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A method for stable electrical connection of a multi-channeled polyimide electrode with PCB

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Abstract— **We propose a novel packaging method of a thin polyimide multichannel microelectrode. For the simple electrical connection of polyimide (PI) electrodes, we made a via-hole at the interconnection pads of thin PI electrodes, and constructed a Ni ring by electroplating through the via-hole for the stable soldering and strong adhesion of the electrode to PCB. For the construction of a well-organized Ni ring, the electroplating condition was optimized, and the electrical property of the packaged electrode was evaluated. A 40 channel thin PI electrode was fabricated and packaged by the proposed method, and we performed the animal experiment with this packaged electrode for the high-resolution recording of neural signals from the skull of a rat.**

I. Introduction

There have been many neuroscience studies for the development of micro-sized multichannel electrodes, which penetrate and contact the cortical cortex or the skull [1-2]. The electrical activity of the brain or nervous system is generated by millions of neurons that have similar orientation, and for the connection of a machine with these neurons, the multiple micro electrode array (MMEA) is essentially required to detect the neural activity as precisely as possible. Microelectromechanical systems (MEMS) technology have been employed in fabricating micro-wire bundles [3-4], silicon based probes [5-6], and polyimide (PI)-based micro devices [7-8]. Despite the advantages of PI-based electrodes, its usage has been limited due to difficulties in their packaging including wire-bonding interconnections, soldering paste, conductive epoxy adhesives, zero-insertion-force (ZIF) connectors, and anisotropic conductive film (ACF) adhesives. The extremely thin PI-based electrode is easily broken with mechanical force during the ACF packaging process, which requires high temperature and high pressure in the bonding process. Additionally, the eutectic solder paste is dissolved in the thin gold film layer and formed with $AuSn_4$. To overcome the limits of conventional packaging methods, a novel method is required. We designed a bypass line for electroplating on the interconnection pads by creating a via-hole at the interconnection pads of thin PI electrodes, and electroplated a nickel ring along the via-hole for the stable soldering and firm adhesion of the electrode to the PCB. The soldering condition for the well-organized nickel ring was optimized, and the electrical property of packaged electrodes was evaluated.

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II. Materials and Method

A. *Design and fabrication of the Polyimide electrode*

Fig. 1 illustrates the schematic of a 40-channel microelectrode fabricated with the photolithography process; the interconnection pads are electroplated with nickel and gold. The Polyimide (PI) electrode was composed of a bypass line, recording sites, and interconnection pads, and was designed using Auto-CAD. The bypass line was used for electroplating of the interconnection pads, and it had a key role in applying the current to the interconnection pads during the electroplating process without significant detriment to the recording sites. While the interconnection pads were electroplated in the electroplating solution, the recording sites were protected by the bypass line.

B. *Microelectronics packaging technology (MPT)*

The PI electrode was fixed on the glass substrate by using Kapton tape, and the bypass lines were covered with silver paste, after which cu-tape was used to cover the silver paste for applying a constant current (Keithley 2400) role of the cathode electrode in Fig. 1(e). The fixed PI electrode on the glass was treated with oxygen (O_2) plasma and the surface of interconnection pads was activated with a $PdCl_2$ solution. After finishing the electroplating process of the nickel and gold for the recording sites, the interconnection pads were dipped in a nickel electroplating solution for 10, 20, and 30 min, and applied currents with a density of 0.25, 0.5, and 1.0 A/cm^2.

The interconnection pads of the PI electrode were aligned with the cavity print circuit board (PCB) and then the PI electrode was soldered at the bottom-side of the PCB following the bypass line, which was incised with a sharp razor.

C. *Electrical characterization*

The electrochemical impedance spectroscopy (EIS) was performed using a three-electrode system and a commercial software package (Garmy Instruments, EIS-300). A solution of 0.1M phosphate buffered saline (PBS, pH = 7) was used as the electrolyte solution at room temperature. An Ag/AgCl electrode was used as a reference electrode, and a coiled platinum wire was used as a counter electrode. The AC sinusoidal voltage with 5 mV root mean square of amplitude was used input signal in the frequency range of 1 Hz to 100 kHz.

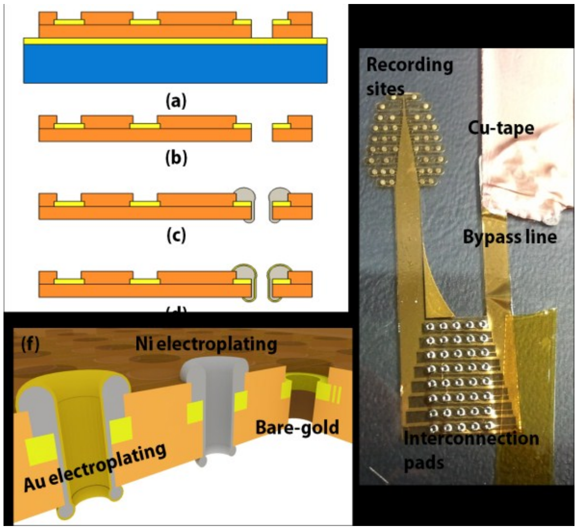

Figure 1. illustrates the schematic of a 40-channel microelectrode fabricated with photolithography process. (a) The PI electrode successfully fabricated on the sacrificial layer, (b) The release from the substrate by using metal dissolution reactions in 0.9% $NaCl_2$ solution, (c) The interconnection pads were electroplated with nickel. (d) The gold was electroplated on the electroplated nickel surface. (e) The Optic image of arrayed PI electrodes, and fabrication process was successful. (f) The schematic of cross-section showing the bare-gold and electroplated nickel and gold structures.

D. Animal test

All surgical procedures were performed under deep anesthesia induced by 20% diluted urethane injection (1.5g/kg, i.p., Sigma-Aldrich Co.). The rat was mounted on a sterotaxic apparatus. The surgical procedure started with a middle scalp incision about 3 cm. The periosteum was removed using cotton swaps without damaging the boundary tissues. The PI electrode was located at -5.6 mm from the bregma. The reference electrode was implanted at the bregma to the right hemisphere skull and the ground electrode was placed at the tail. The EEG signals were recorded (sampling rate: 512 Hz) with a LXE3232-RF amplifier (LAXTHA, inc. KOREA); the EEG signal is recorded for 10 trials during 30 sec. Data analysis was performed with Matlab.

III. RESULTS AND DISCUSSION

A. Design and fabrication of the Polyimide electrode

Fig. 2 (b). illustrates the picture of an arrayed PI electrode fabricated with the photolithographic process, and the packaging process was successful. The thickness of the PI electrode is 10 µm, and the diameters of each interconnection pad and via-hole are 760 µm and 400 µm. The shape of the electroplated nickel ring was grown along the seed layer on the interconnection pads. Although the seed layer was not deposited on the surface of the via-hole of the PI electrode, the electroplated nickel ring of the back-side of PI electrode was formed by the over-growth of nickel ring with 0.5 A/cm^2–30 min, where the increase of electroplating time played a key role as in Fig. 2(a).

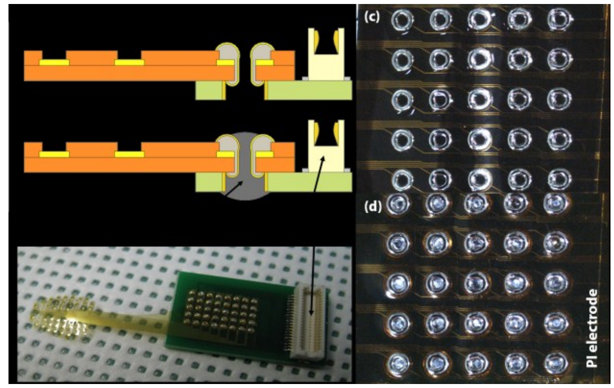

Figure 2. The electroplated via-hole of electrode were aligned to the through-holes of PCB (a – top); the aligned PI electrode and PCB were bonded by soldering (a – bottom). (b) shows the picture of completely packaged PI electrode. (c) indicates the electroplated nickel ring on the interconnection pad. (d) the aligned interconnection pads were soldered; front-side view of soldered interconnect pads and melted solder.

The thickness of the electroplated structure was increased according to the current density and electroplating time. As electroplating time increases, the thickness of the nickel ring increased more sensitively than the increase of current density. Considering the thickness of the electroplated ring on the surface of the front and back side, a 0.5 A/cm^2-30 min electroplating condition was the most suitable for further application in Fig. 3. The electroplated nickel ring protected the seed layer of the thin PI layer from heat during the soldering process and enhanced the adhesive strength between the PI electrode and the PCB mechanically.

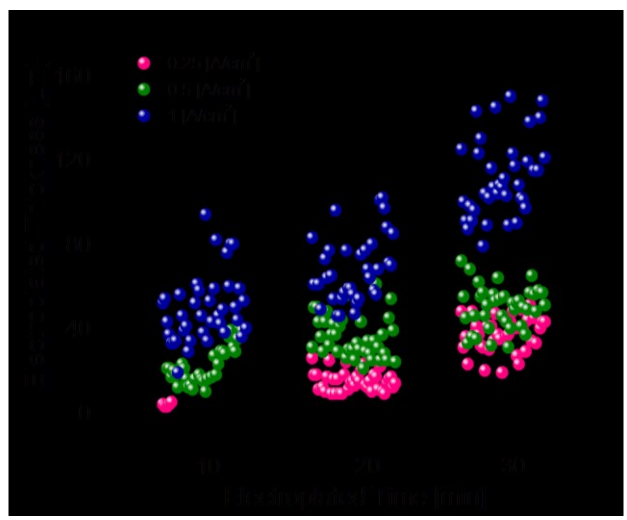

Figure 3. The graph indicates the quantitative measured thickness of the electroplated nickel rings to the change in current density and electroplating time.

B. Packaging assembly for a PI electrode (MPT)

After the nickel electroplating process has formed a nickel ring, gold was electroplated on the surface of the electroplated nickel in order to improve the wettability of the eutectic solder, and to penetrate solder into the via-hole of both electrodes easily in Fig. 2 (d). After finishing the electroplating process, PI electrode was aligned with the through hole of the PCB and manually soldered on the back-side of the PCB. The packaging process of interconnection pads gained over 99% successful electrical connection, and damages to the PI electrode during the soldering process were not observed.

C. Electrochemical Impedance measurement

The impedance values of the packaged PI electrodes were characterized and the magnitude (|Z|) and phase (Φ) of impedance are plotted in Fig. 4. The electric property of the electrochemical impedance spectrum magnitude and phase was measured from 1 Hz to 100 kHz.

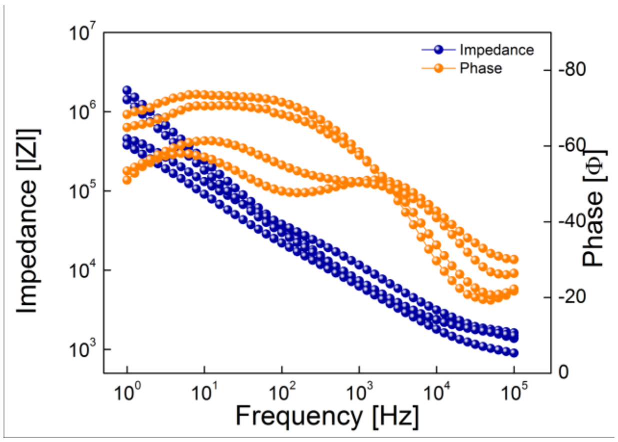

Figure 4. The plots indicate the impedance of packaged PI electrodes was characterized and magnitude (|Z|) and phase (Φ) with the electrochemistry impedance system (EIS).

The magnitude from 10 to 1 kHz is a significant frequency range in typical bio-signals. The magnitude at 100 Hz was 34.9 kΩ±16.0 kΩ (mean±S.D.), which is the biologically relevant frequency of neural activity. The proposed electrical connection method (MPT) does not significantly affect the performance of the electrodes for measuring bio-signals.

D. Animal test

To evaluate the feasibility of the proposed electrical connection method, an electrode was placed on the skull of the rat, and we measured the evoked signals to the whisker stimulation. The 40 channel PI electrode was packaged with a PCB and coupled to a female connector. Whisker stimulation was performed with the non conductor stick once per each 5 sec during 30sec, and the response to stimulation was observed from the evoked signals in Fig. 5. The magnitude of the signal was marked relatively. Red color indicates the highest voltage while blue means the lowest voltage. Because the activities of somatosensory cortical neurons is induced by the whisker stimulation in the rat, we observed a change in neural activity from 4.6 to 5.0 sec.

IV. CONCLUSION

We describe the design of a bypass line for electroplating on the interconnection pads, and the fabrication, electrical characterization, and *in-vivo* test with our new microelectronics packaging technology (MPT). This study suggested a multi-channeled flexible PI electrode for the stable and high yield packaging, We designed the bypass line for electroplating on the interconnection pads for the following reasons.

(1) The bypass line of the PI electrode required with electroplate nickel and gold structure on the interconnection pads to avoid damage to the recording sites during the electroplating process.

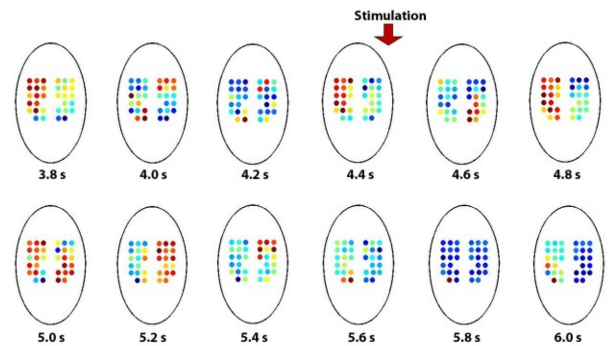

Figure 5. This image presents the evoked potential at the left hemisphere from 4.6s to 4.8s and the evoked potential activated by stimulation of the right whisker at 4.4s.

(2) The bypass line helps to apply the current into the interconnection pads with a similar divided current. This concept is very simple and offers a stable method for electroplating to the interconnection pads with a similar thickness. We conclude that the MPT is a novel discovery and can potentially be used in biomedical devices and neural prosthetics

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