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Flexible ECoG electrode for implantation and neural signal recording applications

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ABSTRACT

Electrocorticography (ECoG) neural signal recording has been widely used for recording brain electrical signals in brain research and clinical applications for disease diagnostic. In this work, we developed a flexible and re-pluggable ECoG electrode based on chromium-silver-chromium (Cr-Ag-Cr) structure which was deposited on 50 μm thick polymide (PI) foil. This electrode was used in neural signal recording tests and the results demonstrate, with low electrochemical impedance values of about 22.7 kΩ, can record the brain signals well. It can also be very nicely mounted on the curved surface of brain gyrus.

1. Introduction

Electrocorticography (ECoG) is a potential generated by an electrical current due to the cellular activities in the brain. It can be recorded by applying subdural gird electrodes on the cortical surface [1]. ECoG recording system is widely applied for monitoring brain electrical signals in brain research, clinical applications, and neuroprosthetics for helping physical incapacitation patients [1,2]. Invasive but non-penetrating ECoG electrodes cause much less damages to tissue or neural cells than other intracortical recording interfaces, hence ECoG is more competitive in chronic recording in vivo [2,3]. Compared with traditional ECoG with hard substrate, flexible ECoG electrode system can fit the wrinkled surface of the cortex well [4,5], it has less inflammatory response and astroglial scar [6–8]. However, there is still no high density and good resolution flexible ECoG electrode system that covering a large area cortex has been reported. In this paper, we proposed a novel flexible and re-pluggable ECoG electrode for neural signal recording. It can be mounted to a large area irregular surface.

2. Experimental

2.1. Flexible ECoG electrode design

The structure of the re-pluggable and flexible ECoG array with 32 electrodes is shown in Fig. 1a. Fig. 1b shows the enlarged view on the electrode terminal with sizes indicated. The electrode array is 16.3 mm wide, 24.8 mm long and 60 μm thick. Each pad of the electrode covers an area of 16.3 mm × 1.5 mm, electrode sites are intensive laid on one end of the electrode with 50 μm diameter each, the diameter of the three small holes, which were used for drug injection, is 300 μm. For high-quality signal recording, total 32 channels which are enough to cover the major area of the rat brain including important subdomains such as visual, retrosplenial, anterior cingulate, and somatosensory are made on the PI substrate. The design can work simultaneously in same cerebral area and is also able to prevent collecting same signal repeatedly.

The proposed ECoG electrode is fabricated on the flexible PI film. PI is a good insulating substrate [5,9] and has good biocompatibility [9]. The most commonly used material for ECoG electrode are silver (Ag), gold (Au) and platinum (Pt) [10] for their excellent anti-oxidation property, high electrical conductivity, good biocompatibility, and softness. Here we choose Ag considering the conductivity and cost. To improve the adhesive of the ECoG metal

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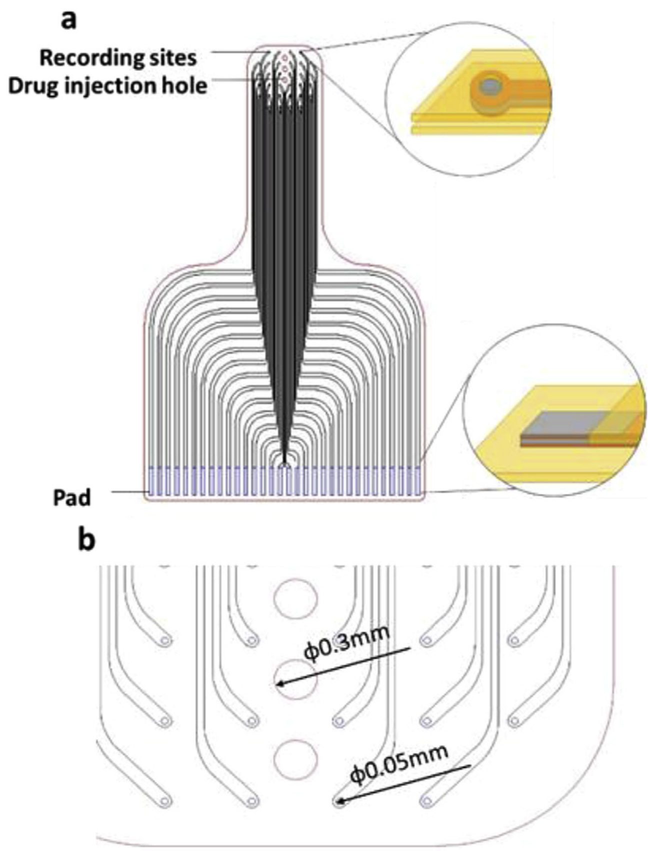

Fig. 1. a) Structure of the re-pluggable and flexible ECoG electrode array; b) enlarged view showing the sizes of the electrode.

and PI, chromium (Cr) is introduced to both sides of the Ag film. The top layer of the electrode was covered by a PI film for protection also as insulator.

2.2. Flexible ECoG electrode fabrication

The fabrication processes of the proposed ECoG electrode is shown in Fig. 2. The glass substrate is first cleaned with acetone and ethyl alcohol, and then rinsed with deionized (DI) water. After the cleaning, the glass spin coat with a 10 μm thick polymethyl methacrylate (PMMA) which was then stirred for 30 min at 180 °C. PI layer of 50 μm thick (using ZKPI-305IIE solution provided by Bomi Science and Technology, Beijing, China) is spin coated and cured at the temperature of 230 °C for 3 h on the PMMA layer. Patterning was done with photolithography process with AR-P 5350 photoresist from German Tech. Co. The sample was treated with oxygen plasma for 10 min to enhance binding force between metal layer and PI. Then a 20 nm thick Cr, 600 nm thick Ag and then 20 nm thick Cr films were magnetron sputtered in turns under high vacuum condition of 3.0×10^{-3} Pa. The thick Ag layer was aimed at reducing the low impedance. However, too thick metal film will reduce the flexibility of the electrode and causes fractures on the film. The top PI film of 10 μm thick was spin coated on the metal layer for insulation. Contact windows and pads were formed by plasma etching using Oxford plasma lab system 100 from Oxford Instrument with vacuum vessel pressure of 10^{-4} Pa [11]. By using thermal evaporation, an Ag layer of 60 nm thick was plating afterwards under 5×10^{-5} Pa to improve contact between metal electrode and cortex, as there is a distance between the electrode and target recording area due to the concave structure on the top insulation PI layer [12]. Lastly, ECoG electrode was removed from the glass substrate. The fabricated electrodes are shown in Fig. 3(a)–(b). Note that the ZIF SMT FPC connector was used as for connecting the proposed ECoG electrode as shown in Fig. 3(c). The electrode array fits well with the wrinkled cortex of organism, which ensures a high signal-to-noise ratio (SNR) recording.

3. Results and discussion

3.1. In vitro testing

The flexible ECoG electrode array with 32 electrode channels was tested in vitro. The electrochemical impedance value at 1 kHz for each electrode was measured (see Fig. 4). All electrochemical impedances of 32 electrode channels were below 120 kΩ at 1 kHz and the averaged value was 22.7 kΩ. Our 32 electrode channels could be considered to be suitable for vivo tests after implantation by a ruler with an impedance of less than 600 kΩ [13]. The impedance of our Cr-Ag-Cr electrodes are also much smaller than those based on Au and Pt [13]. The much lower impedance of present electrode suggests that it should have good performance in neural signal recording. The impedance varied between channels is related to the different lengths, surface areas. The ECoG electrode array further dropped in 5% saline solution for 5 days to check the stability against corrosion. As shown in Fig. 5, the microscopic images of electrode array before and after immersion in 5% saline solution. No any notable change was observed.

The binding force between metal and polymer substrate (PI, Polydimethylsiloxane, parylene, etc.) is usually weak. In order to enhance the binding force between electrode and PI, oxygen plasma treatment was conducted and together with a Cr buffer layer. The experiment results show that those processes do improve the binding characteristics obviously. After insertion and plugging for ten times, the electrodes pads with this treatment remain fairly unchanged (Fig. 6a). For sample without the said treatments (see Fig. 6b), most of the metal wires are split off from the PI substrate.

3.2. In vivo testing

The performance of our ECoG electrode array is further

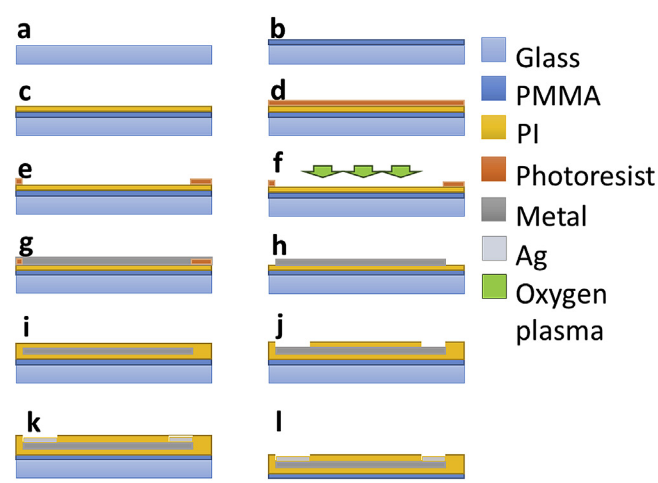

Fig. 2. The fabrication process of proposed ECoG electrode includes: a) glass substrate cleaning; b) PMMA is spin coated; c) PI and d) photoresist spin coated successively; e) photolithography patterning; f) oxygen plasma treatment; g) magnetron deposition of Cr, Ag, and Cr; h) split off; i) spin coated top PI layer; j) pads and electrode windows opening; k) Ag plating Ag for open area; l) removal of ECoG electrode from glass substrate.

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