Discussion

Here, the focus has been on the formation of bi-protein assemblies using cyt *c* as a redox protein, cellobiose dehydrogenase (CDH) as enzyme and DNA as second building block for the construction of new supramolecular architectures. CDH can be incorporated into the protein multilayer arrangement in an active form, thus an electron transfer chain from lactose *via* CDH and multiple cyt *c* molecules toward the electrode can be constructed.

In this study the layer-by-layer technique with DNA for the formation of catalytically electroactive bi-protein multilayer electrodes has been applied. Furthermore the effect of the second building blocks on the formation and electron transfer properties of such architectures are investigated. The conditions of assembly formation and stability are determined by QCM, REM, and AFM. The electrochemical properties of the multilayer arrangements are analyzed by cyclic voltammetry (CV). The second building block significantly influences the layered assembly and the electron transfer chain from substrate to the electrode. The influence of silica nanoparticles (SiNPs) as another second building block has been compared to DNA and is systematically investigated.

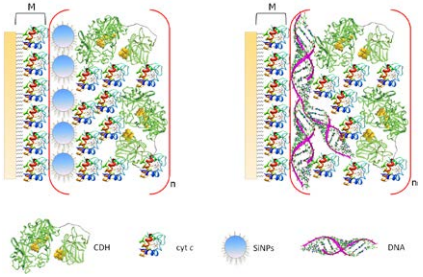

Figure 1: Schematic representation of DNA/cyt c•*CDH architectures prepared on a cyt* c *monolayer electrode (M). Layered architectures [DNA/cyt* c•*CDH]$_n$ (n = 1, 2, 3, 4).*

Conclusions

Supramolecular architectures using artificial matrices exhibit the potential for going beyond the two dimensional limitation in coupling enzymes to electrode surfaces.

References

[1] I. Willner et al., *Angew. Chem. Int. Ed.* **39** (7), 1180-1218 (2000).

[2] M. Fedurco et al., *Coord. Chem. Rev.* **209,** 263-331 (2000).

[3] T. Daido et al., *J. Electroanal. Chem.* **344**, 91-106 (1993).

[4] F. Lisdat et al., *Chem. Commun.* 274-283 (2009).

[5] S. C. Feifel et al. *Langmuir* **28** (25), 9189-9194 (2012).

[6] Wegerich et al., *Langmuir* **27** (7), 4202-4211 (2011).

Acknowledgements

Financial support by DFG, Germany (Li706/7-1) is kindly acknowledged.

Mobility of a supported lipid bilayer on dispersed single-walled carbon nanotubes

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Abstract: The mobility of a supported lipid bilayer spread on a carpet of carbon nanotubes has been studied by fluorescence recovery after photobleaching and scanning force microscopy.

Keywords: supported lipid bilayer, carbon nanotubes, fluorescence recovery after photobleaching

Introduction

Due to their high charge mobility, size compatibility and all carbon nature, carbon nanotubes (CNTs) have a large potential to be used as transducers in electrochemical biosensors [1]. Their combination with lipid membranes represents an important step towards engineering of bionanoelectronic interfaces, as biomembranes represent a nearly universal immobilization matrix for a large variety of protein machineries. However, the interaction between single-walled (SW) CNTs, surfactants and lipid bilayers is poorly understood so far. Here the mobility of a supported lipid bilayer (SLB) that is spread on a thin carpet of SWCNTs was studied by fluorescence recovery after photobleaching (FRAP). The sample morphologies were characterized by scanning force microscopy (SFM). Based on these results, a model for the description of molecular interaction within the hybrid structures was developed.

Results and Discussion

SWCNTs were dispersed using different surfactants such as sodium taurodeoxycholate (TDOC, sodium cholate (SC) and single-stranded DNA (ssDNA) and spread on mica sheets. On top of the CNT carpet a SLB formed by the zwitterionic phospholipid 1,2-dioleoyl-*sn*-glycero-3-phosphocholine was assembled. The mobility of the SLB was characterized by FRAP, i.e. a spot of the fluorescently marked SLB was bleached and the recovery of the fluorescence in this spot due to the diffusion of unbleached molecules from the surrounding studied. This allows the determination of the diffusion coefficient of the SLB [2]. As control, the fluidity of the SLB on a bare mica surface was measured to be 3.7 ± 0.3 µmsec^{-1}, which is in good agreement with values, determined by fluorescence correlation spectroscopy (4.2 ± 0.4 µmsec^{-1}) [3].

The studies reveal that the fluidity of the SLB is almost undisturbed by the TDOC-SWCNT. SC-SWCNTs show more reduction, whereas the highest impact on the fluidity was observed for SWCNTs dispersed by single-stranded DNA.

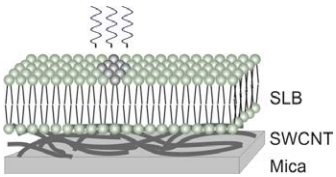

Figure 1: Set-up of the sample with the SWCNT network spread unto the mica and the assembled SLB.

Conclusions

The combined FRAP and SFM study provide insight into the assembly on CNT networks. The observed results depend on the surfactant used for CNT dispersion. In agreement with previous studies, SC is adsorbing less ordered on the SWCNTs. Thus, the diffusion of the supported lipid bilayer is reduced compared to TDOC, which is comprising of a longer side chain, and thus, a more homogenous coverage of the CNTs. The lipid bilayer spread on a network of SWCNTs dispersed by ssDNA has the lowest diffusion constant because DNA covers only part of the CNT surface in this case.

References

[1] C. Jacobs, J. Peairs and J. Venton, *Analytica Chimica Acta* **662,** 105-127 (2010).

[2] D. Axelrod, D. Kopel, J. Schlessinger, E. Elson and W. Webb, *Biophysical Journal* **16**, 1055-1069 (1976).

[3] A. Benda. M. Benes, V. Marecek, A. Lhotsky, W. T. Hermens and M. Hof, *Langmuir* **19**, 4120-4126 (2003).

Acknowledgements

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Sensor system for *in-situ* and real-time monitoring of polymer (bio)degradation

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Abstract: A sensor system for investigating (bio)degradation processes of polymers is presented. The system utilizes semiconductor field-effect sensors and is capable of monitoring the degradation process *in-situ* and in real-time. The degradation of the polymer poly(D,L-lactic acid) is exemplarily monitored in solutions with different pH value, pH-buffer solution containing the model enzyme lipase from *Rhizomucor miehei* and cell-culture medium containing supernatants from stimulated and non-stimulated THP-1-derived macrophages.

Keywords: Field-effect sensor, enzymatic (bio)degradation, poly(D,L-lactic acid), degradation monitoring

Introduction

(Bio)degradable polymers have become very important for the field of medical applications. Their ability to disappear after a certain period of time or under specific conditions has stimulated the creation of a large number of biomedical devices such as temporary implants, scaffolds for tissue engineering, or drug-release systems. Nevertheless, with regard to precise prediction of the degradation process, a large number of parameters need to be studied concerning their impact on the degradation process.

Recently, a novel sensor system based on field-effect electrolyte-insulator-semiconductor devices has been presented that enables real-time and *in-situ* monitoring of polymer (bio)degradation [1]. Due to its option to monitor multiple devices in parallel, the system provides distinct potential for higher-throughput degradation studies. In this work, the applicability of the sensor system for monitoring of polymer (bio)degradation in different degradation media is demonstrated using the commercial biodegradable polymer poly(D,L-lactic acid) (PDLLA) as model polymer.

Results and Discussion

PDLLA layers of 500 nm thickness were applied on the sensor by means of spin-coating. Several sensors were mounted in separate measurement chambers and exposed to different degradation media: buffer solution of pH 7 and pH 11, buffer solution containing the model enzyme lipase from *Rhizomucor miehei* (LipaseRM), cell-culture medium, and supernatants from THP-1-derived macrophages cell cultures with or without stimulation with tumour necrosis factor-alpha (TNF-α). While an increasing concentration of hydroxide ions and LipaseRM induced a substantial acceleration (Fig. 1, top), none of the substances contained in the cell-culture media indicated any significant effect (Fig. 1, bottom). This implies that macrophage activation of the immune system will not influence PDLLA degradation *in vivo*.

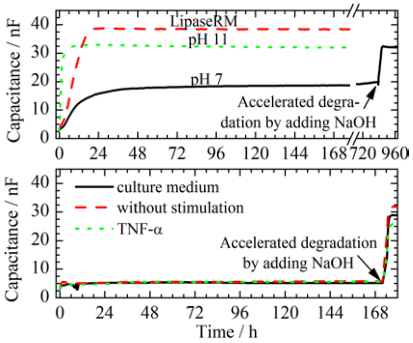

Figure 1: Time-resolved signal of the sensors exposed to pH buffer and enzyme solution (top) and conditioned cell-culture medium (bottom). Progress of polymer degradation is indicated by an increase in the measured capacitance.

Conclusions

The successfully performed experiments and obtained results demonstrate the high potential of sensor-based systems as a novel and promising tool for real-time, *in-situ* electrical monitoring of polymer (bio)degradation.

References

[1] S. Schusser, A. Poghossian, M. Bäcker, M. Leinhos, P. Wagner and M. J. Schöning, *Sens. Actuators B* **187**, 2–7 (2013).

Acknowledgements

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Detection of the peanut allergen Ara h1 by electrochemical impedance spectroscopy and the heat-transfer method

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Abstract: To make the detection of peanut allergens in food faster, easier and cheaper an aptamer based Ara h1 sensor was designed and built. This sensing technique combines electrochemical impedance spectroscopy and the heat-transfer method to detect Ara h1 down to the nanomolar range.

Keywords: aptamers, peanut allergy, Ara h1, electrochemical impedance spectroscopy, heat-transfer method

Introduction

About 1% of the world population is affected by an allergy for peanuts which is the most common cause of fatal-food-related anaphylaxis. Due to the high risk of exposure and the fact that doses of a few milligrams can cause such an allergic reaction, a lot of research has been done towards the detection of these immunogenic proteins. The protein Ara h1 was identified as the culprit in 95% of all allergic reactions to peanuts. To date the assays to detect the Ara h1 allergen rely on the ELISA assay, lateral flow assays and mass spectroscopy all of which are neither cheap nor fast. Aptamers, which are single DNA or RNA oligonucleotides, offer a cheaper and more stable receptor element.

Results and Discussion

Amino (NH2)-terminated Ara h 1 aptamers were covalently attached to carboxylated gold surfaces and to nanocrystalline diamond with hydrogen termination using the EDC coupling chemical route. Subsequently, the functionalized surfaces were used in a setup that combines both electrochemical impedance spectroscopy and heat transfer measurements. The sensor surfaces were placed onto a copper lid which serves as a heat provider. Such an assembly was mounted onto a transparent Perspex flow cell with an inner volume of 110 ml, sealed with a miniature O-ring and fixed with screws. Two miniature thermocouples were placed at the copper backside and at 1.7mm above the surface of the substrate in order to monitor the temperatures of the copper, T1, and of the fluid, T2, respectively. The heat flow was generated with a power resistor with a fixed resistance. For impedance spectroscopy measurements, gold electrodes served as counter electrode within a range of 100 Hz to 100 kHz. Liquids can be exchanged with a syringe-driven flow system. In this work, the aptamer functionalized surfaces were exposed to increasing amounts of Ara h1 in order to acquire response curves. Non-specific binding of the various contaminants that a sample originating from food might bring along are avoided by having the sensor face down to avoid sediments on the sensor while BSA washing is used to block any non-specific binding sites.

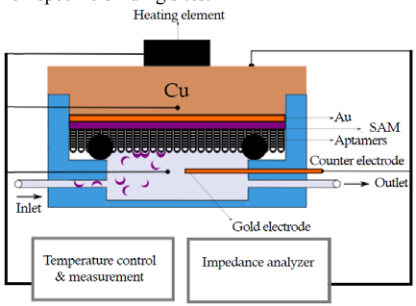

Figure 1: schematic drawing of the flow cell containing a sensor onto which aptamers have been bound using a self-assembled monolayer of thiols and EDC coupling.

Conclusions

Electrochemical impedance spectroscopy and the heat transfer method can be used to detect Ara h1 concentrations down to a detection limit of 3nM. This allows the detection of Ara h1 in a dilution of 50mg peanut butter in a 20.000 times larger volume of buffer solution.

References

[1] M. Peeters et al. Journal of Biosensors and Bioelectronics **5** (3), 155 (2014).

Acknowledgements

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B 8

Controlled transformations in transparent conducting films fabricated from highly stable hydrophilic dispersions of single wall nanotubes

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Abstract: Single wall carbon nanotubes (SWNTs) are considered to be one of the potential candidates for the production of transparent conducting films (TCFs). However, for making optimum usage of the superior properties of SWNTs, a better understanding on the processing and fabrication of thin films is essential. In this work, the effects of the purification conditions applied to SWNTs on the stability of their dispersions as a function of pH and on the quality of the resulting TCFs are studied. The figure of merit (σ_{dc}/σ_{oc}) for such films can be increased by a factor of 2, when the pH of the SWNT dispersion is increased.

Keywords: single wall nanotubes, SWNT, purification, transparent conductors

Introduction

TCFs are integral part of various electronics applications, e.g. organic light emitting diodes, displays, photovoltaic cells and touch panels. Currently, indium tin oxide (ITO) is the commonly used material in such applications due to its excellent combined properties of optical transparency and electrical conductivity. Flexible electronic devices are receiving growing attention as the next generation applications, however, the use of ITO as a TCF in such applications is jeopardized due to its brittle nature [1]. SWNTs are very attractive in these applications due to the fact, that they can be processed in aqueous dispersions at low temperature, which is a key requirement for the fabrication of thin films on low-cost plastic substrates [2].

Results and Discussion

Purification by refluxing in nitric acid was performed in order to remove the metal catalyst particles present in SWNTs. The purification procedure also oxidizes the SWNTs. Various functional moieties are introduced on their surface, e.g. –COOH, –OH and –C=O. After the acid treatment, the purified SWNTs were dispersed in water and transparent thin films were fabricated by doctor blading. The quality of the TCFs was judged by the well-established value of σ_{dc}/σ_{oc}. The influence of the duration of the acid treatment on the properties of the TCFs fabricated from the corresponding acidic SWNT dispersions were examined. Substantial differences in σ_{dc}/σ_{oc} of TCFs prepared from the dispersions of SWNTs treated with nitric acid from two to four hours were observed (Figure 1). Longer reflux durations did not improve the σ_{dc}/σ_{oc} value.

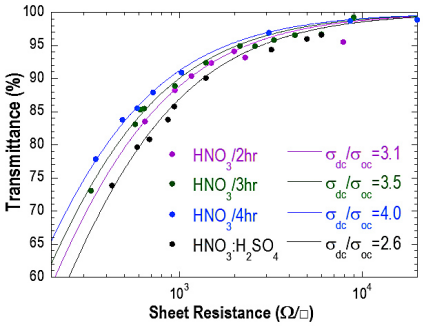

Figure 1: Electrical and optical properties of SWNT TCFs with respect to acid treatment conditions.

Conclusions

Effect of purification SWNTs with nitric acid at different reflux durations have been studied and analysed, based on the σ_{dc}/σ_{oc} value of the TCFs. It was found that the maximum possible σ_{dc}/σ_{oc} for TCFs under optimum purification condition to be 4. The effect of pH of the SWNT dispersion on the electrical and optical properties of TCFs was also studied in detail.

References

[1] D. Cairns *et.al.*, *Appl. Phys. Lett.* **76**, 1425–1427 (2000).

[2] D. Hecht, L. Hu and G. Irvin, *Adv. Mater.* **23**, 1482-1513 (2011).

Acknowledgements

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Electroadsorptive Effect on SnO2 Films

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Abstract: In this work a study on the adsorption properties of a SnO_2 thin film modulated by an electrical field is presented. By applying an electric potential difference between the two faces of a conductor-insulator-semiconductor layered "sandwich" the desorption rate of NO_2 on a SnO_2 surface and its dependence on voltage can be measured.

Keywords: surfaces, electro adsorption, adsorption, thin films

Introduction

Semiconductors can greatly vary their electric resistance in the presence of certain gases, via the generation of surface states. This phenomenon can be promoted or inhibited applying an electrical field perpendicularly to the surface [1]. The observation of this effect in NO_2 adsorbed on a thin SnO_2 film was recently demonstrated by X-ray photoelectron spectroscopy (XPS) [2]. Some issues remained open, such as testing different semiconductor films and different adsorbates. No further study has been performed on the dependence of the adsorption on the applied voltage or on the composition of the desorbed gas. In this work, the identification of the desorbed gases as a function of the applied voltage by mass spectrometry is attempted.

Preliminary Results and Discussion

A metal-insulator-semiconductor layered *sandwich* with SnO_2 as the semiconductor was prepared. A DC potential is applied to the metal layer at the back, with the surface grounded, while the sample is examined by X-ray photoelectron spectroscopy. A mass spectrometer enables the measurement of the partial pressure of the desorbed gasses (Fig 1.). The sample can be transferred from the adsorption chamber to the measurement chamber maintaining an applied potential.

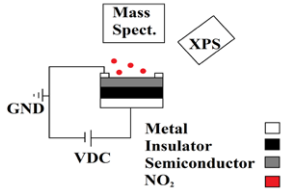

Figure 1: Experimental setup. The sample surface is grounded while a voltage is applied at its back. The sample is exposed to NO2 gas and its surface is measured by XPS, while we observe the desorbed substances using a mass spectrometer.

The semiconductor surface was grounded to avoid any surface charges that may shift the position of our photoelectronic peaks at various DC voltages. The potential at different locations on the sample surface was measured with a point probe while applying +5V and -5V to its back, being zero with differences no larger than 50mV in both cases. However, the XPS spectrum shift is larger, increasing at negative DC voltages (See Fig 2.). This unexpected difficulty is currently being studied.

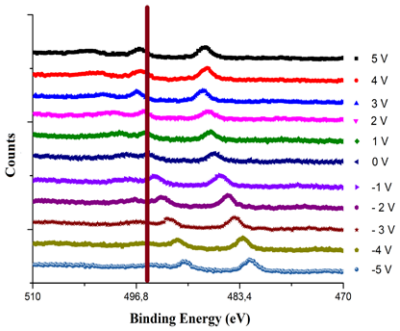

Figure 2: Photoelectric spectrum of the main signal of Sn for various applied voltages on the back cathode. The vertical line passes through the peak of the signal at 0 V.

References

[1] T. Wolkenstein, Electronic Processes on Semiconductor Surfaces during Chemisorption. Consultants (Bureau, New York. 1991).

[2] T. Doll, J. J. Velasco-Velez, D. Rosenthal, J. Avila, V. Fuenzalida, Chemphyschem. **14** (11), 2505–2510 (2013).

Acknowledgements

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Catalytic Graphitization of Mesoporous Carbon CMK-3 by Various Synthesis Approaches to Obtain Improved Electrode Materials

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Abstract: Graphitized porous carbons are applicable as electrode materials, e.g. for metal-air batteries due to improved electrical conductivity and a high surface area as gas-electrolyte interface. Catalytic graphitization is a suitable pathway to graphitize carbons at lower temperatures. Here we show, that catalytic graphitization of ordered porous carbons can be carried out with catalytically active iron oxide species at temperatures below 1000 °C. The results also indicate that the specific catalyst impregnation procedure seems to have a strong influence on the generated pore system.

Keywords: Porous carbon, catalysis, graphitization, electrochemical performance, new battery materials

Introduction

Porous carbon materials are of great interest due to their numerous beneficial properties, e.g. chemical stability, electrical conductivity, high porosity, and low weight. Hence, they are applied in different research fields like catalysis, electrochemistry, gas separation, and biomedical technology [1]. To obtain improved electrode materials, graphitization of porous carbons is carried out. For this process different synthesis pathways are possible [2,3]. Herein, three different pathways for iron oxide catalyst impregnation with subsequent graphitization are presented.

Results and Discussion

The porous carbon CMK-3 (**C**arbon **M**esostructure from **K**orea) was synthesized as reported in the literature [4] and impregnated with an iron oxide catalyst by three different pathways. In brief, CMK-3 was added to a solution of iron(III) nitrate and stirred. For aqueous solutions, the mixture was either treated under hydrothermal conditions or refluxed. For ethanolic solutions, the mixture was dried under vacuum. Subsequently, impregnated materials were graphitized at 700 °C under argon. The graphitized materials were examined by X-ray diffraction (XRD, Fig. 1). Graphitic domains were observed for all impregnation procedures which indicates that iron oxides are suitable catalysts for a catalytic graphitization. Moreover, the catalyst impregnation procedure seems not to influence the graphitization itself. Sorption measurements of the carbon show that, depending on the impregnation conditions, the pore system of CMK-3 is more or less strongly affected. In this connection, temperature and pressure during the impregnation appear to be crucial. The pore systems becoming more and more disturbed the harsher the conditions are. First electrochemical measurements indicate that graphitized CMK-3 has an improved electrical performance compared to non-graphitized CMK-3.

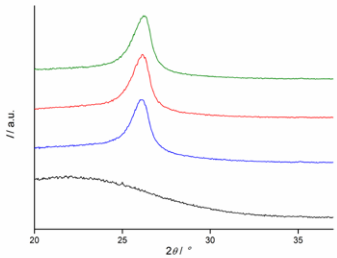

Figure 1: XRD patterns of CMK-3 (black) and the graphitized carbons prepared by different methods: Hydrothermal (blue), reflux (red) and pathway based on ethanolic solution (green).

Conclusions

Iron oxides are suitable catalysts for the graphitization of porous carbon materials. The less harsh the catalyst impregnation conditions are the less the pore system is affected, which is a valuable information with regard to possible applications, e.g. as electrode materials.

References

[1] C. Liang, Z. Li and S. Dai, *Angew. Chem. Int. Ed. Engl.* **47**, 3696–3717 (2008).
[2] M. Xie, J. Yang, J. Liang, X. Gou and W. Ding, *Carbon* **77**, 215–225 (2014).
[3] D. Yuan, X. Yuan, W. Zou, F. Zeng X. Huang and S. Zhou, *J. Mater. Chem.* **22**, 17820–17826 (2012).
[4] S. Jun, S. H. Joo, R. Ryoo and M. Kruk, *J. Am. Chem. Soc.* **122**, 10712–10713 (2000).

Acknowledgements

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Surface effects on the kinetic of the electrochemical deposition of copper on graphite HOPG

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Abstract: Defect induced changes in the electrochemical behavior of highly oriented pyrolityc graphite (HOPG) were studied by electrochemical techniques. The samples were prepared by cleaving commercial HOPG in air and in argon/hydrogen atmosphere, and by ion etching of cleaved samples with argon. The samples were characterized by means of Raman spectroscopy and scanning tunnel microscopy. Cyclic voltammetry and chronoamperometry measurements indicated a decrease in the electrochemical activity of the argon/hydrogen cleaved and the eroded samples, as compared with the samples cleaved in air. This is attributed to hydrogen trapped on the surface of both electrodes.

Keywords: surfaces, electrochemistry, graphite surface

Introduction

Surface properties have a crucial influence in the early stages of deposition. This is particularly true for electrochemical deposition, commonly used to coat large surfaces, where the microscopic effect of those properties on growth is not well known.

Three types of highly oriented pyrolityc graphite (HOPG) samples were prepared:

i) Cleaved in air.
ii) Cleaved in air, argon eroded.
iii) Cleaved in argon/hydrogen atmosphere.

Those samples were characterized by Raman spectroscopy and STM, and then used as working electrodes in an electrochemical cell with a solution of 0.05M of $CuSO_4$, pH 1.

Results and Discussion

The Raman spectra for the argon/hydrogen cleaved sample (fig. 1) detected hydrogen [1]. STM characterization revealed surface structures in the eroded samples.

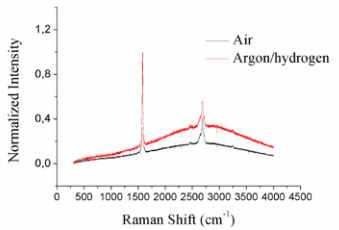

Figure 1: Raman spectra at 632.81nm for samples cleaved on air (black) and on Ar/H_2 (red).

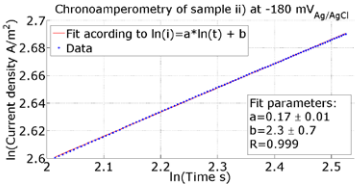

Figure 2: Log-log chronoamperometry of an eroded sample.

Chronoamperometry data were adjusted to a $i(t)=bt^a$ model. The a value adjusted for i) was 0,5, consistent with diffusive transport [2]. For samples ii) and iii) the values were 0,2 and 0,3, respectively, indicating lower electrochemical activity.

Cyclic voltammetry measurements agreed with the chronoamperometric data, showing that the material transport for samples ii) and iii) was slower than diffusive transport.

Conclusions

It is hypothesized that the lower electrochemical activity of the treated samples was caused by the adsorption of hydrogen, present in the vacuum system used to erode the samples.

References

[1] C. Casiraghi, A. C. Ferrari, and J. Robertson, *Phys. Rev. B* **72**, 085401 (2005).
[2] I. Olavarría, Nucleación de cobre por electrodeposición sobre TIO2 [001] (Universidad de Chile, Santiago, 2013) p. 30.

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Catalytic conversion of triaceton triperoxide on different metal oxides

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Abstract: This work presents novel results of catalytic conversion experiments for the degradation of triaceton triperoxide (TATP) on different metal oxides (MO). With this study a better understanding of the processes at the MO surfaces are achieved in order to allow selecting suitable materials for metal-oxide-based semiconductor gas sensors (MOX) for the detection of TATP. For this purpose the degradation of TATP on different MO surfaces is analysed in the temperature range from 50 to 300 °C using FTIR spectroscopy in the gas phase.

Keywords: TATP, catalytic conversion, metal oxides, FTIR spectroscopy

Introduction

The explosive TATP is known for more than 100 years. Due to its quick and easy synthesis combined with its enormous blasting power the interest of terrorist groups in this explosive aroused. This growing threat raised the need to find a reliable detection method for TATP. MOX gas sensors can be used as one possible detection method, particularly in temperature-cycle operation mode [1, 2]. In order to find suitable MOs for the sensitive layer and to understand reactions taking place at the surface, catalytic conversion experiments were performed in the temperature range from 50 to 300 °C. A focus in this work is to clarify why certain MOs show unique reducing or oxidising (red/ox) behaviour in resistance signals when they are exposed to TATP vapour [1]. Therefore, spheres of aluminium oxide were coated with tin-, chromium-, tungsten-, molybdenum-, copper-, iron- and indium oxide and exposed to the gaseous explosive in a reaction chamber. The resulting degradation products were analysed by FTIR spectroscopy.

Results and Discussion

For all examined MOs the main reaction products at low temperatures are small hydrocarbons (HC), above all acetone and acetic acid as well as CO_2. At higher temperatures the ratio between HCs and CO_2 changes to the latter. The main differences between the examined MOs can be found in the temperature dependency of this ratio. For example, at SnO_2 surfaces the dominant degradation product is CO_2 and a nearly complete mineralisation is reached at 300 °C. The reaction at other MOs such as WO_3 at lower temperatures (≤ 150 °C) shows that the ratio between HCs and CO_2 is on the side of the HCs (Figure 1). This indicates that two reactions take place at various MO surfaces at different temperatures. First, TATP is fractured and degrades into smaller HCs, which become fully oxidised in a second step. Different MOs promote either cracking or full oxidation.

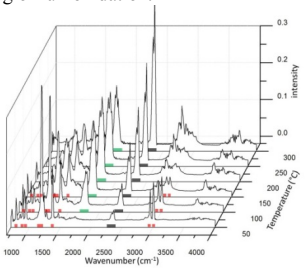

Figure 1: FTIR measurements of TATP degradation from 50 to 300 °C on WO_3. Red lines: TATP bands, green lines: carbonyl region, black lines: CO_2.

These results give a first explanation why WO_3 MOX sensors show unique red/ox behaviour over the studied temperature range [1]. In addition to this, molybdenum (VI) oxide seems to be an interesting candidate for further sensor developments: The FTIR data indicate only a degradation to HCs without further oxidation to CO_2 in a limited temperature zone around 150 °C.

Conclusions

These results contribute to a better understanding of the surface reactions on MOs when they are exposed to TATP. With MO_3, next to WO_3, a second metal oxide could be identified with promising properties to serve as sensitive layer in MOX sensors.

References

[1] J. Warmer, P. Wagner, M. J. Schöning, P. Kaul, *Physica Status Solidi A*, doi:10.1002/pssa.201431882 (2015).

[2] W.-H. Zhang, W.-D. Zhang, and L.-Y. Chen, *Nanotechnology* **21** (31), art. no. 315502 (2010).

Acknowledgements

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Chemical sensors based on the same transducer material of barium strontium titanate

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Abstract: Perovskite oxide of barium strontium titanate (BST) has recently aroused great attention as transducer material for the development of chemical sensors and biosensors for liquids. In this work, two Si-based sensor chips covered with a high-*k* BST layer have been developed for a multi-parameter sensing of charged macromolecules (polyelectrolytes), hydrogen-peroxide vapour, pH value, electrolyte conductivity and temperature. The experimental results of characterization of the individual sensors will be presented.

Keywords: barium strontium titanate, high-*k* material, multi-parameter sensing, hydrogen peroxide, pH, polyelectrolyte, conductivity sensor

Introduction

One of the most intensively studied perovskite oxides is barium strontium titanate (BST). It represents a very attractive alternative transducer material for the development of (bio-)chemical sensors for liquids, due to its multi-functional material properties, high catalytic activity and its large dielectric constant.

In the present study, high-*k* BST thin films have been used for a multi-parameter detection of charged macromolecules (polyelectrolytes), hydrogen-peroxide (H_2O_2) vapour, pH value and electrolyte conductivity. Two Si-based sensor chips were fabricated (s. Fig. 1) and tested. The sensor chip in Fig. 1(a) exhibits interdigitated electrodes covered with BST layer and was used as impedimetric H_2O_2 or polyelectrolyte sensor. Additional meander-shaped Pt electrode serves as thin-film temperature sensor or heater. Fig. 1(b) shows the multi-parameter chip including a capacitively coupled contactless electrolyte-conductivity sensor, a capacitive field-effect pH sensor and a thin-film Pt temperature sensor. The role of the BST layer is of multi-purpose: It serves as a sensitive transducer material for the pH sensor, impedimetric polyelectrolyte and H_2O_2 sensor, as an insulator layer for the contactless conductivity sensor and as passivation layer, which protects the metal electrodes from corrosion and fouling.

Results and Discussion

The BST films of $Ba_{0.25}Sr_{0.75}TiO_3$ composition (with different thicknesses of 100 and 485 nm and dielectric constants of ~190 and ~265, respectively) were prepared by pulsed laser deposition technique. The developed BST-based IDE sensor exhibits a distinct dependence on the concentration of the H_2O_2 vapour, whereat a stepwise increase of H_2O_2 concentration resulted in a decrease of the sensor resistance. The electrostatic adsorption of positively charged PEI on the negatively charged BST surface noticeably affects the real part of the sensor impedance decreasing its value. The pH sensor shows a nearly-Nernstain pH sensitivity of 57-58 mV/pH in the range from pH 2 to pH 12 and a small hysteresis of less than 4 mV. The four-electrode electrolyte conductivity sensor exhibits excellent linearity in a wide range of electrolyte conductivities from 0.084 mS/cm to 20 mS/cm.

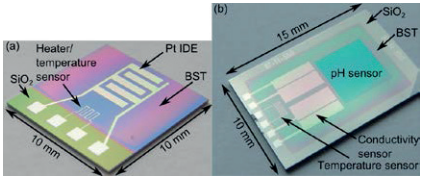

Figure 1: Photograph of the fabricated impedimetric H_2O_2 or polyelectrolyte sensor including meander-shaped Pt electrode serving as temperature sensor or heater (a) and four-electrode contactless electrolyte-conductivity sensor as well as pH sensor (b).

Conclusions

The obtained results demonstrate the potential of the BST films as multi-functional material for the creation of high-order sensor systems, in which the same transducer material can be applied for the detection of various quantities in liquids.

Acknowledgements

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Liquid-infused structured titanium as innovative medically relevant material with antibiofilm properties

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Abstract: Bacterial biofilm-associated implant infections still pose severe problems in modern implant medicine. In the present study, the antibiofouling material concept of slippery liquid-infused porous surfaces (SLIPS) is adapted to the common implant material titanium. First *in vitro* studies demonstrate the complete inhibition of biofilm adherence and serve as a basis for further investigations towards a novel antibiofilm material for medical applications.

Keywords: liquid-infused surface; biofilm; antibiofilm material

Introduction

Although the use of medical implants has become a standard treatment procedure today, implant-associated infections still represent serious complications. They are triggered by sessile microbial communities called biofilms, which harbor inherent resistance to antimicrobial agents and host immune defense. Aiming at avoiding biofilm adherence on implant materials, the concept of slippery liquid-infused porous surfaces (SLIPS) is a promising approach. There, a lubricant is immobilized on a specially structured porous solid resulting in a smooth slippery surface inhibiting bacterial adhesion [1]. The prevention of biofilm attachment was already demonstrated for SLIPS made of polytetrafluoroethylene (PTFE) and silicone [2; 3]. The present study aims at adapting this approach for titanium. Therefore, the surface was structured using ultrashort laser pulse ablation, coated with superhydrophobic polymers and infused with lubricants of different viscosity. These titanium SLIPS were analyzed for initial adhesion and biofilm formation of *Staphylococcus aureus*, a major pathogen of biofilm-associated infections.

Results and Discussion

This study demonstrates that a titanium SLIPS is able to inhibit bacterial attachment. Nevertheless, the lubricants vary in their effectiveness against microbial colonization in the different experimental settings. Biofilm attachment was completely abolished by all lubricants (Fig. 1B). In contrast, initial adhesion was only inhibited when using a high viscous lubricant (Fig. 1A). Contrary to biofilm formation, which was conducted statically, bacteria were incubated under agitation for evaluation of initial adhesion. This may have led to a mobilization of lubricants, especially those with lower viscosity, resulting in an exposure of the structure's tips to the bacterial suspension.

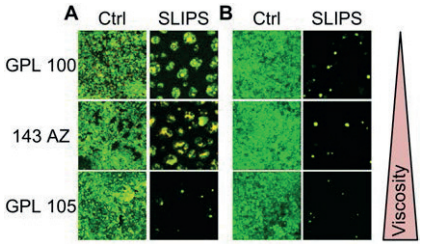

Fig. 1: S. aureus initial adhesion (A) and biofilm formation (B) on titanium control and SLIPS specimens covered with lubricants of different viscosity.

Conclusions

The present study was able to adapt the SLIPS antibacterial approach to the implant material titanium also as validating the inhibition of bacterial attachment *in vitro*. In the future, additional structures in combination with various lubricants will be screened for highly potent antibiofilm materials.

References

[1] T. S. Wong, S. H. Kang, S. K. Tang, E. J. Smythe, B. D. Hatton, A. Grinthal and J. Aizenberg, *Nature* **477**, 443-447 (2011).

[2] A. K. Epstein, T. S. Wong, R. A. Belisle, E. M. Boggs and J. Aizenberg, *PNAS USA* **109**, 13182-13187 (2012).

[3] N. MacCallum, C. Howell, P. Kim, D. Sun, R. Friedlander, J. Ranisau, O. Ahanotu, J. J. Lin, A. Vena, B. Hatton, T. S. Wong and J. Aizenberg, *ACS Biomater.Sci.Eng.* **1**, 43-51 (2015).

Acknowledgements

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Session C

Session C - Tutorial
Human-centered brain interfaces

Finding the most appropriate technology for building electrodes that can be interfaced to the brain in long term implants in humans is a challenging issue. What are the most appropriate technologies? How could one achieve robustness, stability, compatibility, efficacy and versatility, for both recording and stimulation? There are no easy answers to these questions as even the most fundamental and apparently obvious factors to be taken into account, such as the necessary mechanical, electrical and biological properties and their interplay, are still under debate. We present here the most promising approaches for addressing such issues in the context of diagnostics of brain diseases and neuroprostethic applications.

Dr. Davide Ricci

Davide Ricci received the MSc degree in Physics and the PhD degree in Electronic Engineering and Computer Science from the University of Genoa, Italy, in 1989 and 1993, respectively.
He is currently Researcher at the Center of Translational Neurophysiology of the Italian Institute of Technology, Ferrara, Italy, supervising the activity on novel neural interfaces. He has authored or co-authored more than 100 papers in peer-reviewed international journals, conference proceedings, and books. His research interests include the integration of novel materials - conductive polymers, nanocrystals and carbon nanomaterials - with conventional technologies, for the development of devices such as neural electrodes for Brain Machine Interfaces, of flexible nano-actuators and sensors for robotics and of smart interfaces for tissue engineering and prosthetics.

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LAPS-based optoelectronic device for mapping the brain activities *in vivo*

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Abstract: *In vivo* electrophysiological recordings of neuronal circuits are necessary to understand how the brain works and to help diagnose brain disorders. The light-addressable potentiometric sensor (LAPS) constitutes a promising candidate, due to its high sensitivity, to convert the brain activity to an electrical signal via the field effect. In addition, thanks to its light addressability resulting from the photoelectronic effect within the semiconductor, the imaging of brain activity can also be performed. Hence, a LAPS-based optoelectronic device is proposed as a flexible and reliable platform for mapping the brain activities *in vivo*.

Keywords: LAPS, *in vivo* electrophysiological recording

Introduction

Most of the state-of-art brain recordings are performed using electrodes, which has provided basic insights into the organization and the function of the brain. However, the spatial resolution of the recording is restricted by the number and size of the electrodes, which makes it still challenging to study the brain activity on a circuit level. Here the light-addressable potentiometric sensor (LAPS) (Fig. 1), a field-effect sensor with a simple insulator-semiconductor structure, is introduced as a platform for mapping brain activity [1].

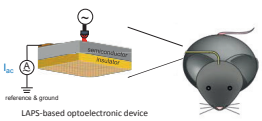

Figure 1: Concept of the LAPS-based optoelectronic device for brain recording.

A modulated light beam is used to read out the surface potential change at the brain-insulator interface in the form of photocurrent, from which a map of brain activity can be generated.

Results and Discussion

The *in vivo* performance of the LAPS-based optoelectronic device was characterized in the hippocampal formation of transgenic Thy1-ChR2-YFP mice. Photocurrent (excited by a single 473 nm laser at 200 Hz with pulse length of 2.5 ms) has been obtained, which captured brain oscillations in the delta frequency band commonly observed under anaesthetized states (Figure 2).

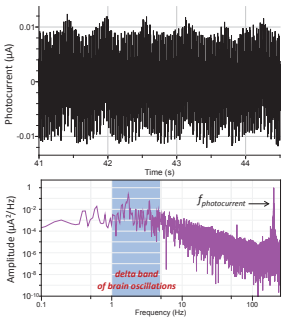

Figure 2: Current response of LAPS and its power spectrum analysis.

Conclusions

In this work, the LAPS-based optoelectronic device is developed and *in vivo* recording of brain activity has been performed to demonstrate its usefulness. In the future, light sources modulated at different frequencies can be utilized, from which the multiplexed photocurrent can be acquired for image acquisition of brain activities.

References

[1] B. Flusberg, A. Nimmerjahn, E. Cocker, E. Mukamel, R. Barretto, T. Ko, L. Burns, J. Jung and M. Schnitzer, *Nature Methods* **5**(11), 935–938 (2008).

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C
1

Light modulated hydrogel stiffness for mechanical stimulation of cells and nerves

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Abstract: An *in vitro* model is being developed to study the mechanical stimulation of fibroblasts and nerve cells. The model uses a new concept to modulate the stiffness and volume expansion of a hydrogel by light. The hydrogel serves a 2D or 3D substrate, respectively scaffold, to cultivate cells in combination with a controlled mechanical stimulation. The long-term goal is to explore a new approach to stimulate nerve cells, in particular as an alternative for existing electric cochlear implants that suffer from limited spatial nerve targeting.

Keywords: hydrogel, actuation, light-responsive, cell cultures, mechanical stimulation, polymers

Introduction

With this approach, light is used to actuate a hydrogel in a spatially and frequency controlled manner. Attachment, growth, and migration of fibroblasts and nerve cells have demonstrated to have a durotaxic and inverse durotaxic behavior respectively, meaning enhanced growth on stiffer material for fibroblasts and softer materials for nerves.[1] In addition, nerve cells have mechanosensitive receptors that open ion channels upon mechanical stimulation resulting in the generation of mechano-induced currents.[2]

Results and Discussion

Thermoresponsive hydrogels made of N-isopropylacrylamide (NIPAM) have optimum temperature sensitivity around 32°C. Gold nanorods were incorporated into this hydrogel as thermoplasmonic heating elements. Upon illumination with near infrared light (NIR), the rods heat the hydrogel from the inside and cause the hydrogel to shrink/expand within milliseconds to seconds. By controlling the size and aspect ratio of the gold nanorods, different NIR frequencies can be selected for the stimulation. Disk-like microgels, with dimensions of 30 µm in diameter and 5 µm in height, swelled and collapsed by 13 vol% with a frequency of 5 Hz. The response time of partial shrinking and swelling, driven by turning the laser on and off, respectively, was as short as 10 ms.

To enable cell culture onto PNIPAM hydrogels, 8 µm thick gels were coated with fibronectin. L929 mouse fibroblasts cultured with different fibronectin coatings demonstrated good adherence at 37°C for a fibronectin coating as low as 1.2 µg per 190 mm² substrate. Cells cultured on patterned PNIPAM hydrogels with ridges of 25 µm width and 2.5 µm height resulted in preferred growth on top of the upper ridges. *In vitro* experiments with nerve cultures from chick embryonic dorsal root ganglions (DRGs) demonstrated good attachment and extension onto the gels, with aligned growth on patterned hydrogels (5-10 µm pattern width).

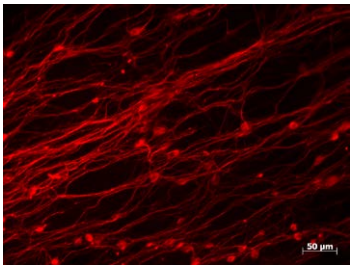

Figure 1: DRG neurons extending on patterned PNIPAM hydrogels coated with fibronectin.

To obtain a hydrogel that exhibits a transition temperature around 37°C under physiological conditions, a copolymer containing NIPAM and N-ethylacrylamide (NEAM) (50:50) will be further applied.

Conclusions

This technique allows us to locally stiffen or soften the hydrogel remotely and reversibly. Such dynamic changes in the mechanical properties open up the possibilities to study cell movement and behaviour, and nerve guidance and stimulation in response to varying elasticity moduli and patterns.

References

[1] A.M. Hopkins, L. De Laporte, F. Tortelli F, E. Spedden, C. Staii, T. Atherton, J.A. Hubbell and D.L. Kaplan, *Advanced Functional Materials* **23**, 5140-5149 (2013).

[2] F. Rugiero, L.J. Drew and J.N. Wood, *The Journal of physiology* **588**, 301-14 (2010).

Acknowledgements

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Electrophoretic deposition of ligand-free nanoparticles affected electrode impedance

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Abstract: Biomaterials are widely used for neuronal stimulation and activity recording. Electrode features critically depend on impedance and interaction with the brain tissue, where nanoscale surface topography is very important. The effect of electrode surface modification by deposition of nanoparticles was studied in vitro and in vivo. Nanostructuring significantly increased electrode impedance. After implantation in a rat model, electrodes coated with particles <10 nm showed the most stable impedance dynamics and recorded the lowest total power of the local field potentials. Immunohistological study revealed no negative effect on tissue reaction.

Keywords: nanoparticles, nanostructuring, biomaterials, biocompatibility

Introduction

Electrophysiological features of the electrodes used to record or modulate neuronal activity e.g. for deep brain stimulation (DBS) critically depend on their surface topography. Nanoscale surface functionalization affects impedance and is important for the tissue-implant interaction [1, 2]. Electrophoretic deposition of nanoparticles (NP) derived by laser ablation is a suitable method to achieve homogenous nano-coating *(Fig. 1)* without the use of chemical precursors and ligands [3, 4]. The impedance of platinum-iridium stimulation electrodes was investigated after coating with NP of different sizes, both *in vitro* and after implantation into the brain of rats. Subsequently, the impedance dynamics were analyzed during DBS, neuronal activity was recorded and the tissue-to-implant reaction was finally assesed.

Results and Discussion

Coating with NP significantly increased electrode impedance independent from NP size. Postoperatively, the impedance of all electrodes was temporarily further increased most likely as an effect from the reactive gliosis around the electrode contact area. This effect was lowest for the electrodes coated with <10nm NP, which also showed lowest impedance fluctuations during stimulation and lowest total power of local field potentials during recording. Improved impedance stability may have a positive clinical effect during long term DBS. Immunohistological study with GFAP and NeuN used as specific markers, revealed that different coating conditions did not affect glial reaction and neuronal count around electrode contact area, which shows that nanoparticles are rather safe for the host tissue.

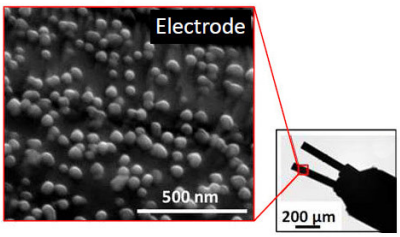

Figure 1: Photomicrograph showing the nano-coated surface of the stimulation electrode.

Conclusions

Electrophoretic deposition of ligand-free NP on the contact surface of stimulation electrodes affects their impedance. Application of NP smaller than 10nm may improve impedance stability. Finally, coatings with different size of the particles did not negatively affect the glial scar around the electrode.

References

[1] A. Curtis and C. Wilkinson, *Topographical control of cells*. Biomaterials, **18** (24):1573-83 (1997).

[2] M.S. Lord, M. Foss and F. Besenbacher, *Nano Today* **5** (1), 66-78 (2010).

[3] J.A. Dahl, M. Hutchison, Toward Greener, *Nanosynthesis*. Chem. Rev. **107** (6):2228-69 (2007).

[4] N. Bärsch, J. Jakobi, S. Weiler and S. Barcikowski, *Nanotechnology 4*, **20** (44):445603 (2009).

Acknowledgements

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Determination of Optimal Excitation Patterns for Intracochlear Inner Ear Stimulation Using a Physiologically-Based Model

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Abstract: A cochlea model is presented which includes a novel boundary condition necessary for modelling intracochlear inner ear stimulation. The boundary condition is defined such that the linear character of the model is retained. Thus, it can be employed for the analysis and optimization of the bionic interface of implant and inner ear: the effect of particular stimulation pattern onto the listeners hearing perception can be determined, and the pattern can be optimized for a desired auditory impression.

Keywords: cochlear implant, cochlea model, inner ear stimulation, EAS

Introduction

Within the field of hearing prosthetics it has been shown that in case of residual hearing, the best hearing perception can be achieved by applying electroacoustic stimulation (EAS), i.e. simultaneous and ipsilateral employment of a hearing aid and cochlear implant (see e.g.[1]). In order to optimize EAS, ongoing research focuses on the integration of these stimuli into a single device to be implanted into the cochlea [2]. This may further enhance the patient's hearing outcome due to the more direct coupling of the acoustic stimulus and the target structure within the cochlea, i.e. the basilar membrane (BM). The frequency a listener perceives is dependent on the oscillation profile of this structure [3]. Thus, optimal stimulation of the BM is crucial for sufficient hearing perception.

Results and Discussion

A cochlea model was developed which is based on the work presented in [4] but includes an additional boundary condition (*Figure 1*): a passive penalty force was incorporated whose magnitude is dependent on the volume difference in between the fluid filled cochlea chambers. This accounts for the balancing of volume in between the chambers which was shown to be the initiator of substantial intracochlear BM stimulation phenomena, i.e. direct and indirect excitation, within preliminary finite element analyses (FEA). The additional boundary condition does not influence the original

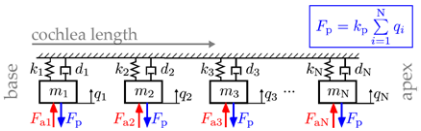

Figure 1: Analogous cochlea model including the passive volume balancing force F_p and the active stimulation forces F_{ai}.

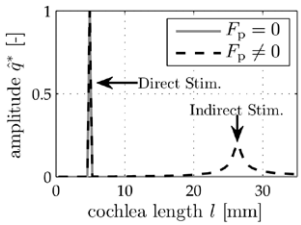

Figure 2: BM oscillation envelope curve showing that the model enhancement also accounts for the indirect stimulation effect discovered within FEA.

frequency distribution properties of the cochlea but enables the model to properly mirror the effects discovered using FEA (*Figure 2*). Furthermore, the model can be inverted such that optimal stimulation patterns for any desired BM oscillation profile can be derived.

Conclusions

The presented methodology can be used to compute both the effect of a particular stimulation as well as the optimal stimulation pattern for a desired BM oscillation. Thus, it represents a useful tool for the interaction analysis of acoustic inner ear stimulus and BM response.

References

[1] C.A. von Ilberg, U. Baumann, J. Kiefer, J. Tillein and O.F. Adunka, *Aud. and Neuro.* **16** (S2), 1–30 (2011).

[2] C. Lee, C.R. Hume, G.Z. Cao and I.Y. Shen, *Proc. IEEE Med. and Bio.*, 1929-1932 (2005).

[3] J. Pickles, An Introduction to the Physiology of Hearing (Academic Press Ltd., London, 1988), p. 37.

[4] A. Saremi, S. Stenfeld, *Journal of the Acous. Soc. of America* **134** (4), 2833-2851, (2013).

Acknowledgements

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Carbon Nanotube Coatings for Neural Interface Electrodes: Cytocompatibility of Fibroblasts and Spiral Ganglion Neurons

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Abstract: Chemical modification of the surface could improve the long-term biointegration and function of cochlear electrodes. Carbon nanotubes (CNTs) are a promising material class for those neural interface applications. Carbon nanotube coatings on platinum substrates were produced via modification of the CNTs and a subsequent spray coating process. These CNT films show enhanced electrical properties and good cytocompatibilty for fibroblasts and spiral ganglion neurons.

Keywords: neural interface, cochlear implant, carbon nanotubes, spiral ganglion neurons, cytocompatibility

Introduction

Long-term biointegration und the improvement of function are main requirements for neural interface electrodes e.g. cochlear electrodes or other stimulating implants [1]. Especially carbon nanotubes are in focus for neural interface applications [2]. The approach is a chemical modification of the electrode surface to improve the contact of the cochlear electrodes and to minimize the impedance of the contact. For this purpose, the platinum surfaces of these electrodes shall be equipped with coatings based on carbon nanotubes (CNTs).

Results and Discussion

Reflux acid-treatment of as-received carbon nanotubes (Fraunhofer IWS Dresden, Bayer Material Science and SouthWest Nano-technologies) leads to a purification due to the removal of catalyst residue and a modification of the nanotubes with carboxyl-groups. Thereby, after a following sonication process, long-term stable aqueous dispersions of carbon nanotubes were obtained. These dispersions were used to coat platinum samples via spray coating. The topographies and thicknesses of CNT films were investigated via SEM and confocal microscopy. SEM and photographic investigations revealed homogeneous covering with CNTs (*Fig.1*). Film thicknesses are in the range of 100 nm.

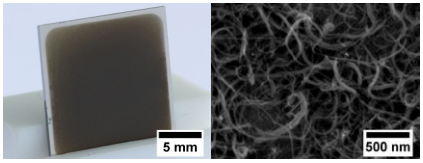

Figure 1: SEM micrograph of CNT coating on platinum substrate.

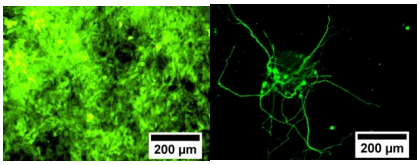

Figure 2: Fluorescence microscopic image of NIH3T3 fibroblasts (left) and spiral ganglion neurons (right) grown on CNT-coated platinum substrates.

Electrochemical investigation was carried out by using impedance spectroscopy. The scans show that the CNT coating leads to decreased impedances at low frequencies [3].

Cell culture experiments of the CNT films were performed with NIH3T3 fibroblasts and spiral ganglion neurons. Morphology and GFP were investigated by fluorescence microscopy and the number of cells on the films was determined after cultivation. These experiments indicate a good cytocompatibility of the CNT coatings for the both tested cell lines (*Fig.2*).

Conclusions

Carbon nanotube coatings on platinum electrodes show enhanced electrical properties and a good cytocompatibility for fibroblasts and spiral ganglion neurons.

References

[1] T. Stöver and T. Lenarz, *GMS Curr Top Othorhinolaryngol Head Neck Surg* **8**, 1–22 (2009).

[2] L. Bareket-Keren and Y. Hanein, *Front Neural Circuits* **6**, 1–16 (2012).

[3] G. Baranauskas *et al*., *J. Neural Eng.***8**, 1–12 (2011).

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Automated Classification of Electrically-Evoked Compound Action Potentials

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Abstract: Auditory nerve fibre group activity can be recorded immediately following cochlear implant electrical stimulation. Correlation between ECAP thresholds and behavioural thresholds is useful for clinical application. Here, an automated ECAP classification method is proposed, that uses a combination of ECAP amplitude and signal-to-noise ratio.

Keywords: cochlear implants, fitting, clinical practise, electrophysiology, data mining, peripheral responses

Introduction

Cochlear implant deliver intracochlear electrical stimulation to the Auditory Nerve. These electrodes contacts are also able to record back evoked-potentials by back-telemetry. Correlation between electrically-evoked compound action potential (ECAP) thresholds (tNRI) and behavioural thresholds is useful for clinical application. Efficiency of this method requires appropriate ECAPs measurement of ECAP growth-functions. Ideally, this should be made as objective and automated as possible to save experiment time and lower expertise requirement. Here, it was assumed that a criterion combining ECAP amplitude (*NRIamp*) and SNR (*SNR*) thresholds would produce highly-specific ECAP response detection. Data mining was conducted over a total of 3445 ECAPs (ca. from 50 patients). Model learning was conducted on 70 % of the dataset, testing on the remaining 30 %. Model verification was applied on a similar dataset made of additional 3461 ECAP traces. Detection performance was assessed in reference to visual judgment of 5 CI professionals specialized in CI electrophysiology. Agreement between judges was taken as reference for the presence or not of a neural response in an ECAP measurement.

Results and Discussion

Strong inter-judge consistency was noticed: at least 4 judges agreed that traces were *ECAP* or *NoECAP* in 86 % of traces (Krippendorff α = 0.91 [1]). Optimal thresholds that discriminated ECAP from NoECAP (*NRI_t* and *SNR_t*) were determined using Recieiver-Operating-Characteristic Curves [2] from projection of subjective *ECAP* and *No-ECAP* conditions on the panel graduated along the objective measures *NRIamp* and *SNR*. For each condition, a clear visual boundary was visible between the *ECAP* and *NoECAP* points. This was conducted separately on three artifact rejection methods: alternate polarity, masker-probe and modified-masker-probe. This model resulted in sensitivity and specificity error of 3.3 % in learning, 4.2 % in testing and 4.7 % in verification. It was found that the following combination of ECAP amplitude and signal-to-noise ratio would be accurate predictors: 22 µV and 1.3 dB SNR thresholds for alternate polarity, 35 µV and -0.2 dB for masker-probe and 44 µV and -0.2 dB for Miller's masker-probe.

Conclusions

The present model gave overall encouraging performance, although anecdotal cases in verification produced a fair amount of false-positives. Fully objective ECAP detection method was proposed that does not require any visual reference judgment and only relies on statistics confrontation of ECAP amplitude to recording noise [3].

References

[1] A. F. Hayes and K. Krippendorff. *Communication Methods And Measures*, **1** (1), 77–89 (2007).

[2] M.H. Zweig and G. Campbell. *Clin. Chem.* **39**, 561-77 (1993).

[3] J. A. Undurraga, R.P. Carlyon, J. Wouters and A. van Wieringen. *IEEE Trans. Biomed. Eng.* **59**, 1912-23 (2012).

Acknowledgements

This worked was conducted at Advanced Bionics European Research Centre.

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Surface Modification of Neural Electrodes by Nanoporous Platinum Coatings

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Abstract: The function of neural electrodes can be enhanced by modification of the surface e.g. by integrating a drug delivery system. To equip a thin material with drugs, a porous coating is needed. For this, a nanoporous platinum coating was deposited with the help of polystyrene latex beads (PLBs) and electrochemical reduction of platinum salt.

Keywords: platinum surfaces, nanoporous platinum, electrochemical deposition, polystyrene latex beads, impedance spectroscopy

Introduction

The aim of this work is to improve the function of the cochlear electrode by enhancing the long-term biointegration and the contact between cochlear electrode and nerve fibers. This can be realized by chemical modification of the electrode surface or by integration of a drug delivery system [1], e.g. by the use of nanoporous platinum coatings. Additionally, the impedance can be reduced due to the porosity of the platinum coatings [2].

Results and Discussion

Nanoporous platinum is deposited on metal surfaces via a three step syntheses. First, gold or platinum substrates are coated with polystyrene latex beads (PLBs) and afterwards stored for 3 days in a climate chamber. The second step is the electrochemical deposition of platinum in the voids of the PLBs layer. By varying the size of the PLBs, the pore size can be adjusted. In the last step, the PLBs are removed. The coatings were characterized by SEM (figure 1 and figure 2) and impedance spectroscopy (figure 3).

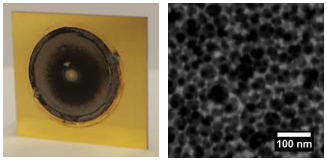

Figure 1: Photographic and SEM images of nanoporous platinum coating on gold surface.

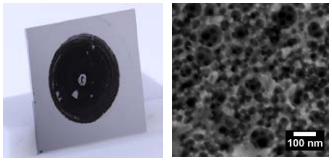

Figure 2: Photographic and SEM images of nanoporous platinum coating on platinum surface.

Both, the platinum coatings on gold and platinum contain nanopores in the range of 30 to 100 nm. The average value of the pore diameter (50 nm) corresponds with the size of the PLBs.

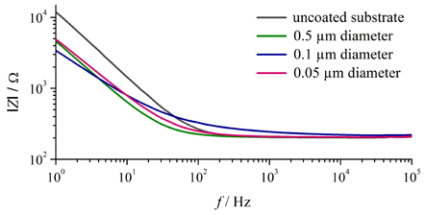

Figure 3: Impedance spectroscopy measurements of bare platinum and platinum coated samples with different diameters of polystyrene latex beads.

Impedance measurements of the nanoporous platinum coatings showed improved impedance in the low frequency range.

Conclusions

The deposition of nanoporous platinum coatings on gold and platinum surfaces by using PLBs as template was successful. The pore size distribution of the platinum coating corresponds with the size distribution of the PLBs. By using different sizes of PLBs, the pore size can be adjusted. Independently of the pore size, the impedance can be improved in the low frequency range.

References

[1] N. Ehlert *et al.*, *Chem. Soc. Rev.* **42**, 3847–3861 (2013).

[2] S. Schlie-Wolter *et al.*, *ACS Appl. Mater. Interfaces* **5**, 1070–1077 (2013).

Acknowledgements

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Kapton® with cell selective coatings to improve electrode-nerve interaction

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Abstract: It is of great clinical interest to reduce formation of connective tissue around the electrodes of auditory implants as like as cochlear implants (CI), since they increase the impedance and, thus, diminish the signal transmission and the performance of the CI. Hereby, electrode carrier material and their coatings are in the focus of interest. This study aimed at synthesis of polymers characterized as protein repellent and their photochemical attachment on polyimide and determination of effects of the polymer coatings on cell behaviour.

Keywords: Cochlear implant, cell viability, polyimide, polymer coating, fibroblast cell line NIH3T3

Introduction

Overgrowth of connective tissue and scar formation around the electrode of the cochlea implant (CI) increase the impedance and, thus, diminish the interactions between the electrode and the auditory nerve. Therefore, it is of great clinical interest to modify the carrier material of the electrode. Hereby, coating of polyimides (Kapton®) with photochemically active polymers may provide the appropriate carrier of auditory implants in future [1].

The photochemically reactive polymers were obtained by polymer analogous introduction of the photoactive arylazido (Az) group into copolymers and the biopolymer chitosan. The polymers were spectroscopally characterized (NMR, IR, UV/Vis). Kapton® was coated with the polymers via spin or spray coating and subsequent irradiation with UV-light. The characterization of the modified polyimide surfaces was performed using ATR-IR spectroscopy, contact angle measurements, AFM and XPS. Cell adhesion was determined by cultivation of the lentiviral modified murine fibroblast cell line NIH 3T3 on the polymer coatings and untreated polyimide surface, respectively. For that purpose cell viability of the fibroblasts was quantified by using the redox dye resazurin. The morphology of the cells was investigated by fluorescence microscopy.

Results and Discussion

The synthesized polymers with the photoactive arylazido groups were thoroughly characterized. Kapton® was successfully coated with the synthesized polymers. In comparison to untreated Kapton® chitosan-Az and PDMAA copolymer revealed the most anti-adhesive effects, followed by the PDEAA copolymer. Fluorescence microscopic control of the green fluorescent protein expressing cells demonstrated any adhesion on chitosan-Az and PDMAA copolymer, instead formation of cell clusters in the culture medium. In contrast PDEAA and PMTA copolymers allowed good cell growth on the surface.

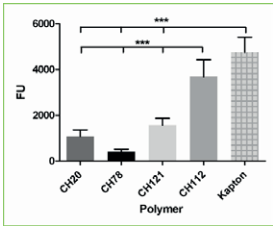

Figure 1: Cell viability assay demonstrated that in comparison to uncoated Kapton® chitosan-Az (CH20) and PDMAA-Co (CH78) strongly inhibited NIH 3T3 cell growth, followed by PDEAA-Co (CH121).

Conclusions

Chitosan-Az and PDMAA copolymer had anti-adhesive effects and did not induce apoptotic signalling due to contact toxicity. These findings indicate chitosan-Az and PDMAA copolymer as clinically relevant coatings to inhibit growth of connective tissue and thus, to reduce impedance. The effect of the polymer coatings on the viability of neuronal cells is subject of ongoing investigations.

References

[1] Richardson RR Jr, Miller JA, Reichert WM. *Biomaterials* **14**, 627-635 (1993).

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Evaluation of the bonding strength between a silicone rubber/polyimide interface for cochlear implants

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Abstract: For improving conventionally available cochlear implants, it is required to increase the number of electrode contacts without increasing the implants stiffness. Therefore, a new design, consisting of a highly flexible thin-film electrode embedded in a silicone rubber shaft will be presented. Since the well-known poor adhesion of polyimide to other materials can lead to delamination, the bonding strength will be investigated between polyimide and silicone rubber interfaces. Furthermore, silica coating as well as O_2-plasma activation was performed and the effects were measured by contact angle measurements and tensile strength tests.

Keywords: silica coating, thin film electrode, plasma activation, cochlear implant

Introduction

Cochlear implants (CI) are used in patients with profound deafness in order to restore the auditory functions of the inner ear [1]. Therefore, a CI electrode array can be inserted into the cochlea of the patient, to stimulate the auditory nerve cells. So far, conventionally available electrode arrays consist of a maximum number of only 22 platinum electrode contacts to stimulate approximately 3500 auditory channels. To improve frequency distribution, more electrodes [2] are required, which in turn leads to an increased stiffness. Thus, flexible and softer electrodes are needed in order to preserve tissue during insertion of the array [3, 4]. To match these problems, a new design of a cochlear implant , based on a flexible thin film electrode array, embedded in a polydimethylsiloxane (PDMS) silicone rubber shaft, will be presented. The array is made of gold, deposited on a polyimide (PI) substrate, and parylene C for the frontal isolation. Since the bonding of PDMS to PI is difficult due to its chemical inertness [5], it is required to achieve a mechanically stable interface with a high durability.

Results and Discussion

For the fabrication of a stable PI / PDMS interface, O_2- Plasma activation as well as silica coating was performed. The interfaces were investigated by using contact angle measurements (CA) and tensile strength tests. As test liquids for the CAs, SYLGARD® 184 (Dow Corning, USA, η= 3500 mPas) and SILPURAN® 2430 (Wacker, Germany, η= 9000 mPas) are used. The results of the tensile strength test show a bad adhesion between all untreated and O_2- plasma treated samples. The best result was observed using the silica coated material with SYLGARD® 184. In comparison, SILPURAN® 2430 shows no improvement with this material, potentially indicating the influence of its higher viscosity.

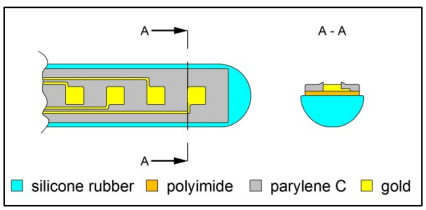

Figure 1: Schematic view of the novel CI prototype. The implant design consists of gold electrode contacts and wires on a polyimide substrate with parylene C isolation and a silicone rubber shaft.

Conclusions

Surface modifications of the polyimide based electrode carrier can be used for improving the interface quality. The best bonding strength was observed with a silica coating.

References

[1] Guimarães AC, de Carvalho GM, Duarte AS, Bianchini WA, Sarasty AB, di Gregorio MF, Sartorato EL and Castilho AM, Braz J Otorhinolaryngology **81**, 190-196 (2015).

[2] Wise KD, Bhatti PT, Wang J, Friedlich CR, Hearing Research **242**, 22-30 (2008).

[3] Zhu Z, Tang Q, Zeng FG, Guan T, Ye D, Hearing Research **283**, 45-58 (2012).

[4] Cosetti M, Roland JT, Operative Techniques in Otorhinolaryngology **21**, 223-232 (2010).

[5] Duo S, Li M, Zhu M, Zhou M, Materials Chemistry and Physics **112**, 1093-1098 (2008).

Aknowledgements

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Silicone rubber spreading during infrared curing for individually shaped neural implant fabrication

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Abstract: The direct fabrication of silicone rubber based individually shaped neural implants require high speed curing systems in order to prevent spreading of the material due to a heating related viscosity drop. Therefore, we present an infrared based curing system as well as first results of the spreading evaluation with respect to the silicone rubber's initial viscosity and the absorbed radiation.

Keywords: Neural implant, infrared curing, customized implant, 3D printing

Introduction

For the treatment of neural diseases like deafness or epilepsy, several standard implants are available in order to restore lost or disturbed neuronal functions. These implants typically consist of a bulk material with embedded electrode contacts and wires individually connected to an electronic circuit. Since every patient comes with an individual anatomic situation, direct fabrication techniques for customized implants need to be developed. State of the art materials are mostly silicone rubber as well as polyimide, in order to preserve tissue and to fit to filigree structures, such as the cochlear or the cerebral cortex [1]. Although these implants are in general suitable for the direct fabrication they cannot be used for the fabrication of medical implants, due to the lack of approved curing agents. Therefore, we develop an infrared based high speed curing system which offers the opportunity to manufacture conventionally available thermal curing "medical grade" silicone rubbers. In a first step, we present a test setup to evaluate the potential fabrication accuracy, limited by the heating related spreading of the silicone rubber during thermal curing.

Results and Discussion

The test setup (figure 1) comprises an

- emission controlled infrared emitter,
- a drop of the sample material
- an object slide and
- a camera for the observation of the spreading.

For the evaluation of the spreading in respect to the absorbed infrared radiation and the initial viscosity, thermal curing silicone rubbers with different viscosities were used. The heat transfer from the emitter into the materials was calculated by using transmission data of the silicone rubber and emissivity data from the emitter's manufacturer. Drops of the materials were applied onto the object slide and cured with the infrared emitter. The curing was observed with the camera and analyzed by using an edge detection algorithm with a following circle fitting. As estimated from the study of Härth and Schubert [2], who found an increased PDMS spreading with decreased viscosity, the best result was observed using the material with the highest viscosity (radial spreading = 3.48%).

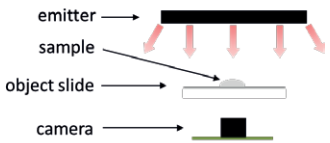

Figure 1: Test setup with infrared emitter, camera and sample upon an object slide. The camera records the silicone rubber spreading during curing.

Conclusions

In view of the direct fabrication of silicone rubber based individually shaped implants, high speed infrared curing techniques can potentially be used for the manufacturing of conventionally available silicone rubber with marginal geometrical irregularities due to the spreading of the silicone rubber.

References

[1] K.C. Cheung, *Biomed. Microdevices* **9**, 923-938 (2007).

[2] M. Härth and D.W. Schubert, *Macromol. Chem. Phys.* **213**, 654-665 (2012).

Acknowledgements

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Neural interfacing via track etch membrane of cell model mediated by human growth factors

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Abstract: To improve neuronal cell stimulation with the cochlea implant, one objective is to realise a direct interaction between electrode contacts and neuronal cells. This may be possible using cell guiding structures between neurites and electrode contacts. Hence, it will be investigated, if neuroblastoma cells are able to form neurites through a track etch membrane, when directed by the growth factor BDNF, using fluorescence microscopy.

Keywords: electrical stimulation, growth factor, guided neurite outgrowth, neuroblastoma cells

Introduction

Cochlea Implants (CI) have been established as a therapy for deaf patients, whose auditory nerve is still intact. The CI consists of an external and an internal part, including an electrode shaft, which is implanted into the Scala tympani of the cochlea in the inner ear. This electrode shaft directly stimulates the spiral ganglion cells (SGCs) via electrode contacts leading to a hearing impression. However, state of the art electrodes leave a distance to the stimulated cells. To improve electrical stimulation of the SGCs, one of many objectives in current CI research is minimizing this distance. This might be achieved by growth factor stimulated neurite growth of the SGCs towards the electrode contacts allowing direct interfacing. Through such a treatment neurite penetration at the side of the Scala tympani was induced in vivo [1]. But it stays questionable, if further extension into the Scala is possible without a growth guiding structure. Therefore, it will be investigated, if cells can be stimulated to form neurites into the 0,8 µm pores of a track etch membrane (TEM) as a model guiding structure. SGCs will be substituted by SH-SY5Y, human neuroblastoma cells, as cell model. Since it has been shown that brain derived neurotrophic factor (BDNF) pro-motes neurite outgrowth in SGCs and SH-SY5Y [2,3], it will be investigated, if SH-SY5Y cells are able to form neurites into a TEM, when stimulated by BDNF.

Methods

A NIH-3T3 cell line (mouse fibroblasts), which is lentivirally modified to synthesize BDNF [2], will be cultured in a 24-well-plate to provide a stable amount of BDNF. Membrane inserts with a porous membrane are modified by attaching the TEM with glue and then put into the well (Fig 1). This modification was optimized testing different biocompatible glues. SH-SY5Y cells will be differentiated on the porous membrane using retinoic acid, leading to neurite growth [3]. In this way the porous membrane serves as a spacer between the TEM and the SH-SY5Y cells, so that the possibility of neurite growth in any direction is given. Neurite penetration through both membranes is evaluated by fluorescence microscopy. The BDNF concentration difference between well and insert on the other hand will be measured using an Enzyme Linked Immunosorbent Assay.

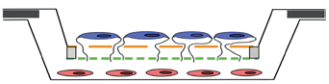

Fig1: Schematic view of the membrane insert in the well with SH-SY5Y cells (blue), NIH-3T3 cells (red), porous membrane (o-range), track-etch membrane (green), glue (grey).

First Results and Outlook

Since both cell lines need individual cell culture media combinations, both have been successfully cultivated in all relevant media combinations. As biocompatible glue for fixation of the TEM to the membrane insert SILPURAN® 4200 silicon glue has shown the most promising results. The next step will be measurements on the BDNF diffusion behaviour, to be able to ensure a stable BDNF concentration gradient.

References

[1] R. Glueckert, M. Bitsche, J. Miller, Y. Zhu, D. Prieskorn, R. Altschuler, and A. Schrott-Fischer, J Comp Neurol **507**, 1602-1621 (2008).

[2] A. Warnecke, K. Wissel, A. Hofmann, N.Berkingali, G. Gro, T. Lenarz and T. Stöver, Neuroreport **18** (16) 1682-1688 (2007).

[3] M. Encinas, M. Iglesias, Y. Liu, H. Wang, A. Muhaisen, V. Ceña, C. Gallego and J. Comella, J neurochem **75**, 991-1003 (2000).

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Investigation of silicone rubber removal from carbon nanotubes by means of wet and dry etching

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Abstract: For the use in neuronal implants, eg. cochlear implants or subdural implants, flexible materials which allow atraumatic implantation are under investigation. Silicone rubber combined with the conducting filler material carbon nanotubes (CNTs) is a promising material due to silicone rubbers flexibility and the good conductivity CNTs provide. Nevertheless, immersion of CNTs into silicone rubbers leads to an insulating layer of silicone rubber on the CNTs. To remove this insulating layer, wet etching (Tetrabutylammoniumfluoride) and dry etching (O2-Plasma) are under investigation.

Keywords: silicone rubber, carbon nanotubes, neural implants, O2-plasma

Introduction

For use in neural stimulation, flexible materials are under investigation to develop atraumatic electrodes which preferably can also be implanted noninvasively. The electrode material needs to be flexible enough to be bend, but also provide conductivities as good as state of the art electrode materials without leaving bio- and neurocompatiblity behind. Silicone rubbers flexibility combined with carbon nanotubes (CNTs) good conductivity is therefore a promising compound under investigation. The compound leaves the CNTs completely immersed in silicone rubber, anchoring them to the material without releasing them into the body. To prevent the complete insulation of the CNTs towards the stimulated neuronal cells and to reach low impedance, silicone rubber needs to be reduced or completely removed from the CNTs on the electrode-cell interface. The challenge is to remove the bound rubber, which, as simulated by Beigbeder et al. (2008), is wrapped around the CNTs and bound with CH-π –binding [1].

Results and Discussion

Wet and dry etching methods are used to remove the bound rubber from the CNTs on the cured CNT-silicone rubber electrode-cell interface. For wet etching, a mixture made of Dimethyl sulfoxide (DMSO, Sigma Aldrich) and Tetra-*n*-butylammonium fluoride (TBAF, 75%H²O, Sigma Aldrich) is used in a 3:1 v/v % solution as used by Takayama et al. (2001) to etch structures into silicone rubber [2]. As dry etching process, O2-plasma etching is used as proposed by Garra et al (2002) for silicone rubber etching [3]. This is also combined with the wet etching to find the best method for the removal of silicone rubber. The success of these methods is investigated via scanning electron microscopy (SEM) and impedance measurements. Figure 1 shows the SEM images of a 15min TBAF/DMSO etch compared to an unetched surface. Impedance measurements show lower impedance on etched surfaces, than on unetched surfaces, suggesting the success of these methods.

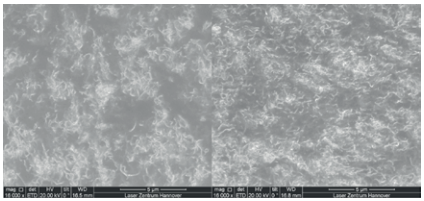

Figure 1: SEM-images left: unetched surface of CNT-Silicone rubber;right: surface etched for 15 minutes with TBAF/DMSO

Conclusions

Even though both wet etching and dry etching showed reduced silicone rubber on the CNTs depending on the etching time and method, a different approach involving more unpolar chemicals is going to be investigated.

References

[1] A. Beigbeder, M. Linares, M. Devalckenaere, P. Degee, M. Claes, D. Beljonne, R. Lazzaroni and P. Dubois, Advanced Materials **20**, 10003-1007 (2008).

[2] S. Takayama, E. Ostuni, X. Qian, J. Cooper McDonald, X. Jiang, P. LeDuc, M.-H. Wu, D. E. Ingber and G. M. Whitesides, Advanced Materials **13** (8), 570–574 (2001).

[3] J. Garra, T. Long, J. Currie, T. Schneider, R. White and M. Paranjape, Journal of Vacuum Science and Technology A **20**, 975-82 (2002).

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High-resolution light-addressable potentiometric sensors (LAPS) based on organic monolayer modified silicon on sapphire (SOS)

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Abstract: An organic monolayer bound to H-terminated SOS was used as the insulator in Light-Addressable Potentiometric Sensors (LAPS) and Scanning Photo-induced Impedance Microscopy (SPIM). Photocurrent measurements showed the same good spatial resolution as SOS with a conventional SiO_2 insulator, but also a significantly improved sensitivity. Surface potential imaging using LAPS was validated by studying micropatterns of poly(allylamine hydrochloride) (PAH) and DNA on PAH (PAH-DNA). The system can image cell impedance and cell surface charges in the cell-attachment area, and produce two-photon fluorescent images.

Keywords: SAMs, LAPS, SPIM, PAH, two-photon, neural cells.

Introduction

LAPS can record surface potentials and impedance with spatial resolution using photocurrent measurements at electrolyte/ insulator/silicon field-effect structures. Good lateral resolution was achieved using SOS substrates [1]. To improve the sensitivity of LAPS, the traditional insulator was replaced with an ultra-thin organic monolayer [2].

Results and Discussion

Resolution estimated from LAPS measurements with a 405 nm laser was ~2.0 µm for undecylenic acid modified SOS, which is comparable to the previous results using an anodic oxide as the insulator [1]. Figure 1 shows LAPS images of PAH and PAH-DNA patterns measured at 0.488 V. The adsorption of PAH (positively charged) caused a higher photocurrent and a negative voltage shift of I-V curve in part "I". Conversely, the further adsorption of DNA (negatively charged) resulted in a decrease of photocurrent and a positive voltage shift. The partial shifts in the depletion region of the I-V curves may due to the incomplete surface coverage with PAH and DNA.

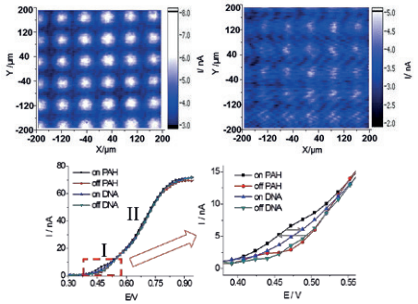

Figure 1: LAPS images of PAH (left) and PAH-DNA (right) patterns on undecylenic acid modified SOS and the I-V curves.

Vybrant® Dil labelled Rat B50 neuronal cells were cultured on a NH_2-terminated monolayer. When measured with a 405 nm laser, most light is absorbed by the silicon resulting in a pure LAPS/SPIM image. The reduction of the maximum photocurrent in the cell attachment area is due to the increase of the local impedance; while the shift of the I-V curve is caused by the negative surface charge of neurons (Fig. 2a and b). In contrast, infrared laser light penetrates SOS and excites two-photon fluorescence in fluorescently labelled cells, resulting in an enhanced photocurrent producing a fluorescence image of the cell (Fig. 2c).

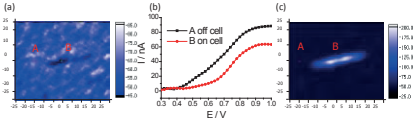

Figure 2: Vybrant® Dil labelled rat B50 neural cell: (a) LAPS image (50 x 50 µm) and (b) I-V curves using 405 nm laser (c) two-photon fluorescence image using IR laser.

Conclusions

Organic monolayers were successfully used as an insulator in LAPS/SPIM measurements and high resolution was achieved. LAPS imaging was validated with PAH and PAH-DNA patterns. Electrochemical and fluorescent images for a single neural cell were obtained with a combined LAPS and two-photon fluorescence measurement setup.

References

[1] L. Chen, Y. Zhou, S. Jiang, J. Kunze, P. Schmuki, S. Krause, *Electrochem. Comm.* **12**, 758-760 (2010).
[2] J. Wang, Y. Zhou, M. Watkinson, J. Gautrot, S. Krause, *Sens. and Act. B: Chem.* **209**, 230-236 (2015).

Acknowledgements

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C
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Electric Stimulation of the Mouse Auditory Midbrain

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Abstract: Electric stimulation of the mouse midbrain can elicit cortical responses that closely resemble auditory evoked responses in their form. Correct positioning of both, recording and stimulation electrode is a crucial factor. Thus, a new animal model for investigations of an Auditory Midbrain Implant (AMI) with considerable genetic and behavioural analysis tools might be established.

Keywords: electrical stimulation, active implants, auditory midbrain implant

Introduction

The Auditory Midbrain Implant (AMI) has been developed to restore hearing to deaf patients who cannot benefit from Cochlear Implants [1]. However, only few patients have been implanted until now and success is limited so far. To date, little is known about neuronal processing of auditory information in the AMI's midbrain target structure, the Inferior Colliculus (IC). Guinea pig experiments using active midbrain stimulation and recordings of local field potentials (LFPs) in the auditory cortex have shown an important relationship between stimulation site and excitation threshold as well as properties of cortical responses [2]. However, no behavioural data have been gained from guinea pigs yet. So far, it is unknown whether IC stimulation elicits a tone- or a noise percept. In order to further investigate the function of the AMI, an animal model is needed that can be used to behaviourally indicate a hearing sensation. Oxidized 16-channel Pt/Ir electrode arrays were used to deliver current, and 32-channel Pt/Ir electrode arrays to record neural signals (Neuronexus, Inc). Stimulation electrode was placed 1.5 mm deep into the tissue at an angle of 45° relative to the horizontal plane.

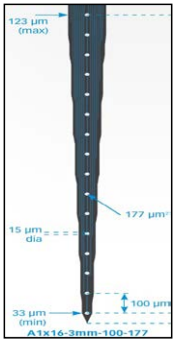

Figure 1: Stimulation electrode contacts were distributed evenly over 1600 µm. Each contact was 15 µm in diameter and comprised 177 µm² of area. Pt/Ir contacts were activated using 300 s of 1 Hz square wave stimulation with an amplitude of ±100 µV in order to form Iridium-oxide and thus decrease in impedance (Neuronexus).

Results and Discussion

Preliminary results revealed that electric stimulation of the mouse IC elicits a cortical LFP comparable to an auditory evoked potential regarding amplitude, duration and latency. For electric stimulation, LFP amplitudes depend on stimulus current levels. Thresholds varied with position of recording and stimulation electrode, but were mainly around 30µA.

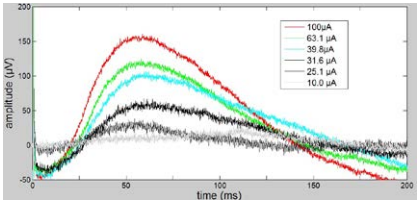

Figure 2: Electrical stimulation of the IC evokes cortical LFPs that vary in amplitude dependent on stimulus current levels.

Conclusions

Cortical LFPs in mouse auditory cortex can be evoked using electrical stimulation of the IC. Thus, a powerful new animal model is about to be established to study AMI improvements.

References

[1] H. H. Lim, M. Lenarz and T. Lenarz *Trends Amplif.* **13** (3), 149–180 (2009).

[2] M. M. Straka, M. McMahon, C. D. Markovitz and H. H. Lim, *J Neural Eng.* **11** (4), 046021 (2014).

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Session D

Session D - Tutorial
Nanoelectronics: Vision and Reality

Scaling down the channel length of metal-oxide semiconductor field-effect transistors (MOSFETs) has been an extremely successful path to increase the performance of integrated circuits (ICs): A larger number of transistors fits onto the same chip area while the transistors themselves exhibit an improved performance. However, scaling the channel length to ever smaller dimensions may lead to dramatically increased leakage currents that result in an unacceptably high power consumption of integrated circuits. Introducing novel materials and in particular three-dimensional transistor architectures as well as reducing the supply voltage of ICs, the semiconductor industry has been able to keep the power consumption at an acceptable level. However, the operational principle of MOSFETs leads to a fundamental limit that does not allow for a further, substantial reduction of the supply voltage (and hence power consumption) with the existing technology. Therefore, novel device concepts that rely on e.g. quantum mechanical tunneling as switching mechanism are currently investigated intensively. In the tutorial talk, an overview of the operational principles of MOSFETs will be given and the relevant measures to keep the scaling pace up (i.e. 3D architectures such as nanowire wrap-gate FETs, novel materials such as graphene, transition metal dichalcogenides, carbon nanotubes etc.) will be presented. Finally, band-to-band tunneling FETs will be introduced and discussed as an alternative device concept for future ultralow power ICs.

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Point-of-care (POC) diagnostics in punctate liquids based on gold nanoparticles

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Abstract: Based on the electrostatic interaction between negatively charged gold nanoparticles and proteins at pH values around 5 protein/nanoparticles aggregates are formed after addition of small amounts of protein. At concentrations above 500 mg/l the color of the suspension changes from red via violet toward blue in a rather small concentration range from 500 to 1000 mg/l. This behavior is used for a fast and sensitive POC-test.

Keywords: protein detection, cerebrospinal liquids, gold nanoparticles, point-of-care

Introduction

Protein concentrations of more than 480 mg/l in samples of liquor cerebrospinalis are an indicator of several neurological diseases. Formerly a semi-quantitative test was done by the Pandy reaction which is abolished now from the clinical practice due to the usage of toxic phenol. But there is a need for such a fast and reliable test procedure in the emergency medicine and also for an efficient choice of more detailed laboratory examinations. Based on gold nanoparticles (GNP) a simple and fast protein test system is developed. Therefore first a test liquor made of albumin (main protein constituent of real liquor) and PBS (phosphate buffered saline) is used simulating liquor samples. The system is tested for different parameters and then applied for analysis of real samples.

Results and Discussion

After addition of a test liquor to a suspension of mercaptopropionic acid (MPA) modified gold nanoparticles it could be shown that already small albumin concentrations can trigger an agglomeration of the nanoparticles due to the electrostatic interaction between the positively charged protein and the negatively charged GNPs. The increased apparent diameter of these nanoparticles agglomerates effects a shift of absorption maximum of the nanoparticle suspension towards larger wavelengths (fig.1). Hence a color change from red to violet or blue corresponds to the added protein amount.

The main parameter influencing the aggregation behavior are pH value, ionic strength and nanoparticle concentration. Lower pH values, higher salt concentrations and decreased nanoparticle concentrations cause an aggregation at lower protein content.

The influence of pH variations in the sample is rather small while the ionic strength has a more pronounced impact on the aggregation behavior. But this can be diminished by a small amount of NaCl already present in the nanoparticle test solution.

After 3 min the agglomeration process is largely completed. Hence the requirement for a POC-test a short analysis time can be met.

Final measurements with human liquor samples reveal a slightly decreased sensitivity. But after adjustment of the assay composition a clear dependency of the absorption behavior on the total protein concentration can be obtained.

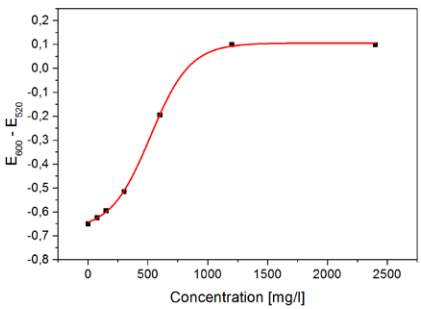

Figure 1: Difference of the absorption values at 600 nm and 520 nm after addition of samples with different protein concentrations.

Conclusions

A fast, simple and sensitive detection system based on gold nanoparticles is developed allowing the semiquantitative detection of the protein content in the liquor cerebrospinalis. For basic studies of system behavior an artificial liquor is used. After adjustment of the composition of the assay solution real human liquor samples can be analysed.

Acknowledgements

Financial support by the BMBF Germany (project: 17PNT013) is gratefully acknowledged.

D
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Light-controllable hydrogels with incorporated graphene oxide as actuators for lab-on-chip devices

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Abstract: The development of micro-actuators is essential for microfluidic devices and lab-on-chip systems. In this work, a hydrogel-based material is presented, which can be stimulated by local illumination. The heat generation within the hydrogel and the temperature of the surrounding was monitored by IR-thermography.

Keywords: hydrogel, microfluidic, light actuation, photopolymerization, graphene oxide

Introduction

Microfluidic devices offer the opportunity to use smaller amounts of analyte and parallel operation leading to a significant decrease in operation time. Furthermore, they give the ability to develop multifunctional lab-on-chip systems. The design of such lab-on-chip systems, esp. if considered to be disposable, requires low-cost actuators. Hydrogels are known as possible materials for micro-actuators. Stimulus-sensitive hydrogels change their volume in response to the variation of certain environmental parameters. In the past, temperature-triggered hydrogel valves were introduced for possible integration in lab-on-chip systems [1]. However, those valves require an additional heating structure beneath the hydrogel layer. To further lower the manufacturing costs, decrease complexity and increase flexibility, this work proposes the laterally resolved stimulation of hydrogel-based materials by a blue light source instead of a heating structure.

Results and Discussion

Temperature-sensitive hydrogels based on N-Isopropylacrylamide (NIPAAm) were modified by incorporation of graphene oxide (GO) nanoparticles to increase the light absorption so that heat is generated during illumination with a blue light source (λ=450 nm). In contrast to pure Poly-NIPAAm hydrogels which have no light absorption within the visible spectrum, these modified hydrogels can be stimulated spatially resolved and heated locally (just depending on the position and geometry of the light beam) as could be demonstrated by IR-thermography (figure 1). In addition, the temporal progress of the temperature profile was monitored during irradiation. Furthermore, hydrogels were polymerized within microfluidic channels and the influence of illumination on the environment of the hydrogels was investigated.

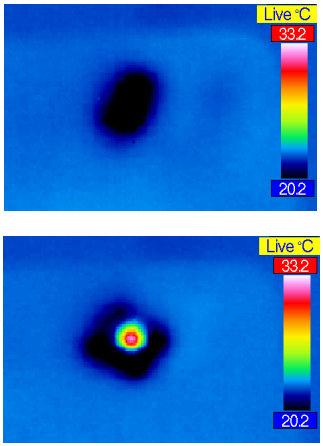

Figure 1: Thermograms of a pure Poly-NIPAAm hydrogel (a) and a hydrogel with GO (b) during illumination with a blue laser (ε=0.95, λ=450 nm).

Conclusions

GO was introduced into Poly-NIPAAm hydrogels and the local stimulation of these gels was demonstrated. The obtained results indicate the ability to be applied as actuators in microfluidic systems.

References

[1] [1] A. Richter, D. Kuckling, S. Howitz, T. Gehring, K. F. Arndt, *J. Microelectromech. Syst.* **12** (5), 748-753 (2003).

Acknowledgements

This work was supported by the German Federal Ministry of Education and Research (BMBF) within "NanoMatFutur" (13N12585).

D
2

Coupling of biochemical reactions with Quantum Dots for light switchable electrodes

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Abstract: Quantum Dots enable the generation of charge carriers upon illumination. By fixation of these particles to an electrode a photocurrent can be generated and allows their use as a light-switchable layer on the surface. In addition to electron transfer reactions between the QDs and the electrode, the particles can also interact with compounds in solution, providing access to the construction of signal chains. The magnitude and the direction of the photocurrent depend on several factors such as electrode polarization, solution pH or composition and have been evaluated with respect to the combination of QD-electrodes with enzyme reactions for sensorial application.

Keywords: quantum dots, linker molecules, photoelectrochemistry

Introduction

Quantum dots are small colloidal semiconductor nanoparticle which have been studied with growing interest during the last decade because of their interesting optical properties. By illuminating the QDs with light of a sufficient wavelength electron-hole-pairs can be generated inside the particles. Thereby electrons switch from the valence to the conduction band, followed by a relaxation in the initial state, resulting in light emission. Here the light emission depends on the diameter of the QDs, which allows a size-tuneable fluorescence and makes QDs very popular as fluorescence label [1]. In addition to the optical application, QDs have been used as building block in electrochemical sensors for the introduction of a light sensitive element [2]. By the attachment of QDs to the electrode light-induced charge carriers can be transferred between the electrode and the QDs, resulting in a photocurrent which can be used as analytical tool. Depending on the potential, an anodic or cathodic photocurrent can be detected. Anodic photocurrents are caused by electron transfer reactions from a donor in solution via the QDs to the electrode. On the other hand, electron flow from the electrode via the QDs to an acceptor in solution can occur, thus generating a cathodic photocurrent. An effective photocurrent generation depends on different factors such as the quality of the QDs, the coupling of QDs to the electrode, the reaction rates for oxidation or reduction of substances at the QDs and the recombination of charge carriers inside the nanoparticles [2].

Results and Discussion

For the construction of QD electrodes, we have attached CdSe/ZnS QDs to gold electrodes. To provide functionalities for electrode and/or biomolecule interaction the nonpolar ligand of the synthesized QDs is replaced by ligands with functional groups (such as mercaptopropionic and cysteamine). The successful ligand exchange is followed by a phase transfer from the nonpolar to the aqueous phase. Subsequently the functionalized QDs were bound via covalent binding or electrostatic interactions to the electrode. Afterwards photoelectrochemical measurements are perfomed, showing stable photocurrents in the anodic and cathodic direction. This provides the basis for the combination of the QD electrodes with biochemical reactions.

The functionality of the prepared QD electrodes have been firstly investigated by using the small redox molecule ferrocyanide in solution which results in a concentration dependent increase of the anodic photocurrent. This gives access to the construction of mediator based electron transfer chains. Furthermore PQQ glucose dehydrogenase was coupled with QD electrodes for photoelectrochemical glucose detection.

Conclusions

In this study it is investigated whether a quantum dot electrode can be combined with a specific biochemical reaction for a sensorial application.

References

[1] V. Biju, T. Itoh, A. Anas, A. Sujith and M. Ishikawa, *Anal. Bioanal. Chem* **391**, 2469 – 2495 (2008).

[2] F. Lisdat, D. Schäfer and A. Kapp, *Anal. Bioanal. Chem.* **405**, 3739 – 3752 (2013).

Acknowledgements

This work is supported by the DFG (Li-706/8-1).

Application of electroosmotic micropumps to a microfluidic system combined with a light-addressable potentiometric sensor

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Abstract: An on-chip electroosmotic micropump system combined with a light-addressable potentiometric sensor is proposed. The microfluidic system is designed as a (bio-)chemical analysis device for measuring a small volume of sample solution.

Keywords: electroosmotic micropumps, light-addressable potentiometric sensor, enzyme sensor

Introduction

In the miniaturization and integration of microfluidic devices, a micropump is a key component. Electroosmotic micropumps (EOPs) have attracted a great deal of attention because of their ability to generate high pumping pressure with continuous pulse-free flow [1]. In addition, these pumps can also offer precision delivery of small volumetric fluids. Notably, by changing the strengths and directions of the applied electric fields through the pumping channels, the fluid flow magnitudes and directions of the EOPs can be controlled conveniently. Most importantly, the EOPs have no moving parts, which can be fabricated and integrated easily into lab-on-a-chip systems [2].

Recently, a light-addressable potentiometric sensor (LAPS) was applied for chemical imaging inside a microchannel [3]. Especially, for biomedical applications, where the volume of the sample is typically very small, combination of a microfluidic system with a LAPS is a prospective strategy [4]. In this study, we proposed a biosensing application of EOPs integrated with LAPS.

Results and Discussion

Figure 1 illustrates the scheme of the measurement system. EOPs are integrated in Y-shaped PDMS channel on LAPS sensor. The sample solution and enzyme solution are transported by EOPs through the channel, in which mixing, reaction and measurement are carried out on chip. The product of the enzymatic reaction is detected at down-stream of the channel. The measurement area can be defined by illumination based on the addressability of LAPS measurement.

In figure 2, it was observed that the pure water could be transported by EOP in the microchannel.

The details of EOPs-LAPS chip and the result of biosensing will be discussed at the conference.

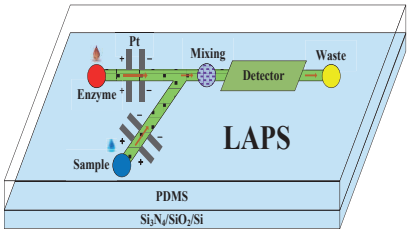

Figure 1: Schematic view of the EOPs-LAPS chip.

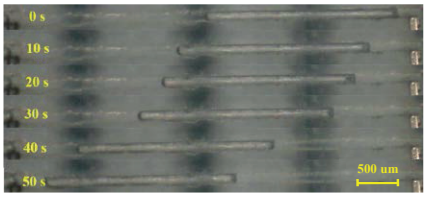

Figure 2: Transport of pure water by EOP.

Conclusions

It was demonstrated that EOPs could be integrated in a microfluidic system to be combined with LAPS. This system is designed as a (bio-)chemical analysis device.

References

[1] L. J. Jin, J. Ferrance, J. C. Sanders and J. P. Landers, *Lab Chip* **3**, 11-18 (2003).

[2] M. Gao and L. Gui, *Lab Chip* **14**, 1866-1872 (2014).

[3] K. Miyamoto, A. Itabashi, T. Wagner, M. J. Schöning and T. Yoshinobu. *Sens. Act. B.* **194**, 521-527 (2014).

[4] T. Yoshinobu, K. Miyamoto, T. Wagner and M. J. Schöning, *Sens. Act. B* **207**, 926-932 (2015).

Acknowledgements

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D
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Near-room temperature sintering of inkjet printed silver patterns

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Abstract: Inkjet printing is a fast, cheap and flexible method to deposit thin and structured layers. In this work precursor based Ag inks were developed instead of the commercially available particle based ones that usually have to be sintered at temperatures of at least 200°C. It is proven that inkjet printed Ag layers can be sintered at temperatures as low as 60°C reaching a resistance of less than 5 Ω/cm with these home-made precursor inks.

Keywords: inkjet printing, silver precursor ink, thermal sintering, low temperature sintering

Introduction

Instead of lithography, using printing techniques such as inkjet printing is gaining more and more attention to deposit functional layers, among which conductive structures. This is due to the cheap and flexible character of the process and its non-contact approach [1].

The formulation of inkjet inks can be performed in two different ways. On the one hand there are the particle based inks in which Ag particles capped to prevent oxidation and aggregation, are dissolved in an organic solvent blend. After the deposition, (thermal) energy is applied and so the solvents will evaporate, the capping agent decompose and the "naked" Ag particles start to sinter together due to diffusing phenomena. In general this works fine but one should use a balanced solvent mix to prevent nozzle clogging. Another issue is the temperature as high as 200°C needed to decompose the capping agent to obtain conductive patterns.

On the other hand ore the so-called precursor inks that consists of Ag ions that are stabilised with counterions until the ink is deposited and sintered. As no nanoparticles are used in the ink the print head nozzle cannot get clogged anymore. Too, via this method no capping polymers have to be removed resulting in sintering temperatures far lower than in the case of particle based inks. In this work two Ag precursor inkjet inks were developed and printed on glass and polyethylene terephthalate (PET). After the printing, they were thermally sintered under a range of different conditions to find the optimal sintering time and temperature.

Results and Discussion

After the formulation of precursor inks A and B, a suitable voltage pulse to fire single droplets was generated for both inks to avoid unwanted phenomena while jetting such as nozzle clogging, formation of satellites or misdirected droplets. In this particular case, a M-shaped waveform was chosen for. The waveform resembles literature ones, in which the first unipolar wave causes the ejection of an ink droplet and the second one pulls back the filament into the nozzle as it were to prevent formation of unwanted satellites. [2]

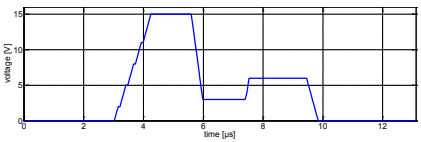

Figure 1: Optimised voltage waveform for ink A.

The two precursor inks were each deposited upon two different substrates, i.e. glass and PET that was corona treated. Best conductivity was reached when the structures were printed using a drop spacing of 10 µm on a 60°C hotplate during printing. After the printing process, a thermal sintering was applied at 60°C for 30 minutes.

Profilometry measurements indicate a very high roughness, around 2 µm (as high as the layer thickness itself), explaining the grey/off-white look of the printed structures. Optimisation of the layers' roughness can be performed by optimising the solvent blend but is out of the scope of this article. The electrical resistance of the layers was measured to be less than 5 Ω/cm.

Conclusions

In this work, Ag precursor inks are formulated that can be inkjeted to achieve homogeneous layers. Further it is shown that a resistance of less than 5 Ω/cm, after a sintering process at temperatures as low as 60°C is reached.

References

[1] A. Teichler, J. Perelaer and Ulrich S. Schubert, *J. Mater. Chem. (C)* **1** (10), 1910-1925 (2013).

[2] H. Y. Gan, X. Shan, T. Eriksson, B. K. Lok and Y. C. Lam, *J. Micromech. Mircoeng* **19**, 8pp (2009).

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Adaptation of silver-based screen pastes to achieve stretchable, conductive patterns

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Abstract: Commercially available screen pastes were enhanced with elastomers to be able to print layers with persistent conductivity upon stretching. Best layers were achieved after an addition of elastomeric material up to 3 wt% after a sintering procedure of only 3 minutes at mild (130°C) conditions.

Keywords: screen printing, silver ink, curing, stretchability

Introduction

Recent publications already propose smart designs of patterns to elongate the lifetime of stretched and/or bent conductive tracks [1]. Another option is to formulate inks in such a way that the conductive path stays intact upon deformation. This can be achieved by the addition of flexible components such as carbon based material (graphene [2,3], carbon nanotubes [3]) or by the use of elastomers [4]. In this work, elastomers are added to standard silver screen pastes and the optimal elastomer-to-screen paste ratio is deduced. These enhanced inks were then screen printed on PET foil and a curing procedure was optimized for resulting electrical properties. Finally, stretch tests were performed to learn about the degradation mechanism of the elastomer enhanced inks relative to standard inks.

Results and Discussion

Elastomers were added to an existing silver-based screen paste from 1 wt% up to 7 wt%. The thereby printed samples were then cured at 130°C for different amounts of time and at once Van der Pauw measured for surface resistance. An optimal conductivity was found to be 0,56 Ω/□ with 3 wt% elastomer after 3 min @130°C. The surface resistivity vs. curing time unexpectedly rose again after 3 minutes, indicating an optimum.

An added 50% decrease of surface resistivity was observed for all samples after 24h. By achieving the same results separately; once with standard paste and once on glass, influences of the added elastomers and used PET substrate were ruled out.

EDX surface chemical composition measurements then showed that for both pastes, standard and 3 wt%, more oxygen was present after curing for more than 3 minutes, indicating oxidation of the silver particles. The measurements were then repeated with a control group in the glove box. No noticeable change in oxygen levels at the surface was found and further experiments should indicate if the drop is linked to a further room temperature evaporation of solvents.

As a last step in this work, straight path samples of both pastes on PET foil were stretched up to 3% while measuring their resistance. It is shown that for the standard ink, the rise in sheet resistance was less than for the adapted ink. Upon relaxation, all samples returned to their initial resistance.

Conclusions

Stretchable inks were prepared by adding elastomers to an existing screen paste. It was shown that adding 3wt% of elastomers and curing for 3 min @ 130°C resulted in the best electrical and morphological properties. The rise in sheet resistance after longer curing times was attributed to oxygen uptake and thus oxidation of the conductive paths. Further surface resistance drops in time are thought to be attributed to slow solvent diffusion throughout the printed layer. In a last step, the stretch behaviour of the standard and the adapted ink were compared and it was found that a stretch up to 3% is feasible for the adapted inks upon an increase in sheet resistance of more than 100%. Further stretch tests, up to the 10% range, should indicate the difference in behaviour between the standard and the adapted inks.

References

[1] K. Kim, K. Jung, S. Jung, *Microelectronic Engineering* **120**, 216-220 (2014).

[2] Y. Jung, S. Oh, S. Choa, *Current Applied Physics* **7**, 1331-1334 (2013).

[3] S. Tuukkanen, M. Hoikkanen, M. Poikelispaä, *Synthetic Metals* **191**, 28-35 (2014).

[4] M. Park, J. Park, U. Jeong, *Nano Today* **2**, 224-260 (2014).

Acknowledgements

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Synthesis of a polythiophene-oligonucleotide-conjugate for site-specific integration into DNA origami

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Abstract: We describe the synthesis and characterization of a water-soluble semiconducting and start group functionalized polythiophene-derivate (P3RT) to provide a component suitable for biomolecular-encoded integration into artificially designed DNA templates. In this context, we further demonstrate the covalent binding of a modified oligonucleotide to the P3RT *via* click chemistry.

Keywords: DNA origami, polythiophene, organic semiconductors, click chemistry

Introduction

Bottom-up methods relying on biomolecular self-recognition processes such as DNA origami assembly [1, 2] have recently proven their suitability for sophisticated functional device fabrication because of their versatile and highly parallel synthesis approach. Due to its capability to attach nanoobjects site-specifically, DNA origami can act as "breadboard" scaffolds for functional heteroelements. Site-specifically attached to DNA origami, conjugated polymers can provide contact patches or wiring. Conjugated polymers are organic (semi-) conductors. The P3RT-type polythiophene-derivates are interesting species because of their controlled synthesis through the chain-growth mechanism [3]. Here we show how to synthesize a water-soluble P3RT and its feasible high yield coupling to a modified oligonucleotide (ON).

Results and Discussion

The P3RT was synthesized *via* Kumada catalyst-transfer polycondensation. The water-solubility was achieved by introducing a triethylene glycol-side-chain to the monomer. A catalyst, functionalized with a protected amine, was chosen to provide a high yield of functionalization. The successful synthesis of the target P3RT was proven by ^{1}H-NMR-spectroscopy and gel permeation chromatography. UV/VIS spectroscopy revealed an absorption maximum corresponding to a bandgap of a semiconductor (Fig. 1).

After converting the amine group into an azide-group, dibenzoyl-cyclooctine (DBCO)-ON were covalently attached to the polymer chains through strain-promoted cycloaddition without any additives in aqueous medium, yielding conjugates ready for the integration into biomolecular-based assemblies like DNA origami.

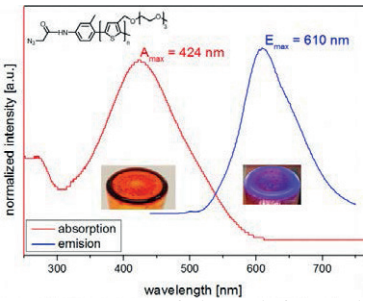

Figure 1: Structure of the azide-functionalized P3RT. Linear absorption and steady-state fluorescence emission spectrum.

Conclusions

We can synthesize a well-defined functionalized polythiophene which provides water-solubility through triethylene glycol side chains. The functional group allows the conjugation in aqueous medium to a modified DBCO-ON. This P3RT-ON conjugate can be used for site-specific attaching to DNA origami structures to build up templated (semi-) conductive devices.

References

[1] P. Rothemund, *Nature* **440** (7082), 297–302 (2006).

[2] F. Fischer, H. Henning-Knechtel and M. Mertig, *Phys. Status Solidi A*, published online (2015) DOI: 10.1002/pssa.201431931.

[3] A. Kiriy, V. Senkovskyy and M. Sommer, *Macromol. Rapid Comm.* **32**, 1503–1517 (2011).

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Design and construction of thermophoretic swimmers

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Abstract: This work focuses on thermophoretic transport on micrometre scale. For that purpose, diverse artificial microswimmers are built that in principle consist of a thermophoretic active element, e.g. a Janus particle, and a motion controlling element, e.g. DNA or DNA-based nanostructures. Furthermore, the DNA can be utilized to attach cargo and to determine involved forces.

Keywords: thermophoretic microswimmer, Janus particle, DNA origami, six-helix bundles, intrinsic force sensor, single-molecule manipulation

Introduction

In recent years, artificial micro- and nanoswimmers have attracted increasing interest due to their proposed potential for biomedical and nanotechnological applications, e.g. drug delivery.

Thermophoretic swimmers are prepared, where the propulsion is based on optically heating an asymmetric swimmer construct [1, 2]. Basically, the swimmer consists of a thermo-active Janus particle, a micrometre-sized polystyrene bead having one hemisphere covered with a 50 nm thick gold layer. In order to reduce rotational diffusion randomizing the particles directed motion [3], double-stranded (ds)DNA or DNA-based origami structures, serving not only as motion control element but also as a linker for loading cargo, are attached (Fig. 1). To this end, functional groups such as thioctic acid and biotin for binding to gold and streptavidin, respectively, were incorporated at the ends of the DNA using the enzymatic toolbox of DNA nanotechnology.

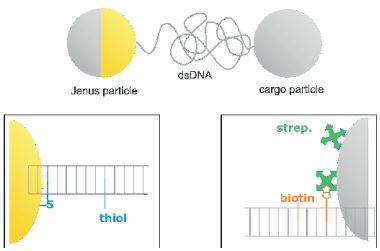

Figure 1: Construction scheme of thermophoretic swimmer hybrids.

Results and Discussion

The asymmetric swimmer construct is heated by laser irradiation resulting in the self-propelling flow field. The motion of the plain Janus particles is compared with the DNA-modified ones (Fig. 2). The unmodified Janus particle exhibits enhanced diffusion upon heating, while the DNA-stabilized Janus particle shows in that case a much more directed motion.

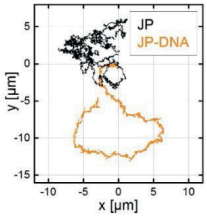

Figure 2: Trajectories of 2 laser-heated Janus particles (JP): Randomized motion of a plain JP and directed motion of a JP with attached 16 µm long λ-DNA.

Additionally, cargo beads can be bound to the free end of the DNA molecule. In such a setup, the stretching of the DNA between the self-propelled Janus particle and the cargo allows the determination of involved forces on the base of the well-known force-extension-behavior of dsDNA.

Conclusions

Hybrid thermophoretic swimmers consisting of a Janus particle, a linear DNA molecule and a cargo particle exhibit a reduced rotational diffusion. A double-stranded DNA molecule linking the thermo-active Janus particle and the cargo particle allows for determining involved forces.

References

[1] H.-R. Jiang, N. Yoshinaga, and M. Sano, *Phys. Rev. Lett.* **105**, 268302 (2010).

[2] A. Bregulla, H. Yang, and F. Cichos, *ACS Nano* **8**, 6542–6550 (2014).

[3] J. R. Howse, A. L. R. Jones, A. J. Ryan, T. Gough, R. Vafabakhsh and R. Golestanian, *Phys. Rev. Lett.* **99**, 048102 (2007).

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D
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Room Temperature Photoluminescence of Strained Ge-layers

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Abstract: Compressively strained, ~2 nm thick Ge films were grown on relaxed $Si_{0.5}Ge_{0.5}$ virtual substrate using molecular beam epitaxy. Grown films exhibit no-phonon assisted direct optical transition at around 1520 nm up to 300 K. Ge films on relaxed $Si_{1-x}Ge_x$ virtual substrates show potential for Si based light emitting sources.

Keywords: Epitaxy, Germanium, Silicon, Photoluminescence, On-chip communication

Introduction

Strain engineered group-IV semiconductor heterostructures have been found to be attractive for Silicon (Si) based light emitting source for on-chip communication[1]. Germanium (Ge) can be integrated into existing silicon technology[2] due to the small lattice mismatch of 4.2% to Si. Although both Si and Ge have no direct bandgap, optical transitions from tensile strained Ge-layers have been observed[3]. Due to unfavourable band alignment relatively less attention has been paid on the optical transitions from compressively strained Ge films. Here, the direct band gap optical emission from compressively strained Ge films grown by Molecular Beam Epitaxy (MBE) on fully relaxed $Si_{0.5}Ge_{0.5}$ substrate (RSG) is reported.

Results and Discussion

Compressively strained, ~2 nm thick Ge films were grown using a VG 80s solid source MBE-system. Grown films show comparably smooth surfaces ($R_{rms} < 1$ nm). The degree of relaxation was identified using Gracing Incidence Diffraction to r < 0,5% (Ge(004) peak at 67.385°). Photoluminescence spectrum (PL) of the grown Ge films were measured at different temperatures 10 K < T < 300 K using λ_{exc} = 980 nm excitation wavelength (P_{exc} = 40 mW). Two distinct and broad emission peaks at around 1520 nm and 1422 nm are observed (see figure 1). The peak at 1422 nm is attributed to the TO-phonon assisted transition in $Si_{0.5}Ge_{0.5}$ relaxed layer (PL of RSG not shown here). The peak at 1520 nm is observed only in the grown Ge and can be attributed to the no-phonon direct band gap transition within the surface Ge layer. The direct band gap optical transition in tensile strained Ge has been reported earlier due to population of electrons in the "Γ" valley of the conduction band[2]. However, results show direct band photoluminescence emission in compressively strained Ge grown on virtual $Si_{0.5}Ge_{0.5}$ substrate. The PL intensity decreases with increasing temperature from 10 K to room temperature. A significant emission at 1520 nm is observed up to 300 K, which is shown in the inset of figure 1.

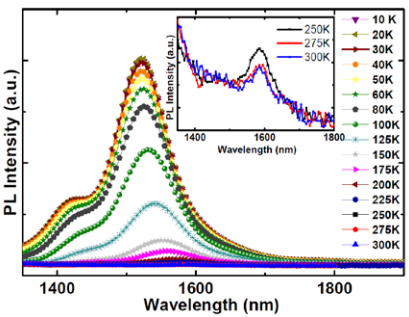

Figure 1: Temperature dependent PL spectra of 2.0 nm Ge film grown on relaxed $Si_{0.5}Ge_{0.5}$.

Conclusions

The growth of 2 nm compressively strained Ge-layers (degree of relaxation r < 0.5%.) on relaxed $Si_{0.5}Ge_{0.5}$ substrate was conducted via MBE. PL Intensity due to strained Ge-layer up to room temperature shows a direct optical transition (no-phonon assisted) at communication wavelength (~1520 nm). Ge films on relaxed $Si_{1-x}Ge_x$ virtual substrates appear to be attractive for Si based light emitting sources.

References

[1] Liu et al., *Thin Solid Films*, **520** (8), 3249–3254 (2012).

[2] Liu et al., *Opt. Lett.*, **15** (18), 11272 (2007).

[3] Liu et al., *Opt. Lett.*, **35** (5), 679-681 (2010).

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Printing of organic light emitting diodes on textile

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Abstract: Smart textiles with light-emitting properties open a whole new world of innovative textile applications such as indoor and outdoor design and safety clothing. To achieve light-emitting properties on textiles, organic light emitting diodes are printed or integrated onto textile substrates. The advantage of this approach is that typical textile properties like flexibility and drapabilty are maintained.

Keywords: smart textiles, OLED, printed electronics

Introduction

The future of smart or intelligent textiles with light-emitting properties is looking very bright. Besides the use as protective or safety clothing for road workers, police and fire departments, these light-emitting textiles can also be used as indoor and outdoor design. Lighting wallpaper or tiles and textile banners and flags used for advertisement are among this wide variety of applications. Even healthcare applications, such as light therapy are within reach.

To achieve light-emitting properties on textiles, organic light emitting diodes (OLEDs) are printed or integrated onto textile substrates [1]. These OLEDs are built up out of 4 to 6 very thin layers ending up with a device stack of maximum 0.5 micrometer and therefore maintain the flexibility and drapability of the textile substrate. Further they have a high brightness and very low power consumption. To protect these devices from fast degradation from contact with oxygen or water vapour, an encapsulation layer will be applied on top [2].

Results and Discussion

The roughness of most textile substrates is in the micrometer range, however the thickness of the different layers in the OLED stack and of the encapsulation layers are in the nanometer range. Firstly the influence of different smoothing layers, among which poly-urethane (PU), acrylate and polymethylmethacrylate (PMMA), are investigated. As a next step, encapsulation layers are applied using plasma techniques and their transparency, chemical composition and barrier properties for oxygen and water vapour are measured. On top of this encapsulation, the OLED stack is deposited. By using spin coating and evaporation techniques, OLEDs are fabricated and their resolving light output and luminous efficacy are measured. To finalize the complete stack, a last encapsulation is applied and the final properties of the device are measured and compared with reference devices on PET foil (figure 1) and glass substrates.

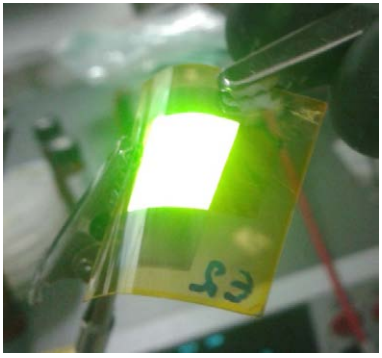

Figure 1: OLED printed on flexible PET foil.

Conclusions

It is shown in this work that efficient OLEDs can be printed or integrated onto a textile carrier to be used in a wide range of applications.

References

[1] D.-Y. Chung, J. Huang, D.D.C. Bradley, A.J. Campbell, *Organic Electronics* **11 (6)**, 1088–1095 (2010).

[2] J.-S Park, H. Chae, , H. K. Chung & S. I. Lee, *Semiconductor Science and Technology* **26 (3)**, (2011).

Acknowledgements

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Strained Ge layers on virtual $Si_{1-x}Ge_x(001)$ substrates

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Abstract: Strained Ge layers were grown on relaxed virtual $Si_{1-x}Ge_x(001)$ substrates using surfactant mediated epitaxy. In good agreement with theoretical considerations, the beginning of plastic relaxation via the formation of misfit dislocations after reaching a critical layer thickness is observed. By varying the composition of the VS, the critical thickness for strained Ge layers can be tuned, making it applicable for high mobility channels.

Keywords: epitaxy, germanium, strain relaxation, high mobility structures

Introduction

Strained Ge layers have become very interesting for their use in high mobility channels for modern metal oxide semiconductor field-effect transistors (MOSFETs) [1]. Due to the large lattice mismatch between Ge and Si (~ 4.2%), the use of a virtual substrate (VS) is required in order to grow pseudomorphically strained Ge layers of higher thickness. In contrast to conventional methods like graded buffers, the use of surfactant mediated molecular beam epitaxy (SME) using Sb as a surfactant provides smooth, fully relaxed virtual substrates with a thickness of 500 nm [2]. The surfactant decreases the surface free energy of the film and reduces the diffusion length of adatoms on the surface, thereby suppressing the island growth that would otherwise occur at the chosen process temperature.

Experimental

Using SME, 12 samples were grown to investigate the impact of film thickness, surfactant and VS composition. The samples were characterized with HRXRD, GIXRD, TEM, SEM, AFM and Raman spectroscopy.

Results and Discussion

The critical thickness for plastic relaxation is found to be in good agreement with theoretical considerations regarding the force-balance model [3]. For Ge on $Si_{0.22}Ge_{0.78}$, it is between 10 and 20 nm and for Ge on $Si_{0.31}Ge_{0.69}$ between 5 and 10 nm, respectively. TEM investigations show relaxation of the layers via the generation of misfit dislocations after reaching the critical thickness, confirming the change in lattice parameters acquired by HRXRD / GIXRD (Fig. 1).

Regarding surface morphology, the need for a surfactant is confirmed to grow smooth layers (Fig. 2). A change in growth mode is observed for different VS compositions. At higher misfit, the Ge layer grows in Stranksi-Krastanov mode until the islands start to merge and the roughness decreases.

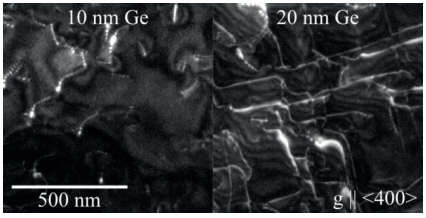

Figure 1: TEM weak beam dark field images of defect structures of SME-Ge/$Si_{0.22}Ge_{0.78}$ systems with different Ge layer thicknesses.

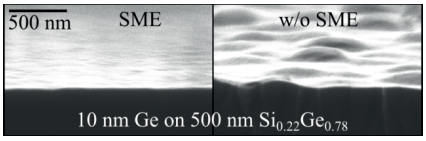

Figure 2: SEM crosssection image showing the impact of the surfactant on the Ge growth.

Conclusions

Ge layers were grown on $Si_{1-x}Ge_x$ VS using SME. Up to a thickness of 10 nm they show no sign of plastic or elastic relaxation, thus having the potential for high-mobility layers. It is shown that the surfactant is necessary in order to grow smooth layers at the chosen process temperature.

References

[1] M. L. Lee et al., *J. Appl. Phys.* **97** (1):011101 (2005).

[2] T.F. Wietler et al., *Thin Solid Films* **557**:27–30 (2014).

[3] J. W. Matthews and A. E. Blakeslee., *J. Cryst. Growth* **27**:118 – 125 (1974).

High-throughput structural characterization of DNA origami

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Abstract: DNA origami objects provide defined surfaces on which nanoobjects can be arranged with unprecedented site specificity and resolution. However, the characterisation of DNA origami is very time consuming. Here a novel quality control method for the origami formation is presented. It outplays currently used techniques in data throughput and ease of application but utilizes precise single molecule analysis.

Keywords: DNA origami, nanoanalysis, computer-aided data processing

Introduction

The DNA origami method [1] allows the formation of nanoscaled 2D and 3D templates. These templates can arrange a variety of nanoobjects on their surfaces with unprecedented site specificity and spatial resolution. This makes the method applicable e.g. in the bottom-up fabrication of nanoelectronic or nanophotonic devices [2, 3]. Mandatory for efficient device fabrication are suitable characterization methods. In this context, the structure evaluation of single objects is as important as the statistical bulk assessment. For single structure investigation, mostly atomic force microscopy (AFM; Fig. 1), transmission electron microscopy (TEM) and scanning electron microscopy (SEM) are employed. All of these methods provide resolution at the nm scale, but they require expensive equipment. Neither of them allows investigating a statistically significant number of objects (> 1000) on larger fields of view and in a reasonable time span. TEM and SEM are also highly invasive and include time-consuming sample preparation. For bulk characterization, gel electrophoresis is to date's standard technique for DNA origami. It is time-consuming as well and determines only mean global sample properties. All in all, a method yielding a maximum of sample-relevant information at a minimum of processing is still not established.

Results and Discussion

Here a new approach is presented that provides both nanometer-precise single origami analysis and statistical sample assessment. The measurements are carried out in "origami-friendly" aqueous conditions. The method allows the investigation of several thousand structures per hour, with a minimal sample preparation. The material for first test experiments was the DNA origami structure "tPad" [4]. As expected, structure-related data of several hundred tPads could be collected within minutes, i. e. two orders of magnitude faster than by AFM. The data was analysed using customized software [5]. The analysis yielded tPad dimensions that match the theoretical predictions with the small error of 10 % at most.

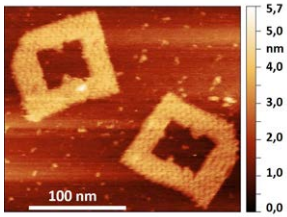

Figure 1: Liquid AFM image of the DNA origami structure tPad taken in 8 min. AFM yields high resolution images of single tPads, however, the number of investigated objects per time unit is low.

Conclusions

A robust, quick and feasible standard method for the structure evaluation of DNA origami nanoobjects is shown here that allows statistical and single object characterization simultaneously.

References

[1] P. W. K. Rothemund, *Nature* **440**, 297-302 (2006).

[2] H. T. Maune, P. W. K. Rothemund, and E. Winfree, *Nat. Nanotechnol.* **5**, 61-66 **(**2010).

[3] V. V. Thacker, L. O. Herrmann, and U. F. Keyser, *Nature Commun.* **5**, 3448 (2014).

[4] F. Fischer, A. Henning-Knechtel, and M. Mertig *Phys. Status Solidi (A)*. published online.

[5] F. Ruhnow, D. Zwicker, and S. Diez, *Biophys J* **100**, 2820–2828 (2011).

Acknowledgements

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Membrane Stiffness Tuning for Micro-machined Pressure Sensors

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Abstract: The utilisation of standard silicon on insulator substrates for the realization of integrated pressure sensors the thickness of the monocrystalline top layer isn't a technology parameter that is free to scale in the process. To extend the measurable pressure ranges and to implement a sticking prevention an easy adjustable initial tension of the membrane is eligible. Therefore a solution based on controlled pre-stressed thin layers deriving from a combined high and low frequency plasma enhanced deposition is presented in this work.

Keywords: Pressure sensor, MEMS, membrane stiffness, sticking prevention, cavity, PECVD deposition

Introduction

Pressure sensors, especially realized as monolithic integrated micro-electro-mechanical system (MEMS) are vitally important for a wide range of applications [1]. If silicon on insulator substrates are used for integration, the resulting membrane thickness is depending on the geometry of the top layer of the used starting material. The introduced method uses thin films that derive from plasma enhanced chemical vapour depositions (PECVD), which are often used as standard passivation for integrated circuits. This process is optimized with regard to a membrane stiffness tuning where the tensile and the compressive stress are actively controlled by varying the plasma frequency.

Results and Discussion

In context with cantilever MEMS structures the impact of the plasma frequency concerning the resulting stress has been examined by Tarraf et al. The duty cycle ψ is given by equation (1) where t_{HF} is the deposition time with high frequency and t_{LF} with low frequency [2]:

$$\Psi = \frac{t_{HF} - t_{LF}}{t_{HF} + t_{LF}}. \qquad (1)$$

In this work the tension is adjusted by duty cycles between ±0.8 and observed by the deflection w. Figure 1 shows the result of the analysis whereby a stress compensation for silicon nitride requires a duty cycle of 0.3.

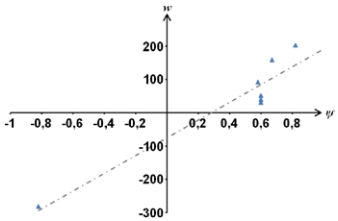

Figure 1: Resulting membrane deflection w depending on the duty cycle ψ.

This discrepancy to the publication of Tarraf et al. who found an equilibrium in a range of ψ = 0,6 is predominantly based on the usage of different process gases and low frequencies. Figure 2 shows different examples of tuned membranes. While the top scanning electron micrograph shows the cavity and the membrane after depositing a layer with tensile stress the bottom micrograph present the results of a compressive layer. The equilibrium is given in the middle.

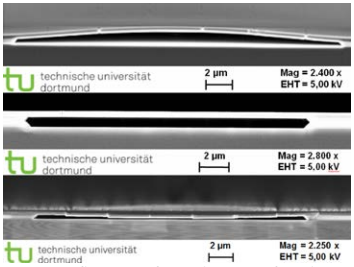

Figure 2: Deflection of membranes after depositing layers with different duty cycles.

Conclusions

The presented work shows the possibility of adjusting the membrane stiffness and initial tension by depositing silicon nitride and silicon dioxide films using such PECVD process steps. Furthermore sticking during the operation of the sensor is prevented by a convex surface using a corresponding duty cycle.

References

[1] A. Witvrouw, F. Van Steenkiste, D. Maes, L. Haspeslagh, P. Van Gerwen, P. De Moor, S. Sedky, C. Van Hoof, A. C. de Vries, A. Verbist, A. De Caussemaeker, B. Parmentier and K. Baert, *Microsystems Technologies* **6** (5), 192-199 (2000).

[2] A Tarraf, J Daleiden, S Irmer, D Prasai and H Hillmer, *Journal of Micromechanics and Microengineering* **14**, 317-323 (2004).

Miniaturization improves device performance of organic electrochemical transistors

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Abstract: The miniaturization of devices down to the nanoscale plays a major role in semiconductor manufacturing for biosensor applications. At nanoscale dimensions, high surface area available for biomolecular interactions offers a number of advantages including signal amplification, improved sensitivity and selectivity towards specific targets (analyte). In this work, organic electrochemical transistor (OECT) devices based on polymeric semiconductor materials (PEDOT:PSS) as an active channel are presented. In order to improve their device performance, a fabrication process for nano-sized interdigitated transducer electrodes (IDEs) was developed.

Keywords: nanoimprint lithography, interdigitated electrodes, OECT

Introduction

Organic electrochemical transistors based on conducting polymers have undergone significant progress in recent years and became the device of choice for biosensor fabrication. The characteristics of the gate electrode regarding the width and length of the channel effects the behaviour of OECTs in terms of their electrical performance. In order to improve their performance a fabrication process for nano-sized interdigitated transducer electrodes (IDEs) was developed and first devices were tested compared to their micro-scale counterparts.

Results and Discussion

In this work the fabrication of a nanoimprint lithography (NIL) mold and wafer scale fabrication of an IDE array with an established protocol based on NIL is presented. A NIL mold with IDE structures with finger width and space from 200-300 nm was designed. Definition of the structures was performed on a 4" Si/SiO_2 (200 nm) wafer by electron beam lithography. Structure transfer was performed by dry etching of SiO_2 with a CHF_3 plasma. For the fabrication of metal nanostructures a bi-layer resist lift-off technique (TU7 on LOR3A) was used [1]. NIL was applied for the definition of the structures followed by plasma etching of TU7 and wet isotropic etching of LOR 3A to create an undercut for the subsequent lift-off after e-beam evaporation of a metal layer (Au on a Ti adhesion layer). An optical mask was designed for the integration of contact lines in order to determine the electrical characteristics of the IDE array and PEDOT:PSS as an organic semiconductor was deposited on the open gate area. Micro- and nano-scaled electrodes were characterized in terms of their transconductance (Fig. 1).

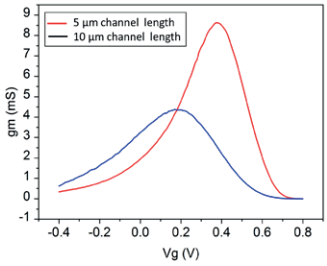

Figure 1: Transconductance of OECT increase by decreasing channel length.

Conclusions

A fabrication process of OECT devices for bio-assays based on PEDOT:PSS with excellent electrochemical gating properties is presented. Nanoscale gate features improve the device performance in terms of an increase of the bandwidth and the S/N ratio of the OECTs.

Reference

[1] M. Beck, F. Persson, P. Carlberg, M. Graczyk I. Maximov, T. G. I. Ling and L. Montelius, *Microelectronic Engineering* **73-74**, 837 – 842 (2004).

Acknowledgements

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Integration of FET-based biosensors into a Wheatstone bridge for purely resistive sensing

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Abstract: Field-effect transistor (FET) – based biosensors e.g. ion-sensitive FETs (ISFETs) and silicon nanowire FETs (SiNW-FETs) require complex amplification circuitry and temperature control when used as sensors. Therefore the goal of this work is the integration of such sensors into a Wheatstone bridge.

Keywords: Silicon nanowire field-effect transistor, ion-sensitive field effect transistor, Wheatstone bridge

Introduction

The Wheatstone bridge layout has advantages like simple readout and intrinsic temperature compensation. The integration of FET-based sensors in such configurations is promising. In earlier works different methods using reference FETs (REFETs) were presented [1, 2].

Results and Discussion

If the resistance are set in a configuration that they have opposite sensitivity, a maximum sensitivity of the bridge can be obtained, which is given by:

$$U_D = \frac{\Delta R}{R} \cdot U_S$$

where U_D is the diagonal voltage, ΔR the resistance change, R the basic resistivity and U_S is the supply voltage. Another advantage of the "crossed" sensitivity is the temperature compensation.

To get the highest possible sensitivity it is necessary to reach this kind of "crossed" sensitivity with FETs. This can be done by using both n- and p-channel devices. First some simulations have been realized with LTSpice. The schematic is shown in Figure 1:

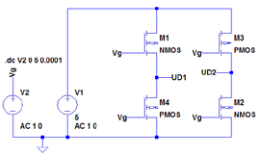

Figure 1: The schematic of a Wheatstone bridge with integrated p- and n-channel FETs.

The left half-bridge is a linear follower and the right one is in logic circuitry used as inverter and in motor driving circuitry for amplification. Lee et al. presented very high sensitivity with this configuration in [3]. Simulation results are shown in Figure 3. In the region from 2.495 to 2.505 V of gate voltage change, the change of the diagonal voltage is 460mV.

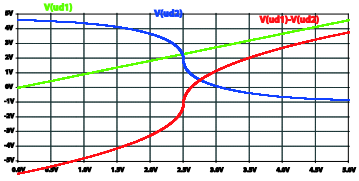

Figure 3: LT Spice simulation results

This is an amplification factor of around 46. This circuitry gives the possibility to balance the bridge via the voltage on the reference electrode and therefore the sensing can be bipolar.

Conclusions

In this work a very promising readout technique is proposed. It has to be checked if a higher sensitivity can be obtained by implementing depletion mode transistors and if the temperature compensation is working with this setup. First experiments are realized with ISFETs and later wafer-scale fabrication for SiNW-FETs is in work.

References

[1] A. Morgensthein, U. Dinnar, C. G. Jackobson and Y. Nemirovsky, *16th European Conference on Solid-State Transducers (*2002)

[2] A. Morgensthein, L. Sudakov-Boreysha, U. Dinnar, C. G. Jakobson and Y. Nemirovsky, *Sensors and Actuators B* ***98***, 18-27 (2004)

[3] J. Lee, S. Hwang, B. Choi, J. H. Lee, D-I. Moon, M-L. Seol, C-H. Kim, I-Y. Chung, B-G. Park, Y-K. Choi, D. M. Kim and S-J. Choi, *IEE IEDM13-385* (2013), 978-1-4799-2306-9/13

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Organic electrochemical thin-film transistors by spin coating fabrication

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Abstract: In this work PEDOT:PSS organic electrochemical transistors (OECTs) for biosensing applications are shown. These devices show very promising characteristics for sensing applications, mainly due to their high transconductance values, transparency and high biocompatibility. Devices can be fabricated easily and in a cost-effective manner to realize transistors which can surpass the properties of typical silicon based sensors.

Keywords: Organic field-effect transistors, PEDOT:PSS, impedance, cell adhesion, interdigitated electrodes

Introduction

Polymer transistors offer a wide spread usability for many fields of research, especially poly(3,4-ethylenedioxythiophene) doped with polystyrene sulfonate (PEDOT:PSS). In the field of biosensing, PEDOT:PSS has shown its capability for several different purposes such as glucose sensing [1], gas sensing [2], action potential measurements [3], and for *in vivo* applications [4]. Traditional silicon devices need a costly and rather complex fabrication, with strong limitations to device performance. OECTs offer a solution and an attractive alternative to silicon-based methods due to lower cost and ease of fabrication, with remarkable sensing properties.

It has been shown that thin polymer films down to 40 nm can be fabricated easily by spin coating, while thinner PEDOT:PSS layers should be favourable for high frequency operation, while thicker layers should increase the transconductance (g_m) and hence the sensitivity. A correlation between both was investigated to customise polymer devices with certain properties. A high cut-off frequency is beneficial for action potential (AP) measurements, to enable the recording of the fast components of the signal, while higher g_m values benefit cell impedance measurements.

Results and Discussion

Poly(3,4-ethylenedioxythiophene) doped with poly(styrene sulfonate) (PEDOT:PSS) was used for the organic electrochemical transistors. PEDOT:PSS was spin coated on glass chips with gold interdigitated electrodes (IDEs) as source and drain contacts. Figure 1 shows the optical differences between inkjet-printed and spin-coated chips, while inkjet printing produces layers of around 70 nm, spin coating can achieve way thinner polymer layers. A layer of ethylene glycol (EG) was then spin-coated and annealed on top of the PEDOT:PSS to increase the polymer conductivity as well as the carrier mobility and additionally increasing the stability of the polymer.

The fabricated devices were investigated towards their topographical differences caused by the stacking of several layers of PEDOT:PSS and changes due to the addition of EG. In both cases the changes in g_m and cut-off frequency were investigated to determine the ideal configuration of layer thickness for individual sensing purposes.

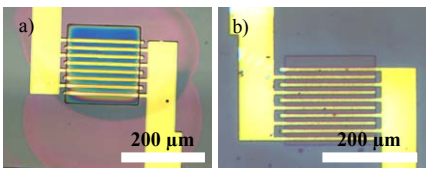

Figure 1: IDE chips of the same dimension, a) with inkjet-printed PEDOT:PSS layer, which can be identified by optical microscopy and b) spin coated chip.

Conclusions

An organic transistor was presented which can be used for a variety of biosensing applications by simple adjustments of the active polymer layer.

References

[1] Z.-T. Zhu, J.T. Mabeck, C. Zhu, N.C. Cady, C.A. Batt, G.G. Malliaras, *Chem. Commun.* **96,** 1556-1557 (2004).

[2] C.-Y. Lin, J.-G. Chen, C.-W. Hu, J.J. Tunney, K.-C. Ho, *Sensor Actuat B-Chem.* **140**, 402-406 (2009).

[3] K.A. Ludwig, J.D. Uram, J. Yang, D.C. Martin, D.R. Kipke, *J Neural Eng* **3**, 59 (2006).

[4] D. Khodagholy, T. Doublet, M. Gurfinkel, P. Quilichini, E. Ismailova, P. Leleux, T. Herve, S. Sanaur, C. Bernard, G.G. Malliaras, *Adv. Mater.* **23** H268-H272 (2011).

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Optimization of reduced graphene oxide-based field-effect transistor for impedimetric immunoassays

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Abstract: In the present study, reduced graphene oxide (rGO) was used as transducer material for biosensors. Graphene oxide (GO) flakes were deposited in between two metal electrodes using di-electrophoresis technique. GO was then thermally reduced to resume conductive and field-effect properties. A comparison of reduction time and device property was performed. The optimized devices were further used for human immunoassay. The low fabrication cost and high sensitivity of such devices might offer an alternative biosensor platform.

Keywords: Reduced graphene oxide, impedance sensing, immunoassay

Introduction

Field-effect transistor (FET)-based devices are popular choices for biosensors due to their ability to directly translate the interactions between target biological molecules and the FET sensor surface into readable electrical signals [1]. In the present study, reduced graphene oxide (rGO) was used as a transducer to convert the interactions of human brain-derived neurotropic factor (BDNF) and its specific antibody to measurable impedimetric signals. To achieve high sensitivity of detection, rGO properties were studied in different reduction time. A comparison of the limit of detection was carried out in between 50% and 100% reduced graphene oxide (GO) devices.

Results and Discussion

The gold microelectrode devices were fabricated on glass substrates in the cleanroom of the University of Applied Sciences Kaiserslautern in Zweibrücken. GO flakes were deposited in between a pair of gold microelectrodes (with 5 µm gap) using di-electrophoresis. The GO devices are initially insulating due to the large fraction of oxygen functional groups [2]. Therefore, a thermal reduction process was carried out (Fig. 1). The electronic properties of the devices were studied in a stepwise manner, from 1 h to 6 h reduction, at 300 °C in argon atmosphere (Fig. 2).

The rGO-based FET devices were then functionalized with specific human BDNF antibodies using EDC chemistry [3]. Both 50% and 100% reduced devices were used for the impedimetric immunoassay. The comparative data showed that the 50% reduced devices could detect down to 50 pg/ml BDNF, while the 100% reduced devices could not. The difference can be due to the capacities of the free functional group after thermal reduction for capture antibodies immobilization on the rGO surface. In the case of 100% reduction not enough functional groups are left for functionalization with capture molecules.

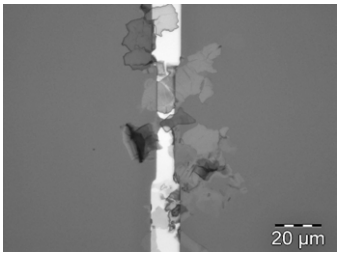

Figure 1: Microscopic image of the rGO device.

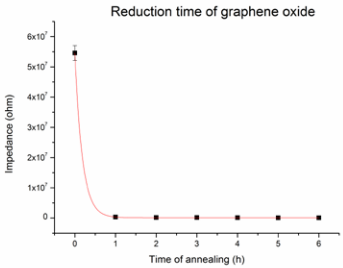

Figure 2: Impedance changes of GO in relation to the reduction time.

Conclusions

A study using rGO as transducer material for biosensing is described. The results indicated that a balance between material electronic properties and immobilization capacities is required to obtain the most sensitive biosensors.

References

[1] W. Wang, *Proc Natl Acad Sci USA* **102** (9), 3208–3212 (2005).

[2] D. Late, *Solid State Commun.* **150** (15-16), 734–738 (2010).

[3] D. Dreyer, Chem. Soc. Rev. **39** (1), 228–240 (2010).

Optimization of organic electrochemical transistors based on PEDOT:PSS for biological applications

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Abstract: In this work, the stability over time of organic electrochemical transistors (OECTs) in combination with inkjet printed poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) was investigated for the purpose of biological applications.

Keywords: PEDOT:PSS, organic electrochemical transistors, Inkjet printing

Introduction

PEDOT:PSS is a widely used conductive polymer [1] because of its beneficial properties such as high conductivity [2], flexibility [1] and stability at different levels of pH [3]. Films can be easily prepared by inkjet printing, which reduces costs of fabrication [1]. The use of PEDOT:PSS as a channel for organic electrochemical transistors has gained attraction for biosensing purposes [4]. The design allows operation in electrolyte at relatively low voltages (< 1V), this in combination with the biocompatible channel makes the sensor suitable for cell sensing applications [4]. In this view, the sensor is a promising alternative method as a pharmacological platform [1, 4].

Results and Discussion

In this work, experiments were conducted to gain more insights into the use of PEDOT:PSS as the active layer for OECTs for biological applications. Stability measurements were conducted to establish the stability over time of the transistors. Over 25 days, chips were continuously immersed in cell culture medium and kept in an incubator. Medium was changed before each measurement to mimic cell culture proceedings. Measurements involved the transfer characteristics of the transistors, from which the transconductance (g_m) was calculated. Nearly half of the transistors showed a reduction of 50% in g_m after 3-4 days, about 20% of the transistors remained stable over 25 days (figure). Afterwards the polymer film looked deteriorated. The main reason for the deterioration of the polymer is believed to be the amount of measurements combined with the conditions the sensors were kept at. For certain cell-sensing applications stability of g_m for several days (3-5) is required. Therefore, the found results are promising. In addition, different studies suggested that cross-linking the polymer, using epoxy silanes, decreases deterioration because it reduces swelling of the film during measurements [1, 5]. Hence, further research in this direction should be conducted to improve stability over time.

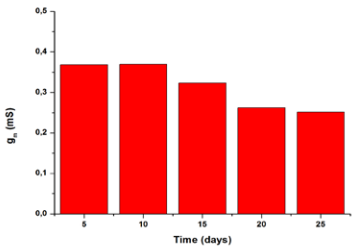

Figure: Transconductance (g_m) over 25 days for one transistor, 5-day steps.

Conclusions

The beneficial properties of PEDOT:PSS combined with the stability over time, make the transistor a promising sensor for multiple bio-sensing purposes.

References

[1] C. Yao, C. Xie and I. M. Hsing. *Adv Mater*. **25**, 6575-6580 (2013).

[2] D. Khodagholy, J. Rivnay, G. G. Malliaras. *Nat Commun*. **4**, 2133 (2013).

[3] L. Kergoat, B. Piro, M. C. Pham. *Anal Bioanal Chem*. **402**, 1813-1826 (2012).

[4] P. Lin, X. Luo and F. Yan. *Adv Mater*. **23**, 4035-4040. (2011).

[5] D. Khodagholy, T. Doublet, G. G. Malliaras. *Nat Commun*. **4**, 1575 (2013).

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Fabrication of graphene oxide field-effect transistor devices

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Abstract: Via the spincoating technique it is possible to structure and reduce graphene oxide (GO) over a 4-inch glass and silicon wafer for large scale processing of sensors. The reduced GO (rGO) offers promising properties for the application as a transducer material for the opto-electronic detection of biomolecules.

Keywords: GO-synthesis, micro structuring, optical lithography, FET-chips

Introduction

To generate high quality thin-films of reduced graphene oxide (rGO) over silicon and other versatile surfaces, this project aims to establish a scalable synthesis procedure for high-quality graphene-oxide in solutions. The use of the modified Hummers method make it possible to prepare uniform GO thin-films over the wafer surface with an optimized chemical modification of the functional groups. The Hummers method of synthesizing graphene oxide (GO) was improved by introducing additional process steps such as low temperature, filtering, centrifugation, and dialysing to enhance the quality of GO[1].

Results and Discussion

Silicon substrates were activated and modified by thin layers of (3-Aminopropyl)triethoxysilane (APTES) in an optimized gas-phase silanization process. This procedure formed ultra-thin, homogenous GO layers covalently coupled to the carboxylic group of the GO and the amino groups of the silane (APTES) as confirmed with different characterization techniques. The GO layers were reduced by chemical or physical methods and then subjected to standard micro-structuring techniques for device fabrication. In standard photolithography techniques, an image reversal resist was used for the subsequent pattering of the GO films. The GO etching was carried out in pure O_2 plasma leading to precise GO structures followed with physical vapour deposition of gold contact pads. The process for the preparation of GO films was characterized using spectroscopic ellipsometry techniques in a multi-angle arrangement. Topographical characterisation of GO films and devices was executed using the AFM, TEM and SEM and chemical composition was confirmed by Raman microscopy. After all these steps the micro structured rGO over silicon surfaces structural resolution limit was investigated. Figure 1 (a)

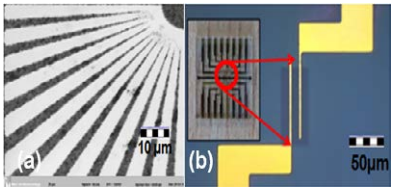

Figure 1: (a) GO-Siemens star (b) FET-electrodes covered by the thin film of rGO.

shows the tested resolution limit of rGO which is only limited by the optical lithography method and not by the GO material itself. In all likelihood this GO-solution will also be a good candidate for the Nano imprint lithography (NIL) patterning. Figure 1 (b) illustrates the final FET-chip with the structured rGO on top of the electrodes. Thus devices were fabricated on wafer-scale and characterized for their electronic-transport characteristics and deployed as ion-sensitive field-effect transistors demonstrating excellent reproducibility and uniform characteristics [2].

Conclusions

With that route it is possible to measure field-effect behaviour with these FET-chips. Tests of the reduced GO layer, the stability and sensor characteristics will be important further steps to develop a stable platform for the opto-electronic detection of various biomolecules.

References

[1] D. C. Marcano, D. V. Kosynkin, J. M. Berlin, et al. *ACS Nano* **4** (8), 4806-4814 (2010).

[2] J. Warner, F. Schäffel. A. Bachmatiuk. Graphene – Fundamentals and emergent applications. Oxford 2013 p.388f.

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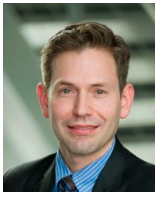
Session E

Session E - Tutorial
Nanoscale characterization of tribological surfaces

Although not well recognized, friction and wear phenomena are omnipresent in our society and affect many processes that range from transportation to data storage, health and cosmetics. To understand these phenomena it is important to realize that sliding surfaces in dry or lubricated conditions undergo significant changes in terms of topography, chemistry and microstructure and a nanoscale so-called "third body" [1] develops. The third-body formation strongly influences the frictional and wear behavior of the system. In this tutorial presentation I will introduce general tribological concepts and will present novel in-situ tools, modern surface analytical techniques and simulations. Finally I will present case studies to illustrate how to combine these results in order to understandi underlying basic mechanisms.

[1] M. Godet, Wear, 100 (1984) 437–452.



Prof. Dr. M. Dienwiebel

Martin Dienwiebel studied Physics in Dortmund and Bonn, Germany and conducted his Master thesis research in the field of low temperature STM at the National Research Center Juelich. He obtained his PhD in the field of friction force microscopy and Superlubricity at Leiden University, The Netherlands. During his PhD research he also spent nine months at Tokyo Institute of Technology in the group of Prof. Takayanagi.

After his PhD in 2003 he worked in automotive industry at the tribology research department of IAVF Antriebstechnik AG company. In 2008 he received an Emmy-Noether fellowship from the German Research Foundation and set up a junior research group at Karlsruhe Institute of Technology and the Fraunhofer Institute for mechanics of Materials. He obtained his habilitation 2011 at the Mechanical Engineering faculty of KIT.

Influence of different ion composition on the protein film formation on dental materials

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Abstract: For albumin and lysozyme the protein amount, the adhesion forces and the enzymatic activity were investigated on different dental materials like titanium, gold, ceramics and PMMA for different dentally relevant ion compositions in the buffer solution (fluoride, calcium, and phosphate). The effect of these ions on the protein layer formation vary greatly and depend on the used protein as well as on the dental material on which the experiments were conducted.

Keywords: dental materials, albumin, lysozyme, scanning force spectroscopy, enzymatic activity, BCA-assay

Introduction

In dental medicine, many different biomaterials like titanium, gold, ceramics and PMMA are used as reconstruction, prosthesis or implant materials. They are brought into the oral cavity, where they are exposed to human body fluids and bacterial suspensions. As in every proteinaceous fluid, a protein film will be formed on solid surfaces. After the proteins, bacteria will adsorb on the now protein covered biomaterial surface. These bacteria are responsible for many different dental diseases like caries and periodontitis [1]. In the experiments, the protein layer formation can be influenced by changing the ion composition in the buffer solution. Here the influence of fluoride, calcium and phosphate ions on the amount of protein adsorbed on the biomaterial surface, the adhesion forces between surface and protein and the enzymatic activity of lysozyme on these surfaces was investigated.

Results and Discussion

In the case of albumin on titanium, fluoride ions lead to a slightly increased protein surface concentration, but the adhesion forces between the protein molecules and the surface decrease sharply after addition of 1 ppm fluoride ions in comparison to the control without fluoride [2]. The antibacterial effect of lysozyme is not affected. Thus, application of fluoride ions might facilitate easier removal of the adsorbed protein layer from titanium substrates during daily oral hygiene, which could lead to a reduced bacterial biofilm formation. Calcium ions reduce the albumin surface concentration on titanium as well as the enzymatic activity of lysozyme. Here the adhesion forces are unaffected. If lysozyme is used instead of albumin, the amount of protein on the titanium surface increases with increasing calcium concentrations (Figure 1). This could be due to aggregation of lysozyme molecules with divalent calcium ions.

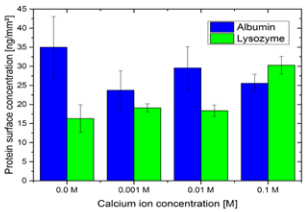

Figure 1: Amount of albumin and lysozyme on Ti as a function of the calcium ion concentration.

In case of phosphate the amount of protein and the enzymatic activity are unaffected for both, albumin and lysozyme. The adhesion forces of albumin are much lower for smaller phosphate ion concentrations.

Conclusions

Changing the ion composition in the buffer solution is a good way to influence the protein layer formation and therefore the following bacterial adhesion. The effect depends on the used ion, on the surface material and the investigated protein, so all three factors have to be considered to achieve the desired effect.

References

[1] Hannig, M. and Hannig, C., Oralprophylaxe **29**, 73-82 (2007).

[2] Kratz, F., Müller-Renno, C., Davoudi, N., Umanskaya, N., Grass, S., Hannig, M. and Ziegler, Ch., Biomed Tech **59** (s1), 81-84 (2014)

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E 1

Self-assembly of tomato bushy stunt viruses (TBSV) investigated by scanning force and scanning electron microscopy

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Abstract: The self-assembly of tomato bushy stunt viruses (TBSV) with different modifications on mica and silicon were investigated by scanning force and scanning electron microscopy. For this purpose amino acid side chains were integrated in the capsids of the viruses by extending the coat protein (CP) with different charged amino acids via point mutation. The influence of the electrostatic forces between the whole virus and the surface on the formation of self-assembled monolayers will be presented and discussed in the context of differences in surface coverage for different pH values.

Keywords: virus crystals, tomato bushy stunt virus, bottom-up approach, nanomaterials

Introduction

In nanotechnology, fabrication technologies based on a top-down approach reach physical and technical limits. Therefore bottom-up approaches have been of increasing interest. Here small building blocks form larger elements through self-assembly. Because of their advantageous properties plant viruses with simple structures and high potential for self-assembly are employed here.
In this work the crystallization of tomato bushy stunt viruses on mica and other surfaces were investigated by scanning force and scanning electron microscopy.

Results and Discussion

The behavior of TBSV (wild type, with histamine and with aspartic acid residues) on mica was already investigated [1]. But for future applications it is desirable to get a more homogeneous two-dimensional virus monolayer over an area of several micrometers. For this purpose, the surface coverage of different TBSV-types (wild type, histidine, cysteine and arginine residues) were controlled by varying the pH value of the virus solution or by modifying the surface with 3-aminopropyltriethoxysilane (APTES) to enhance the virus-surface attraction. These modifications change the electrostatic interaction forces: The surface charge of the viruses depends on the isoelectric point (IP) of the TBSV particle. One possibility to change the IP is the genetic manipulation of the TBSV particle by adding an amino side-chain. This results in a shift of the total virus IP. Another option consists of a substrate surface modification with APTES, which changes the substrate surface charges.

To change the pH, acetic acid was added in varied concentrations to the virus solution. The SFM images of the obtained self-assembled monolayers of TBSV (cysteine) at mica are shown in figure 1.

In all images a hexagonally closed structure of viruses is visible. However, at pH 3.7 the coverage of the virus has a maximum. This fact can be explained by the charges at pH 3.7: the attractive forces between the positively charged surface and the negatively charged viruses are strong enough, but the repulsive forces between the viruses are as small as possible.

Similarly, a large surface coverage can be obtained by APTES coating of the surface which creates a more positively charged surface.

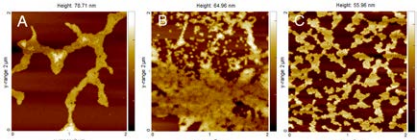

Figure 1: 2 x 2 µm² SFM images of TBSV (cysteine) on mica prepared at different pH values.

Conclusions

It could be shown that the electrostatic interaction between virus and surface is very important for the 2-dimensional virus crystal formation. The surface coverage can be controlled by varying the surface charge of the virus and/or the substrate.

References

[1] A. Lüders, C. Müller, K. Boonrod, G. Krczal and Ch. Ziegler, *Colloids and Surfaces B.: Biointerfaces* **91**, 154-161 (2012).

Acknowledgements

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E 2

Analysis of the adsorption behavior of carbohydrates on dental materials

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Abstract: Carbohydrates are a major class of biological macromolecules besides proteins, lipids and nucleic acids. They serve many purposes, from energy storage to chemical communication, in the form of simple sugars as well as polysaccharides. In the matrix of an oral biofilm the polysaccharides contribute to bacterial adhesion and thus the formation of a biofilm. Due to their metabolism the adsorbed bacteria favor the development of caries and periodontal disease [1]. Therefore, a further understanding of the adhesion processes of carbohydrates is of great importance for dentistry.

Keywords: dextran, adsorption, phenol-sulfuric acid assay, quartz crystal microbalance

Introduction

To investigate the adsorption behavior of carbohydrates on dental materials, two polysaccharides with average molecular weights of 550 kDa and 20 kDa are used to consider differences between the longer and shorter molecular chains. The polysaccharide dextran is particularly suitable because it is produced by bacteria present in the oral cavity [2].

Results and Discussion

To obtain a detailed understanding of the adsorption behavior of dextran on titanium and silicon the amount of adsorbed dextran was studied as a function of different parameters such as the pH of the buffer and various rinsing steps by a phenol-sulfuric acid (PSA) assay.

The detected amount of dextran shows an increase with increasing pH values. The PSA-assay indicates a greater amount of adsorbed dextran on titanium than on silicon. Furthermore, the adsorbed amount of the 550 kDa dextran tends to be higher than the adsorbed amount of the 20 kDa dextran on both surfaces. The detected amount of dextran shows a decrease towards a higher number of rinsing steps and therefore a part of the dextran appears to be rather loosely bound to the surfaces.

The adsorbed amount of dextran on titanium was also analyzed by a quartz crystal microbalance (QCM) which in addition provides information about the viscoelastic properties of the layers. It was found that a certain proportion of the 550 kDa dextran is adsorbed irreversibly and this proportion increases to a saturation value with increase of the dextran concentration. A comparison between the 550 kDa dextran and the 20 kDa dextran shows that the adsorbed amount of the 550 kDa dextran is higher than the adsorbed amount of the 20 kDa dextran.

Contact angle measurements show more hydrophilic behavior of the surfaces with adsorbed dextran in comparison to the surfaces without adsorbed dextran. In addition, topography and thickness of dextran layers were investigated by scanning force microscopy.

Conclusions

The measurements show that the adsorbed amount of the 550 kDa dextran is higher than the adsorbed amount of the 20 kDa dextran. Furthermore the PSA-assay indicates that the amount of adsorbed dextran increases towards higher pH values. A portion of the adsorbed dextran appears to be rather loosely bound to the surfaces and decreases towards a higher number of rinsing steps. The QCM measurements show for both dextrans that a certain proportion is adsorbed irreversibly.

References

[1] A.F. Paes Leme, H. Koo, C.M. Bellato, G. Bedi and J.A. Cury, *Journal of Dental Research* **85** (10), 878–887 (2006).

[2] A. Täufel and K. Täufel, *Journal of Food/Nahrung* **14** (5), 331–337 (1970).

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E 3

Measurement of Lateral Strength for Bacterial Adhesion by Scanning Force Microscopy

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Abstract: Scanning force microscopy was used to measure the lateral adhesion strength of individual bacterial cells on the surface in liquid. Two modes of scanning force microscopy (quantitative imaging (QI™) mode and contact mode) were used in this work. The scan size of at least 50 x 50 µm² was taken to capture an adequate number of attached bacteria on the desired surface in QI™ mode. An increase of applied force in contact mode from 1pN to 2 nN was required to dislodge bacteria from smooth (glass and polished cp-titanium) respectively rough surfaces (premilled cp-titanium and microstructured cp-titanium).

Keywords: lateral detachment force, shear strength, bacterial adhesion, scanning force microscopy

Introduction

Bacterial adhesion on surfaces results in bacterial colonization and, finally, biofilm formation. A thorough understanding of initial bacterial adhesion on the surface can reveal more knowledge of biofilm formation on a specific surface. The bacterial adhesion process has been studied by various experimental techniques to provide information, on one hand, on the number of attached bacteria via microscopy techniques [1] and, on the other hand, on the strength of the attachment via flow cell techniques using shear forces [2]. The scanning force microscopy can be a promising technique to measure the lateral adhesion strength of adhered bacteria with high force resolution [3].

Results and Discussion

In this work, a large area was imaged by QI™ mode (non-destructive imaging mode) to visualize bacteria (here: *Paracoccus seriniphilus*) before and after bacterial dislodgement test. A small area around one single bacterium was scanned in contact mode to dislodge the bacterium (Figure 1). Each bacterium was scanned with different forces in the range of 1 pN to 2 nN. It was shown that at the higher forces, the cantilever detaches and pushes the bacterium out of the selected scan area. Whereas, at lower forces the cantilever cannot detach the bacterium mostly and therefore, the cantilever tip scans over the bacterium and damages the bacterial membrane. In the case of successful dislodgement of bacteria, the bacteria were found out of the scan area and in the other case they were still in place, but with a drastically reduced height. in the order of nanometers. The measurements of bacterial lateral adhesion strength on smooth and rough surfaces showed that on rough surfaces the bacterium might be trapped in the grooves of the surface. In these cases, it is not possible to detach the bacterium from the surfaces.

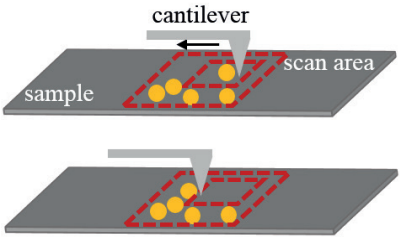

Figure 1: Schematic figure of bacterial dislodgement with a cantilever tip.

Conclusions

This work has shown the use of scanning force microscopy via quantitative imaging and contact mode, as precise method to investigate the lateral detachment force of individual bacteria on the surface.

References

[1] H.H.P. Fang, L.C. Xu and K.Y. Chan, Biotechnol. Lett. **22**, 801-805 (2000).

[2] A. Roosjen, N.P. Boks, H.C. van der Mei, H.J. Busscher, W. Norde, Colloid Surf. B **46**, 1-6 (2005).

[3] K.A. Whitehead, D. Rogers, J. Colligon, C. Wright, and J. Verran, Colloids Surf. B **51**, 44-53 (2006).

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Role of carbohydrate-protein interaction in adsorption processes

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Abstract: Carbohydrates and proteins are the main constituents of bacterial biofilms besides lipids, nucleic acids and bacteria [1]. The primary step of biofilm formation is the adsorption of organic substances on surfaces. Here, the interaction of carbohydrates and proteins in the adsorption process on solid surfaces is studied. Established films are characterized according to the adsorbed amount of carbohydrate and protein and film thickness.

Keywords: carbohydrates, proteins, adsorption, biofilm, phenol-sulfuric acid assay, quartz crystal microbalance, ellipsometry

Introduction

Under humid, non-sterile conditions a primary organic conditioning film will form on solid surfaces. In the process of biofilm formation bacteria will interact with this film rather than with the surface itself. So, this film serves as a mediator for bacterial adhesion [2] und is thus a key factor in biofilm formation. Therefore it is important to investigate the building and composition principles of this pre-adsorbed film which is done here for the components carbohydrates and proteins.

Results and Discussion

The interaction of carbohydrates and proteins in adsorption processes is investigated here by using dextran, which is a polymer of glucose present in oral biofilms, and the protein bovine serum albumin (BSA) on titanium and silicon samples.

Layer thicknesses are determined by scanning force microscopy scratching experiments (see Fig. 1) and ellipsometry. It was found that established dextran layers are significantly thinner than BSA layers.

Thicknesses of pure dextran and pure BSA layers are also compared to layers containing both biomolecule types to investigate possible cooperative adsorption effects.

In addition, quartz crystal microbalance (QCM) is applied to characterize adsorbed biomolecule amounts and viscoelastic properties of the layers. A combination of two biochemical assays, namely phenol-sulfuric acid (PSA) and bicinchoninic acid assay (BCA), are capable of determining the amount of carbohydrate and protein in the layer separately. Care was taken to exclude that one biomolecule type is interfering with the biochemical assay of the other biomolecule type.

The biochemical assays show that the amount of BSA on the sample is not altered by previous or subsequent exposition to dextran solution. Also QCM data indicates that a primary adsorbed dextran layer does not prevent subsequent BSA adsorption, but a BSA layer seems to be able to passivate the surface for further dextran adsorption.

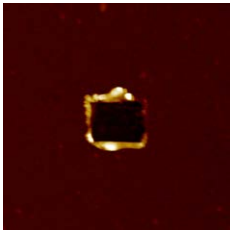

Figure 1: 5x5µm² Scanning force microscopy image of a BSA layer on silicon where BSA is removed by scratching in the center to determine the layer thickness.

Conclusions

Dextran shows less adsorption than BSA on the surfaces which is also reflected in smaller layer thicknesses for dextran. In the presence of both, BSA and dextran, the BSA adsorption is dominating.

References

[1] W. Sutherland, *Trends in microbiology* **9** (5), 222-227 (2001).

[2] M. Hannig, and C. Hannig, *Oralprophylaxe* **29**, 73-82 (2007).

Acknowledgements

The authors acknowledge funding by Deutsche Forschungsgemeinschaft within SFB 926, 3T Analytik for using qCell T and the Nano Structuring Center, Kaiserslautern for providing the ellipsometer.

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Coaxial electrospun scaffolds with piezoelectric effect for tissue regeneration

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Abstract: In neural tissue engineering piezoelectric polymers are being investigated as potential scaffolds for supporting nerve regeneration processes. A promising material is polyvinylidene fluoride (PVDF) because of its proven biocompatibility and piezoelectric properties, which can possibly stimulate cell ingrowth with its electrical activity upon mechanical deformation [1]. This work reports the coaxial electrospinning of polyvinylidene fluoride (PVDF) and polycaprolactone (PCL) core/sheath nanofiber mats in order to enhance the mechanical and physical properties of the PVDF fibers.

Keywords: Tissue engineering, nanofiber mats, piezoelectric, coaxial electrospinning

Introduction

Regenerative medicine represents an alternative to conventional transplantation procedures using either permanent or degradable biomaterials with living cells. Since the 1950s biological and synthetic piezoelectric polymer structures have been investigated such as polyvinylidene fluoride (PVDF).

In studies of peripheral nerve regeneration it has been shown that micro electric pulses of films of PVDF positively influence directional axon growth. The piezoelectric effect supports and accelerates the axonal regeneration in artificial grafts. The direction of the growth of axons is controlled by the electrical polarization and a faster growing of neurites is induced [2].

Experimental methods

Coaxial electrospun scaffolds were produced from PVDF 20% dissolved in N,N-dimethylformamide and acetone (4:1) as a core and PCL 170 mg/ml dissolved in Tetrafluoroethylene as a sheath. In the electrospinning process flow rates of 0.5 ml/h for the core and 1 ml/h for the sheath and voltages of 22 kV were applied to produce defined fibers. The structures of the PVDF/PCL scaffolds were observed and analyzed with SEM to determine their morphology and fiber diameter. The mechanical properties of the scaffolds were tested using a tensile testing machine (BOSE-Electroforce-LM1-Test-Bench). To determine the configuration of the core/sheath structure in the coaxially electrospun scaffolds and their piezoelectric properties the scaffolds were compared with untreated/raw PVDF pellets with respect to the presence of the nonpolar α-phase and piezoelectric polar β-phase by using FTIR and DSC. Physical behaviour and hydrophility of the scaffolds surfaces ware evaluated using static contact angle experiments. Subsequently all results were analyzed and evaluated comparing with single-jet electrospun PVDF scaffolds

Results and Discussion

Coaxial electrospun PVDF/PCL Scaffolds exhibited a higher tensile strength of 1.9 MPa and strain at break of 130% as compared with the maximum tensile strength of the single-jet electrospun scaffolds of 138 kPa with 75% elongation at break. The PCL layer increases the hydrophilic property of the coaxial PVDF/PCL scaffolds, which could enhance the adhesion and proliferation of the neural cells on the scaffolds. Similar to single-jet electrospinning of PVDF scaffolds, the coaxial PVDF/PCL scaffolds resulted in a polar β-phase formation, which is relevant for the piezoelectric effect, and showed a β-phase adsorption ratio of 53% at 841 and 1277 cm^{-1} in the FTIR-spectrum

Conclusions

This study shows the ability to produce coaxial nanofibers of PVDF and PCL with better mechanical and physical properties. The FTIR and DSC results demonstrate the piezoelectric effect of the coaxial PVDF/PCL scaffolds. Next steps will be carrying out in vitro and in vivo experiments to evaluate the cytotoxicity of the coaxial scaffolds and to investigate the neural cells culturing on the piezoelectric PVDF/PCL scaffolds.

References

[1] F. AL Halabi, P. Behrens, and B. Glasmacher, *Biomed Tech* **59** (s1), 193-197 (2014).

[2] C. H. Hung, Y. L. Lin, and T. H. Young, *Biomaterials* **27** (25), 4461-4469 (2006).

Acknowledgements

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Long-Term Tracking of Bruxism during Day Time by Implementing Conducting Hollow-Sphere Polymers into a Splint

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Abstract: Bruxism is defined as an instance of grinding or clenching of the upper and lower teeth, and is often an unconscious action. Although it is common for people to clench their teeth, bruxism is distinguishable because it results in damage to the teeth, due to abnormal amounts of wearing, as well as damage to the muscles and surrounding tissues that are associated with clamping the jaw. Current perceptions and research options are focused around night time bruxism due to the bulky sensing equipment. In this project we will overcome this limitation by developing a monitoring device based on based on polypyrrole.

Keywords: Diurnal bruxism, device development, photochemistry, polypyrrole

Introduction

While nighttime bruxism is typically characterized by teeth grinding, bruxism can also occur during the day. Daytime grinding is uncommon in the general population, but daytime clenching, also a form of bruxism, occurs in approximately 10% of the population. Like nocturnal bruxism, daytime bruxism or diurnal bruxism is closely related to stress. Most people have experienced teeth clenching in response to stress at some point, but it is when this clenching becomes chronic and starts to cause damage and pain that it becomes a problem rather than a periodic response to high stress situations. Diurnal bruxism is unusually common in high stress professions. Though it occurs in only 10% of the population at large, an estimated 50% of law enforcement officers [1] and 59.2% of IT professionals [2] suffer from the effects of daytime clenching. Clenching seems to be a natural human response to stress, but in those who are unusually susceptible to stress or who have highly stressful careers. Though both classified as bruxism, nocturnal and diurnal bruxism seem to operate through differing mechanisms [3]. While diurnal occurs in 10% of the general population, nocturnal bruxism affects only 5% of the population [2]. The main goal of this work is the development of a product that's extremely sensitive towards impact of the jaws in order to monitor and treat daytime bruxism.

Results and Discussion

The development of a flexible conductive pressure sensitive sensor is our point of interest. For polypyrrole films it is known that they have conducting properties [4]. Moreover, recently it has been stated that these films are excellent candidates as ultra-sensitive pressure sensors [4]. Hence, polypyrrole offers all the characteristics we need for a miniaturized sensor in a mouth piece; conductivity, flexibility, thin layer film formation, and pressure sensitivity. Currently, a rough prototype based on polypyrrole as a sensor has been developed. Polypyrrole has been synthesized according to the literature procedure by Pan et al. Pyrrole has been polymerized by oxidative polymerization via the formation of a radical cation. The polymerizations are carried out in water and due to the hydrophobic nature of polypyrrole it will spontaneously form hollow sphere microstructures. These micelles induce a certain form of elasticity into the polymer, which is necessary in order to work as a pressure sensor. But in contrast it decreases conductivity. To overrule this, p dopants (e.g. phytic acid) are mixed with the monomers during the polymerization process. In addition the dopants crosslink the polymers, furthermore enhancing the conductivity. The main problems which still have to be overruled are the properties of the polymer film.

Conclusions

The ultimate goal of this project is to develop a working device, capable of tracking bruxism activity during daytime. Given the quality of the results and the developed prototype based on polypyrrole it is expected to have a proof-of-device in the fall of 2015

References

[1] A. Carvalho et al., *Brazilian Oral Research* **22**, 31-35 (2008).

[2] S.K. Rao et al., *International journal of dentistry* doi:10.1155/2011/650489.

[3] D. Manfredini et al., *Journal of Oral & Facial Pain and Headache* **23**, 153-166 (2009).

[4] L. Pan et al., *Nature Communications*, 1-8 (2012).

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Optical properties and morphology of spray coated polystyrene nanoparticle layers

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Abstract: Nanoparticles have been increasingly studied due to their unique properties. The deposition of uniform layers is a crucial step in almost all of its applications. Ultrasonic spray coating is by design especially well-suited for the deposition of nano-suspension dispersions. Due to the narrow distribution of the droplet size and the deagglomeration of the particles trough ultrasonic vibrations it is possible to mass-produce uniform nanoparticle (NP) layers by printing techniques like pray coating.

Keywords: spray coating, nanoparticles

Introduction

Polymeric NPs with controlled surface compositions or functionalization have been increasingly studied and used in a variety of applications, including drug delivery systems, medical diagnostics, separation media, adhesive technology and coating, etc.

Pristine polystyrene NPs, prepared using the mini-emulsion technique [1-2], were used to study the layer formation, packing density and uniformity under different conditions.

Results and Discussion

An ultrasonic spray coater with an average droplet size of 20 µm was used to print water-based polystyrene NP dissolved in a water-ethanol mixture under different conditions.

First the spray coater settings (flow rate, spray speed and temperature) and ink formulation (Water and co-solvent ratio and NP content) were optimized in order to find the right wetting properties. This is required to achieve thin and homogeneous layers, fully covering the substrate.

As a next step the influence on the NPs of stacking layers under different conditions was studied. Different multilayer approaches to improve the coverage and density of the NP layer were compared to single layers.

Finally the effect of heat post-treatments was studied. Temperatures above the glass transition temperature (Tg) to increase adhesion to the coated surface and above the melting point (Mp) to create dense thin layers.

Optical Microscopy, profilometry and Scanning Electron Microscopy (SEM) are performed to study the roughness, surface structure, thickness and coverage of the spray coated layers.

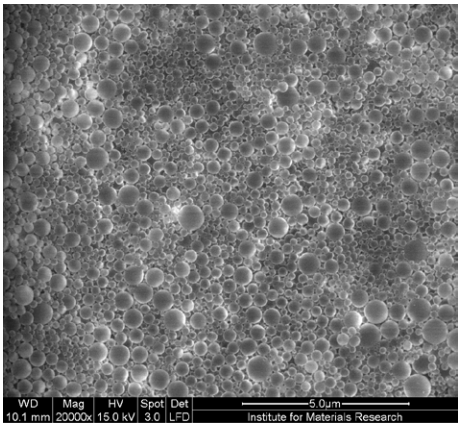

Figure 1: SEM-image of a spray coated pristine polystyrene NP layer.

Conclusions

Spray coating is a reliable, flexible and cost efficient fabrication method for printing nano-suspension dispersions. Uniform polystyrene nanoparticle layers where successfully deposited from water-based dispersions.

References

[1] K. Landfester, Angew. Chem. Int. Ed. **48**, 4488–4507 (2009).

[2] A. Ethirajan, K. Landfester, Chem. Eur. J. **16**, 9398–9412 (2010).

Acknowledgements

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Immobilization of bacterial spores on biosensor substrates with organosilanes

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Abstract: In this work, different immobilization strategies with organosilanes to immobilize bacterial spores on biosensor substrates are presented. Here, several functionalization methods (*e.g.,* (3-Aminopropyl)triethoxysilane, (3-Glycidyloxypropyl)trimethoxysilane) are optimized and characterized for the immobilization of *Bacillus atrophaeus* (DSM 675) endospores on different biosensor substrates (*e.g.,* glass, SiO_2, Al, Pt).

Keywords: Immobilization, organosilanes, silanization, endospores, *Bacillus atrophaeus*, biosensors

Introduction

Bacterial spores are suitable for use as detectors to recognize microorganisms (*e.g.,* bacteria, viruses) or evaluate aseptic processing due to their ability to sense environmental changes and survive prolonged harsh conditions (*e.g.,* high temperature, extreme pH levels).

Spore-based biosensors have been recently used, for instance, to detect bacteria [1] or to monitor sterilization processes [2]. The immobilization of bacterial spores onto the substrates of such biosensors is a critical factor; it may affect the sensitivity and reproducibility of the sensor signal.

Organosilanes have been used to functionalize surfaces both to reduce non-specific adsorption and to provide moieties suitable for covalent attachment of spores. Many of the substrates can be modified to contain surface hydroxyl groups which reach with methoxy/ethoxy residues of silanes (Fig. 1). The other end of the silane provides a reactive residue to bind to biomolecules or cross-linkers.

In this work, different functionalization methods are characterized and optimized with organosilanes (silanization) on different biosensor substrates (*e.g.*, glass, SiO_2, Al, Pt) for the immobilization of *Bacillus atrophaeus* (DSM 675) endospores.

Experiments and results

Silanization in liquid and gas phase will be optimized and characterized. Several parameters such as: concentration of the silane molecules (e.g., (3-Aminopropyl)triethoxysilane, (3-Glycidyloxy-propyl)trimethoxysilane)), silanization time, and curing time will be investigated. Finally, the optimized silanization methods will be characterized (*e.g.,* AFM, contact angle measurement, ellipsometry).

Furthermore, the bacterial spores will be immobilized onto different substrates (*e.g.,* glass, SiO_2, Al, Pt) with the optimized silanization method. The immobilization efficacy will be measured by the spores recovered from the substrates immersed in a buffer solution with a non-ionic surfactant and emulsifier in ultrasound bath.

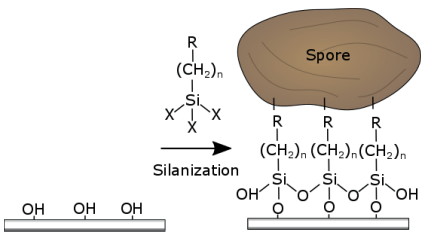

Figure 1: Simplified schematic process of the functionalization with organosilanes (silanization) of oxide surfaces and immobilization of spores.

Outlook

The presented silanization methods are expected to provide a robust immobilization to spore-based biosensors used in harsh conditions (*e.g.,* sterilization processes).

References

[1] X.Tang, D. Flandre, J. Raskin, Y. Nizet, L. Moreno-Hagelsieb, R. Pampin and L. A. Francis, *Sensors and Actuators B: Chemical* **156** (2), 578-587 (2011).

[2] J. Oberländer, A. Bromm, L. Wendeler, H. Iken, M. Palomar Durán, A. Greeff, P. Kirchner, M. Keusgen and M. J. Schöning., *physica status solidi (a),* 1-7 (2015) / DOI: 10.1002/pssa.201431900.

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Biocompatibility of Carbon Nanotubes for targeted Drug Delivery

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Abstract: Carbon Nanotubes are fibre-like nanomaterials composed purely out of carbon that show multiple interesting properties. In this study the cytotoxic potential of two Carbon Nanotubes designated for developing targeted drug delivery carriers was determined. The results indicate that pristine Carbon Nanotubes are not save to use as drug delivery carriers.

Keywords: carbon nanotubes, cytotoxicity, cell cycle arrest, drug delivery carrier

Introduction

Carbon Nanotubes (CNTs) are novel, carbon based nanomaterials that gain more and more interest in fields like mechanical engineering [1], pharmacy and medicine. The high surface to volume ratio and other features, like the ability to passively cross cell membranes, indicate the potential use of CNTs as drug delivery carriers [2][3]. This study aimed at estimating the cytotoxic potential of two multi-walled Carbon Nanotubes that were determined for the development of a multifunctional drug delivery carrier.

Results and Discussion

Two types of multi-walled CNTs were produced using the identical CVD synthesis for both types (IFW, Dresden). The first type was used as produced, still containing an iron catalyst that was added during synthesis (Fe-CNT). The second type was heat treated after synthesis for 1h at 2600°C to eliminate all remaining iron from the CNT structure (nonFe-CNT). The heat treated CNT type (nonFe) showed a significantly reduced number of surface defects, indicated by a reduction in d-peak intensity during Raman spectroscopy (fig.1). Additionally both CNT types appeared curved/flexible in REM investigation (fig.2).

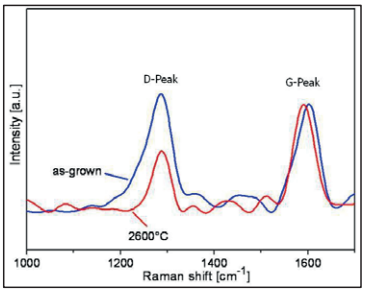

Figure 1: Results of the Raman Spectroscopy for both CNTs.

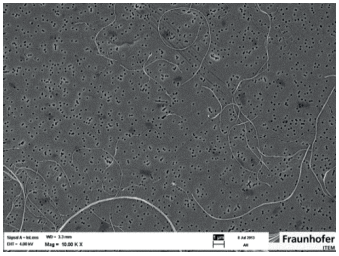

Figure 2: REM picture of curved (untreated) Fe-CNTs.

The results of the WST-8 assay showed a time and dose dependent decrease in cell viability for both cell lines used (A549 and HepG2). In A549 cells the leakage of lactate dehydrogenases (LDH) after 48h of exposure resulted in a total cytotoxicity of 25% (Fe-CNT) and 45% (nonFe-CNT). Increased ROS production was shown using the DCFH-DA assay, primarily under the influence of the nonFe-CNTs. Cell cycle analysis revealed an increased number of cells in the G2/M-phase while the number in S-phase was reduced under the influence of the nonFe-CNTs, indicating a G2-phase arrest.

Conclusion

Summarizing, most cytotoxic effects were more prominent for the nonFe-CNTs. This indicates that the number of surface defects plays an important role in CNT-related cytotoxicity. Additionally it can be concluded that the CNTs can't be used as drug delivery carriers without first achieving biocompatibility via further modification.

References

[1] H. Miyagawa, M. Misra and A.K. Mohanty, J. Nanosci. Nanotechnol **5** (10), 1593-1615 (2005).

[2] S. Peretz and O. Regev, Curr. Opin. Colloid Interface Sci. **17**, 360-368 (2012).

[3] Z. Liu, S. Tabakman, K. Welsher and H. Dai, Nano Res. **2**, 85-120 (2009).

Detection and separation of the bacteria strain *Escherichia coli* BL21 (DE03) using surface modified polymer particles

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Abstract: The surface of polyethylene can be modified in various ways to create functional groups (-COOH, -NH_3, -NHR_3) which enables the interaction with other compounds. In this case two different surface modified polyethylene beads were synthesized. The first one (type A) was functionalized with poly(ethylene imine) (PEI) and the other one (type B) with PEI and succinic anhydride. The material can act as a very weak ion exchanger and was filled into a cartridge. The goal of this investigation was to separate *Escherichia coli* cells in a chromatography-like manner from other cells. A light scattering detector and UV-Vis detector was used for the detection.

Keywords: poly(ethylene imine), functionalized polyethylene beads, *Escherichia coli*, light scattering detector

Introduction

Most microorganisms have a negative surface charge at a pH of ≥5.0 largely due to ionization of the carboxyl (-COOH) groups of the cell wall [1]. This negative charge means that bacteria can potentially be adsorbed to positively charged surfaces and particles such as food and ion exchange resins. These chemical interactions can be exploited when attempting to develop effective bacteria separation and concentration methods. Negatively charged microorganisms can be adsorbed by lower pH on the ionic exchanger matrix and desorbed by increasing the pH or salt concentration using NaOH or NaCl solutions as eluent [2].

The amino functionalized polyethylene beads A and B seem to be a suitable material for the separation of the negative charged *E. coli* [3]. The amino groups on the surface of the polyethylene can be found protonated or deprotonated depending on the pH conditions. By this strategy a positively charged surface was produced which allowed the binding of negatively charged cells but also a neutral surface at increased pH which results in a desorption. While the type A polymer contains primary, secondary, and tertiary amino groups, the type B material has converted virtually all primary amines to non-ionizable amides. Therefore, both of the polymers should be presented different retention behaviours of same sample.

Results and Discussion

E. coli sample was applied to a cartridge (100 mm x 5.4 mm) filled with amino-functionalized polyethylene. The following step gradient was applied: start with water (0-480sec) followed by 0,1mM NaOH pH 10 (480-1080sec), 1mM NaOH pH 11 (1080-1680sec), 10mM NaOH pH 12 (1680-2280sec). In Figure 1 *E. coli* showed different retentions for the beads of type A (red line) and type B (blue line). As expected the bacteria could be detected earlier and at lower pH from the slightly negatively charged polymer B which presented more amides and some carboxyl group on the surface (because of succinic acid).

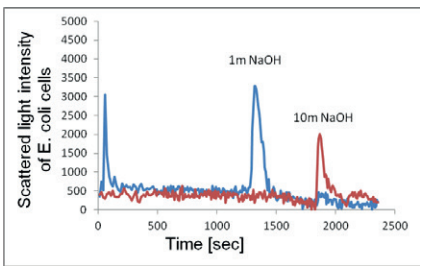

Figure 1: Amino functionalized polyethelene A (red line) and B (blue line) showed two different retentions of Escherichia coli using 10mM NaOH as step gradient.

Conclusions

Surface functionalized polyethylene beads seem to be a promising material for the separation of E. coli from other cells.

References

[1] D. S. Thomas, *J. Appl. Bacteriol* **65**, 35 (1988).

[2] K. A. Stevens, L. A. Jaykus, *Critical Reviews in Microbiology* **30 (1)**, 7-24 (2004).

[3] A. Holländer, M. Keusgen, J. Krämer, Ferner, Patent WO002006077020A2 (2006).

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Investigation of fibroblast growth factor-binding protein anti-tumor effects using surface plasmon resonance

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Abstract: Fibroblast growth factor (FGF-2) is frequently upregulated in tumors, but tightly binds to heparan sulphate proteoglycans of the extracelullar matrix (ECM). The FGF-binding protein (FGF-BP) leads through its reversible binding to FGF-2 to its release from the ECM. In the present work the FGF-BP1 interference of the FGF-2/FGFR-1 binding was analyzed by surface plasmon resonance (SPR).

Keywords: SPR, fibroblast growth factor-binding protein (FGF-BP), FGFR-1, FGF-2

Introduction

Fibroblast growth factor (FGF) plays, because its upregulation in tumors, an important role in cancer and other deseases (e.g., prostate, endometrial or breast cancer). In order to understand its mediating role, the activation of membrane bound receptors (so-called FGF signaling) has to be studied [1]. FGF-1 (acid FGF) and FGF-2 (basic FGF) are the most studied factors tightly binding to heparan sulphate proteoglycans of the extracellular matrix (ECM). Acting as a chaperone molecule, the FGF-binding protein (FGF-BP1) could influence the bioactivation of FGFs in terms of releasing them from the ECM for futher binding to FGF-receptors (FGFR-1). The aim of the present work was to reproduce the biological conditions experimentally by the use of SPR platform in order to show a dose-dependent effect of FGF-BP1 on FGF-2 binding to the FGFR-1, as well as further investigation of possible interactions regarding the specific binding behavior of FGF-BP1 on FGFR-1.

Results and Discussion

The work was performed with FGF-2 (288AA, gene location: 4q27-q28), a member of the fibroblast growth factor cytokine family, which contains a heparin binding domain and acts as ligand for several FGF-receptors (FGFR). FGF-2 is taking part in limb formation, angiogenesis as well as tumor growth. As the corresponding receptor, a recombinant human FGFR-1 alpha (IIIc) Fc chimera (purchased from R&D Systems) was chosen. The ratio receptor to ligand was 1:2. To ensure a measurable effect and reproducible results, chosen concentrations of biomolecules were larger as *in vivo*. A recombinant human FGF-BP1, expressed in *E. coli*, His-tagged and stored in 8M urea elution buffer (buffer E) was used for experiments. A dose-depended modulation of FGF-BP1 to the ligand EGF2 to FGFR could be observed (Figure 1).

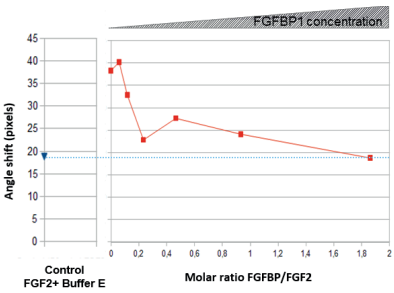

Figure 1: Modulation of FGF-BP1 on FGF ligand binding to FGFR-1.

Conclusions

A working model for FGF-2/FGFR-1 binding in vitro was established. Hereby FGF-BP1 seems to inhibit dose-dependently FGF-2/FGFR-1 binding. Conversely, a positive FGF-BP1 effect on FGF-2/FGFR-1 binding at lower concentrations could be observed. To confirm and to expand these investigations, additional FGF-BP concentrations have to be tested.

References

[1] N. J. Brady, P. Chuntova, L. and K. Schwetfeger, *Expert Rev. Endocrinol.* ***8****(4), 391-402* (2013).

[2] D. Schulze, P. Plohmann, and, A. Aigner, *Molecular Cancer* **10**:144 (2011).

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Surface area enhancement of microchannels by vertically and horizontally aligned growth of multiwalled carbon nanotubes

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Abstract: In this contribution, a fabrication process is introduced which allows the complete filling of microchannels with multiwalled carbon nanotubes (CNTs) and therefore enlarging the surface area by a factor of up to 60. The fabrication process is based on standard microsystems technology. The CNT growth by catalytic-induced thermal chemical phase deposition is perpendicular to the catalyst covered surfaces. As the CNT growth rate is dependent on the Fe particle size a uniform deposition of the catalyst material on the surfaces is vital for microstructures to be completely filled with horizontally and vertically aligned CNTs.

Keywords: carbon nanotubes, surface area enhancement, microchannels

Introduction

Carbon nanotubes (CNTs) are remarkable regarding their chemical and physical properties. Therefore they were integrated in a huge range of different applications in the field of micro- and nanotechnology over the last years. The growth of vertically aligned multiwalled CNTs is state of the art while the achievement of horizontal alignment is still coupled to great technological effort, e.g. complex technology [1] or the usage of electrical fields [2]. Another way is the utilization of the perpendicular growth angle between surface and CNTs [3]. In this contribution, a simple fabrication process is introduced which allows the complete filling of 3-dimensional microstructures via vertically and horizontally aligned CNT growth.

Fabrication

The fabrication process is based on standard microsystems technology. The microchannels are created by deep reactive ion etching (DRIE) resulting in 200 µm wide and 50 µm deep channels. Afterwards the surface is coated with sputtered silicon dioxide (SiO_2), since no CNT growth was observed on the polytetrafluoroethylene coated surface resulting from the DRIE process. The iron (Fe) used as catalyst is deposited by sputtering upon the SiO_2 coated surface. SiO2 and Fe on surfaces beside the channel are removed with a lift-off process. Finally the CNTs are grown by the catalytic-induced thermal chemical phase deposition method.

Results and Discussion

The CNT growth rate depends on the Fe catalyst particle size. By varying the sputter parameters a catalyst distribution was achieved, so that sufficient catalyst reached the lateral surfaces while the amount at the planar surfaces was still sufficiently low. The resulting CNT filled channel is shown in figure 1. The CNT growth is perpendicular to the catalyst covered surfaces, resulting in vertically growth on the planar surfaces and horizontal growth at the lateral surfaces of the channel. Where CNTs with different growth direction are crossing each other the CNT density increases, slowing down the growth in this region. The diameter of the shown CNTs is approx. 15 nm with a length of 50 µm and a distance of 200 nm from each other. In this way the surface area is enlarged by a factor of about 60 compared to a simple surface.

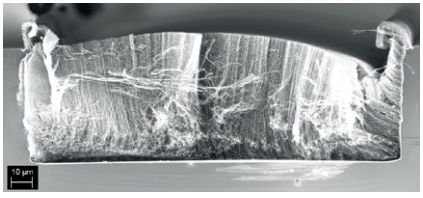

Figure 1: Cross section of the created channel (200 µm x 50 µm) filled with vertically and horizontally aligned CNTs.

Conclusions

In this contribution it is shown, that vertically and horizontally aligned CNTs can be grown in the same process via catalytic-induced thermal chemical phase deposition. Important growth factors are a surface coating with SiO_2 and a uniform distribution of the catalyst.

References

[1] J. Lu, J. Miao, T. Xu, B. Yan, T. Yu und Z. Shen, *Nanotechnology* **22**, p. 1-6 (2011).

[2] Y. Chai, Z. Xiao and P.C.H. Chan, *Nanotechnology* **21**, 235705 (2010).

[3] S. Riekeberg, A.S. Nawaz, H.K. Trieu, J. Müller, MikroSystemTechnik Kongress 2013 (GMM; VDI/VDE-IT, Aachen, 2013), 151.

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Wafer-scale dielectrophoretic deposition of graphene oxide for biosensing platforms

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Abstract: Gold electrodes were fabricated on glass and silicon substrates and functionalized with graphene oxide at a wafer-scale as the basis for impedimetric and field-effect measurements. The graphene oxide flakes were consequently subjected to two fast thermal annealing steps in ambient to improve their source-drain contacts. The devices were characterized for their electrical transport in an electrochemical-gate configuration.

Keywords: Graphene, impedance spectroscopy, dielectrophoresis, wafer-scale

Introduction

Due to its many interesting properties, graphene has been used in a wide variety of biosensing techniques. It has been employed as a transducer in field-effect transistors, electrochemical biosensors, impedance biosensors, and fluorescence biosensors, as well as biomolecular labels [1]. Graphene oxide (GO) having different oxygen containing functional groups attached to "defect-sites" in the hexagonal lattice of graphene, is highly hydrophilic and therefore easier to obtain in solutions and chemical processing. These defect-sites offer the possibility of easier functionalization for further biomolecule detection [2]. In this study, an array of microelectrodes functionalized with GO was developed. The samples were further subjected to a fast annealing process and characterized electrochemically.

Results and Discussion

Microelectrode fabrication on glass and silicon substrates was carried out by employing a standard optical lithography process followed with metal evaporation and lift-off techniques. A GO solution was fabricated using sonication and centrifugation techniques on GO flakes in DI water in order to separate the flakes according to their size [3]. The GO flakes were transferred from the solution onto the microelectrode gaps using dielectrophoresis (DEP), a noninvasive, nondestructive method to manipulate particles. The chips then underwent two annealing procedures in ambient at 600 °C for 40 s in order to improve the source and drain contact resistances to the flakes. Using impedance spectroscopy and field-effect measurements the devices were characterized showing nearly identical electrical characteristics.

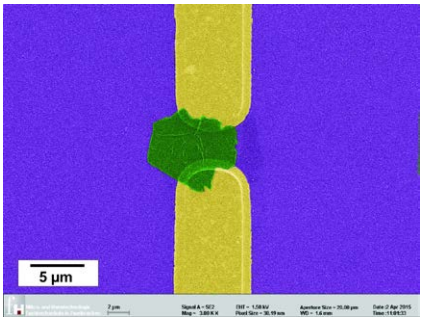

Figure 1: GO flake trapped between two gold microelectrodes on a silicon sample.

Conclusions

A straight-forward protocol for the fabrication of multiple sensor arrays based on graphene oxide flakes is described. The ability to fabricate the sensors in a wafer-scale process could be applied to other graphene-based nanomaterials and other 2D and 1D nanomaterials such as MoS_2, carbon nanotubes or nanowires, as well.

References

[1] M. Pumera, *Materials Today* **14**, 308 (2011).

[2] A. Bonanni, A. Ambrosi and M. Pumera, *Chemistry* **18**, 1668–1673 (2012).

[3] U. Khan, A. O'Neill, H. Porwal, P. May, K. Nawaz and J. N.Coleman, *Carbon* **50**, 470–475 (2012).

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Enhanced adhesion of NIH3T3 fibroblasts mediated by magnetic beads

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Abstract: Long-term drug delivery to the inner ear for improving spiral ganglion neuron (SGN) survival is envisaged in cochlear implant (CI) related research. However, effective strategies in order to coat round implant surfaces with cells need to be developed. The aim of this study is to magnetically label growth factor releasing cells to enhance their adhesion onto magnetic material surfaces.

Keywords: Drug delivery, BDNF, magnetic beads, atomic force microscopy, cytotoxicity

Introduction

Today, different concepts for drug delivery systems have been introduced. State of the art is a depot with certain amount of drugs that are released for several weeks, before the depot is empty. On the other side, such systems eventually exceed the clinically relevant drug concentrations, which can lead to unwished results such as unspecific affection of the tissue. Therefore, new systems mimicking the drug delivery within the living organism need to be developed to allow specific long-term provision of drugs. This may be achieved by functionalization of CI electrodes with cells providing neuroprotective factors. Our long-term vision is to make benefit of electromagnetic field attracting forces generated by CI electrodes to bind cells that are labelled with magnetic beads (MB) on round electrode surfaces. Within this study, the ability of cells for taking up the MB, the effects of MB-labelling on cell viability and BDNF production, when cultured on cylindrically-shaped magnets as model surface for CI electrodes, were investigated.

Results and Discussion

Murine NIH3T3 fibroblasts - genetically modified to produce BDNF - were labelled with MBs covered with a cell specific antibody recognizing surface antigens. Atomic force microscopy illustrated the internalization of MB by fibroblasts. Using the neutral red uptake (NRU) cytotoxicity assay, MB-labelling of cells revealed to expose no cytotoxic effects on fibroblasts. In addition, cells labelled with magnetic beads and seeded on magnets showed improved adhesion on round surfaces with sufficient release of BDNF.

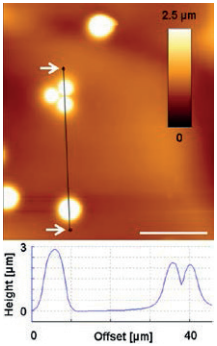

Figure 1: AFM-height image of magnetic beads (MB) glued onto glass surface. The dimension of MBs was found to be within the nominal size given by the manufacturer (ca. 4.5 µm), as out-lined by the cross section in the image.

Conclusions

Our data demonstrate a novel approach for mediating enhanced long-term adhesion of BDNF-secreting fibroblasts on model electrode surfaces for cell-based drug delivery applications in vitro and in vivo. This therapeutic strategy, once transferred to cells suitable for clinical application, may allow the biological modifications of CI surfaces with cells releasing neurotrophic or other factors of interest.

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Molybdenum oxides in efficient antibacterial coatings

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Abstract: Zn, Cu and Ag molybdates were synthesized and tested for antibacterial activity against *E. Coli*. Powder suspensions of different concentrations containing these compounds were mixed with bacterial culture and put on agar plates on the optimal conditions (37°, shaking). It has been shown that the growth of the bacteria is indeed completely inhibited in the presence of molybdates, with the more efficient inhibition being observed when the concentration of molybdates powder suspension is increased.

Keywords: antibacterial actvity, molybdates, E. Coli

Introduction

Polyoxomolybdates are being extensively investigated due to their complex structure and possible wide applications. It has been reported that compounds consisting of polyoxomolybdates show catalytic nature, photoluminescence and magnetic properties. Nevertheless, the most appealing characteristics are definitely their antitumoral, antiviral and antibiotic activities. Many scientists believe that exactly these properties can be a useful tool in the fight against nosocomial diseasse [1]. The following compounds that are believed to have antimicrobial activity have been synthesised and investigated – $ZnMoO_4$, Ag_2MoO_4, $CuMoO_4$ and $Cu_3Mo_2O_9$.

Results and Discussion

Antibacterial activity was tested on three different concentrations of powder suspensions – 1mM, 5mM and 10 mM. The presented figure (Figure 1) clearly shows the inhibition of the growth of the bacteria.

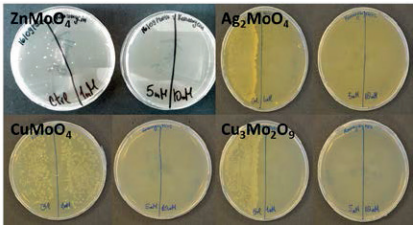

Figure 1: Photographs of the agar petri dishes plated with bacterial cultures with different concentrations of tested powders.

The values for optical density (Figure 2) also show the difference between the control sample containing only bacterial culture and samples having bacterial culture in the presence of various concentrations of Ag_2MoO_4. Similar plots were obtained for other three powders as well.

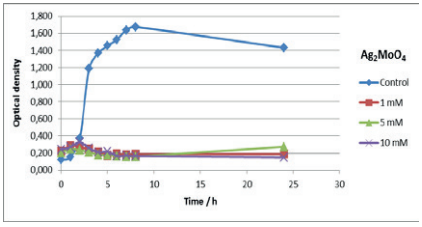

Figure 2: Optical density values versus time plots for Ag_2MoO_4 containing different concentrations of tested powders.

Conclusions

The remarkable activity of the aforementioned molybdates indicates potential beneficial application of these compounds in materials for antimicrobial surfaces and coatings.

References

[1] M. Cindric, Z. Veksli, B. Kamenar, *Croatian Chemical Acta* **82**, 345-362 (2009).

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