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Development of Si Opto-Neural Probe with Multiple Optical Waveguides and Metal-cover as Versatile Tool for Optogenetics

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1. Introduction

Recently various studies related with the brain such as medical treatments for brain diseases, brain function analysis, and brain-machine interface have been strongly promoted. A Si neural probe is one of the most important tools for these studies. Various types of probes have been developed by many researchers [1]. We have also proposed the intelligent Si neural probe system which has a multifunctional property [2].

Direct optical stimulation of genetically targeted neurons expressing the light sensitive channel protein (Channelrhodopsin-2: ChR2) has recently reported [3,4]. Figure 1 shows a conceptual drawing of optical stimulation of gene-transfer neurons using Si neural probe with optical waveguides. This offers the expectation of enabling local delivery of millisecond temporal controlled optical stimulation with cell-type selectivity. Various kinds of neural probes which have optical stimulation capability have been reported [5,6]. However, these neural probes used a chemically-thinned optical fiber which was manually attached with neural probes. Therefore, it is very difficult to control positions of optical stimulation accurately. Moreover, it is also very hard to assemble lots of optical fibers precisely into the same probe.

In this paper, we have proposed a novel Si opto-neural probe with multiple optical waveguides and metal-cover for optical stimulation of neurons. Since many optical waveguides covered by metal will be simultaneously fabricated on the Si neural probe, multisite optical stimulation can be realized without light leakages. We have fabricated a Si opto-neural probe with the multiple waveguides and assembled with optical fibers to evaluate optical characteristics.

2. Fabrication of Si opto-neural probe with multiple waveguides and metal-cover

A fabrication process of our Si opto-neural probe is shown in Figure 2. A 100-μm-thick Si wafer was used as the substrate of the probe. First, a 1-μm-thick SiO_2 layer was formed by thermal oxidation. Then, an 1-μm-thick SiN waveguide core layer was formed by plasma-enhanced chemical vapor deposition (PECVD) and reactive-ion etching (RIE) with CHF_3 gases. Next, a 1-μm-thick SiO_2 waveguide clad layer was formed by PECVD. Then, Au/Ti wirings were formed on the surface of the wafer by sputtering and wet etching with an iodine etchant and a ceric ammonium nitrate solution. Then, a 1-μm-thick SiO_2 layer was deposited by PECVD for isolation of the wirings. After that, both recording sites and bonding pads were formed. Next, Au recording sites and metal-covers of optical waveguides are formed using lift-off process. These metal-covers prevent a light leakage from optical waveguides except for light outlets. Finally, the probe shape was formed by deep reactive-ion etching with SF_6 and C_4F_8 gases. Figure 3 shows the fabricated Si opto-neural probe with multiple optical waveguides. The Si opto-neural probe was assembled on a printed circuit board (PCB). In addition, optical fibers were connected to the Si opto-neural probe. Using these optical fibers, it becomes possible to inject lights into optical waveguides of Si opto-neural probe. Cross sectional scanning electron microscopy (SEM) image of three optical waveguides is shown in Figure 4. Optical waveguides were well formed on the opto-neural probe shank and covered by metal. As shown in these photographs, we successfully fabricated the Si opto-neural probe with optical waveguides and metal-cover.

3. Experiment results

At first, we evaluated electrochemical characteristics of our fabricated probe. We measured electrochemical impedance of recording sites in an electrolyte. Measurements were performed with the 10 mV AC signal and the frequency ranging was from 100 Hz to 100 kHz in phosphate buffered saline. Fig. 5 shows the impedance characteristics. The impedance value is about 2 MΩ at 1 kHz. From this result, we confirmed that this probe has the suitable impedance for neuronal recording.

Figure 6 compares the light leakage from optical waveguides between with and without metal-cover. In Fig. 6 (b), we observed a light leakage from the optical waveguide. As shown in Fig.6 (a), however, there was no light leakage observed from optical waveguides with the metal-cover. Using our fabricated opto-neural probe, we can optically stimulate neurons more precisely without stimulating an unwanted area.

4. Conclusion

We successfully fabricated the Si opto-neural probe with multiple waveguides and metal-cover for multisite optical stimulation of neurons. SiN film was employed as an core of optical waveguide. The Si opto-neural probe with optical waveguides was well assembled with optical fibers. From electrical experiments, it became clear that our probe has the suitable impedance for neuronal recording. The light leakage from waveguides was successfully suppressed by metal-cover over waveguides. It means that we can stimulate neurons with avoiding stimulating unwanted neurons. The Si opto-neural probe with multiple optical waveguides and metal-cover is one of the most versatile tools for optogenetics.

Acknowledgment

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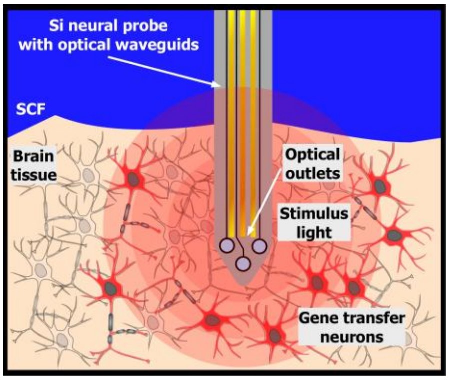

Fig. 1. Optical stimulation of gene-transfer neurons using Si neural probe with optical waveguides.

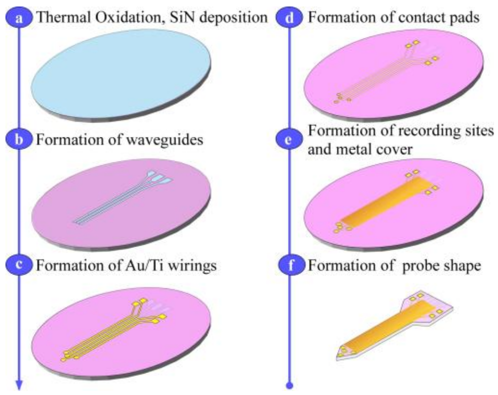

Fig. 2. Fabrication sequence of the Si neural probe with multiple optical waveguides.

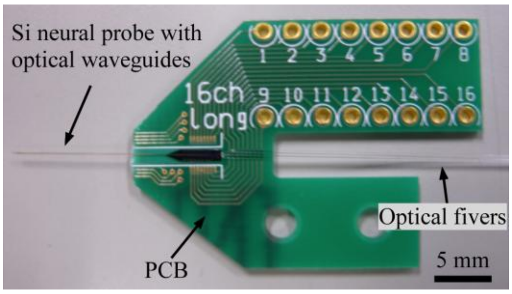

Fig. 3.Fabricated Si neural probe with multiple optical waveguides assembled with PCB.

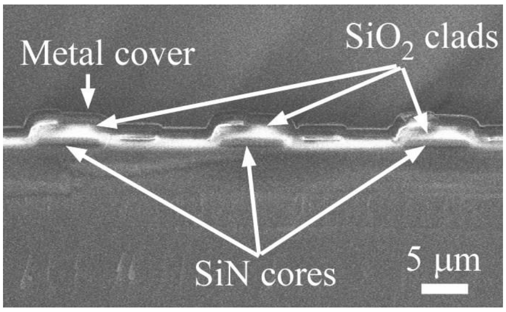

Fig. 4. Cross sectional SEM image of three optical waveguides.

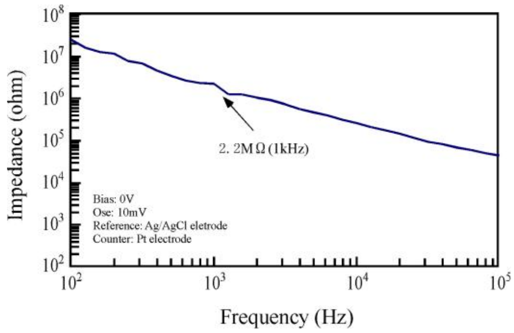

Fig. 5. Relationship between impedance and frequency for the fabricated Si neural probe.

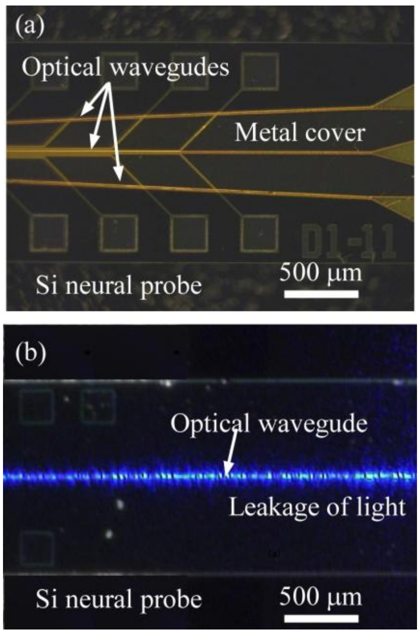

Fig. 6. Comparison of the light leakage from optical waveguides between with and without metal-cover.