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Flexible multi electrode brain-machine interface for recording in the cerebellum

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***Abstract*—A new type of chip based microelectrode for acute electrophysiological recordings in the CNS has been developed. It's designed to be adaptable to a multitude of specific neuronal environments, in this study the cerebellar cortex of rat and cat. Photolithographically patternened SU-8 is used to yield flexible and biocompatible penetrating shanks with gold leads. Electrodes with an impedance of about 300 kΩ at 1kHz have excellent signal to noise ratio in acute recordings in cat cerebellum.**

I. INTRODUCTION

The field of Brain Machine Interfaces (BMI:s) have promises to open up new possibilities to treat conditions such as chronic pain, motor symptoms associated with Parkinsons disease [1] and essential tremor as well as controlling prosthetic limbs [2]. So far, the field has been centred around wire arrays and more or less rigid silicon and/or polymer probes [3,4]. Like any technical device, these have compromises, first and foremost between performance, biocompatibility and life expectancy of the interface. To obtain durable multichannel electrode implants that can record and/or stimulate neurons for prolonged periods of time a more mechanically flexible solution is called for. It would also be an advantage if the interface application could be tailor-made to the specific neural network studied. Therefore, we here present a new BMI construction that incorporates features such as tailor made architecture and mechanical flexibility.

In the present study, SU-8 polymer needles carrying gold microelectrodes were implanted in cat cerebellum. The geometry of the polymer arrays are such that measuring sites are located at the depth of Purkinje cell somata as well as interneurons in the surrounding molecular layer when the array is inserted perpendicular to the folia of the cerebellum. We predict that the design of the array and the method of implantation will yield high neuronal survivability and low scarring.

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II. ARRAY DESIGN

A novel electrode designed for the architecture of the molecular layer of the cerebellum was developed. SU-8 was chosen as the bulk material for the array because it is photostructurable with UV-light, is relatively flexible (with a Youngs modulus of 4.02 GPa, compared to that of silicon, 150 GPa) and known from other biological applications [5]. Prototypes based on polyimid and silicon were also made for similar reasons and abandoned based on the detail resolution of the photolithography process. Resolution and detail quality was a priority as a purpose of the design was to decrease the histological footprint left by larger designs and as we wanted the tip of the electrode to be as sharp as possible to easier penetrate the pia mater of the cerebellum.

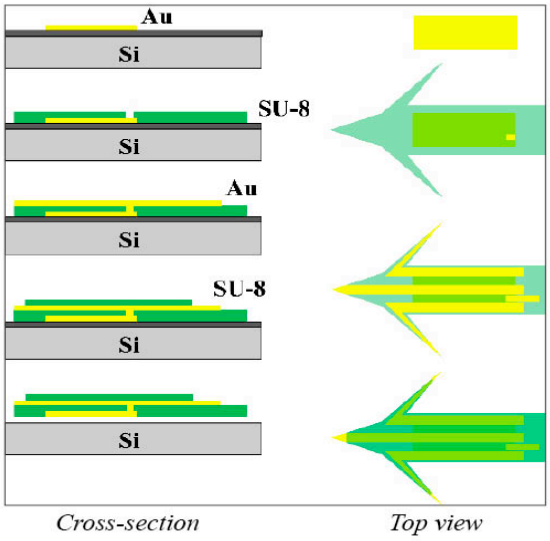

Fig. 1. Gold is deposited and patterned on a silicon wafer, followed by additions of alternating SU-8 and gold layers. Additional gold leads and recording channels can be added by repeating the layering process and adding new anchoring points.

The resulting array is a 8 – 12 µm thick needle composed of gold electrodes photolithographically patterned and sandwiched between insulating layers of SU-8 (fig. 1). Using this model, we've stacked 3 electrodes and a ground electrode into each array, although the number of channels in one array can be varied according to needs or the restrictions of ones data acquisition apparatus. While the ultimate goal of this project is to record from a large number

of channels simultaneously, a prototype array of a few channels was used in these initial trials. The array has the form of a needle with anchors protruding backwards at an angle of about 60° from the shank, each bearing a separate recording channel (fig 2). The recording sites are the tips at which the gold is exposed in a triangle ~15 µm high and a few microns wide. Extending from the needle, wiring to a connector site is incorporated in the photolithographical process in the form of an extension of the SU-8 insulation. This wire ends in a square enlarged to correspond to a 32 channel Kyocera Elko 5605 0.4mm connector chosen for its small size and suitability to attach to the rat skull for transcutaneous contacts.

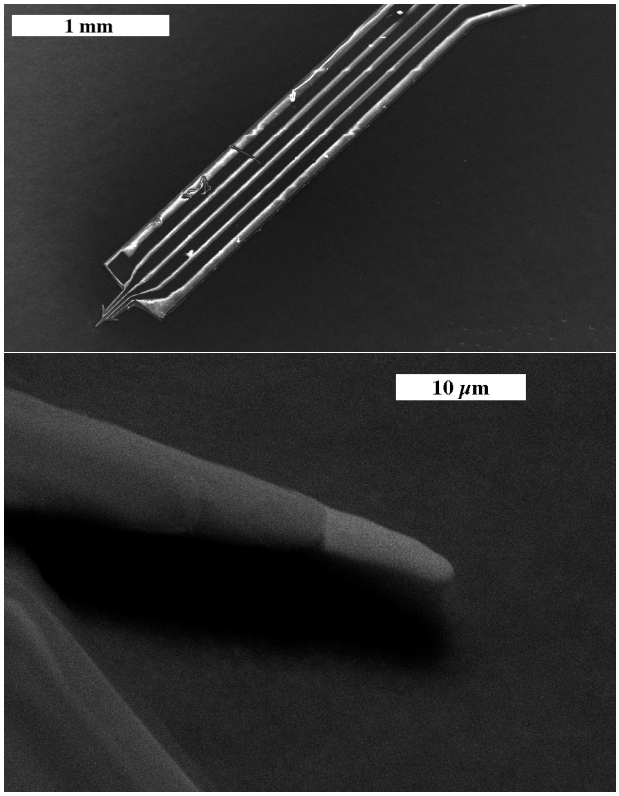

Fig. 2. Top: Penetrating tip in lower left corner of figure; cable to connector. Bottom: Detail showing measuring sire on side electrode.

III. Electrical properties

The electrical properties of the arrays when soldered to the connectors was evaluated with impedance measurements against saline solution (fig. 3). Impedance around 1 kHz was approximately 300 kΩ, which is comparative to values for traditional metal microelectrodes used for neuronal unit recordings.

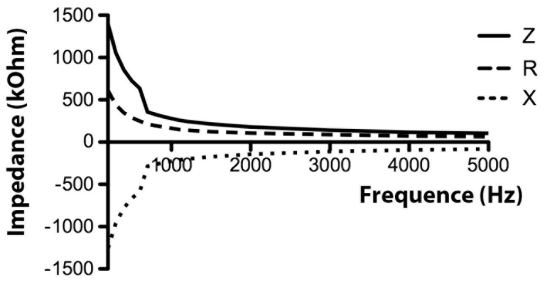

Fig. 3. Impedance measurement of a sample electrode in saline.

IV. Acute recordings

Successful acute recordings were obtained from decerebrate cat (fig 4), using a custom amplification and recording setup used in previous studies [6]. All animal experiments were performed with permission from the local Lund/Malmö ethical committee. The signal to noise ratio was high and discrete neuronal types could be distinguished from each other.

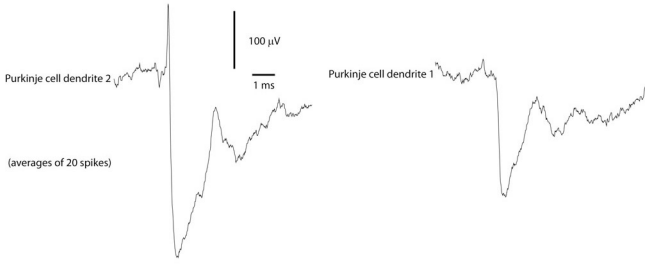

Fig. 4. Recordings from two distinguishable Purkinje cells. Dendritic spikes can be distinguished from somatic sodium spikes by their much longer duration. The longer duration is due to the fact that dendritic spikes are carried by voltage-gated calcium currents, which have a slower inactivation time than sodium currents. In cerebellar Purkinje cells, dendritic spikes are typically driven by climbing fiber inputs, which have a characteristic, low spontaneous activity. This was a property also of the slow spikes recorded here. An example of a previously published Purkinje cell dendritic recording, which are essentially identical in time course and spontaneous firing activity to those reported here, can be found in Ekerot and Jörntell (2003). [7]

V. Conclusions

The developed protocol for fabrication of needle electrodes can easily be expanded to numerous electrodes. First the number of electrodes on each shaft can be increased and furthermore, these shafts can be arranged in an array format and thus yielding more than one hundred electrode sites on each implant. The electrodes are shaped like arrows and placed at the tips of the protruding parts of the probe and thus should result in more promising recording capability compared to standard round surface electrodes. The fabrication process enables easy change of evaporated or sputtered electrode materials, e.g. platinum or in combination with electroplated materials, such as platinum black. Using platinum black is appealing as it enhances the surface area of the measuring or recording sites of an

electrode array and hence the capacity to deliver or receive electrical charges from the surrounding tissue.

Importantly, we found that our multichannel electrode yields recordings with a much higher quality than attained before from the molecular layer of the cerebellum. The signal to noise ratio attained with the presented electrode array allows for monitoring of very small electrical events in the cerebellar or any other neuronal environment. Existing BMI:s enable rough spike counts and recordings of local field potentials (LFP:s) that have proven useful for some applications, most notably rudimentary control of cursors [8] and simple prosthetic devices [9]. However, these electrode arrays have not yielded suitable recordings for basic physiological research and have yielded little insight into the neuronal circuitry surrounding the implanted structures. We believe that the good recording properties of our presently developed electrode is due to the anchoring function together with the sharp electrode design.

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