

Proceedings

Demonstration of Intracortical Chronic Recording and Acute Microstimulation Using Novel Floating Neural Probes [†]

Andreas Schander ^{1,*}, Heiko Stemmann ², Andreas K. Kreiter ² and Walter Lang ¹

¹ Institute for Microsensors, -Actuators and -Systems (IMSAS), University of Bremen, Bremen, Germany; wlang@imsas.uni-bremen.de

² Institute for Brain Research, University of Bremen, Bremen, Germany; stemmann@brain.uni-bremen.de (H.S.); kreiter@brain.uni-bremen.de (A.K.K.)

* Correspondence: aschander@imsas.uni-bremen.de; Tel.: +49-421-218-62590

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Abstract: This paper presents long-term stable multichannel recording of neural activity using novel intracortical floating probes implanted chronically in rat cortex. The novel flexible probe design approach allows recording of action potentials for at least 38 days after implantation. Furthermore the capability of the PEDOT: PSS coated microelectrodes for electrical stimulation is characterized in vitro and in an acute in vivo experiment. The in vitro results show a charge injection capacity of 2 mC/cm² and the in vivo results demonstrate reproducible response of the neural network to charge injection up to 1 mC/cm². The optical inspection of the explanted neural probe reveals sufficient stability of the PEDOT: PSS microelectrode coating for the acute microstimulation experiment. These preliminary results indicate the capability for long-term stable microstimulation.

Keywords: neural probe; chronic recording; intracortical microstimulation; multichannel floating probes; PEDOT: PSS; polyimide; neural activity; cortex

1. Introduction

Bidirectional neural interfaces are fundamental tools for neuroscience and medicine. For medical applications these tools have to interface the neural network in the brain for several months and in the optimal case for several years. In recent years many research groups focused on different approaches to solve this “chronic challenge” [1]. To reduce the foreign body response due to the micromotion of the brain the mechanical coupling between the cortex and the skull has to be reduced to a minimum [2,3]. In our previous work [4] we developed a microfabrication process to enable a monolithical integration of the multichannel neural probes with highly flexible polyimide cables to reduce this mechanical coupling after chronic implantation of the probes. Furthermore the microelectrodes are coated with the long-term stable polymer PEDOT: PSS to reduce the microelectrode impedance and enable microstimulation [5]. In this paper new probe designs improved for electrical microstimulation purpose are presented and evaluated in vitro and in vivo.

2. Microfabrication of Floating Neural Probes

For the monolithical integration of a highly flexible electrical connection to the silicon stiffened neural probe a microfabrication process was developed previously [4]. Using the existing microfabrication process and some minor modifications new probes were fabricated carrying microelectrodes of geometric surface areas up to 4000 μm² for intracortical microstimulation experiments (see Figure 1). Compared to the previous generation of these neural probes the electrical

insulation stability of the used biocompatible polymer polyimide [6] could be further improved by increasing the adhesion strength between two polyimide layers that encapsulate the gold conductive paths on the probe shaft and flexible cable. This is achieved by a short O₂ plasma treatment (30 s) using a reactive ion etching process directly prior to the second polyimide coating.

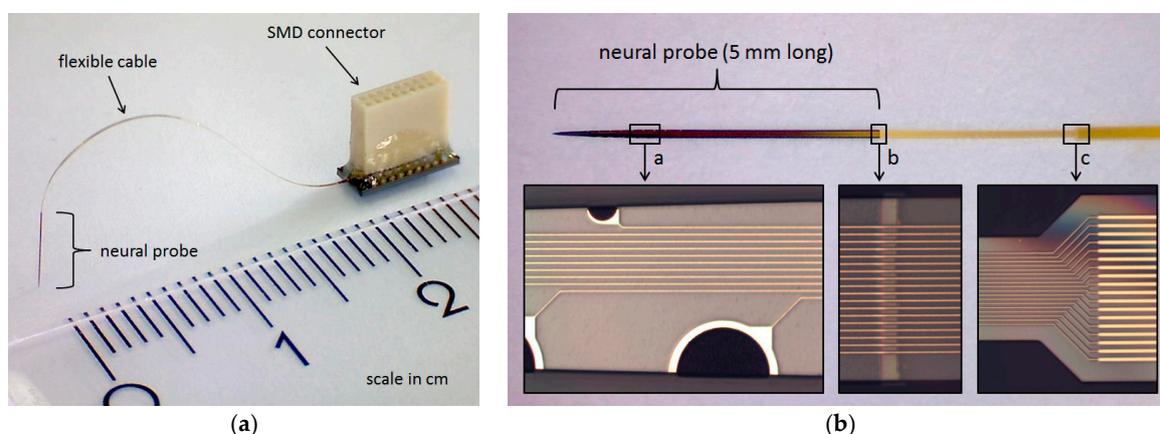


Figure 1. (a) 5 mm long silicon stiffened multichannel neural probe (30 μm thick and maximum 130 μm wide) with a monolithically integrated 25 mm long highly flexible ribbon cable (10 μm thick PI) connected to a base with a soldered 0.64 mm pitch SMD Omnetics connector; (b) Top view of the multichannel neural probe connected to the flexible cable with enlarged view of (a) PEDOT: PSS coated gold microelectrodes of different geometric areas (160 μm² to 4000 μm²); (b) transition of the silicon stiffened shaft to the flexible cable and (c) widening of the gold conductive paths from 2 μm to 5 μm widths.

3. Functional Characterization In Vitro and In Vivo

3.1. In Vitro Characterization

After the microfabrication process, soldering of the connector and PEDOT: PSS coating of the gold microelectrodes the functionality of the probes is evaluated in vitro using Ringer’s electrolyte solution. As the electrode double-layer capacity rises by increasing the geometric surface area, the total impedance of the microelectrodes decreases to a minimum of approx. 10 kΩ @ 1 kHz (see Figure 2a). For microstimulation purposes the charge injection capacity of the fabricated electrodes is essential. Bipolar current pulses were applied to PEDOT: PSS coated electrodes with different geometric surface areas to evaluate the maximum charge injection before electrolysis occurs (see Figure 2b). The linear regression reveals a charge injection capacity of 2 mC/cm², which is comparable to in vitro results using PEDOT: PSS electrodes reported by Venkatraman et al. [7].

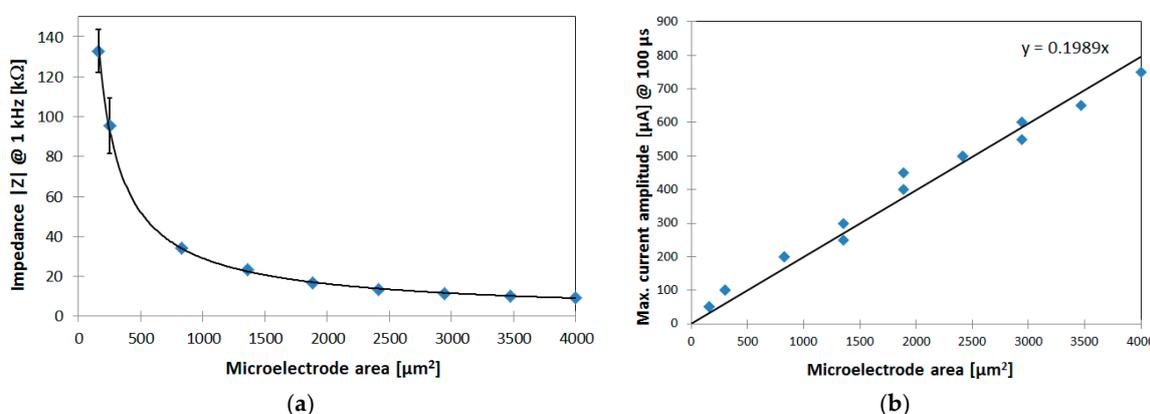


Figure 2. (a) In Vitro impedance measurement results of PEDOT: PSS coated gold microelectrodes with different geometric areas on the silicon stiffened shaft (measurements were done in Ringer’s solution and platinum counter electrode); (b) In Vitro evaluation of the maximum current amplitude

for bipolar 100 μs long current pulses in Ringer's solution with PEDOT: PSS counter electrode, before electrolysis occurs. Linear regression results in a charge injection capacity of approx. 2 mC/cm^2 .

3.2. In Vivo Characterization

All procedures used in this study were performed in accordance with the guidelines for the welfare of experimental animals issued by the Federal Government of Germany, approved by local authorities and conformed to the guidelines of the National Institutes of Health for the care and use of laboratory animals.

For the evaluation of the in vivo stability of intracortical neural recording and microstimulation the floating neural probes were implanted in rat cortex. The implantation procedure using a developed insertion tool is described in detail elsewhere [4]. Figure 3a shows data traces with recorded neural activity 38 days after chronic implantation of a 16 channel probe with only 160 μm^2 microelectrodes. Action potentials can be clearly identified on several channels.

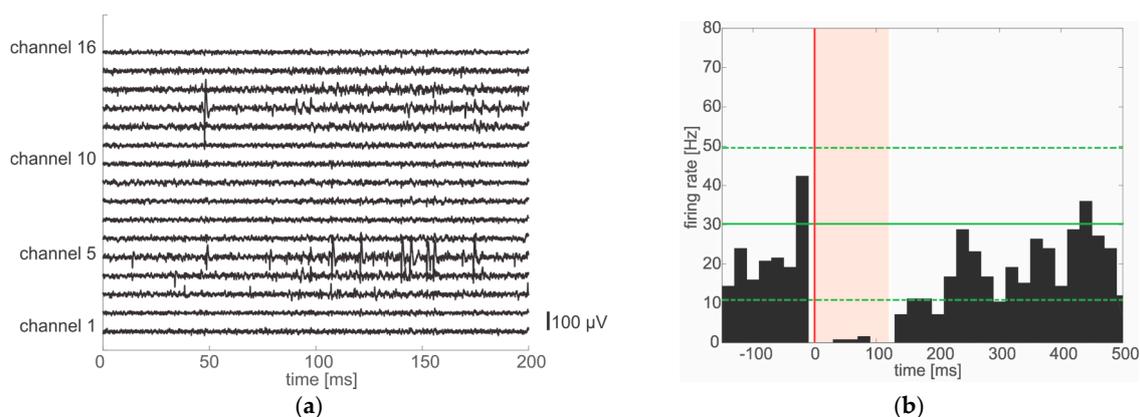


Figure 3. (a) Data traces of 200 ms duration showing data recorded 38 days after chronic implantation of the multichannel neural probe. Single unit activity can be observed on several channels; (b) Microstimulation effects on neural activity: single bipolar pulses (20 μA per phase, 100 μs phase duration) were applied at one electrode while the others were recorded. (P)eris(S)timulus(T)ime(H)istogram shows a suppression of activity directly after the pulse (red line at time 0) for 120 ms (red shaded area) at one microelectrode with spiking activity. Recovery of activity may take up to 400–500 ms. The green line depicts the average firing rate before electrical stimulation. Broken green lines depict two times the standard deviation.

Figures 3b and 4 show the response of the neural network to the application of a microstimulation pulse at a 2000 μm^2 microelectrode in an acute experiment at one recorded microelectrode and at all recorded microelectrodes, respectively. The neural activity recorded with the non-stimulated electrodes of the probe is reproducibly suppressed for 100 to 150 ms after the application of a single bipolar pulse of 20 μA current amplitude with a phase duration of 100 μs and interphase duration of 50 μs . These results verify the functionality of the neural probes for acute intracortical microstimulation.

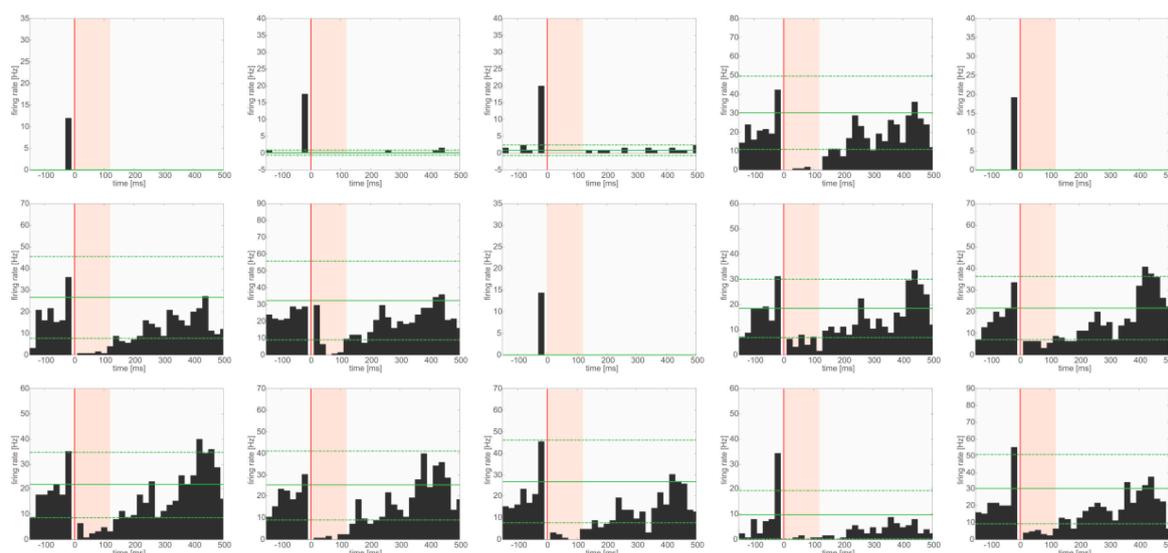


Figure 4. Microstimulation effects on neural activity: single bipolar pulses ($20 \mu\text{A}$ per phase, $100 \mu\text{s}$ phase duration) were applied at one electrode while the others were recorded. (P)eris(S)timulus(T)ime(H)istograms show a suppression of activity directly after the pulse (red line at time 0) for 100 to 150 ms (red shaded area) at all recorded microelectrodes with spiking activity. Recovery of activity may take up to 400–500 ms. The green line depicts the average firing rate before electrical stimulation. Broken green lines depict two times the standard deviation.

4. Conclusions and Outlook

The presented results show chronically recorded neural activity in rat cortex with high signal quality using novel multichannel floating neural probes. Furthermore the preliminary microstimulation results indicate the capability of the improved probes for long-term stable stimulation of the neural network in the brain. These promising findings are fundamental for chronic, bidirectional neural interfaces.

In the next step the microstimulation stability will be evaluated in vivo for chronically implanted neural probes.

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Conflicts of Interest: The authors declare no conflict of interest.

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