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Flexible intra-fascicular nerve electrodes for the recordings of autonomous nerves

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Abstract- **In this article, we propose a flexible intra-fascicular nerve electrode for the control of an artificial heart fabricated by micro machining techniques. We have studied the methods of the control of an artificial heart by using the autonomous nerves information. Though several approaches have been reported for chronic measurements from peripheral nerves, stable and long-term measurements from autonomous nerves has not yet been established. In order to realize stable and low-invasive measurements, we focused on the electrode's flexibility. Our electrode is fabricated on a flexible polyimide film using micro machining techniques. The electrode consists of four needle-shaped flexible probes. After the planer patterning process, the tips of each probe are bent perpendicularly for the insertion into the nerve bundle. The recording sites are placed on the tips of the each probe for the purpose of contacting non-damaged nerves areas. And the hook-shaped structures are fabricated near the tips to avoid tips and nerve bundle shifting. As a result of the preliminary experiments, the thickness of the film that is able to be inserted into the vagal nerve bundle of goat is 75um. As the first step of the evaluation for the electrodes, we were able to successfully measure neural activities of the sciatic nerve bundle of rats.**

Keywords **- flexible, intra-fascicular, polyimide film, artificial heart**

I. INTRODUCTION

The several methods of an artificial heart control have been studied [1][2]. These methods are not able to respond to the physical needs rapidly. Therefore, an artificial heart control system that is able to respond to signals from the autonomic nervous system as the same as our natural heart will be required.

In order to realize an artificial heart control system using the autonomous nerves information, we have researched three following problems.

1. Nerve electrodes to enable stable and long-term measurements from autonomous nerves
2. Algorithms to generate control commands to an artificial system from recorded autonomous neural signals [3] [4] [5]
3. Control programs to implement our system

The extra-fascicular cuff electrode was fabricated to address problem 1 (Fig. 1). Twisted stainless steel wires were positioned in a silicone tube, and the neural activity was measured between two twisted wires that were attached to the nerve bundle. For stable and long-term measurements, a silicone gel was injected in the silicone tube after the electrode positioned. The nerve bundle and the electrode were fixed in the silicone gel to reduce the body movement noise. Using this type of electrode, we were able to measure cardiac sympathetic neural activity and cardiac vagal neural activity in a goat that has been generally used for artificial heart evaluation in our project team. The longest term we were able to measure autonomous neural signals is about two weeks. The connective tissue and body fluids generated between the nerves and electrodes insulated the surface of the electrodes after a few weeks.

To overcome this problem, we have focused on intra-fascicular nerve electrode. Several types of intra-fascicular nerve electrodes have been developed [6][7][8]. These electrodes have rigid structures to be inserted into the nerve bundles. This will cause the damage of the nerve fibers when the body moves. Therefore these electrodes will not suitable for stable chronic recordings. If the electrodes are too flexible, it cannot be inserted into the nerve bundles at the same time.

In this article, we propose a flexible but insert-able intra-fascicular nerve electrode.

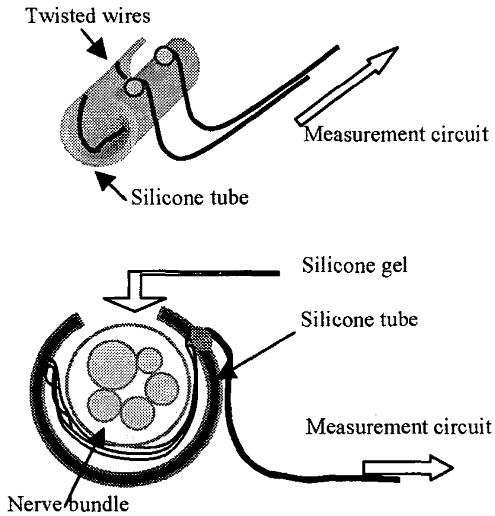


Fig. 1. Cuff electrodes

II. Fabrication

The fabrication process of our flexible intra-fascicular nerve electrode is shown in Fig. 6. As a preliminary experiment, 25 um, 50 um, 75 um, and 125 um thickness of needle-shaped polyimide films were inserted into the vagal nerve bundle of a goat. The widths of the needle-shaped film were 0.5mm, 1 mm, and 2mm. As the result of this experiment, the 75 um thick 1 mm width polyimide film was adequate as the electrode substrate for a goat's vagal nerve bundle. Our flexible intra-fascicular nerve electrode consists of four needle-shaped flexible probes as shown in Fig. 2. The ground channel is placed in the center of the electrode. It attaches to the surface of the nerve bundle.

A gold layer was used as a metal of electrode because of the low-invasiveness. Chrome was evaporated between the polyimide substrate and the gold layer to connect them. These metal layers were patterned on the polyimide substrate using photolithography techniques. The thickness of this layer is about 1 um. Nickel was patterned on these metal layers using the electroless plating. This Nickel covered the tiny cracks on the gold layer. The thickness of this nickel layer is about 1 um. These metal layers were used as an electrode pad (Fig. 6 (a)).

The polyimide (PIX110SX, HD Microsystems, Inc.) was spin coated at 500 rpm for 10 sec and 3000 rpm for 30 sec. It was baked in the oven at 200 degrees for 15 min and 350 degrees for 20 min. The thickness of this layer is about 2 um. Aluminum was evaporated in a vacuum. It is used for patterning the polyimide layer. The aluminum layer was patterned using photolithography techniques. The non-covered polyimide was made by ashing with the O2 plasma. The covering aluminum was removed by wet etching (Fig. 6 (b)).

The substrate of the polyimide film was cut (Fig. 6 (c)). The tips of each probe were bent perpendicularly to be inserted into the nerve bundle (Fig. 6 (d)).

Finally, the hook-shaped structures are fabricated near the tips to avoid tip and nerve bundle shifting (Fig. 6 (e), Fig. 5).

Fig. 4 shows pictures of the probe tips. Fig. 3 shows pictures of the electrode in a silicone cuff.

For stable and long-term measurements, the silicone gal was injected in the silicone tube after the cuff electrode positioned. It fixed the nerve bundle and electrode to reduce the body movement noise.

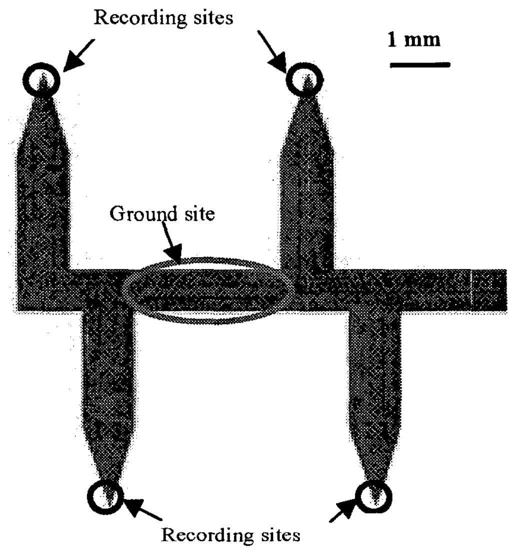


Fig. 2. Design of the four probes and the ground site

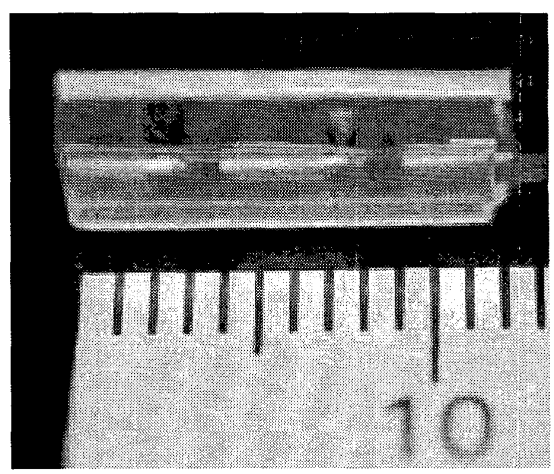


Fig. 3. Picture of the electrode in a silicone cuff

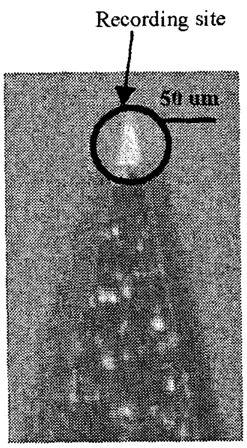


Fig. 4. Picture of the probe tips

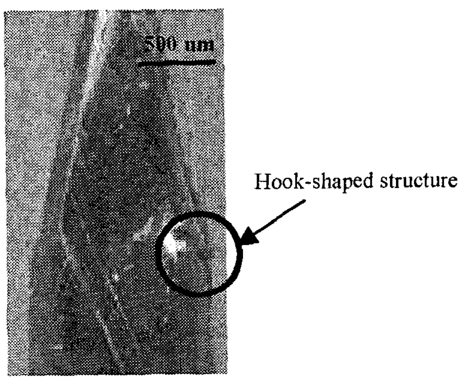
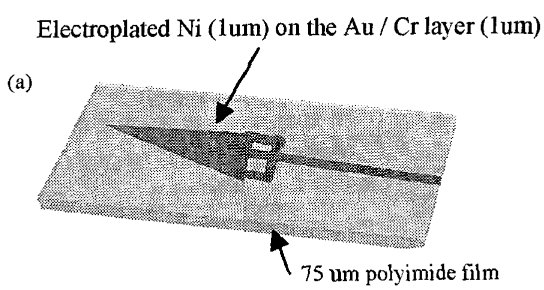


Fig. 5. Picture of the hook-shaped structure



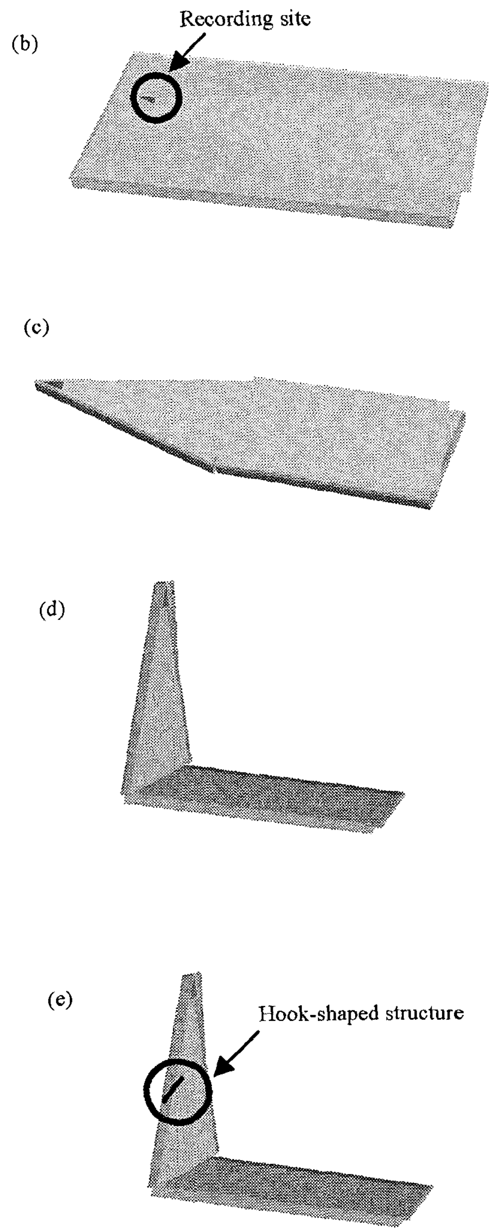


Fig. 6. Fabrication process of our flexible intra-fascicular nerve electrode

(a) A gold layer on chrome was patterned on the 75 um polyimide film. Nickel was patterned on these metal layers using the electroless plating. (b) The polyimide layer was patterned on the metal layer for insulation. (c) The substrate of the polyimide film was cut. (d) The tip of each probe was bent perpendicularly. (e) The hook-like structure was fabricated.

III. RESULTS OF EXPERIAMENTS

We measured the impedance between two recording sites of our electrode using an LCR meter (Hewlett Packard, Inc., 4263B). The results of this measurement are shown in Fig. 7. The measured impedance between two recording sites of our electrode was 113 k ohm at 1 kHz, which is the usual frequency of the neural signals.

As the first step to evaluate our electrodes, we were able to successfully measure the nervous activities of the sciatic nerve bundle of rats.

IV. CONCLUSION

We propose a flexible intra-fascicular nerve electrode. Our electrode was fabricated on a flexible 75 um-thick polyimide film using photolithography techniques. The electrode consists of four needle-shaped flexible probes with recording sites and hook-shaped structures are placed on these tips. The thickness of the gold layer on chrome is about 1 um. Nickel was patterned on these metal layers using the electroless plating. The thickness of the nickel layer is about 1 um. The polyimide was patterned on the metal layer for insulation. The thickness of this polyimide layer is about 2 um. The measured impedance between two recording sites of our electrode was 113 k ohm at 1 kHz, which is the usual frequency of the neural signals. As the first step in evaluating our electrodes, we were able to successfully measure the nerve activities of the sciatic nerve bundle of rats.

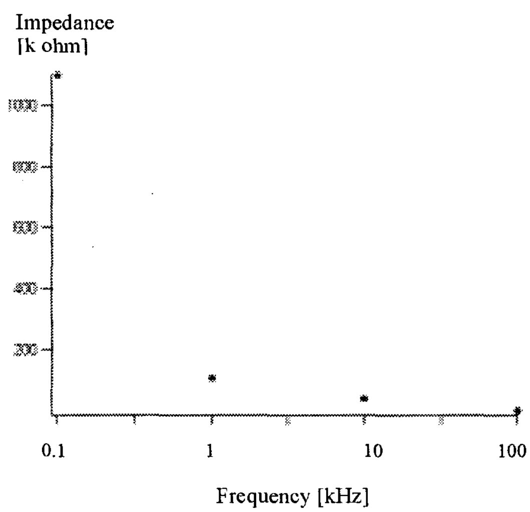


Fig. 7. Measurement result of the electrode impedance

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