

On the development of modular miniaturized neural prostheses

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Abstract

Neural prostheses have reached clinical practice to partially restore body functions and to support other therapies in neurological rehabilitation. However, new concepts often need decades to come from the first experimental results to clinical approval. Micromachining technologies paved the way to smaller and more complex neural implants but new materials often do not match the legal requirements for chronic implantations. Device approval with respect to national and international laws is time consuming and expensive. Therefore, we are joining a German initiative to develop modular miniaturized implants and standardized interfaces to speed up the development and decrease the costs. Within this paper, we describe our concept of interfaces and modules as well as the basics for a biocompatible assembling technology for neural microimplants.

1 Introduction

Neural prostheses in clinical practice may help patients to improve gait after hemiparesis, to manage the bladder function after spinal cord injury or to restore grasp in tetraplegia, for example [1]. The miniaturization of sensors and actuators and their integration with electronic circuits paved the way towards new applications in medicine for diagnosis, therapy, and rehabilitation within the last decades. Implantable biomedical microsystems need special assembling, encapsulation, and housing technologies to integrate mechanical, (bio-) electrical, and electronic components when titanium or ceramic housings are too space consuming and too stiff. International standards for physico-chemical tests of implants with flexible substrates, encapsulation and housing materials that take care on the small amount of material and the “micro” dimensions of biomedical microimplants are neither approved nor established. The surface biocompatibility of materi-

als was standardized several years ago [2] but aspects of structural biocompatibility with respect to the design, the weight and the flexibility of microimplants are still in the experimental state [3].

Taking the complexity of micromachining technology and the variety of anatomical and physiological needs and constraints into account, it might be a good idea to develop a “microsystem construction kit” with standardized modules and the description of interface standards. Within the “Initiative MicroMedicine” [4], we focused on demonstrators for telemetric micro systems with a special emphasis on neural prostheses in our group.

The typical interfaces can be classified in four groups (Figure 1):

- Interface I-0: functional interface between tissue and multiple sensors for implantable systems. It includes the transducer performance as well as aspects of biocompatible and biostable encapsulation.
- Interface I-1: micro-opto-electro-mechanical interface that connects multiple sensors with intelligent chip technology, e.g. signal amplification and filtering.
- Interface I-2: interface between chip technology and signal processing circuitry and telemetric transceiver.
- Interface I-3: wireless connection of an integrated implantable telemetry unit with an external transmission and receiver station.
- Interface I-4: external interface to a monitor or a telematic data transmission for telemonitoring, telediagnosics or a virtual doctor’s round.

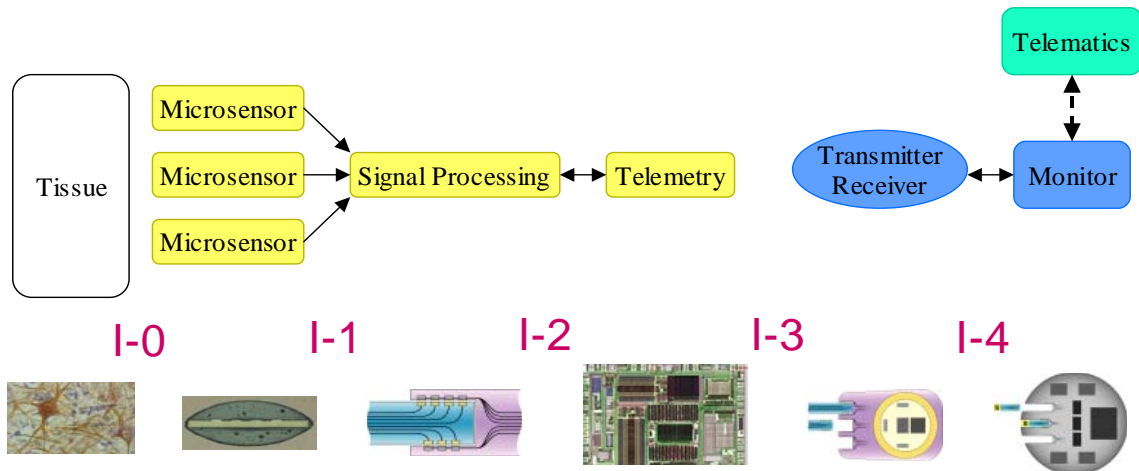


Figure 1: System concept of a modular, telemetric in vivo sensor system or microimplant, respectively, with core modules and interfaces I-0 to I-4 (modified from [4]).

2 Methods

The approach of a modular neural implant was investigated on the example of a cuff electrode with an integrated multiplexer to reduce the number of cables. The single modules were designed and fabricated on different substrates. We chose polyimide as substrate and insulation material with respect to its low weight, its flexibility and its biocompatibility [5,6]. The polyimide PYRALIN PI 2611 (HD Microsystems, Bad Homburg, Germany) was supposed to act biostable because of its extremely low water uptake of 0.5 %. A process technology was developed for ultra light-weighted and highly flexible electrodes [7].

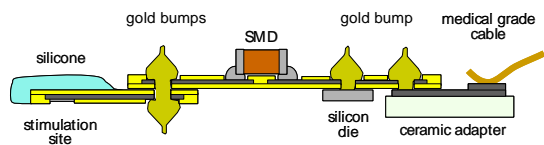


Figure 2: Schematic view of a modular neural implant; electrodes and electronic circuitry on flexible polyimide substrate.

A biocompatible and stable assembling technology that is based on ball stud bonding, the so-called MicroFlex Interconnection- was used for chip assembly [8] while gluing or soldering was used for SMD (capacitors, resistors). Cables were fixed by welding on a screen printed alumina oxide ceramic as interface to the thin-film substrate (Figure 2). Hybrid cuff electrodes were fabricated of polyimide and silicone rub-

ber and connected to the multiplexer via MicroFlex connections. The complete system was encapsulated with silicone rubber. Functional tests were done in vitro to evaluate the system concept and the biostability of the approach [9].

3 Results

Micromachining technologies were used to fabricate substrates and assemble the cuff electrodes and multiplexer systems, respectively. The simple alignment of the connection arrays of different modules under visual inspection led precisely set MicroFlex bonds between two thin and flexible substrates as well as between chip and substrate (Figure 3).

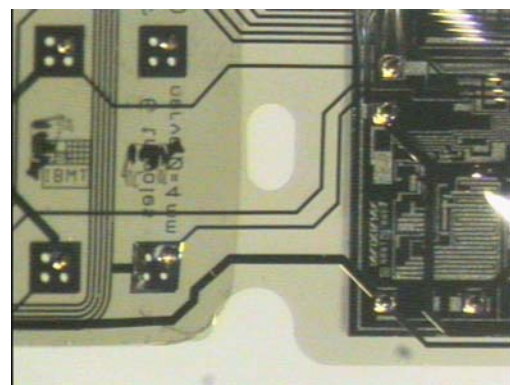


Figure 3: Biocompatible assembly of two modules; microsensor (e.g. electrode) with signal processing module using double side "MicroFlex" ball stud technology.

Function tests proved the electrical connection of the assemblies. After encapsulation in silicone rubber, the 18 channel hybrid cuff electrode (6 tripoles) with integrated multiplexer and Cooner wire cables (Figure 4) worked in soaking tests in physiologic saline solution.



Figure 4: Modular assembly of a cuff electrode with multiplexer and Cooper cables.

4 Discussion and Conclusions

Flexible biomedical microimplants have been fabricated for neural prostheses applications with a new modular approach. First results have been promising. A modular assembly was feasible with a high yield. With respect to a “microsystem construction kit”, the interfaces must be specified in a more detailed way and general data structures must be defined for an exchange between modules from different research groups or distributors. Further on, the development and evaluation of thin polymer-based encapsulations with respect to long-term biostability is only at a very early development stage for biomedical microimplants. Studies on the long-term stability and functionality of polyimide-based biomedical microsystems for neural prostheses as sieve-like interfaces to regenerating nerve stumps [10] and atraumatic cuff-like interfaces to intact peripheral nerves [11] showed excellent biocompatibility, biostability and functionality of the implants in chronic animal models. The deposition of parylene C on hybrid electronic assemblies improved the electrical insulation and biostability of the implants with no cytotoxic side effects [12].

A modular approach to design and develop biomedical microimplants for neural prostheses led to promising results with a first demonstrator. If the standardization of interfaces and transmission protocols proceeds, this approach might help to speed up the introduction of new neural prostheses into clinical applications.

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Acknowledgements

Part of this work was funded by the German Federal Ministry for Education and Research within the IMEX project (16SV1588). The authors thank Thomas Doerge and Sascha Kammer for their fabrication of the implants and Dr. Martin Schuettler, (Implanted Devices Group, University College London, UK) for many fruitful discussions during the concept development and his work towards the first demonstrators.