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Highly Accurate Optical Stimulation of Neuron using Si Neural Probe with Optical Waveguide

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1. Introduction

Recently various studies related with the brain such as the medical treatment for brain diseases, the analysis of brain functions, or brain-machine interface (BMI) have been strongly promoted. For these researches, various kinds of neural probes have been developed to record neuronal action potentials or other brain activities. Especially, due to strong requirement of high density recording of neuronal activities for further minute brain analysis, various types of Si neural probes which enable high density recording have been developed [1]. We have also proposed an implantable intelligent Si neural probe system which has a multifunctional property [2][3].

In this paper, we proposed a novel Si neural probe with optical waveguide for the optical stimulation of neurons. We fabricated a Si neural probe with the optical waveguide and assembled with an optical fiber to evaluate the optical characteristics. The Si neural probe with the optical waveguide was successfully implemented.

2. Fabrication of Si neural probe with optical waveguide

Direct optical stimulation of genetically targeted neurons expressing the light sensitive channel protein (Channelrhodopsin-2: ChR2) has recently reported [4]. This offers the prospect of enabling local delivery of millisecond temporal controlled optical stimulation with cell-type selectivity. Various kinds of neural probes which have optical stimulation ability have been reported [5]. However, these neural probes were based on or consisted of an optical fiber which was used for an optical communication system. Comparing with conventional optical sources including of band-filtered white light, light emitting diodes (LED) or laser-coupled optics, the optical fiber would realized a local optical stimulation. Generally, however, an optical fiber has a comparatively large diameter of over 100 µm, since these probes could stimulate only one site. Therefore, to realize multisite optical stimulation, neurophysiologists have to employ a bundled optical fiber close to a millimeter-sized diameter causing large neuron damages. Additionally, for an accurate and simultaneous neuronal activities recording with an optical stimulation, stimulation sites should be mounted on neural probes directly. Hence, we proposed a novel Si neural probe with micromachined optical waveguide for optical stimulation of neurons. Since many optical waveguide can be simultaneously fabricated on the Si neural probe, multisite optical stimulation can be realized. By using micromachining technology, the optical outlet field can be controlled purposefully. Furthermore, by integrating optical waveguide with our double-sided recording and fluid delivery technology as shown in Fig. 1, the optogenetic methodology could dramatically progress. To confirm the fundamental characteristics of optical waveguide, we fabricated a Si neural probe with only one optical waveguide.

3. Experiment results and discussion

The Si neural probe was fabricated by standard micromachining process. Figure 2 shows the photographs of the fabricated Si neural probe with an optical waveguide. We employed silicon nitride (SiN) film as the optical waveguide, because it`s optical transmission characteristics are match to the excitation spectrum of ChR2 and has compatibility with micromachining process. SiN film has 800-nm thick. This Si neural probe has 40 mm length for measuring deeper parts of the brain. The width and thickness of the Si neural probe are 160 µm and 100 µm, respectively. An optical outlet used as an optical stimulation site was located at the tip of the probe. To evaluate the controllability of output patterns of the light, we prepared two types of outlet patterns: straight pattern and 22.5-degree angled pattern. At the end of the probe, an optical inlet part was formed to connect with an optical. Figure 3 shows SEM images of the probe tip with 22.5-degree angled outlet pattern and the cross-section of optical waveguide. As seen in the figure, the optical waveguide of SiN was well formed on the neural probe. The precise alignment was required for connecting the Si neural probe to the optical fiber. Figure 4 shows the alignment procedure between the Si neural probe and the optical fiber. The optical fiber was successfully adjusted to the optical inlet position by tri-axial stage. The light leakage from the optical waveguide was measured as shown in Fig. 4 (b). After the alignment procedure, the optical fiber was connected using a UV-curable epoxy as shown in Fig. 5. The assembled system consisted of the Si neural probe with the optical waveguide, a glass epoxy board, and an optical fiber. A near field pattern (NFP) of the cross-sectional optical waveguide with 15-µm-width was measured by passing a blue laser with wavelength of 452 nm as shown in Fig. 6. The multimode light propagation in the fabricated optical waveguide was clearly observed. Figure 7 shows the light output patterns from two types of the optical outlets with 5-µm-width optical waveguide. These images were taken in colloidal solution to observe the light output pathways by scattering. The difference of light output patterns between straight pattern and 22.5-degree angled pattern were clearly observed. Especially, the light from 22.5-degree angled pattern mainly turned 45-degree direction by total reflection.

4. Conclusion

We proposed the novel Si neural probe with optical waveguide for multisite optical stimulation of neurons. SiN film was employed as an optical waveguide. The Si neural probe with the optical waveguide was well assembled with the optical fiber. The light propagation in the optical waveguide was confirmed by the NFP. The controllability of output patterns of the light was clearly confirmed by two outlet design patterns. It means that we can control the arbitrarily output patterns of the light.

Acknowledgment

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References

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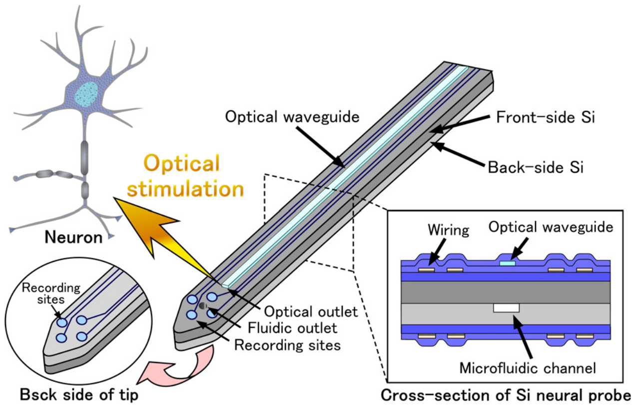


Fig. 1. Multifunctional Si neural probe with optical waveguide, microfluidic channel, and double-sided recording sites.

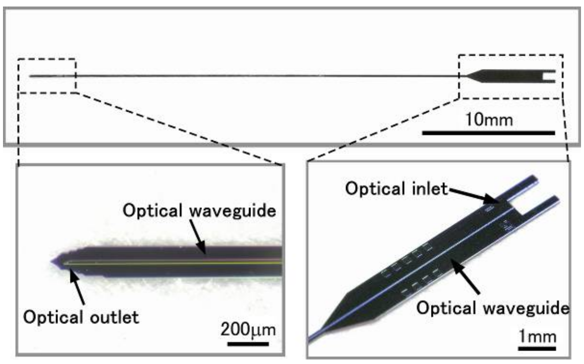
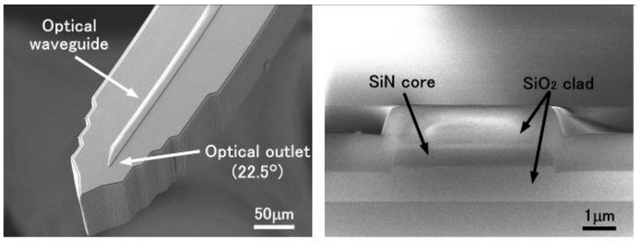
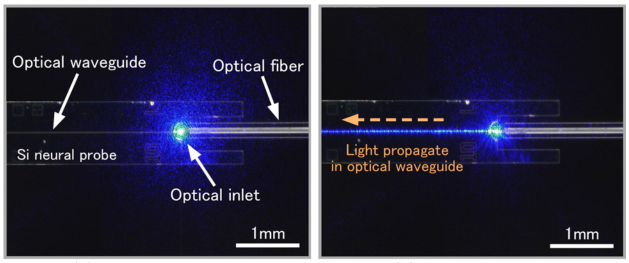


Fig. 2. Photographs of fabricated Si neural probe with optical waveguide.



(a) Si neural probe tip (b) Cross-section of optical waveguide

Fig. 3. SEM images of fabricated Si neural probe.



(a) Before alignment (b) After alignment

Fig. 4. Photographs of alignment procedure.

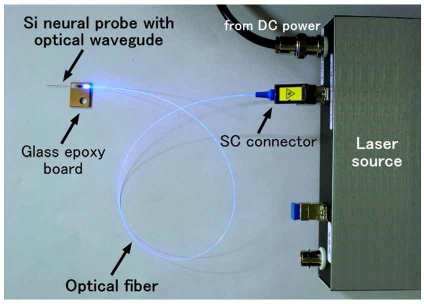


Fig. 5. Photograph of fabricated Si neural probe assembly.

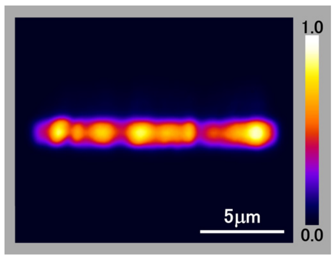
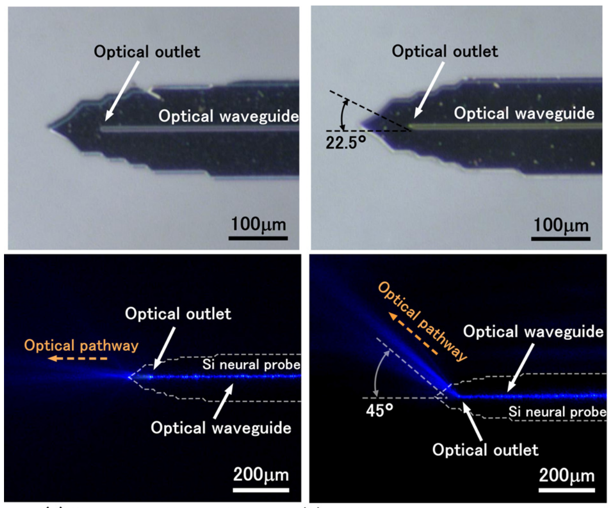


Fig. 6. NFP of cross-section of fabricated optical waveguide.



(a) Straight outlet pattern (b) 22.5-degree angled outlet pattern

Fig. 7. Photographs of optical outlet and light outlet pattern.