Implantation of Elongated Silicon Neural Probe Array in Rat Cortex

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***Abstract*— Neural microprobes represent an important component of neural prosthetic systems where implanted microprobes record the electro-potentials generated by specific thoughts in the brain and convey the signals to algorithms trained to interpret these thoughts. Here, we present novel elongated multi-site neural probe that can reach depths greater than 10mm. We hypothesize that reaching such depth allows the recording of cognitive signals required to drive cognitive prosthetics. The impedance of the recording sites on the probes was in the order of 500 kΩ at 1 kHz, which is consistent with probes used for neurophysiological recordings. We implanted the elongated probe in rats and showed that the elongated probes are capable of recording spikes from various recording sites.**

Keywords-Cognitive neural prosthetics; Brain machine interfaces; Porous silicon; Microprobes.

I. INTRODUCTION

Brain Machine Interfaces (BMIs) have the potential to improve the lives of paralyzed patients by allowing them to use their neural activity to operate computers, robots, or even their own limbs [1] [2]. BMIs are designed to function in real time and benefit from real or simulated feedback. The development of BMIs as a direct communication pathway between the brain and external devices has generated novel methods and techniques to interface with and to study the brain. A BMI platform is comprised of 1) a system to record neural signals, 2) algorithms to interpret the neural signals and 3) the device to be controlled. In this paper, we focus on recording platforms composed of multiple probes implanted in the brain. These platforms must be biocompatible, must be designed to minimize the short term and long-term trauma inflicted during and after insertion. The probes must also be long enough to reach variable depths. Thus, probes must be made durable without increasing their width. Implantable probe arrays have traditionally been metal microprobes [3]-[5]. However, these have been recently supplanted by silicon probes [6]-[10]. Implanting probes into the brain elicits a tissue response that degrades the recorded signals. Regardless of substrate, probe design must curtail this response to ensure long-term recording.

Relative movement of the probes within the brain causes long-term tissue response due to the difference in mechanical properties between the probes and the neural tissue [11]-[13]. This process is exacerbated by arrays implanted deep in the brain due to their longer moment arm. Silicon probes can be made thin enough to increase compliance in the brain but without some rigidity, thin probes cannot penetrate neural tissue. Devices to assist implantation have been tested but may still cause neural damage during insertion and can only be used for surface arrays [14] [15].

We previously researched methods to develop implantable arrays made from silicon that can record signals from areas that are 6.5mm deep in the brain [16] [17]. Considerable progress in the design and fabrication of elongated silicon probes that can reach depths in the brain required for our applications were made. Silicon probes were reinforced probes with metallic structures making them more stable [10]. The rest of the paper is structured as follows: Section 2 details the fabrication process of the proposed probes. In section 3, the characterization and testing of the neural probes are presented. Section 4 is the conclusion where a summary of the work, main challenges, lessons learned, and future work are presented.

II. MICROFABRICATION PROCESS

The microfabrication process for the non-porous probe array has been described in detail in our previous publication [17]. In the current work, the microfabrication process follows similar steps at the beginning to form the probe array structure. During the end of the process, we perform additional processing to obtain porous probes. In brief, the microfabrication process begins with dicing a 50 μm thick 4" diameter double side polished silicon wafer (boron doped,

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resistivity of 20 ohm-cm and <100> oriented) into small square pieces by using a dicing saw.

Metal layers of titanium (adhesion layer, 500 nm thick) and gold (conducting layer, 750 nm thick) are then deposited by sputtering process on the silicon wafer, as depicted in Figure 1(a). The gold and titanium layers are photolithographically patterned and wet etched, with solutions of 1:2:10 I2:KI:H2O and 20:1:1 H2O:HF:H2O2, respectively, to define the recording pads, interconnects between the recording sites, and bonding pads as illustrated, in Figure 1(b). The silicon substrate was then patterned using photolithography and etched using isotropic xenon difluoride (XeF2) dry etching system to form the probe structures, as illustrated in Figure 1(c).

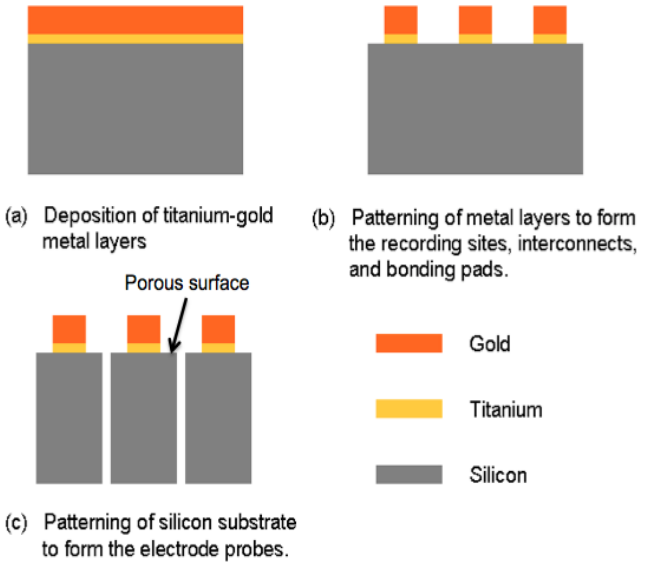

Figure 1. Schematic illustration of the steps involved in the fabrication process of the neural probe array (The Figure is not to scale).

The photoresist mask used in the previous step is removed and the silicon probe array is exposed etched using isotropic XeF2 dry etching system to form porous surfaces on the probe array. The formation of porous silicon using XeF2 dry etching system is described in our previous publications [18]-[20]. A 2µm thick layer of parylene-C, a biocompatible material widely used for coating a wide variety of implantable biomedical devices, such as pacemakers and silicon [21] and metal-wire neural probes [3], is conformably deposited, at room temperature using a Chemical Vapor Deposition (CVD) system, on the top side of the probe. It is mainly used to insulate the interconnects between the recording sites and bonding pads. Openings to expose the recording sites (used to measure the neural electrical activities) and the bonding pads (for wire-bonding to an external Printed Circuit Board (PCB) for read-out) were defined with photolithography. The exposed parylene-C is etched with oxygen Plasma Ashing System (PVA TePla Inc., Model: 200).

Figure 2(a) is a close-up view of the probe clearly showing the chisel-shaped tip, the titanium-gold recording site, and interconnects. Figure 2(b) is a magnified top view of the base of the probe showing the bonding pads used to connect the recording sites to external circuitry.

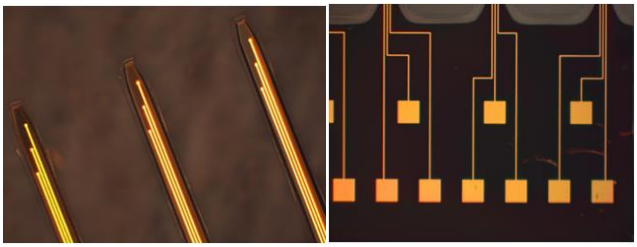

Figure 2. Images of the fabricated porous neural probe array. (a) Close-up image of the probe probes with recording sites; (b) Bonding pads.

The recording probe impedance is critical in the design of neural probes and is dominated by the size of the recording probe site.

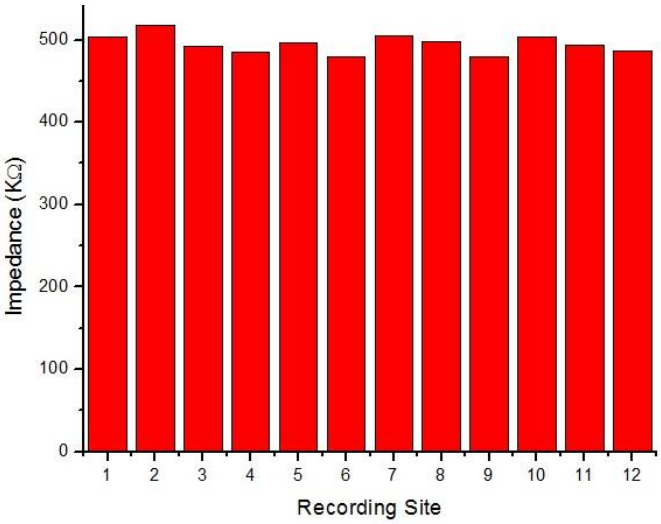

Figure 3. Impedance of the recording sites at 1 KHz.

The values of the impedance of the recording sites are obtained by recording the electric current while submerging the neural probes in saline solution and injecting current through them. Figure 3 shows the measured impedance for the twelve recording sites forming the current neural probe at 1 kHz and was found to be approximately 500 kΩ, a suitable impedance to record both single neuron activity and Local Field Potentials (LFPs) [3].

III. TESTING AND RESULTS

The developed neural probe was tested in the barrel cortex of a rat. All procedures were approved by the McGill University Animal Care Committee on May 18, 2010 and were also in compliance with the guidelines of the Canadian Council on Animal Care. The protocol number is 5314. A Sprague–Dawley rat was handled for several days before the surgery in order to accustom it to handling by the investigators. We tested the probe array in the barrel cortex of a rat using a procedure described previously in [3]. Our

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target was subcortical nuclei. The probe was centered at 3 mm lateral and 2 mm anterior of the bregma and lowered 100-200-micron steps to a depth of 5 mm. The dura of the rat was not dissected prior to silicon probe insertion. A thin silver wire was placed under the skin and attached to a screw in the skull for use as an additional ground.

Spiking activity was recorded using a multi-channel acquisition processor (MAP, Plexon Inc., Dallas, TX, USA) where single units were isolated online using time–voltage windows and their timing and spike waveforms stored on computer.

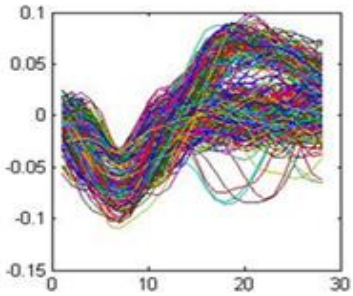

Figure 4. Neural recordings from six recording sites from the developed neural probe array.

Figure 4 shows recordings from one recording site of the developed neural probe array. Action potential waveforms from multiple neurons are visible in the signal. Multiple implantations are planned to gauge longevity of recordings. The rat was given pain, anti-inflammatory and antibiotic medication, as directed by our protocol and the McGill veterinarian. The rat was allowed to recover for at least 1 week before recordings were performed.

IV. CONCLUSION

The goal of the work reported here is to prove the functionality of the developed neural probe in accurately recording neural activity. We described a novel methodology to fabricate elongated multi-site neural microprobes. The probes were inserted through the pia and cortex of live rats to test their penetration ability. Results show a full insertion of the probes was successful without any bending, buckling, or breakage. Spiking activity was recorded simultaneously from the probes. The greatest challenge facing the use of neural probes is the resultant tissue response to the neural injury which effects the long-term functioning of the implanted neural probe. Future work will focus on improving the biocompatibility of these probes.

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