Electrochemical characterisation of laser-opened electrode contacts of implantable neuroprostheses

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Abstract

This paper describes the electrochemical characterisation of electrode contacts of novel neural interfaces. The fabrication materials are medical grade silicone rubber and platinum foil what accredits the electrode for clinical applications. The openings for the electrode contacts are made with a Nd:YAG marking laser by crystallizing and ablating the silicone encapsulation. Within this paper such fabricated electrode contacts with four different sizes were investigated with regard to their electrochemical properties. Impedance measurements with a three electrode configuration setup were carried out. The impedances are shown against the frequency and the electrode contact sizes. Furthermore, a measuring station for the electrical field distribution for recording was designed, and measurements for all four electrodes were taken.

1 Introduction

A new laser technology to fabricate implantable microelectrode arrays was developed, using medical grade silicone rubber or polydimethylsiloxane (PDMS) as substrate and insulation material and platinum foil as electrode material [Schuettler, 2005]. Possible application for such electrode arrays is the recording of brain signals for presurgical epilepsy monitoring and brain machine interfaces.

For opening the electrode contacts the best and most practicable method has turned out to be laser ablation [Schuettler, 2007]. This technique is excellent conformable with the whole laser fabrication process, as we use exclusively a spin-coater to create the thin silicone rubber sheets and a Nd:YAG laser for structuring the silicone gum and the metal foil. To get the best cut quality, the laser opening of the electrode contacts is done in two processing steps: 1.) changing the chemical and physical structure towards a crystal like consistency and 2.) ablating the ‘crystallized’ PDMS. An 8 channel electrode array, based on this technology, is shown in Fig 1. The electrode is interconnected via microflex technology to a screen printed ceramic, to which a standard connector is soldered [Meyer, 2001]. Recording neural signals requires a high surface quality of the contact openings. The knowledge about electrochemical properties is mandatory and an important precondition for the design of the amplification and signal analysing equipment.

2 Methods

For the investigations within this paper, electrodes with four different electrode contact sizes (Ø: 300 µm, 680 µm, 950 µm, 1160 µm) were fabricated (see Fig 2). The electrode contacts were examined with regard to their impedances in Ringer’s solution. Fur-
thermore, potential field measurements were carried out in order to calculate the transfer function.

Fig. 2 AutoCad design of the four channel test electrode.

2.1 Impedance Measurement

The impedance measurement setup was designed as a three electrode configuration (see Fig. 3), using the SI 1287 Electrochemical Interface and a SI 1260 Frequency Response Analyzer (Solartron Analytical, Farnborough, United Kingdom) which delivered the alternating voltage and measured the impedance. The setup was controlled by the software Zplot (Scribner Associates Inc., Southern Pines, North Carolina, USA).

The impedance of each electrode contact was measured within a frequency range of $10 - 10^6$ Hz in Ringer’s solution at room temperature. An excitation amplitude of 5 mV sine wave voltage was applied.

Fig. 3 Design of the impedance measurement setup as a three electrode configuration.

2.2 Scanning potential Measurement

For electrical field assessment a computer controlled scanning potential measurement setup was designed (see Fig. 4). The electrode probe was fixed on the planar base of a petri dish, which was filled with Ringer’s solution. The scanning electrode mimics a point current source, and was excited with an amplitude of 50 µA sine wave current at 1 kHz. It scanned a predefined area over the electrode contact with 100 µm steps. The distance between the electrode under test and the scanning probe was kept constant at 1 mm. The voltage potential was hundredfold amplified recorded and the position of the scanning electrode was controlled and stored via a LabView program. With the transfer function, voltages can be calculated, which can be measured with such electrodes, when neurons are firing with a defined current.

Fig. 4 Design of the scanning potential measurement setup with an $x$, $y$, $z$ – scanning electrode (platinum wire, $\varnothing = 25$ µm, parylene-coated).

3 Results

After fabrication of the electrode probes, the laser opened contacts had to be cleaned electrochemically. That has to be done, because the impedances of the contacts showed results, not typically for platinum electrodes. In fact, X-ray photoelectron spectroscopy measurements showed that there were still particles of silicone gum left. Electrochemically cleaning, realized by connecting alternating voltage (3V amplitude) and different frequencies to the electrode contacts, showed dramatical improvement.

3.1 Impedance Measurement

Impedance spectra of four laser opened platinum foil electrode contacts, which differed in contact size, were recorded (see Fig. 5). The cut-off frequencies were calculated as follows: $f_{300\mu m}=365$ Hz, $f_{600\mu m}=210$ Hz, $f_{950\mu m}=160$ Hz, $f_{1160\mu m}=140$ Hz.

Fig. 5 Impedance spectra of platinum electrode contacts with four different contact sizes.
Impedances were measured at 1 kHz for each of four electrode sizes. They are shown in Fig. 6.

![Fig. 6](image)

**Fig. 6** Impedances of platinum foil electrodes at 1 kHz against the electrode size.

### 3.2 Scanning Potential Measurement

The transfer function of the electrode contact with the diameter of 680 µm is shown in Fig. 7, whereas the transfer function is defined as the quotient of the measured voltage and the applied current [Andreasen, 2000]. It is presented three dimensional with a perspective view over an area of 25 mm². The maximum measured resistance is 38.5 Ω.

![Fig. 7](image)

**Fig. 7** Three dimensional transfer function of an electrode contact. The diameter of the electrode is 680 µm.

One dimensional scans were carried out for all four electrode contacts over a distance of 20 mm. Fig. 8 shows the transfer function as function of the position of the scanning electrode.

![Fig. 8](image)

**Fig. 8** Linear measurements and calculated transfer functions as function of the position.

### 4 Discussion and Conclusion

The measurements of the transfer functions do not show a proportional relation to the electrode size. One reason could be that the surface quality of the different electrode contacts is varying. Obviously the spatial resolution is not changing with the different contact sizes, whereas the signal amplitude of larger contact sizes is much higher.

For transferring the results of the potential measurement *in vivo*, it has to be considered that the tissue impedance is different to the Ringer’s solution. Recording signals from the brain, several tissue layers with different impedances are involved. Also it is not exact known, in which depth in the brain specific signals are generated. Though, there is just a first impression about the transfer function of laser fabricated electrodes with different contact sizes.

### 5 References


