HIGH-ASPECT RATIO MICROELECTRODES ARRAY WITH DIFFERENT PENETRATING LENGTH FOR NEURAL APPLICATIONS

S.B. Goncalves[1], A.C. Peixoto[1], F. Pinho[1], A.F. Silva[2], J.H. Correia[1]

[1]*Department of Industrial Electronics, University of Minho, Guimaraes, Portugal*
[2]*MIT Portugal Program, School of Engineering, University of Minho, Guimaraes, Portugal*

***Abstract* — This paper presents a simple fabrication method for high-aspect ratio recording and stimulation neural microelectrodes array with different penetrating depths. A 4.5 mm thick silicon wafer undergoes a set of dicing processes resulting into a 6 x 6 matrix of microelectrodes 150 μm wide and graded heights from 3 mm to 4 mm along the length of the array. Current microelectrodes arrays based on the same technology are limited to 1.5 mm deep electrodes. The design of arrays with different length electrodes allows to decrease the number of redundant electrodes, providing graded access to multiple layers within a neural structure. Along with the different depths, the long electrodes allow the recording and stimulation of deeper neural structures than the cerebral cortex. The hippocampal formation of the rat brain, which is a deep neural structure divided into multiple layers, is an important neural application for the proposed high-aspect ratio with different depths microelectrodes array.**

Keywords: **Microelectrodes array, Invasive neural electrodes, Different penetrating length, Dicing**

I – Introduction

Attempts to achieve interfaces capable of recording neural signals and stimulate neural tissue have been made in the last three decades. These interfaces can rely on electrodes inserted inside the brain (invasive neural electrodes) or on those that simply rest on the scalp (noninvasive). Developments in fabrication and the applications variety of invasive neural electrodes made them a widely used tool in neuroscience. Disorders such as irregular heart rate, deafness and Parkinsons disease can be treated with these neural prostheses.

The increasing need to reach different groups of neurons has led to the development of microelectrodes arrays, which allow the recording of neural signals from a number of sites with a predetermined spatial distribution [1]. A well-known configuration of microelectrodes arrays is the Utah Electrode Array (UEA). The design of these microelectrodes arrays restricts its application to surface structures of the cortex, and the current maximum length available of 1.5 mm further constrains what is accessible for recordings [2, 3]. Uniform length electrodes are within the same plane so they cannot target multiple cortical layers and they are not adjustable once placed [4].

The UEA design was later modified to the Utah Slanted Electrode Array (USEA) to be better suited for use in peripheral nerve as well as neuroscience applications [2, 5, 6]. Electrodes with different penetrating depths allow to reach a broader spatial region and decrease the number of redundant electrodes [4]. USEA can reach different depths so a more selective stimulation can be achieved [2, 6]. Moreover, variable height of the electrodes might improve the ability to selectively activate specific cortical lamina or specific regions of the peripheral nerves [7]. Despite all advantages of this design, its shanks' length are also limited to 1.5 mm.

The microelectrodes arrays with shanks' lengths of 1.5 mm may seem to be enough to access the cerebral cortex, however recording and stimulation of deeper neural structures such as the hippocampus cannot be reached using microelectrodes arrays with this kind of length limitation.

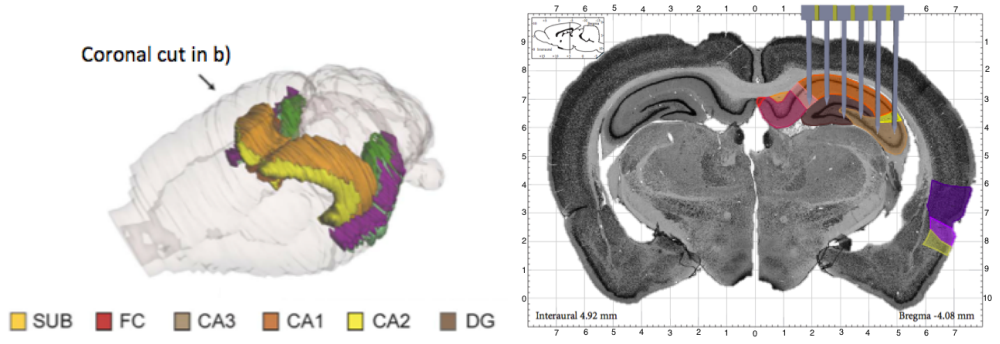
This paper presents a method of fabrication of a three-dimensional silicon-based neuronal microelectrodes array with high-aspect ratio and different penetrating depths that can be modified in the fabrication process. The final 6 x 6 matrix comprises three different shanks height with the longest being 4 mm while the shortest is 3 mm.

The rat hippocampal formation is a frequently used research model for exploring both normal and pathological conditions of the nervous system, including the processes involved in memory and learning and neurodegenerative diseases [8]. The fundamental divisions of the rat hippocampus are the cornus ammonis (CA) areas and dentate gyrus (Fig. 1a), delineated by cell body location, shape and size, proximal terminations, complex spines, distal branching characteristics and afferent and efferent projections [9]. Figure 1b shows the proposed microelectrodes array implanted in a rat brain. Through the graphical overlay showing color-coded segmentation of the hippocampal regions, one can see that the proposed microlectrodes array can access deeper neural structures than the cerebral cortex and provide graded access to multiple layers of the hippocampal region.

II – Fabrication Process

A. Microelectrodes array structure approach

Figure 2 illustrate the process flow of the microelectrodes array fabrication. The array consists of a 6 x 6



(a) (b)

Figure 1: *a) Three-Dimensional reconstruction of an adult male Long Evans rat brain showing color-coded surface representations of hippocampal structures [8]. The arrow indicates the location of image shown in (b). b)Illustration of the implantated microelectrodes array in a histological image stained for NeuN with graphical overlay showing the color-coded segmentation of the hippocampal regions. SUB – Subiculum; FC – Fasciolarum cinereum; CA1 – Cornu Ammonis 1; CA2 – Cornu Ammonis 2; CA3 – Cornu Ammonis 3; DG –Dentate gyrus.*

matrix, fabricated out of a (100) p-type silicon wafer with 1.3 mΩ.cm resistivity and 4.5 mm thick (Fig. 2a).

The fabrication process started by making cuts on backside of silicon substrate to create the electrical contacts of the microelectrodes array, resulting into squared pad regions with dimensions of 0.45 x 0.45 x 1 mm^3 (Fig. 2b). The pad regions were then filled with cyanoacrylate (Fig. 2c) in order to electrically isolate each electrode from its neighbors and to support the final shanks.

Afterwards, the frontside of the silicon substrate was diced to produce the sharpened shanks' tips. The goal of the sharpened design of the shanks' tips is to facilitate the implantation of the array in the neural tissue. The cuts for the higher shanks were made in the substrate surface. The following cuts were made at increasing depths with an index of 0.5 mm between cuts. Therefore, it was produced a graded and sharpened silicon substrate, as it is shown in Figure 2d.

Finally, the silicon substrate was diced in order to produce a 6 x 6 matrix of micropillars with 0.15 x 0.15 mm^2 wide shanks and different penetrating depths. The pads are connected by a 0.45 mm thick layer of cyanoacrylate (Fig. 2e).

B. Dicing

The cutting stages were performed on a Disco DAD 2H/6T dicing machine, equipped with Disco NBC–ZB blades capable of performing cuts 4 mm deep and 0.15 mm wide. The dicing step that produced a graded and sharpened silicon substrate was accomplished by a sharpened Disco Z09 blade with a 60° angle. The cutting speed was 0.5 mm/s.

The shanks were produced by making two sets of deep orthogonal cuts on the upper side of substrate. The minimum spacing between the electrodes was limited by the blade width used in the cuts. Therefore, the space between microelectrodes in the array is 0.6 mm.

C. Electrodes insulation

Cyanoacrylate was the adhesive polymer selected to cluster the shanks in a single structure. This polymer offers good biocompatibility, adhesive properties and also ensures electric insulation. It is deposited in the back grooves and the excess is removed through grinding and polishing.

III – Results and Discussion

The final array is shown in Figure 3. A matrix of 36 microelectrodes spaced by 0.6 mm and with different penetrating electrodes from 3 mm to 4 mm deep was successfully fabricated.

A. Microelectrodes array characterization

The boron doped p-type silicon has low resistivity, resulting in a substrate with good electrical characteristics. Also silicon has the required mechanical properties to be used as the bulk material of a neural microelectrodes array. It is strong under compression with a Young modulus of 130 GPa. In fact, the silicon structure demonstrated to be hard enough to withstand the dicing technique without suffering any damage.

During the fabrication of the array, it could happen alignment errors with the technology process used. Alignment errors of the order of 10 μm can occur between upper and back face cuts due to parallax errors, as the blade is optically positioned by the operator.

B. Comparison with other silicon arrays

Previous work [2, 3] based on the same technology process and with silicon as bulk material shows electrodes with a maximum length of 1.5 mm, having more fabrication steps and complexity than the present approach. For example, those electrodes need to

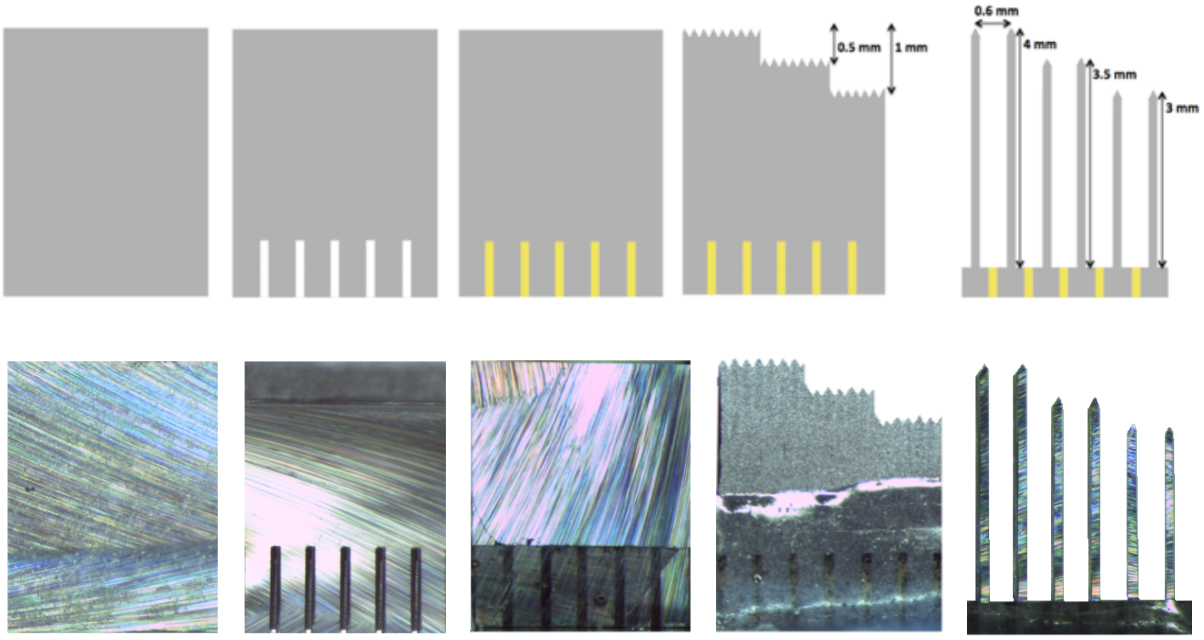


Figure 2: *Cross-sectional drawings (above) and photos (below) of the microelectrodes array fabrication steps. a) 4.5 mm thick silicon substrate; b) Diced contact pads; c) Interelectrode insulation by adhesive filling with cyanoacrylate (yellow); d) Diced shanks' tips at different depths; e) Diced shanks with 4 mm (left), 3.5 mm (center) and 3 mm (right). The space between shanks is 0.6 mm.*

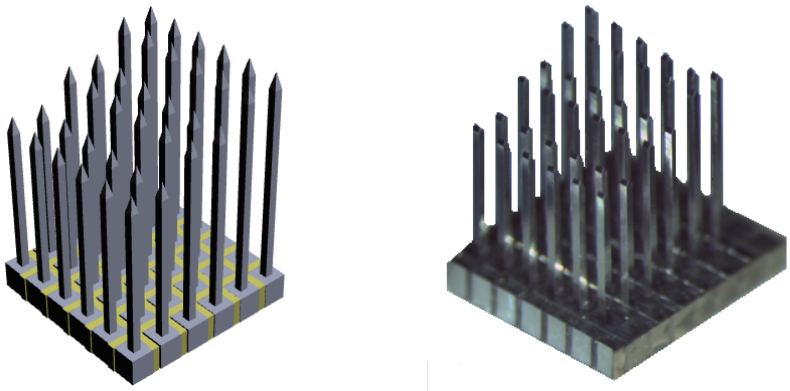


Figure 3: *a) Three-dimensional drawing and b) photo of the final microelectrodes arrays with different penetrating depths (left: 3 mm, center: 3.5 mm and right: 4 mm).*

undergo etching processes to create the sharpened shanks along the array in order to facilitate the implantation of the microelectrodes in the neural tissue [4, 7]. The proposed fabrication method is very simple as it avoids etching processes. In one cutting step and using a sharpened blade, it is produced the sharpened shanks' tips.

IV – Conclusion

This paper proposed a different method of fabrication of a three-dimensional silicon-based neural microelectrodes array with high-aspect ratio and electrodes with different penetrating depths. The proposed fabrication method is simple, reproducible and flexible as it allows to choose different penetrating depths along the array. Thus, this fabrication process is mainly characterized by the deep and different penetrating pillars heights.

Arrays up to 4 mm long, 150 μm wide and individually addressable were fabricated. In comparison with previous state-of-the-art silicon-based arrays, the proposed microelectrode structure provides the hability to reach deeper neural structures.

V – Acknowledgments

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