DESIGN AND MICROFABRICATION METHODOLOGY OF SU-8 BASED NEURAL PROBES

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Abstract: *This work aims to establish and validate the current methodology of design and process of microfabrication of polymer-based neural probes with planar microelectrodes, both to record and stimulate neuronal activity in animal models of epilepsy. SU-8 was chosen as structural material due to its good electromechanical properties, and biocompatibility, which makes it a suitable candidate for chronic and acute applications. A parametric design methodology was produced in order to easily change the probe's geometry according to future specifications. Besides, a simple and low-cost fabrication process successfully produced narrow, flexible and thin devices specifically designed to minimize tissue damage during insertion. Furthermore, an encapsulation process is being developed to easily handle the devices and perform in vivo studies and electrochemical characterization. Although silicon probes are still widely used, it is important to note that SU-8 has great potential to serve as structural material for neuroprosthetic devices and BioMEMS in general.*

Keywords: *Neural Probes, Microfabrication, BioMEMS, Neurotechnology, Neuroengineering.*

Introduction

Microelectromechanical systems (MEMS) refers both to devices at the micro scale and to the microfabrication techniques and processes originating from the semiconductor industry. They often consist of elements with certain physical or chemical properties which allow them perform specific tasks as sensors or actuators. Over the last decades, besides its enormous economic and commercial impact, MEMS devices have been assisting the development of several fields of engineering and life sciences. In particular, biological or biomedical applications of this technology (BioMEMS) have already demonstrated suitable to a wide variety of problems in medicine and pharmaceutical research [1]. Their singular features such as small size, portability, high sensitivity and capacity to integrate different functions make them remarkable tools to applications ranging from biosensors for diagnostic systems to implantable and prosthetic devices [2-4].

Recently these microdevices have roused particular interest to neuroscience and neurobiology, due to their inherent convenience to both *in vitro* and *in vivo* applications. Furthermore, neural implantable biomedical devices have great potential to the development of novel therapies, diagnostic methods and to improve the quality of life of patients with several neurological diseases and spinal cord injury. Among the most successful examples are retinal and cortical visual prosthesis [5], cochlear implants [6] and deep brain stimulators (DBS) for the treatment of movement disorders, epilepsy and depression [7,8].

In fact, BioMEMS are being established as a key technology to the deployment of neuroengineering and neurotechnology [9,10]. In this context, neural probes have been seen as an important instrument to neuroscience, allowing the study of the brain activity and its underlying neuronal networks with minimal invasiveness. These devices are inserted accurately at specific sites of the brain cortex, permitting the establishment of a connection between the biological tissue and external circuitry. This interface is used, for instance, for stimulation and recording of the neuronal electrical signal by the microelectrode array present in the probe.

Besides the widespread use of silicon-based neural probes, more recently polymeric materials and surface micromachining techniques are receiving a great deal of attention due to their simple and low cost fabrication processes, flexibility and biocompatibility. Silicon stiffness and brittleness associated to the micro motion of the device inside the brain contribute to local tissue inflammation, scar formation, probe encapsulation and, consequently, signal deterioration [11]. On that account silicon-based neural probes may not have the necessary properties and stability required for reliable chronic implants. For these reasons different polymers are being investigated as structural materials, such as parylene [12], polyimide [13], BCB [14] and SU-8 [15]. However, in contrast to the others, the latter is flexible enough to minimize damage during micro-motions, with no need to reinforce the probes with another material and sufficiently rigid to penetrate the tissue. Moreover, SU-8 biocompatibility has shown to be suitable as an implant material [16]. This work aims the study and establishment of the current processes of design and fabrication of BioMEMS based SU-8 neural probes to record and stimulate neuronal activity in animal models of epilepsy. In order to enhance neural interface, planar recording sites were achieved through well-established

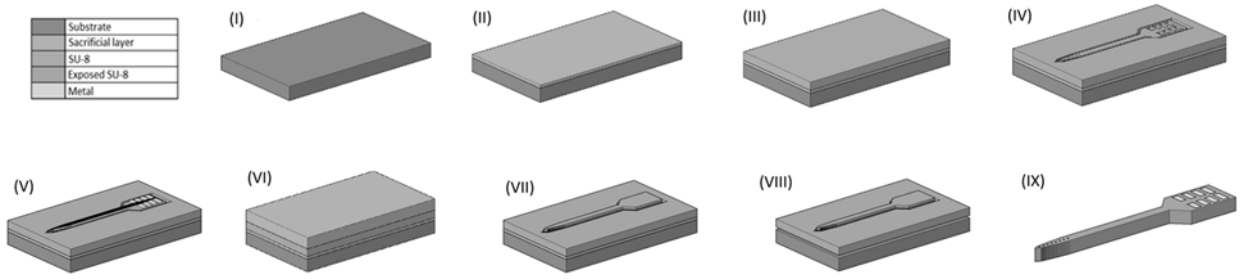

Figure 1: SU-8 based neural probes fabrication process; (I) Substrate; (II) Metallic sacrificial layer deposition; (III-IV) SU-8 deposition and patterning; (V) Metal sputtering and lift-off process; (VI-VII) SU-8 deposition and patterning; (VIII-IX) Sacrificial layer etching and probe release.

microfabrication techniques and an adapted procedure from the original developed by Altuna et al [17,18].

Materials and methods

The neural probes layouts were parametrically designed using *Python/IPKISS* and currently available CAD tools. They were fabricated using well established surface micromachining methods. In order to obtain planar microelectrodes, we followed the procedure described by Altuna in [17] and showed in Figure 1. This process was initiated with the patterning of the neural probe's geometry, pads and microelectrodes with SU-8. Subsequently, the conductive material was deposited to fill these areas and define the sensing sites. On top of it, another SU-8 layer was deposited to cover the probe. To finish the process, the devices were released by etching the sacrificial layer.

Polymer SU-8 (SU-8 2 and SU-8 50, MicroChem Corp., Newton, MA) was chosen to serve as structural material, due to its relative flexibility and to enhance physiological integration of the device. Different conductive materials were deposited as microelectrodes, such as TiN and Ti/Au.

Design – A parametric design methodology was produced in order to easily change the probe's geometry according to future specifications. Figure 2 shows the design of the SU-8 based neural probe. The length and width of the probe is ≈ 5 mm and 240 µm, respectively, with 50 µm thickness. In order to ensure good penetration and minimal damage, the insertion area was designed with a sharp tip and to increase the width gradually. This shaft is 3.5 µm long, and contains 8 microelectrodes with 28 µm in diameter and spaced 110 µm apart, enabling recordings from different brain layers simultaneously.

Fabrication process – The fabrication procedure starts with the sputtering of 200 nm of aluminum on a silicon wafer or glass substrate (Figure 1; (I, II)). In order to release the probes once the procedure is finished, this layer serves as sacrificial one. After that, 350 nm of SU-8 2 is spin-coated, properly baked [19] and exposed to UV light, in order to define the probe's geometry and open the pads and microelectrode areas (Figure 1; (III, IV)). On the top of it, a positive photoresist is spin-coated and exposed to pattern the conductive areas. Then, a deposition of ≈ 400 nm of the metal (TiN, Ti/Au) is performed by sputtering. Subsequently, lift-off process is performed to leave the metal on the desired areas (Figure 1; (V)). Next, a thicker layer of SU-8 (≈ 50 µm, SU-8 50) is spin-coated and exposed [20] to isolate the metal and define the probe's geometry (Figure 1; (VI, VII)). Finally, diluted KOH at 70 ºC is used to etch the sacrificial layer and release the probes from the substrate (Figure 1; (VIII, IX)). Note, that an additional etching step is necessary if an adherence metal is used, like Ti/Au, since the first sputtered material is the one exposed.

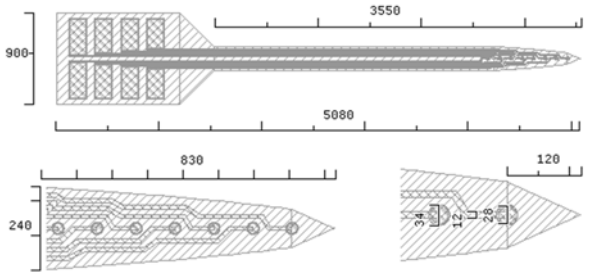

Figure 2: SU-8 based neural probes design.

Packaging – In order to easily handle the devices, perform mechanical/electrical characterization and acquire preliminary data, a printed circuit board (PCB) was designed and fabricated. Firstly, the probe was fixed on the PCB with an epoxy resin (Loctite, Henkel Corp.). After that, the PCB was heated until the resin was completely cured. Then, a silver based conductive epoxy (OxyChem) was applied at the probe's pads and cured, in order to micro-weld it at the PCB.

Results

Figure 3 shows a neural probe before the release process. Figure 3 (a) and (b) show the TiN pads and microelectrodes, respectively. Figure 3 (c) demonstrates the thicker SU-8 layer and (d) shows a closer view of the microelectrodes. A picture of a completed SU-8 and

TiN neural probe and a close view of its tip can be observed in Figure 4 (a) and (b), respectively. Figure 5 shows scanning electron microscope (SEM) pictures of the insertion shaft tip and Au microelectrodes. In Figure 6 a packaged neural probe with Au sensing sites can be observed. Finally, Figure 7 shows the cyclic voltammetry of each Au microelectrode in phosphate-buffered saline (PBS) electrolyte, in order to demonstrate the functionality of the device.

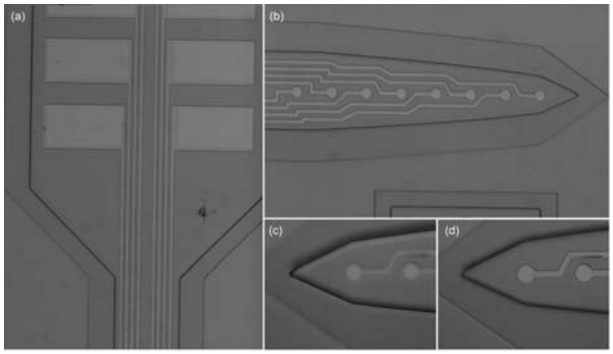

Figure 3: Optical microscopy of a neural probe before the release process. (a) TiN contact pads area; (b) Tip of the probe with TiN microelectrodes; (c) Thick SU-8 layer; (d) Closer view of the microelectrodes.

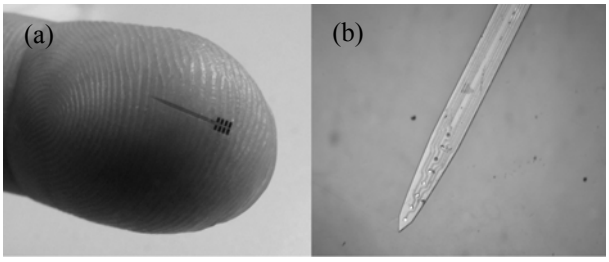

Figure 4: (a) Finalized SU-8 and TiN neural probe; (b) Close view of the tip.

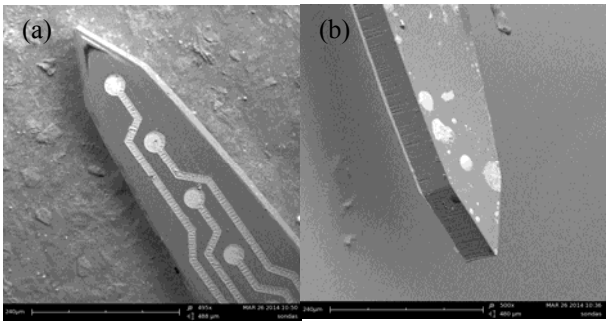

Figure 5: SEM images of the insertion shaft tip; (a) Exposed planar Au microelectrodes; (b) Other side view.

Discussion

The parametric design methodology has proved efficient to generate novel devices and geometries. Narrow and thin SU-8 neural probes were successfully produced with a high-throughput, expeditious and low-cost method. Besides, planar microelectrodes were obtained (Figure 5, (a)), which could improve the recording capability of the device. Figure 7 shows its functionality, which is studied and elucidated in more detail at another submitted work. Following these good results, different and more suitable probe designs will be produced to perform *in vivo* studies and more detailed tests.

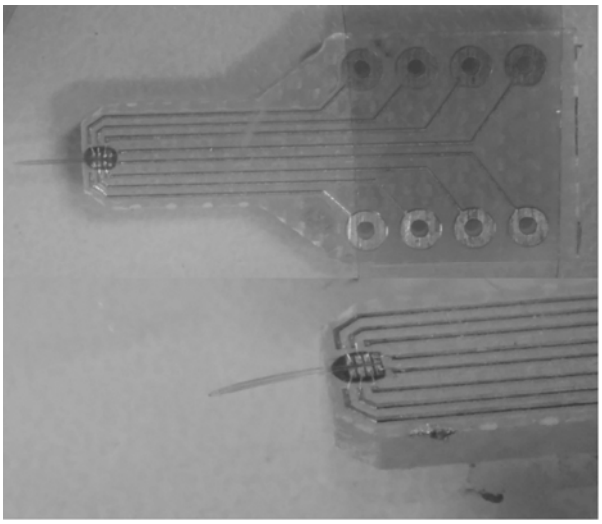

Figure 6: Packaged neural probe with Au sensing sites.

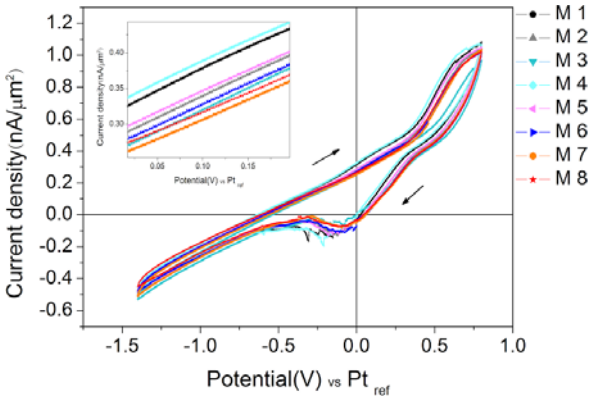

Figure 7: Cyclic voltammetry of each Au microelectrode ranged from -1.5 to 1.0 V vs. Pt.

However, in Figure 6 it is possible to note a slight undesirable curvature of the shaft, which indicates the presence of residual stress. Future work aims to optimize the microfabrication steps, eliminate this curvature, test different materials as microelectrodes and sacrificial layer, and improve the encapsulation process in order to enhance electrical contact.

The present work confirms the microfabrication viability of SU-8 based neural probes already documented in the literature. Novel devices could be easily fabricated through the described process, both for acute and chronic implants. Although silicon probes are still widely used, SU-8 has great potential to serve as

structural material for neuroprosthetic devices and BioMEMS in general.

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