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Insertion Characteristics Investigation of Si Neural Probe with Sharpened Tip for Minimally Invasive Insertion to Brain

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1. Introduction

In order to analyze brain function in detail, both high density recording of neuronal action potentials and stimulation of neuron using Si neural probes are one of the most important methods. Until now, various types of Si neural probes which enables high density recording have been developed [1]. We have developed novel multifunctional Si neural probes having double-sided recording sites, microfluidic channel, and optical waveguide [2]. However, there are still some issues in Si neural probes. One is recording signal fluctuations over time after insertion, and other is buckling and fractures of the probe during and after insertion. Therefore, it is strongly required to clarify insertion behaviors and develop new Si neural probes for achieving minimally invasive insertion and stable recording. In this paper, insertion characteristics into a brain phantom of the various types of Si neural probes are evaluated under various insertion conditions.

2. Insertion measurement method

Fig. 1 shows photographs of the insertion measurement system. The Si neural probes were inserted into a brain phantom. The small force during insertion can be measured by the load cell of 10mN and 50mN. The brain phantom made of agarose (0.6%) is 75-mm-long, 60-mm-wide, and 35-mm-thick. Both a long Si neural probe (40mm) and a short Si neural probe (14mm) were used in insertion experiments. The insertion measurements were performed with various insertion and removal rates of 10, 50, 100, 200, 300, 500, and 1000μm/s, and various move distances of 0.4, 1, 5, and 25mm, respectively. Here, the move distance was defined by the position change of the probe pad, and was not identical to the insertion distance of the probe tip. Experimental steps are as follows;

step1: Insert the probe to target position
step2: Pause (until measured force becomes constant.)
step3: Remove the probe to initial position

3. Fabrication of the Si neural probe and insertion measurement

The Si neural probe was fabricated by combining a standard photolithography with bulk micromachining process. Fig. 2 shows a process flow and fabricated Si neural probe. The fabricated Si neural probe has nine recording sites on both front and back sides. To analyze the brain of larger animals like primates and deeper regions of the brain such as basal ganglia in smaller animals, the Si neural probe was designed with a length of 40mm. This probe has 100-μm-thick, 135-μm-wide, and 60°-tip-angle.

A typical force–move distance curve for the insertion and removal in the brain phantom are shown in Fig. 3. The insertion and removal rate is 10μm/s. The insertion angel, move distance, and pause time are 90°, 0.4mm, and 64s, respectively. This result showed that the force over 1.5mN and length longer than 380μm were necessary to penetrated the surface of brain phantom, indicated at point b. Fig. 4(a) shows time dependences of the force and move distance for the insertion and removal rate of 100μm/s. The insertion angle, move distance, and pause time are 90°, 5mm, and 50s, respectively. An initial buckling phenomenon occurred at point b, and a definite buckling occurred at point d, which will cause damages to neurons. Fig. 4(b) also shows time dependences with the insertion angle of 50° and photographs after definite insertion. The insertion and removal rate, move distance, and pause time are 100μm/s, 5mm, and 140s, respectively. This result indicated that the initial buckling did not occur at point b, unlike the insertion angle of 90°. To reduce insertion angle is effective method for suppression of the initial buckling of the Si neural probe.

4. Fabrication and evaluation of the Si neural probe with sharpened tip

In order to further suppress buckling phenomena, the Si neural probe having sharpened tip was designed and fabricated by combining standard photolithography with bulk micromachining process, as shown in Fig. 5(a). A probe tip was sharpened by utilizing wet-etching rate difference of Si crystal orientation. Fig. 5(b) shows the sharpened tip with angles of a=90° and b=55° , in comparison with the normal tip of a=90° and b=90° . Fig. 6 shows force–move distance curves at the insertion and removal rate of 10μm/s, 100μm/s, and 500μm/s, respectively. The insertion angle, move distance, and pause time are 90°, 1mm, and 180s. As results, insertion forces of the Si neural probe with sharpened tip were smaller than these of the Si neural probe with normal tip for the all insertion speed conditions. It is clearly demonstrated that sharpening of the probe tip significantly reduced insertion force, leading to minimally invasive insertion into brain.

5. Conclusion

We fabricated various types of Si neural probes and evaluated insertion characteristics in order to reduce damages to neurons in the brain. We obviously demonstrated mechanical behaviors of the Si neural probe during insertion. And we quantitatively clarified that both small angled insertion and sharpened probe tip remarkably suppress buckling phenomena, which realizes minimally invasive probe insertion and less damages to neurons. With such structures, the multifunctional Si neural probe becomes stronger and versatile tools for brain science and neuronal engineering.

Acknowledgements

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References

[1] K. D. Wise *et al., Proc. IEEE,* **92** (2004) 76.
[2] R. Kobayashi *et al., Extended Abstracts SSDM*, (2008) 942.
[3] S. Lee *et al., Extended Abstracts SSDM*, (2009) 691.

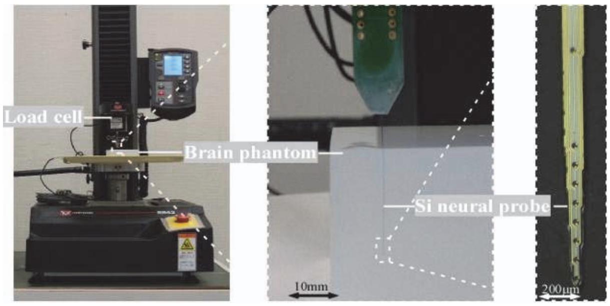
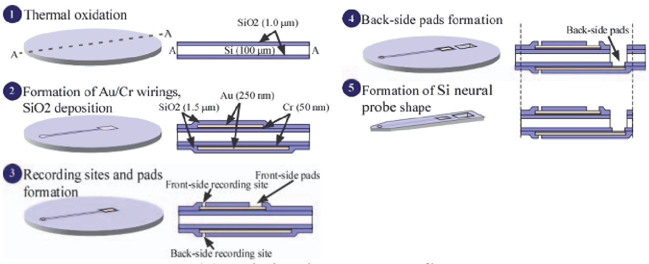
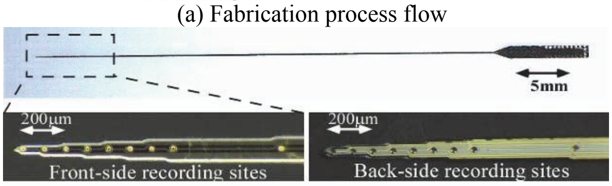


Fig. 1 Insertion measurement system



(a) Fabrication process flow



(b) Photographs of the fabricated Si neural probe

Fig. 2 Process flow and photographs of the Si neural probe

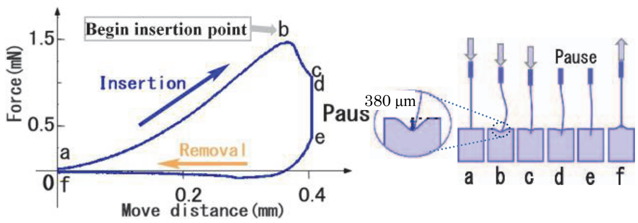
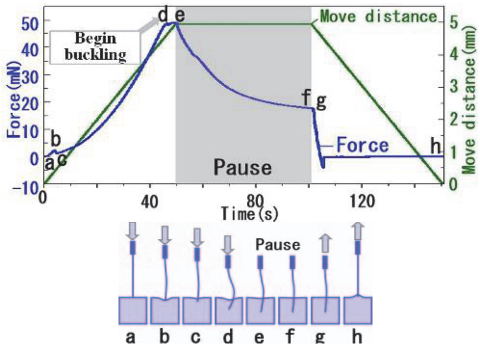
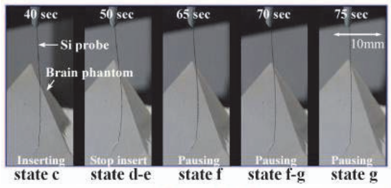
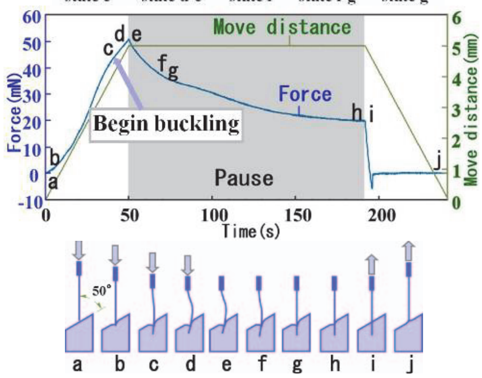


Fig. 3 Relationship between force and move distance



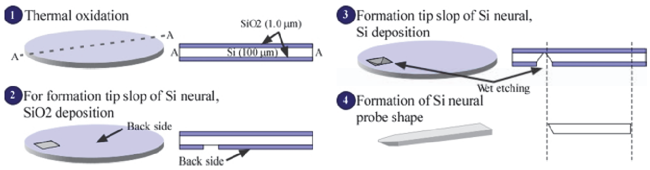
(a) Result of insertion angle of 90°



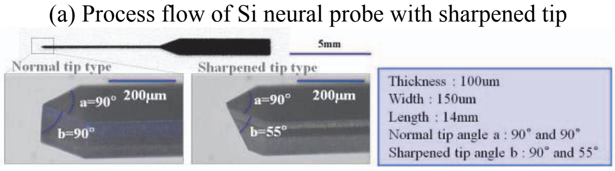


(b) Result and photographs of insertion angle of 50°

Fig. 4 Time dependences of force and move distance during insertion



(a) Process flow of Si neural probe with sharpened tip



(b) Photographs of the fabricated sharpened probe tip

Fig. 5 Process flow and photographs of Si neural probe

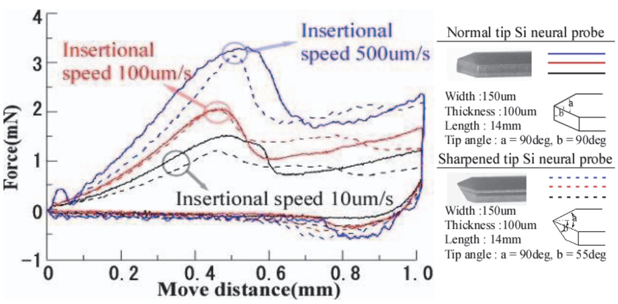


Fig. 6 Relationships between force and move distance for various insertion speeds