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Electrochemical Stability of Thin-Film Platinum as Suitable Material for Neural Stimulation Electrodes

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Only thin-film electrodes can meet the demands of highly selective and high channel-count electrical neural stimulations. They are used in neural applications to ensure efficacious stimulations and recordings. In comparison to the often used platinum-iridium electrodes in active implantable medical devices, such as for cardiac pacemakers, thin-film platinum as standard material has been widely used in micromachined neural interfaces with the advantage of a very high miniaturization level.
For clinical applications a high longevity and integrity of the electrode metallization is important for safe and reliable stimulation.
In this work we investigate the influence of typical stimulation protocols for clinical neural stimulation on flexible polyimide-based thin-film platinum electrodes for neuroprostheses. Different fabrication processes of sputter deposited and evaporated thin-film metallization have been compared and evaluated based on stability during biphasic stimulation electrochemical analysis of the electrode surface. For biphasic stimulation, 120 million cathodic-first, charge balanced pulses with a charge density of 60 µC/cm^2 and a frequency of 500 Hz were applied, corresponding to standard neural stimulation protocols.
Both sputter deposited and evaporated platinum thin-films showed similar electrochemical surface properties and therefore no dependencies on the different fabrication processes. The electrochemical analysis showed that the surface roughness of the thin-film was not altered significantly by the stimulation. Directly after stimulation, cyclic voltammetry showed a larger and negatively shifted platinum oxide reduction peak. This indicates that the oxidation of the electrode surface during stimulation exceeded the PtO monolayer range. However, this effect was shown to be fully reversible as confirmed by further cyclic voltammetry. No degradation or irreversible change of the thin-film electrodes due to the stimulation was observed.
The presented in vitro data suggest that platinum thin-film electrodes can be used for typical stimulation protocols without any deviation in electrochemical characteristics. A temporarily observed oxidation of the electrode surface during stimulation is fully reversible. From the results obtained, it can be concluded that the electrode integrity is maintained during electrical stimulation.

Assembling technology for personalized printed neural electrode arrays

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Printing technologies open new opportunities to manufacture electrode arrays based on anatomical and morphological data gathered by imaging techniques like (functional) magnetic resonance imaging ((f)MRI) and computer tomography (CT). They are one opportunity towards personalized implants for neural implants and applications in bioelectronic medicines. Silicone rubber (PDMS) is the material of choice for substrate and insulation material. Using fillers like silver/silver chloride particles electrode sites, interconnection lines and contact pads can be printed onto one layer of insulating silicone rubber. We used UV curing PDMS to vulcanize the printed silicone rubber directly after deposition using a custom made device. Connection of these electrode arrays to (standard) connectors was challenging since the conductive filler materials turned out to be brittle and prone to abrasion when directly connected. Therefore, a hybrid assembling technology has been developed integrating flexible polyimide-metal-polyimide substrates into the PDMS electrode arrays and interfacing them with zero insertion force (ZIF) connectors. A flexible interconnection structure (6 microns polyimide-300 nm platinum-6 microns polyimide) matching the PDMS lines of the electrode array and the pitch of a ZIF connector on the other side has been layer on the bottom layer of insulating PDMS. Conductive lines for electrode sites, interconnection lines and contact have been printed on top ending on the platinum pads of the polyimide. Another layer of insulating PDMS has been printed on top. The assemblies have been characterized by measuring the impedance of the assembly proving conductivity of the contacts. Cross sections of the arrays have been investigated with means of light microscopy and showed integrity of the compound. The presented technology allows the integration of PDMS electrode arrays with flexible printed circuit board technology and future integration into wireless implants using combinations non-hermetic and hermetic encapsulation depending on the medical application in diagnosis and treatment.

Active Microelectrodearray for a Bioelectronic Diabetes Therapy Approach

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Bioelectronic medicine is based on the electrical modulation of the vegetative neural system and bioelectrically active tissue. Since the target area is extremely small and delicate while the signal density is high, this approach requires innovative technological solutions for interfacing to the biological system. We present the development of a flexible chip-in-foil-system comprising electrodes and application specific integrated circutis for recording and stimulating as well as data and energy transfer. This technology aims to bringing the recording amplifiers as close as possible to the target area to increase the signal-to-noise ratio and to multiplex the signals within an active microelectrode array, obtaining a high electrode count with few tracks. The bare dies are embedded in silicone rubber, polyimide and parylene C. Tracks are realised by sputtering titanium-gold-titanium with the contacts being created by sputtering the tracks directly onto to chip pads. Therefore the chip-in-foil-system possesses no plugs, discrete wiring or additional interconnection layers.

The presented system is developed for a bioelectronic approach to support the therapy of diabetes mellitus type 2. The approach is based on electrical stimulation, controlled by the analysis of the recorded electrical activity, of the pancreatic surface. Recordings with flexible microelectrode arrays taken for the first time on perfused pancreata verified the correlation between the activity pattern and blood glucose level. ß-cells in Langerhans islets generate slow synchronised electrical bursts, followed by phases of inactivity. The temporal ratio of these active and inactive phases directly correlates with the blood glucose concentration. This slow and pseudo binary signal can be analysed and interpreted easily in vitro. However, the signal amplitude at the organ surface is very low, recording is demanding and requires application specific interfaces, electronics and signal processing.

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Silicone-based Chip-in-Foil System

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In the research on bioelectronics medicine, small and flexible devices need to be developed to ensure a localized stimulation of the nervous tissue while maintaining a good biocompatibility. Chip-in-foil systems are a promising way to combine the space benefits of micro technology with the mechanical benefits of polymer systems. By placing ultra-thin, flexible dies in a foil substrate, the functionality of bulkier systems can be achieved with a fraction of the space requirements. However, in microfabrication, even edges of several micrometers height from the chip to the surrounding polymer foil can prove critical for the fabrication of continuous metal tracks. Therefore, a flip-chip process is envisioned that combines backside filling with silicone rubber with the microfabrication of a polyimide-based foil implant. The thin dies are glued face-down onto a polyimide-coated glass substrate and the backside gap is filled using silicone. A second glass substrate is placed on top of the uncured silicone, preventing misalignments in the transfer process. After curing, the bottom glass substrate can be detached, leading to face-up dies placed under an even layer of polyimide. Due to the placement of the silicone rubber between polyimide and glass, the following cleanroom processes are not impeded. Using a two-step etching process, vias with slanting edges are fabricated, followed by a thin-film metallization and Parylene-C encapsulation. A platinum and aluminum metallization of the base substrate enables the selective detachment of the foil substrate from the carrier by electrochemically dissolving the aluminum. Laser profilometry has shown no detectable step in the metallization between chip edge and polymer substrate. For the die, a custom-made test-chip designed using standard semiconductor fabrication techniques is employed. The chip hosts two meandered resistors and two interdigital electrode structures, allowing both the testing of the embedding process as well as the mechanical and biostability of the system.

Characterization of biostable atomic layer deposited (ALD) passivation layers/coatings on flexible substrates

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The growing interest in electrically active and flexible implants in medicine demands novel methods for protection against corrosion, layer delamination and other degrading effects due to the harsh biological environment inside the human body.

Atomic layer deposition (ALD) as a thin film deposition technology provides a versatile technique to achieve these requirements by creation of passivating layers [1]. ALD offers the atomic-level control of film deposition even on complex shaped substrates leading to conformal growth and pinhole-free coatings. As a gas phase coating technique, it is possible to deposit different layers in one process and therefor take advantage of the qualities of different coating types at once, e.g. from oxides and nitrides. The usage of plasma-enhanced ALD allows coatings on temperature sensitive substrates like polymers, such as parylene C or polyimide [2]. These coatings enhance the electrical passivation and reduce the water vapor permeability to the underneath sample. By combining several ALD layers to a newly created layer stack, it is possible to create a highly sophisticated passivation.

These passivating (multi-)layer stacks were characterized regarding their electrical passivating features and compared to each other. Therefore, impedance measurements, DC leakage and high voltage breakdown measurements alongside with accelerated aging tests by saltwater induced corrosion were performed. These coatings were further investigated regarding their mechanical stability, by exposing them to mechanical stress. This stress was induced via a physiological medium in a pressure chamber, hence, bending the samples. The stability of these ALD passivation systems exposed to such harsh treatment was determined for classification of the best layer stack for coating flexible implants in future.

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Miniaturization of Medical Implants and Devices – Fabrication Solutions based on Thin Film Technology and Micro Assembly

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Electronic devices which are used inside the body require the usage of special technologies and selected materials for manufacturing to provide compatibility for long term application (e.g. for implants) without negative interaction with the body. Additionally such devices have to fulfill the requirements of small form factor and compatibility with the insertion methods (surgery or catheter/endoscope) into the body.
The usage of thin film technology during the manufacturing of such devices provides solutions for these important prerequisites. Dedicated conductor materials, like titanium, gold or platinum, can be used for conductive pattern, instead of the copper in conventional printed circuit boards. Extremely thin layers in the range of 10s of nanometers up to thick layers of 30 µm thick gold are generated by vacuum deposition or electroplating, respectively. Thin layers typically are used for sensing, and manufacturing of very thin circuits; thick metal allows e.g. to have thick coils for wireless energy and data transmission.
Substrate and insulator materials are chosen form polymers, e.g. for very thin layers or passivation layers, or from the ceramics that are e.g. also used for mechanical implants. Traditionally, polyimide-type materials and alumina ceramic are used for the production of this type of circuits. The thickness of these materials range from as thin as several microns for polymer materials to higher thicknesses of up to 1 mm or more in the case of ceramics.
These structures, which are of passive nature can be combined or equipped with added active functionality (e.g. active circuits) by means of micro assembly. Especially the the high accuracy of state of the art methods and equipment, and the operation under clean environment are important parameters to build circuits and components for medical applications.
This contribution will describe different technologies and application examples from the area of sophisticated medical prototypes and products.