Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp606-607

Lower invasive in vivo brain insertion of the Si neural probe with triangular shank and sharpened tip

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Abstract

A Si neural probe is one of the most important tools for neuroscience because it can record neuronal activities in a brain densely. However, it would damage the brain during insertion. Therefore, it is necessary for the Si neural probe to reduce invasiveness to the brain. In this study, we proposed the lower invasive Si neural probe having both triangular shank and sharpened tip fabricated using Si anisotropic etching technique. From in vivo mouse brain insertion experiments, it was clearly indicated that the proposed Si neural probe had insertion force of 15 % compared to a Si probe with normal tip. The lower invasive Si neural prove becomes a versatile tool of neurophysiology and neuroscience.

1. Introduction

Neural probes have been widely used for neuroscience for more than 50 years. Among them, Si neural probes are one of the most useful tools because they are fabricated by using Si LSI processes which have several important advantages such as design flexibility of recording electrodes, low cost, and high biocompatibility. However, there is a possibility of causing severe damages to neurons during the Si neural probe insertion to the brain [1]. It was reported that the Si neural probe with a smaller cross-section decreased the damage after insertion [2]. A smaller cross-section also decreases a second moment in the Si probe and causes a buckling during insertion. Considering these situation, we proposed the Si neural probe having both triangular shank and sharpened tip to achieve less invasiveness to the neuron with keeping the probe strength.

2. Neural probe fabrication and In vivo insertion experiment

Fabrication of probe

In this study, the sharpened tip and triangular cross section of the Si neural probe were fabricated using semiconductor nanofabrication technology, as shown in Fig. 1 [3,4]. A 100 µm thick Si wafer was used as the substrate of the Si neural probe. First, a 1-µm-thick SiO_2 layer was formed on the Si wafer by thermal oxidation, and Au wire was fabricated by a sputtering and wet etching. Next, after a 1-µm-thick SiO_2 layer was deposited on Au wire by CVD and formed contact holes using an RIE, Au recording electrodes were fabricated using a lift off process. The wet etching pattern was

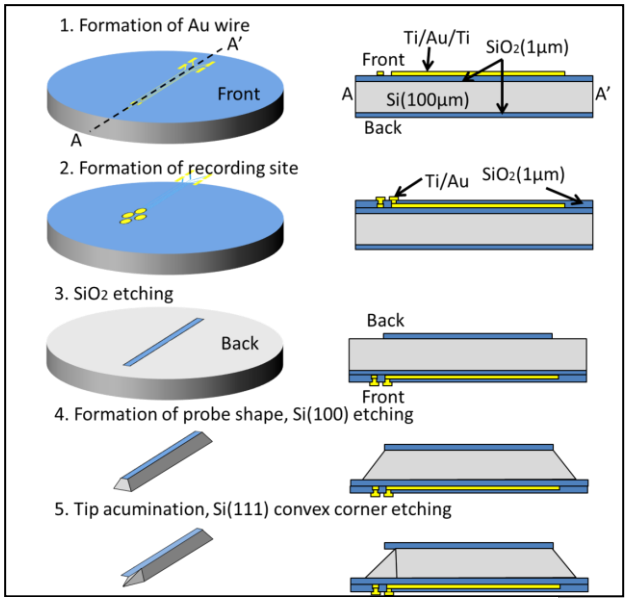

Fig. 1 Fabrication process flow

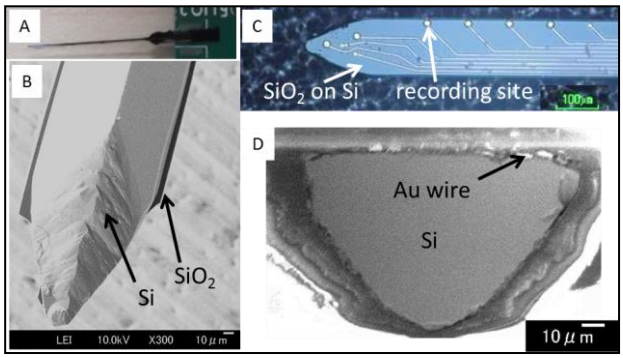

Fig.2 Photographs of the Si neural probe with triangular shank and sharpened tip.
(a) The whole structure, (b) SEM image of sharpened tip (backside), (c) Probe tip surface,
(d) Cross-sectional SEM image of probe shank

formed on the back-side SiO_2 layer using a standard photolithography process. The SiO_2 layer was wet etched with buffered HF solution (HF/ NH_4F: 1/10) to form etching windows. Then, Si with a thickness of 100 µm was wet etched using TMAH for triangular cross section. After that, the Si neural probe was also wet etched using TMAH. Fig. 2 shows probe images. The probe has a shank length of 14mm, a width of 133µm, and angle of electrode surface of

43◦. Fig. 2(d) clearly shows that a cross section of the probe becomes triangular.

In vivo insertion experiments

To measure the actual force occurring in the probe during insertion to the brain, the probe was inserted to a mouse brain. The animal was cared in accordance with the Guiding Principles for the Care and Use of Laboratory Animals of the National Institutes of Health and the Guidelines for Institutional Animal Care and Use published by our institute. A mouse was administered an anesthetic drug and fixed a head in a jig (NARISHIGE SG-4N). The hole were formed in the skull by a drill. The mouse was fixed in a testing equipment (INSTRON 5943). The insertion measurements were performed with various insertion and removal speeds of 10 and 100m/s, and with various insertion distances of 2 and 5 mm. Insertion experiment has four steps.

Step 0: Determination of zero point at the measured force of 0.1mN.
Step 1: Insertion of the probe in accordance with insertion distances.
Step 2: Pause until measured force becomes constant.
Step 3: Removal of the probe to initial position.

For a comparison, a normal probe without sharpened tip and triangular shank was also measured. The normal probe has a shaft length of 14mm, a width of 150μm, and angle of electrode surface of 30◦. Fig. 3 shows the probe insertion into the mouse brain.

3. Results and discussion

Fig. 4 shows the measured force–insertion distance curves with sharpened and normal tips at the insertion and removal rates of 10 and 100mm/s respectively. In Fig. 4, P1 is a point when probe penetrates through a dura matter, P2 is a point of insertion stop, P3 is start point of remove of probe, and the minimum force is measured in P4. Table 1 settles these details. From the results, the Si neural probe with triangular shank and sharpened tip had insertion force of 15 % compared to a Si probe with normal tip when penetrating the dura matter. At the time of P2 and P3, the Si neural probe with triangular shank and sharpened tip showed better characteristics compared with normal probe in the insertion speed of 10μm/s and 100μm/s.

4. Conclusions

In this work, the Si neural probe with triangular shank and sharpened tip was proposed and successfully fabricated in order to reduce the damage occurring during the Si neural probe insertion. Both triangular shank and sharpened tip were completely formed by anisotropic wet etching of the Si, and led to a lower invasiveness. The lower invasive Si neural prove becomes a versatile tool of neurophysiology and neuroscience.

References

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Fig. 3 In vivo mouse brain insertion of the Si neural probe.

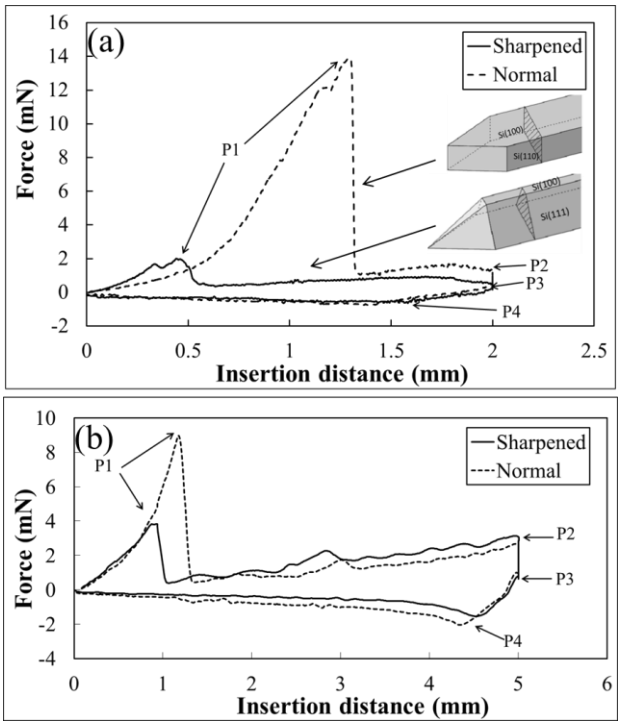

Fig. 4 Insertion distance dependences of the measured force for the Si neural probes. (a) Insertion speed is 100μm/s. (b) Insertion speed is 10μm/s.

Table 1 Insertion results summary

		10μm/s		100μm/s	
		Sharpened	Normal	Sharpened	Normal
P1	Force(mN)	2.08	13.75	4.07	9.55
	Time(s)	44.2	126.1	9.3	11.7
P2	Force(mN)	0.52	1.32	3.03	3.05
	Time(s)	200	200	50	50
P3	Force(mN)	0.25	0.53	0.81	0.97
	Time(s)	380	380	230	230
P4	Force(mN)	-0.76	-0.72	-1.64	-2.17
	Time(s)	421.2	437.1	234.8	236.1