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In vivo Neural Signal Recording using Double-sided Si Neural Probe

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1. Introduction

In the past few decades, various kinds of electrodes have been developed to record neuronal action potentials. But in order to analyze brain function in detail, high density recording of neuronal action potentials is strongly required. Therefore, various types of Si probes which enable high density recording have been developed [1]. We have developed a novel double-sided Si neural probe and recorded neuronal action potentials from hippocampal slice [2].

In this paper, we describe a double-sided Si neural probe for *in vivo* neural signal recording. We evaluated electrical and mechanical characteristics of the Si neural probe, and we performed an *in vivo* experiment with Japanese macaque. We recorded neuronal action potentials in motor area of the brain.

2. Fabrication of double-sided Si neural probe

The overall structure of the double-sided Si neural probe is shown in Fig. 1. This Si neural probe has 9 recording sites on both front- and back-side. To analyze a deeper part of the brain such as basal ganglia or apply to large animals like primates, this Si neural probe has a length of 40 mm. Recording sites are made of Au with circular pattern. Diameter of circular pattern is 15 μm, and the distance between two patterns is 100 μm from center to center. Behind 1255 μm from the tip of the Si neural probe, the recording site for differential amplification is placed. At the end of the Si neural probe, bonding pads for connecting to external recording apparatus were formed. The double-sided Si neural probe was fabricated by combining standard photolithography with bulk micromachining process. The 100-μm-thick Si wafer was used as a substrate of the Si neural probe. Fig. 2 shows photographs of the fabricated Si neural probe.

We measured electric impedance of the fabricated double-sided Si neural probe. Measurements were performed with the frequency ranging from 100 Hz to 10 MHz using the 10 mV AC sine signal in 0.9 % saline solution. Fig. 3 shows the impedance characteristics of the fabricated Si neural probes. While front-side recording site has the impedance value of 1.5 MΩ at 1 kHz, back-side recording site has the impedance value of 1.2 MΩ at 1 kHz. It is indicated that both sites have almost the same electrical characteristics.

3. Mechanical characteristics of double-sided Si neural probe

In *in vivo* experiment, breaking of the Si neural probe in animal body is impermissible. Additionally, to insert the Si neural probe into the brain, the probe must have sufficient mechanical strength. We evaluated mechanical characteristics of the fabricated Si neural probe by bending and buckling experiment. Fig. 4 shows photograph of bending and buckling experiment with the fabricated Si neural probe. Fig. 5 shows mechanical characteristics of the fabricated Si neural probe. The maximum tolerable fracture stress and deflection of the fabricated Si neural probe were estimated from these experiments as shown in Table I. We compared fracture stress of the fabricated Si neural probe with the strength of dura mater. The strength of dura mater is within 2 N/mm^2 to 4 N/mm^2 [3]. From this comparison, our double-sided Si neural probe has ability to insert into the dura mater.

4. *In vivo* experiment using fabricated double-sided Si neural probe

Fig. 6 shows photographs of fabricated Si neural probe inserted into the brain. We used a female Japanese macaque (b.w. = 5.5 kg) for neuronal activity recording. The double-sided Si neural probe was inserted into the left supplementary motor area (SMA) by the manipulator. The recorded neuronal signals were amplified (× 5,000), band-pass filtered (0.3-3.2 kHz), sampled at 20 kHz and stored in a computer disk for offline inspection. Individual action potentials of neurons were discriminated by a spike-sorting software (MSD; Alpha Omega Engineering, Nazareth, Israel) based on template matching. As shown in Fig. 7, we successfully recorded neuronal action potentials from brain of Japanese macaque.

5. Conclusion

We fabricated double-sided Si neural probe for *in vivo* neural signal recording by combining standard photolithography with bulk micromachining process. We evaluated electrical characteristic, and it was indicated that the both front- and back-side recording sites have almost the same electrical characteristics. From evaluation of mechanical characteristics, it was also indicated that our double-sided Si neural probe has ability to insert into the dura mater.

We successfully recorded neuronal action potentials from brain of Japanese macaque using fabricated double-sided Si neural probe.

Acknowledgements

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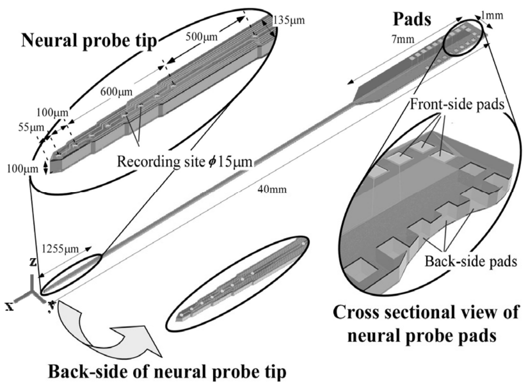

Fig. 1 Structure of double-sided Si neural probe.

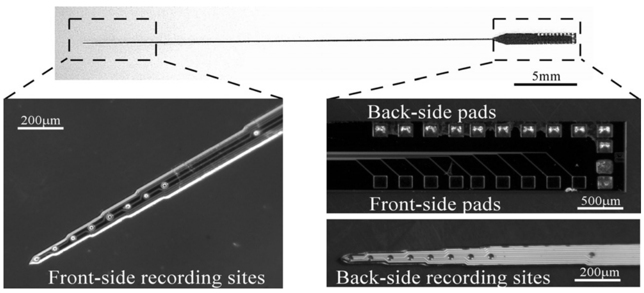

Fig. 2 Photographs of double-sided Si neural probe.

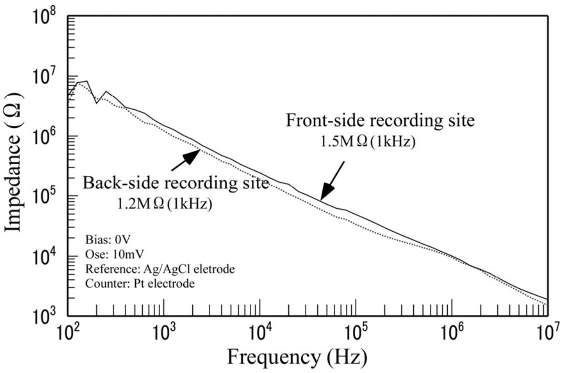

Fig. 3 Impedance of double-sided Si neural probe.

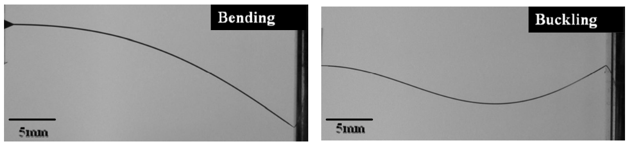

Fig. 4 Photographs of bending and buckling experiment with fabricated Si neural probe.

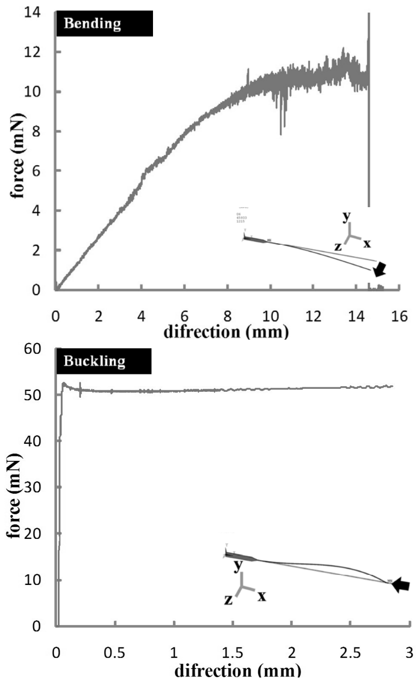

Fig. 5 Mechanical characteristics of fabricated Si neural probe.

Table I Maximum tolerable strength and deflection

	Maximum tolerable strength(mN)	Maximum tolerable deflection(mm)
Bending	11.87	14.54
Buckling	39.82	2.66

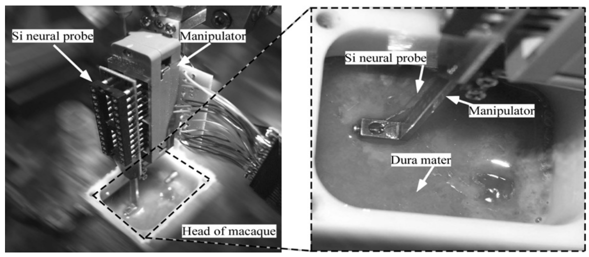

Fig. 6 Photographs of fabricated Si neural probe inserted into brain of Japanese macaque.

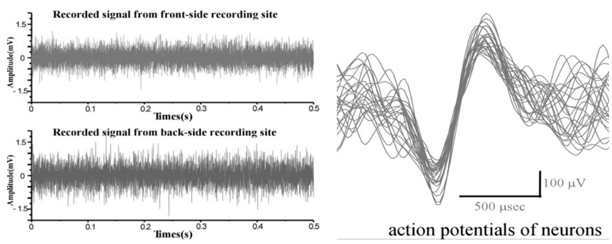

Fig. 7 Recorded neuronal action potentials using fabricated Si neural probe.