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Flexible PET/ITO Electrode Array for Implantable Biomedical Applications

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Abstract— **Flexible PET/ITO (PolyEthylene Terephthalate/ Indium Tin Oxide) implantable electrode array for spinal cord stimulation and retina prosthesis have been developed. The electrode array is fabricated on a thin PET/ITO substrate and encapsulated with insulating material, SU-8. The PET substrate made electrodes flexible so that they could shape to contoured tissues. A layer of gold on the stimulation sites served to reduce the electrode/tissue interface impedance. Prototypes of 1×8 and 3×8 electrode arrays are fabricated for monophasic and biphasic stimulation of spinal cord respectively. The exposed electrode dimensions are 3mm² for monophasic and 6mm² for biphasic stimulation with 100µm of interconnection paths. The prototype of 4×4 electrode arrays were also fabricated with the same process for retinal prosthesis with exposed electrode diameter of 125µm. To verify the functionality of the subdural electrodes, the electrochemical impedance spectroscopy was measured. The electrode/tissue impedance was 500Ω at 1*KHz* for 3mm² area.**

I. INTRODUCTION

In order to promote injured or sick nerves for the restoration of function, scientists have developed chronically implantable microelectrodes to record from and/or stimulate cells of the remaining nervous system. Partial restoration of lost function has been achieved by advances in functional electrical stimulation [1].

For recording the behavior of different types of biological tissue and stimulating biological nerves, microfabricated electrodes have become a critical tool in biosciences. Also they play a significant role in studying the interactions among functional subunits as they transmit or process information. They are now widely used in the field of implantable microsystems, which leads to dominating variety of physiological disorders [2].

Typically, the electrode sites are made of a conducting metal deposited on a silicon-based substrate. Microelectrode is usually insulated by a passivation layer, leaving the electrode sites and bonding pads exposed [3].Silicon microelectrodes show good biocompatibility and have the advantage of being compatible with CMOS-based on-chip signal conditioning circuitry [2]. The main problem in silicon-based micro electrodes is that the silicon substrate is mechanically rigid and brittle; therefore if the electrode moves spontaneously, it may cause severe damage in tissue. Therefore, for accommodation for movement, a flexible electrode is highly operational in implantable micro electrode arrays.

The main approach for flexible electrodes is polyimide-based electrode which has drawn widespread attention [4]. In 1992, Boppart presented a first flexible electrode [5]. The research in this field then followed by more advanced designs by Gonzalez [6] and Weiland [7].

Another approach for flexible implantable electrode has been presented in this paper using ITO/PET (Indium Tin Oxide / PolyEthylene Terephthalate). Among the flexible electrodes, ITO/PET electrode combines good biocompatibility, proper mechanical characteristics, high dielectric strength and is well known in microfabrication. An ITO/PET electrode structure which provides biocompatibility, mechanical stability and flexibility is designed and fabricated in this work. A retinal implantable electrode and an electrode array for stimulation and recording from spinal cord have been fabricated with ITO on PET substrate. Although ITO is very biocompatible, it has relatively high impedance in contrast with other conductors like gold, therefore a layer of gold was evaporated on electrode sites for reducing electrode tissue interface impedance.

II. MICROFABRICATION

In this work, PET was used as a flexible substrate during array fabrication. The PET/ITO sheets supplied by Aldrich Company, in 100nm layer of ITO coated upon 1mm thick substrate of PET. The transparency of ITO/PET sheets is in the range of 75–80% and they have a measured sheet resistance of about 45Ω/square. Process flow of fabricating the flexible electrodes is shown in Fig. 1.The conducting layer of ITO is patterned on PET using optical lithography technique. On the ITO surface a 1.8µm thick support layer of photoresist was spin coated and photo-structured. The photoresist was soft baked and hard baked, both for 30 minutes at 100ºC temperature. The conductive layer of ITO was patterned using wet etching. The ITO was etched for 30 seconds in a solution of 450mL HCL in 450mL of deionized water.

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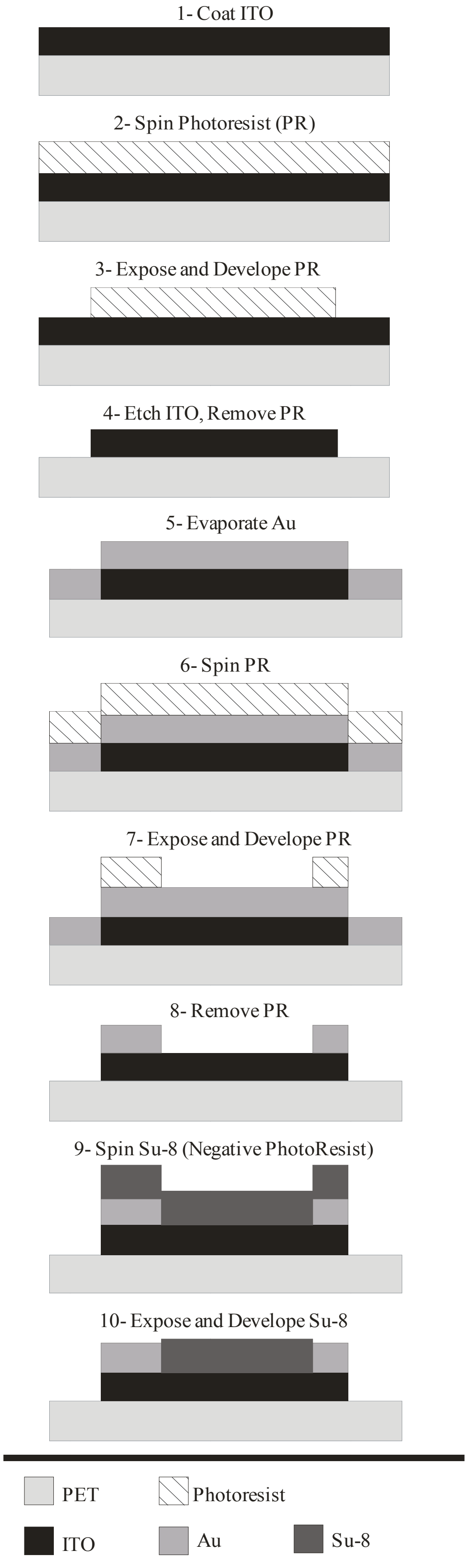


Fig. 1: Process flow of ITO/PET electrode Array fabrication.

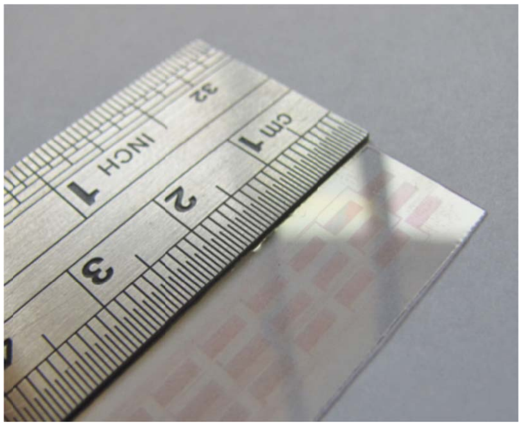


Figure 2: An implantable electrode array for biphasic stimulation of spinal cord stimulation microsystem.

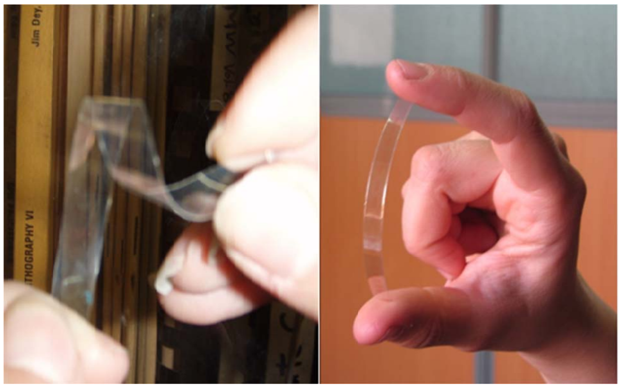


Figure 3: An implantable electrode array for monophasic stimulation of spinal cord stimulation microsystem. The electrode can be folded and rolled and still maintains the original shape.

To reduce the impedance of the electrode/tissue interface, the electrode sites were coated by gold, using vapor deposition technique. An etching procedure was used in order to coat a 200 nm layer of gold on stimulation sites. To passivate the electrode array and ensure biocompatibility, the electrodes were coated by an insulating material, SU-8. The polymer SU-8 was chosen because of its excellent lithographic properties. It also provides biocompatibility and flexibility features for the passivated electrodes.

III. EXPERIMENTAL RESULTS

A. Spinal Cord Stimulation Electrodes

Spinal cord stimulation microelectrode arrays were fabricated in two structures. A single column structure for monophasic stimulation and a three column electrode array for biphasic stimulation. Each site area in one column structure was 1×3 mm^2 and in three columns structure was 1.5×4 mm^2. Electrical testing showed approximately 500 Ω for monophasic stimulation sites at 1 KHz frequency. Stimulation sites were connected via 100 μm interconnects with 100 μm spacing. Biphasic spinal cord stimulation electrode array has been shown in Fig. 2.

The electrodes inserted and remained in rat plasma for three days to test for protein absorption and thirteen days for stability. Electrodes showed resistance to body solvents and maintained the original shaped and properties. These electrodes also recover to their original shape even after rolling or folding as it is shown in Fig. 3.

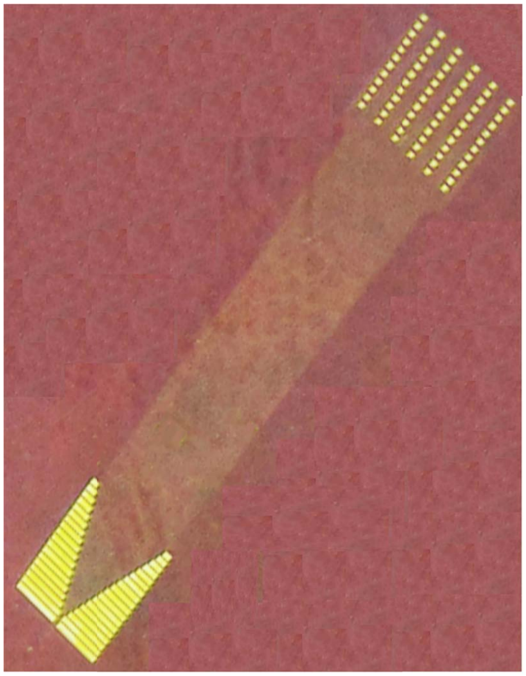


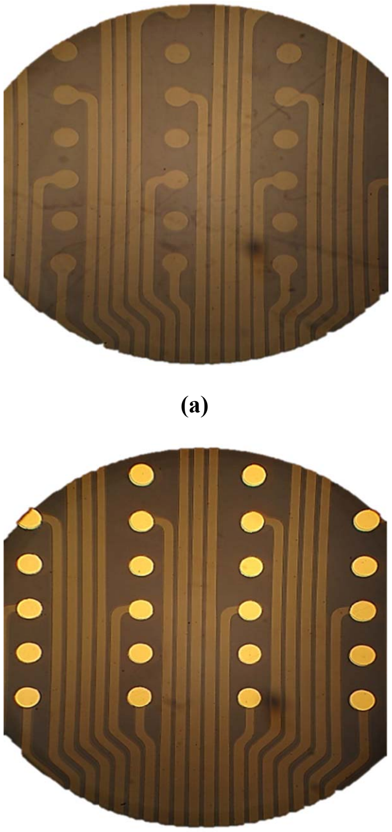
Figure 4: Fabricated biomimetic electrode array contains 72 sites with 100-µm-diameter. The stimulation sites and bonding pads have been coated with gold.

B. Retinal Prosthesis Stimulation Electrodes

Retinal prosthesis stimulation electrodes, microfabricated on the ITO substrate, consisted of 72 (12×6) stimulation sites with 100µm diameter and 200µm pitch. This fabricated microelectrode array is shown in figure 4. Stimulation sites and bonding pads were coated with gold and other areas were covered by SU-8 polymer. 35µm width traces with 20µm spacing connect 36 sites to bonding pads. As it was mentioned, due to high impedance of the ITO/tissue interface, the electrodes were covered by gold. Figure 5 shows the microscopic view of stimulation sites covered and uncovered by gold.

C. Impedance Spectroscopy

To verify the functionality of the subdural electrodes, the electrochemical impedance spectroscopy was measured. The electrical interaction between electrode and tissue was experimented in vitro in a saline solution (9 mg/ml HZO, pH 7). The measurements were carried out between 100*Hz* to 100 KH*z* frequency with a sinusoidal signal of 0.5mV to 2V in amplitude. The electrode surface area and impedance shows an inverse relationship. Also electrode impedance decreases by elevating frequency while phase angels increases from -80 to -10 degree. All the mentioned tests carried out on electrodes with gold covered stimulation sites. The impedance characteristics have shown in Fig. 6. For stimulation site of 3mm^2 area.



(a)

(b)

Figure 5: stimulation sites of visual prosthesis electrode array taken by electron microscope; a) ITO electrodes; b) ITO electrodes covered with gold.

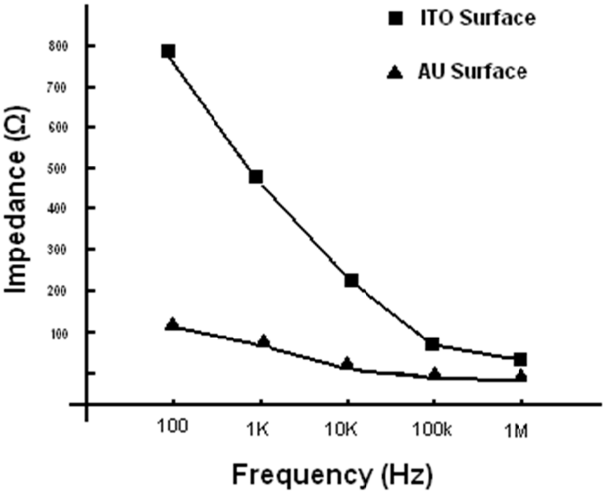


Figure 6: Impedance characteristics of ITO and gold stimulation site with 3mm^{2}area.

IV. CONCLUSION

Flexible PET/ITO implantable electrode arrays for spinal cord stimulation and retina prosthesis have been presented. Theses implantable electrodes have been fabricated by biocompatible and flexible materials and it is expected that these electrodes reduce the tissue damage of non-flexible electrodes after surgical implantation. Also a flexible electrode would contact the tissue according the subject tissue form and shape, which is essential for proper stimulation. The PET/ITO electrodes provide safe contact while obtaining low resistance of equivalent electrodes by coating the stimulation sites with gold.

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