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Fabrication and Evaluation of Neural Recording Microelectrode on Opto-Neural Probe with Upconversion Nanoparticles Light Emitter

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Abstract

To optically stimulate neural cells and to electrically record the neural signal simultaneously, we proposed and fabricated an opto-neural probe with upconversion-nanoparticles (UCNP) light emitter and neural recording microelectrodes. The base material of the opto-neural probe was the photosensitive resin of SU-8. Especially, the tip of the probe consisted of UCNP-mixed SU-8 for the light emission with near-infrared (NIR) irradiation. Also, the gold microelectrodes were formed on the opto-neural probe for electrically recording the neural signals elicited by optical stimulation. In this study, we evaluated the effect of UCNP, NIR irradiation, and visible light emission on the electrical characteristics of the neural recording microelectrode.

1. Introduction

Optical stimulation has been widely used in neuroscience, especially in optogenetics, to induce both inhibition and excitation effects on neuron cells. Recently, upconversion nanoparticles (UCNP) have attracted much attention as optical stimulus material in optogenetics. Typical UCNP consists of ytterbium and erbium and can emit visible light when irradiated by near-infrared (NIR) light. On the other hand, SU-8 is a photosensitive epoxy with good mechanical properties [1]. Particularly, the high biocompatibility makes SU-8 useful material for neuroscience. In our previous work, we developed a wireless opto-neural probe with UCNP light emitter and successfully observed that the mouse expressing the light-sensitive protein moved with NIR irradiation [2].

In this study, we proposed and fabricated an opto-neural probe having both UCNP light emitter and neural recording microelectrodes. Figure 1 shows the schematic drawing of the optical stimulation and electrical recording of gene transfer neurons using the opto-neural probe. The gene transfer neurons can be optically stimulated with NIR irradiation. Then the neural signals are recorded by the recording microelectrodes and transferred to external devices. Furthermore, we evaluated the effect of UCNP, NIR irradiation, and visible light emission on the electrical characteristics of the neural recording microelectrode through the electrochemical impedance spectroscopy (EIS).

2. Fabrication process of opto-neural probe

Figure 2 shows the fabrication process flow of the opto-neural probe with UCNP light emitter and recording microelectrodes. First, the 3-μm-thick SiO_2 layer was deposited on a 2-inch Si wafer with plasma-enhanced chemical vapor deposition as a sacrificial layer. Then, the light emitter was formed with green-light-emission UCNP. UCNP was dispersed into SU-8 with a concentration of 20 vol%. The light-emitting (LE) SU-8 had a 1-mm length, 150-μm width, and two different thicknesses of 10 μm and 70 μm. Next, another SU-8 layer was formed over the LE-SU-8, and the patterning of SU-8 formed the probe shape. The shank length was 10 mm. Then, 50-nm-thick Ti and 500-nm-thick Au wirings were formed on the probes. SU-8 passivation was coated over the samples, and electrode holes were formed. Finally, the opto-neural probe was released from the Si wafer by dipping in an aqueous hydrofluoric acid solution. The total thickness of the opto-neural probe was 25 μm and 85 μm for the thin and thick LE-SU-8, respectively. Besides, the neural probe having neural recording microelectrodes without UCNP was fabricated for the comparison.

3. EIS evaluation results and discussion

Figure 3(a) shows the whole image of the opto-neural probe with UCNP light emitter and neural recording microelectrodes. Fig. 3(b)-(d) and Fig. 3(e)-(g) show the enlarged images of various types of the opto-neural probe tip without and with 980-nm-NIR irradiation, respectively. We observed the visible light emissions according to the thickness of UCNP-mixed SU-8. It is possible to strengthen the visible light emission from the thin LE-SU-8 by increasing the UCNP concentration. Also, we measured the electrochemical impedance of two types of electrodes with and without UCNP light emitter, as shown in Fig. 4. The measurements were performed with no NIR irradiation in a darkroom. As there was no significant impedance difference between with and without UCNP, UCNP did not affect the recording characteristics when no visible light emission.

To evaluate the effect of NIR irradiation and visible light emission, we measured the electrode impedances with different types of opto-neural probes. First, we measured the electrode impedances without UCNP, as shown in Fig. 5. The electrode impedance at 1 kHz was between 0.31 MΩ and 0.74 MΩ and between 0.49 MΩ and 1.1 MΩ with and without NIR irradiation, respectively. Next, we measured the electrode impedances with UCNP, as shown in Fig. 6. All the electrode impedances for both with and without UCNP became small with the NIR irradiation. When the Au electrodes and wirings were irradiated by NIR light, the photoelectric effect occurred and may lower the impedance. And the low impedance reduction rate with UCNP shown in Fig. 6 may indicate that the NIR light was partly used for upconversion in UCNP. As a result, the neural recording microelectrode will be very possibly used during NIR irradiation and visible light emission. Further investigation is necessary for in-vitro and in-vivo experiments from the viewpoint of artifacts of light.

4. Conclusions

We successfully fabricated the opto-neural probe with UCNP light emitter and neural recording microelectrodes. From EIS evaluation with 980-nm NIR irradiation and visible light emission, the electrode impedance of the opto-neural probe was proved to be appropriate for neural recording. It is required to investigate the effect of light artifacts further. The opto-neural probe having UCNP light emitter and recording microelectrodes becomes one of the most versatile tools for optogenetics.

Acknowledgments

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References

[1] Lorenz, H. *et al.*, *J.M.M.*, 1997, 121–124.
[2] S. Urayama. *et al.*, *SSDM*, 2019, 41-42.

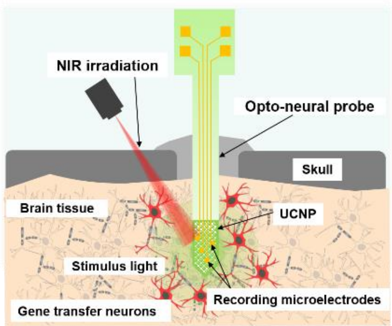

Fig. 1. Schematic drawing of the optical stimulation and electrical recording of gene transfer neurons using the opto-neural probe.

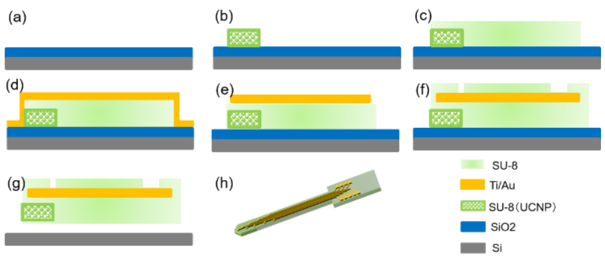

Fig. 2. Fabrication process of the opto-neural probe with UCNP light emitter and recording microelectrodes.

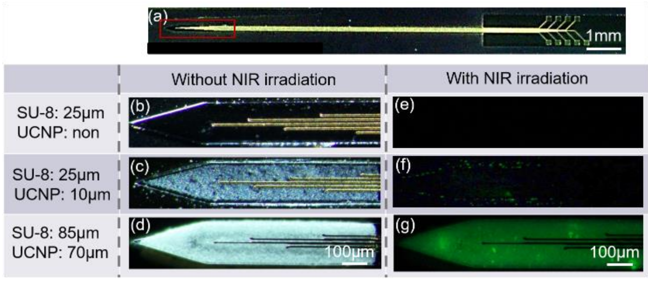

Fig. 3. Fabricated opto-neural probe with UCNP light emitter and recording microelectrodes and the enlarged views of the probe tip with and without 980nm-NIR irradiation.

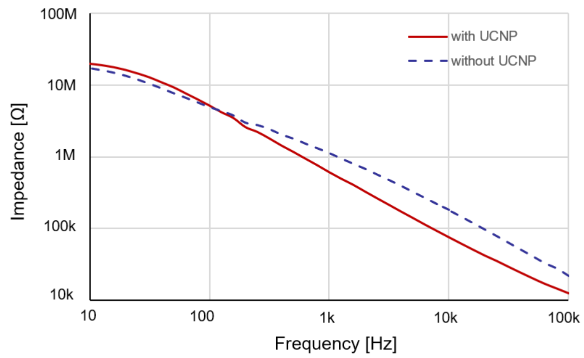

Fig. 4. Impedance characteristics of the recording microelectrode of the opto-neural probes with and without UCNP light emitter. NIR light was not irradiated. The total probe thickness was 25 μm.

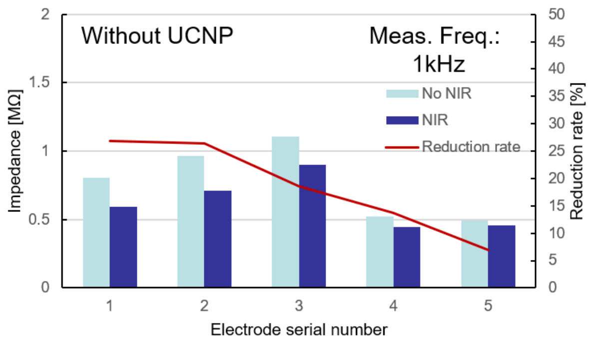

Fig. 5. Impedance magnitudes of the recording microelectrode of the opto-neural probes without UCNP light emitter and their reduction rates with 980nm-NIR irradiation.

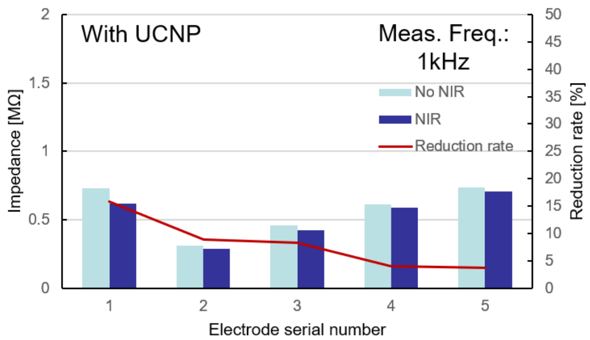

Fig. 6. Impedance magnitudes of the recording microelectrode of the opto-neural probes with UCNP light emitter and their reduction rates with 980nm-NIR irradiation.