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A novel polyimide – platinum – SU-8 microelectrode array for various electrophysiological applications

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Abstract

Precise and reproducible construction of microelectrode arrays (MEAs) is possible due to the advanced technology of microelectromechanical systems (MEMS). Polymer-based MEMS devices are gaining increasing attention in the field of experimental electrophysiology, since their mechanical flexibility allows smooth coupling with the soft neural tissue. In this paper we present a novel MEA with a layer structure of polyimide – platinum – SU-8. A single row of electrodes with arrow-like shapes were formed, designed to make possible a slight penetration of the sites into the tissue. Functional tests were performed on rat brain slices (in vitro) and on intact rat neocortex (in vivo).

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Keywords: electrophysiology; MEMS; neural probe; microelectrode array; MEA; polymer; flexible; polyimide; platinum; SU-8;

1. Introduction

An increasing number of studies in experimental neurophysiology are carried out with the application of microelectrode arrays (MEAs) constructed with microelectromechanical systems (MEMS) technology. The traditional bulk material of such devices is silicon [1-3], but polymer-based sensors have also gained attention recently, since their production and fabrication costs are relatively low, and their flexibility allows smoother

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coupling with the neural tissue than rigid substrates [4]. Such flexible arrays can be realized for in vivo interfacing with the surface of neocortex [5-7] or with peripheral nerves [8, 9]. Under certain circumstances, the implantation of flexible MEAs into the tissue is also possible [10, 11]. Several types of polymers, e.g. polyimide and SU-8 are sufficiently biocompatible for such purposes [12, 13]. In this paper we present a polymer-based sensor array with a single row of arrow-shaped recording sites, placed on the edges of microscopic spikes, designed for various neurophysiological experiments.

2. Materials and methods

A schematic of the fabrication process is shown in Fig. 1. A 4-inch double-side polished, (100) oriented Si wafer functions as a substrate, which is cleaned and a 1 µm thick thermal silicon-dioxide layer is grown on both of its sides. In the next step, a 7 µm thick P84 polyimide layer is spin-coated onto the front side. Then a 30 nm thick TiO_x and a 270 nm thick Pt layer is deposited and patterned by lift-off technique, using 500 nm thick Al and 1.8 µm thick Microposit 1818 photoresist sacrificial layers. The layout of this conductive layer includes electrodes, bonding pads and wiring between them. Following this, a 20 µm thick SU-8 upper insulator layer is spin-coated onto the front side, and patterned with photolithography. The SU-8 is removed in this step above the electrodes, bonding pads and at the locations that are outside of the contour lines of the devices. Reactive ion etching (RIE) is applied for transferring the contour line pattern onto the PI layer, which partially etches the top SU-8 layer as well, while leaves the Pt relatively unchanged. Thus, the bottom PI layer will be preserved below the electrodes, providing sufficient mechanical stability. Following this, the substrate wafer is submerged into distilled water and the flexible device components can be peeled off. The MEA is glued and soldered onto a custom-made printed circuit board (PCB), equipped with a Preci-Dip electrical connector for interfacing with the preamplifier.

The devices were tested in vitro on brain slices and also vivo on the somatosensory cortex of anesthetized Wistar rats using operation procedures and recording systems described elsewhere [2]. All procedures were in accordance with the European Council Directive of 24 November 1986 (86/609/EEC), the Hungarian Animal Act, 1998 and the Animal Care Regulations of the RCNS-HAS.

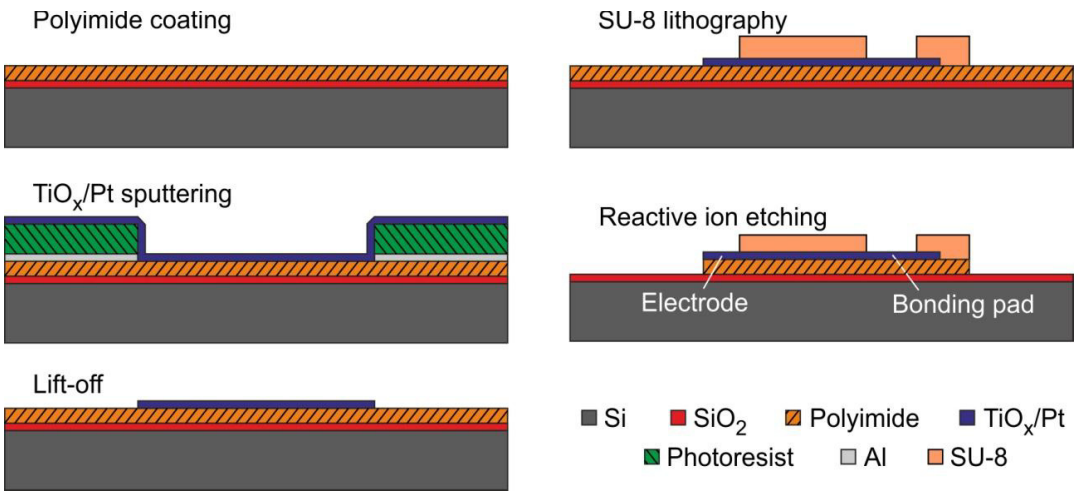

Fig. 1. MEMS processes utilized for fabrication

3. Results and discussion

This structure of the applied layers allowed a rapid and reliable technological process flow. Polyimide sufficiently adhered to the SiO_2, yet it could be peeled off relatively easily, while the robust nature of SU-8 lithography was advantageous during the patterning of the top insulator layer. Fig. 2. shows photographs of a microfabricated sensor array.

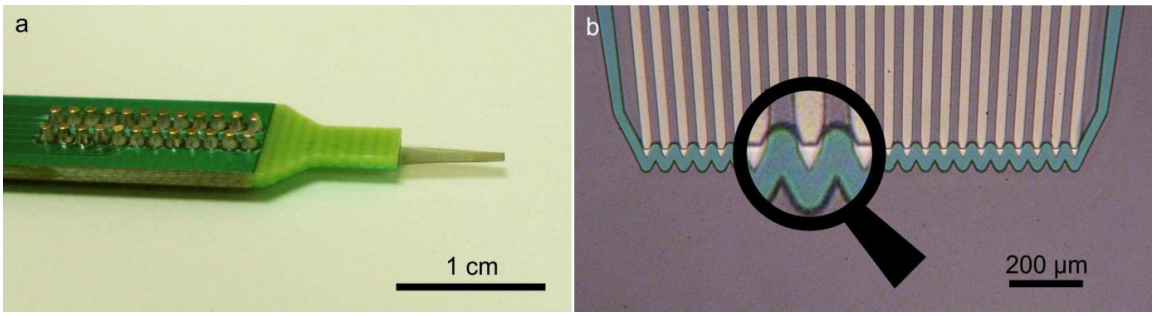

Fig. 2. (a) Photograph of the polymer MEMS device, electrically and mechanically connected to a printed circuit board; (b) Microscopic image of the linear microelectrode array with arrow-like platinum sites.

Fig. 3. shows sample local field potential signals, obtained during in vivo recordings. The PI-SU8 layer composition at the bulk of the device and the single 7 µm thick PI layer under the electrode sites have been able to provide sufficient mechanical robustness for the MEA to endure the experiments without damage. Typically, polymer-based electrocorticographs created with MEMS technology are designed to be laid onto the surface of the brain during measurements. Our arrow-like electrodes protruding from the shank allowed a slight penetration into the tissue, so a more direct interface was created, however, this also means a higher grade of invasivity.

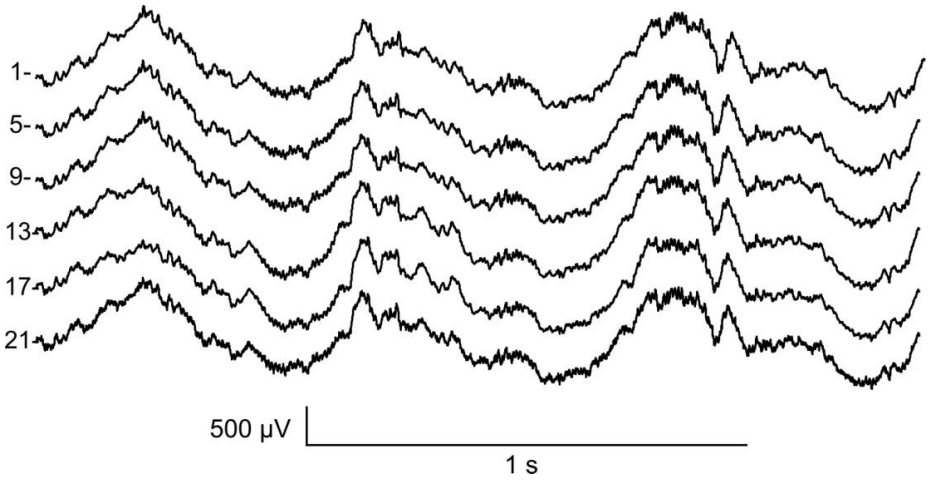

Fig. 3. Sample local field potential signals recorded from six channels during in vivo use of the device, on rat brain cortex. The slow-wave (1-1.5 Hz) oscillation is the result of the ketamine-xylasine anesthesia.

4. Conclusion

The robust bulk of the device allowed easy handling during these acute measurements, while the bottom PI layer provided enough stability for the pointy electrodes to slightly penetrate into the tissue without causing extensive damage. During in vitro and in vivo recordings we have learned that the MEA can be suitably used for electrophysiological experiments which do not require chronic implantation.

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