Fabrication, optimization and surface modification of flexible microelectrode array for retinal prosthesis

Bin Sun[1,], Huimian Lu[1,], Xia Kai[1], Qi Zeng[1], Tianzhun Wu[1,*] and Mark S. Humayun[1, 2]

1). Shenzhen Institutes of Advance Technology, Chinese Academy of Sciences, Shenzhen, China
2). USC Roski Eye Institute, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA

* Email: tz.wu@siat.ac.cn; Tel.: +86-(0755) 8639-2339

Retinal prosthesis could electrically stimulate the survival retinal cells (ganglion, bipolar cells, etc.) to restore impaired vision function, which is expected to benefit people with visual degeneration due to inherited retinal degenerations like retinitis pigmentosa (RP) or age-related macular degeneration (AMD). To ensure effective stimulus and long-term implantation, some requirements of microelectrodes need to be satisfied stringently such as miniaturized geometry, reliability and good electrochemical performances.

Argus II (Second Sight, Sylmar, CA) as the world's first commercial retinal prosthesis had only 60 channels and showed poor acuity [1]. From the simulation reported by James D. Weiland *et al.* [2], blind individuals became able to read newspaper, recognize faces and navigate in unfamiliar environments using 1000-channel flexible microelectrodes array (fMEA). More than 1000-channel fMEAs had also been investigated by Yu-Chong Tai *et al.* and Sangmin Lee *et al.* respectively [3][4]. In the paper, the fabrication, optimization and modification of 1025-channel fMEA are provided.

The schematic of fabrication of 1025-channel fMEA is shown in Fig.1. The 1025-channel fMEA contains two metal layers as the electrodes and metal trace and the polymer layer was used as insulation or substrate. In the micro-fabrication of the 1025-channel fMEA, Polyimide (PI) and parylene-C (PA) were chosen as the two substrate materials due to their excellent biocompatibility, flexibility and mechanical strength. The first and second metal layer was fabricated by the successive processes including photolithography (EVG 610, Austria) by using mask 1 and 2 respectively, deposition of titanium (Ti) and platinum (Pt) by using E-beam evaporation (SKY Technology Development, China) and lift off process. Each metal layer was covered with a deposed polymer as insulated layer. The pattern of each metal layer after lift off is given in Fig.2. After the formation of the final polymer layer, the sample was etched twice by oxygen reactive ion etching (RIE) using AZ4620 as hard mask to expose the electrodes for plating. One extra step was to electroplate the Pt gray on the exposed microelectrodes, as Pt gray electroplating would bring large surface which would reduce the impedance considerably and is desirable for retinal prosthesis [5].

Metal peeling phenomenon has happened during the fMEA fabrication, and it is indicated that Ti/Pt layer peeled from the polymer substrate through the energy dispersive spectrometer (EDS) analysis result. Pt and carbon atom percentages of two areas were 99.73% and 99.79% respectively as shown in Fig.3 (1). The results indicate the Ti/Pt metal layer peeled from the PI substrate. In order to enhance the adhesion between Ti/Pt layer and PI, O_2 plasma pre-treatment was presented to roughen the PI surface. Figure .3 (2) and (3) show the scanning electron microscope (SEM) and atomic force microscope (AFM) image of the surface of O_2 plasma-treated PI films with different RIE chamber pressure. Obviously, the treated PI surface showed irregular nano-scale hairs. The root-mean-squared (RMS) roughness of treated PI film was 34.7 nm, 22.8 nm, 18.9 nm and 15.2 nm respectively. A 10-channel fMEA was fabricated on untreated PI and pre-treated PI, shown in Fig.3 (4). It indicates plasma surface roughening treatment could enhance adhesion between metal layer and PI substrate.

A 24-channel fMEA was used to facilitate the investigation of the electrochemical properties for the 1025-channel fMEA. The contact pads were wire-bonded to a printed circuit board (PCB) as shown in Fig.4 (1). The electroplated fMEA is shown in Fig.4 (2). Therefore, the impedance of microelectrodes or electroplate Pt-gray became measurable. The charge storage capacity (CSC) of the plated microelectrodes is calculated as 83.2 mC/cm^2 by integrating the areas under voltammograms from the CV curve as shown in Fig.5. The EIS presents a comparison of the impedance for the microelectrodes with and without Pt-gray as shown in Fig.6. The electrochemical impedance was significantly reduced from 110 kΩ to 16 kΩ at 1 kHz.

In conclusion, the 1025-channel fMEA was fabricated. O_2 plasma pre-treatment (RIE) is proved to be useful to enhance the adhesion between the metal layer and PI as it has roughened the PI surface. CSC of fMEA with Pt coated is found to be larger comparing with those without Pt-gray. The electrochemical impedance reduced to 16KΩ on samples coated with Pt-gray. The interface impedance reduced around one order of magnitude, which is promising for various high-density neural electrodes in rehabilitation medicine and brain sciences.

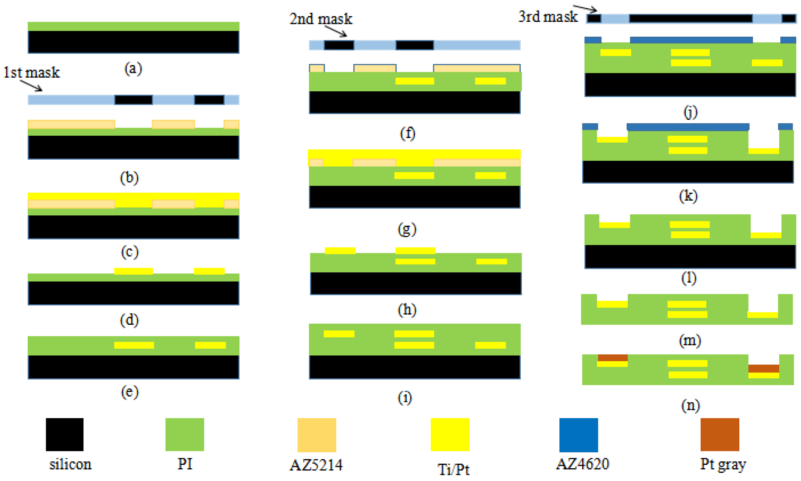

Fig.1 Schematic diagram of the fabrication process of 1025-channel microelectrodes array

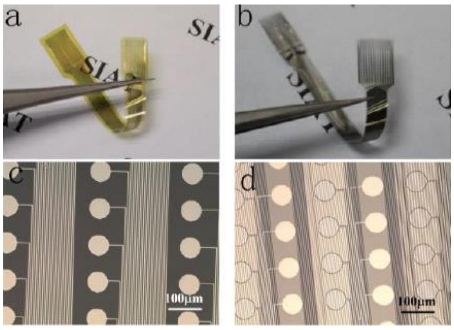

Fig. 2. 1025-channel fMEA. a) PI substrate, b) PA subsrate, c) first layer pattern, d) second layer pattern.

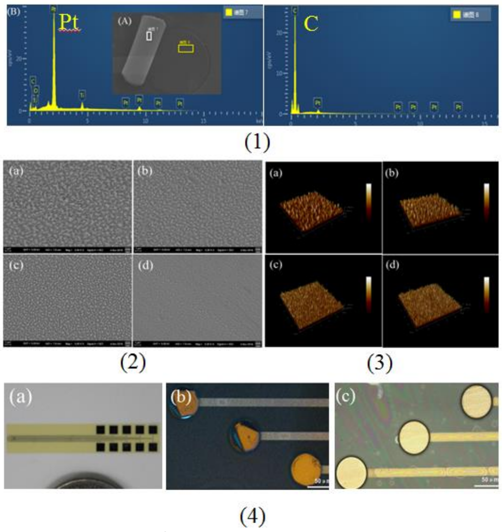

Fig. 3. 10-channel fMEA, (1) Failure analysis, (2) SEM of pre-treated PI with different chamber pressure. (a) 20Pa, (b) 30Pa, (c) 40Pa, (d) 50Pa., (3) AFM images of pre-treated PI with different chamber pressure. (a) 20 Pa, (b) 30 Pa, (c) 40 Pa, (d) 50 Pa. (4) 10-channel fMEA was fabricated on untreated PI and pre-treated PI respectively.

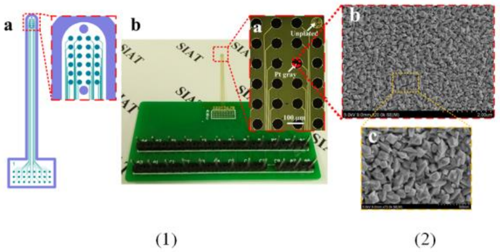

Fig. 4. Simplified 24-channel fMEA (1) Bonding with PCB, (2) SEM image of the electroplated electrode.

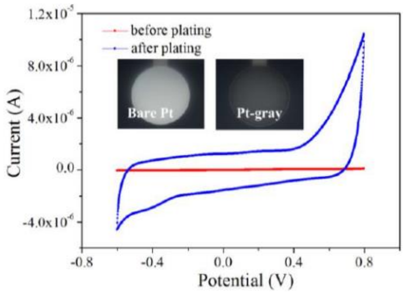

Fig. 5. CV of Pt microelectrodes with and without Pt-gray in a phosphate buffered saline solution (PBS, 0.01 M, PH 7.4), swept at 50 mV/s

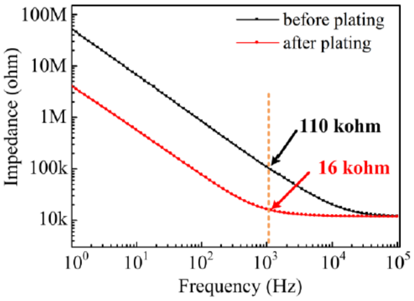

Fig. 6. Impedance spectrum for Pt microelectrodes with and without Pt-gray, measured in PBS

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