Insertion Characteristics Evaluation of Si Opto-Neural Probe with Embedded Optical fiber

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Abstract

The Si opto-neural probe with embedded optical fiber was proposed and successfully fabricated. A chemically-thinned optical fiber was completely embedded in the trench of the probe shank, which leads to less damage to tissues. Probe insertion characteristics were evaluated in detail and the lower invasive insertion was clearly indicated for the Si opto-neural probe in comparison with conventional optical neural probe.

1. Introduction

Recently, lots of studies related to the brain are conducted using various methods. Especially, optogenetics that uses a combination of techniques from optics and genetics attracts much attention. Optical stimulation of genetically targeted neurons expressing the light sensitive channel protein (Channelrhodopsin-2: ChR2) has been reported [1,2]. Figure 1 shows a conceptual drawing of optical stimulation of gene-transfer neurons using a neural probe [3,4]. Although neural probes which have optical stimulation device/structure such as micro-LED and optical waveguides have been reported, these neural probes have complicated structures and resultant high fabrication costs. In these situations, a neural probe which has a chemically-thinned optical fiber have been developed [5], and it can be easily used in many experiments owing to its simple structure. However, such neural probe induces damage to the brain tissues during probe insertion due to protrusion of optical fiber and the resultant large cross-section of the probe.

In this paper, we have proposed a Si opto-neural probe with embedded optical fiber in probe shank. Since a chemically-thinned optical fiber was fully embedded in the probe shank, the Si opto-neural probe can be inserted into the brain without injuring tissues and can optically stimulate the tissues. We fabricated several types of the Si opto-neural probe and evaluated insertion characteristics experimentally.

2. Fabrication of Si opto-neural probe with embedded optical fiber

Fabrication process flow of the Si opto-neural probe was shown in Fig. 2. A 100-µm-thick Si wafer was used as the substrate of the probe. First, a 1-µm-thick SiO₂ layer was formed by thermal oxidation. Then, base polyimide layer was spin-coated on the silicon substrate. Ti/Au/Ti wirings were formed on the surface of base polyimide layer by sputtering and wet-etched by an iodine etchant and HF solution. Then, insulation polyimide layer was also spin-coated and contact holes were formed. Next, Au recording electrodes were formed on the insulation polyimide layer by sputtering and wet-etching. Finally, the probe shape with a trench for embedding was formed by deep reactive-ion etching with SF₆ and C₄F₄ gases. In addition, an optical fiber was etched by HF dipping. The fabricated Si opto-neural probes with the chemically-thinned optical fiber were shown in Fig. 3. The optical fibers adhered to the Si opto-neural probe with UV curable epoxy.

3. Experiment results and discussion

Insertion forces were measured for two types of the Si opto-neural probes. One type had the chemically-thinned optical fiber placed on the probe shank and the other type had the same optical fiber embedded in the trench of the probe shank. A conventional Si neural probe was also evaluated as a reference. Insertion measurements were performed with both insertion and removal speeds of 0.01 mm/s, and with insertion distance of 0.5 mm. The probes were inserted into 0.6 wt% agarose gel. Insertion experiment has four steps below.

Step 0: Set of probe contact point with a force of 0.1 mN.
Step 1: Insertion of the probe until the depth of 0.5 mm.
Step 2: Pause until measured force becomes constant.
Step 3: Removal of the probe to initial position.

Figure 4 shows the time dependence of the insertion force for the conventional Si neural probe. The maximum insertion force and constant insertion force at step 2 were 0.7 mN and 0.4 mN, respectively. Figures 5 and 6 also show the time dependences of the insertion force for the Si opto-neural probe with the chemically-thinned optical fiber placed on the probe shank and the same optical fiber embedded in the trench of the probe shank. As shown in Fig. 5, the maximum insertion forces and constant insertion force were 0.99 mN and 0.5 mN. The insertion force at time of 140 sec was 0.8 mN which was correspondent to the insertion force of optical fiber placed on the probe shank. As shown in Fig. 6, the maximum insertion forces and constant insertion force were 0.86 mN and 0.45 mN. The insertion force at time of 160 sec was 0.6 mN which was correspondent to the insertion force of optical fiber embedded in the probe shank. There insertion
forces can be explained from the viewpoint of probe cross-sectional area which was dependent on with or without protrusion of optical fiber. Consequently, it was obviously shown that the Si opto-neural probe with embedded optical fiber induced less tissue damage.

4. Conclusions

The Si opto-neural probe with embedded optical fiber was successfully fabricated. The optical fiber was etched by HF dipping and thinned to a diameter around 65 μm. From insertion experiments, the Si opto-neural probe with embedded optical fiber indicated smaller insertion forces than other Si opto-neural probe, which was mainly due to less protrusion of the optical fiber. This probe can optically stimulate neurons without injuring the brain tissues. The Si opto-neural probe with embedded optical fiber becomes one of the most versatile tools for optogenetics.

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References

Fig. 1 Drawing of optical stimulation of gene-transfer neurons using a Si opto-neural probe.

Fig. 2 Fabrication process flow.

Fig. 3 Photographs of Si opto-neural probe with (a) an optical fiber on probe shank and (b) embedded optical fiber in probe shank.

Fig. 4 Time dependence of the insertion force for conventional Si neural probe without optical fiber.

Fig. 5 Time dependence of the insertion force for Si opto-neural probe with optical fiber on probe shank.

Fig. 6 Time dependence of the insertion force for Si opto-neural probe with embedded optical fiber in probe shank.