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A Polyimide Based Split-Ring Neural Interface Electrode for Neural Signal Recording

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***Abstract*—**We have developed a polyimide based neural interface electrode to record nerve signals from the sciatic nerve of a rat. The neural interface electrode has a split-ring shape, with four protruding gold electrodes for recording, and two reference gold electrodes around the split-ring. The split-ring electrode can be opened up to encircle the sciatic nerve. The four electrodes can be bent to sit on top of the nerve and hold the device in position, while the split-ring frame remains flat. In comparison, while traditional cuff electrodes can only fit certain sizes of the nerve, the developed device can fit a variety of rat sciatic nerve dimensions from 0.6 mm to 1.0 mm, and adapt to the chronic changes in the nerve as the electrode tips are bendable. The electrochemical impedance spectroscopy measurement was conducted. The gold electrode impedance is on the order of 10 kΩ, showing excellent charge injection capacity to record neural signals.

***Keywords*—**Impedance, neural interface, split-ring electrode.

I. Introduction

In the past decades, scientific and technological research has been dedicated to restore the motor and sensory functions in patients, whose peripheral nerve axons are damaged by disease or injury. Recording and stimulation of peripheral neural activity through implantable neural interface electrodes fabricated using micro-electromechanical systems (MEMS) technologies have been one of the focus areas [1], [2]. Currently, there are several types of electrodes to record physiological signals, either commercialized or in the research stage, including surface electrodes, muscle electrodes, cuff electrodes, longitudinally implanted intra-fascicular electrodes (LIFE), regenerative sieve electrodes [3]-[7]. Among these electrodes, the surface electrode and muscle electrode are minimally invasive to the body, but may not extract sufficient signal information for motor and sensory recovery. For LIFE and sieve electrodes, they are intra-neural electrodes that need to penetrate the nerve wall for recording and stimulation. This is quite invasive and may cause a secondary injury to occur, even though the signal quality is quite good. As a compromise between good neural signal quality and non-invasiveness, extra-neural electrodes such as cuff electrodes, which wrap around the nerves, are a good choice.

The size of the nerve, even in the same species, may vary to a certain degree. For instance, the diameter of the sciatic nerve in a rat ranges from 0.6 mm to 1.0 mm. In addition, the nerve diameter will change chronically with the insertion of the neural interface electrode due to tissue inflammation, scaring, etc. Therefore, the traditional cuff electrodes have to be customized in size for each specific animal, and have to have diameters larger than 1.3 to 1.5 times that of the nerve, which leads to poor signal quality as the electrode may thus be too far away from the nerve [5]. In this paper, we propose and demonstrate a polyimide based flexible split-ring electrode that can be used with a range of nerve sizes and can adapt to the chronic changes in the nerve while maintaining good electrode contact by using protruding bendable electrodes on the device's ring frame.

II. Design, Fabrication and Packaging

As shown in Fig. 1, the polyimide split-ring electrode consists of an opened ring on one end, and the wire connection pads at the other end. Around the split-ring structure, four triangular electrodes protrude from the split-ring frame as bendable neural interface electrodes. There are two additional electrodes on the split-ring frame that serve as reference electrodes for noise cancellation (by taking the difference in signal between a neural electrode and the reference electrode). The end with the connection pads can connect to a FPC connector to send the signal to an amplifier for neural signal recording. The area of the protruded electrodes and reference electrodes are 8000 μm^2 and 0.1 mm^2, respectively.

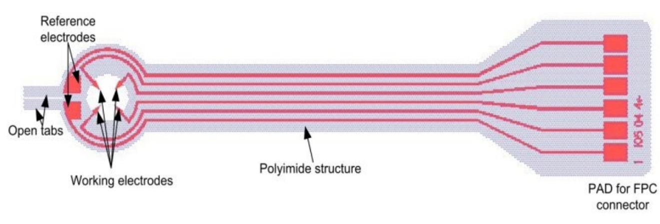

Fig. 1 Schematic of polyimide based neural interface electrode

The fabrication process flow is demonstrated in Fig. 2. First, a 1 μm thick Al layer was deposited on a silicon substrate as a scarification layer (Fig. 2 (a)). A 6 μm thick polyimide film (HD4100, HD microsystem) was then spin coated and hard cured (Fig. 2 (b)). The Pt/Au metal electrodes, traces and pads

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were subsequently patterned by metal evaporation and a lift-off process (Fig. 2 (c)). Next, a second 6 µm polyimide layer was coated and cured on top, followed by a 200 nm Al hard mask sputtering and patterning (Fig. 2 (d)). Then, the polyimide was etched by a plasma etching process (O_2 gas flow 10 sccm and CF_4 gas flow 10 sccm, RF power 300W). The etching process was self-terminated once the 1 µm Al was exposed for the non-Au pad/trace area, whereas etching stopped on Au for the Au-pad/trace area (Fig. 2 (e)). Finally, the polyimide chip was released by Al sacrificial etching from an anodic dissolution process (Fig. 2 (f)). The released chip is shown in Fig. 3 (a).

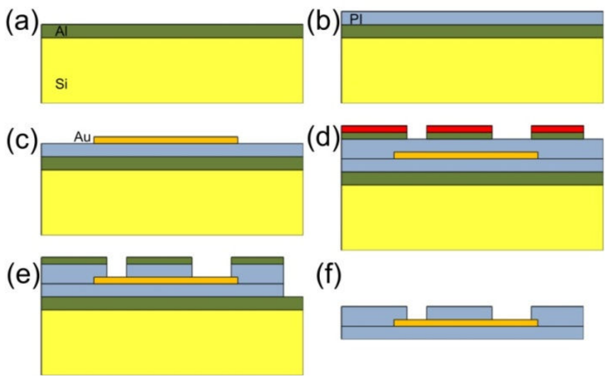

Fig. 2 Fabrication flow of neural interface electrode

The chip was then connected to a FPC connector by a spacer inside. A FPC cable was fixed onto the other end of the FPC connector through silver conductive epoxy and UV glue to seal the exposed metal wire to reduce environmental noise (shown in Fig. 3 (b)).

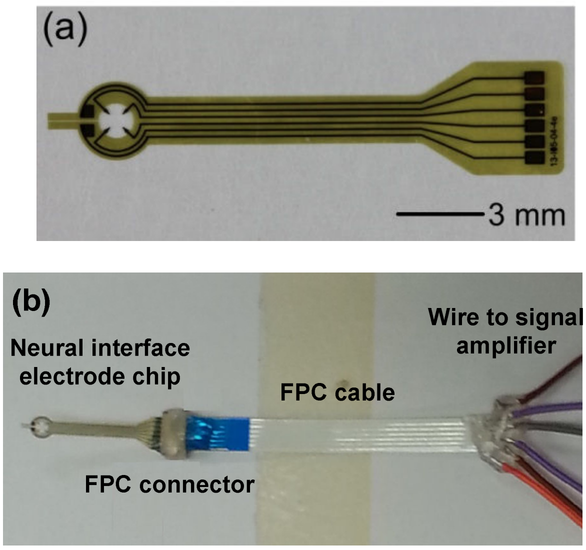

Fig. 3 (a) Photography of released chip, (b) packaged device

III. Characterization

A. Impedance Measurement

Prior to *in vivo* characterization, impedance measurements were conducted in order to characterize the electrode-electrolyte interface to verify the functionality (charge-injection capability and ion-transport conductivity) of the electrode as a neural signal recorder. Fig. 4 shows the impedance measurement result of the Au electrode in the PBS solution with the frequency range of 10 Hz to 100 kHz. At the frequency of 1 kHz, the impedance of our electrode was ~11 kΩ, which are small enough for neural signal recording.

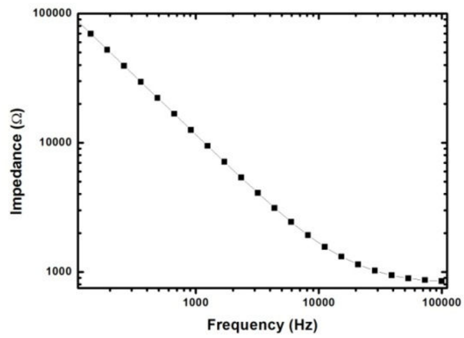

Fig. 4 Electrochemical impedance measurement of neural electrode

B. In vivo Mechanical Test

Before the neural signal recording, the polyimide chip was implanted into the rat's sciatic nerve to prove the mechanical property of the electrode. The *in vivo* test was conducted at the National University of Singapore (NUS). All the procedures were approved by the Institutional Animal Care and Use Committee (IACUC) at the National University of Singapore. Male Sprague Dawley rats were anesthetized with pentobarbital sodium (50 mg/kg). The position of the sciatic nerve was first marked. The sciatic was then separated from its surrounding tissues through a surgical procedure. The split-ring was opened by twisting the two tabs above the ring by tweezers, facilitating insertion of the ring onto the nerve. The two tabs were then bonded by UV glue. Fig. 5 shows the images after implantation of the chip. It is evident that the protruding electrode tips contact the nerve well, while keeping the ring frame structure flat without any ring structure deformation showing excellent device flexibility.

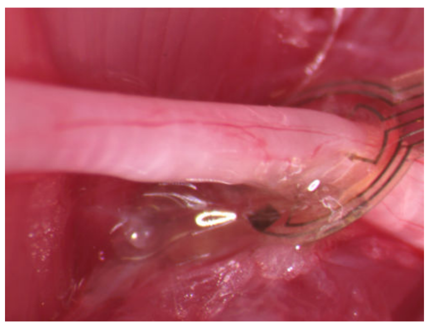

Fig. 5 Mechanical test of the flexible neural interface electrode

IV. Conclusion

A flexible split-ring electrode with four protruded electrodes has been designed and fabricated. The device can be used with nerves across a range of sizes. The impedance measurement of the electrode was performed as well. The low electrochemical impedance implies good functionality of the electrode. The *in vivo* mechanical test of the device was conducted, proving that the electrode can closely contact the nerve to obtain good quality recordings.

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REFERENCES

[1] L. Weiner and K. L. Reed, "Peripheral neurostimulation for control of intractable occipital neuralgia," *Neuromodulation*, vol. 2, no. 3, pp. 217–221, 1999.
[2] R. M. Paicius, C. A. Bernstein, and C. Lempert-Cohen, "Peripheral nerve field stimulation for the treatment of chronic low back pain: Preliminary results of long term follow-up: A case series," *Neuromodulation*, vol. 10, no. 3, pp. 279–290, 2007.
[3] H. E. Nelson Jr, M. B. Smith, B. R. Bowman, and R. L. Waters, "Electrode effectiveness during transcutaneous motor stimulation," *Arch Phys Med Rehabil*, vol. 61, pp. 73-77, 1980.
[4] N. Bhadra, K. L. Kilgore, and P. H. Peckham, "Implanted stimulatorsfor restoration of function in spinal cord injury,"*Med Eng Phys*, vol. 23, pp. 19–28, 2001.
[5] T. Stieglitz, H. Beutel, M. Schuettler, and J. U. Meyer, "Micromachined, polyimide-based devices for flexible neural interfaces," *Biomed Microdev*, vol. 2, pp.283–294, 2000.
[6] S. M. Lawrence, G. S. Dhillon, and K. W. Horch, "Fabrication and characteristics of an implantable, polymer-based, intrafascicular electrode," *J Neurosci Methods*, vol. 131, pp. 9–26, 2003.
[7] L. Wallman, Y. Zhang, T. Laurell, and N. Danielsen, "The geometric design of micromachined silicon sieve electrodes influences functional nerve regeneration," *Biomaterials,* vol. 22, pp. 1187–1193, 2001.