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Development of Vertically-Stacked Multi-Shank Si Neural Probe Array with Sharpened Tip for Cubic Spatial Recording

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Abstract

A vertically-stacked multi-shank Si neural probe array with sharpened tip has been developed for neuronal recording of spatially distributed neurons. This Si neural probe array has vertically-stacked 16 shanks with 208 recording sites and sharpened tips. The probe cross-sectional area was reduced and the probe tips were sharpened for less-invasive insertion. Fabricated vertically-stacked Si neural probe array had sufficient characteristics for neural recording. Also, the vertically-stacked Si neural probe array with sharpened tips needed smaller insertion forces compared to normal tip probes for all the insertion conditions, leading to less damages to the neurons.

1. Introduction

For studying of neural networks in brain, it is necessary to analyze neuronal activities three dimensionally. As a Si neural probe array has several shanks and lots of electrodes, recording of neuronal signals and analyzing of neural networks can be achieved with high accuracy. Until now, several kinds of Si neural probe arrays were reported [1, 2]. Particularly, a vertically-stacking of planar Si neural probes is a promising method to integrate multi-functions into the Si neural probes. However, several issues exist in the vertically-stacked Si neural probe array. It is not possible with a stacking method using adhesives to electrically connect among the planar Si neural probes. Furthermore, many dense probe shanks would increase damages to the brain tissues and decrease quality of recording signals. Therefore, it is necessary to optimize the shape of probe shank for easily insertion [3].

2. Vertically-stacked multi-shank Si neural probe array with sharpened tip

Fig. 1 shows a schematic drawing of the vertically-stacked multi-shank Si neural probe array with sharpened tip. Since this stacking method uses metal bumps and pads without adhesives, electrical connections can be certainly achieved. Furthermore, probe tips are sharpened and probe shanks are decreased simultaneously with anisotropic etching. Therefore, the optimized probe shape can be formed to decrease insertion damages to the neurons.

Fabrication process

The vertically-stacked multi-shank Si neural probe array with sharpened tip was fabricated with LSI/MEMS technologies, as shown in Fig. 2. 2-inch Si wafers with a thickness of 100-µm were used for probe fabrication. First, a 500-nm-thick SiO_2 layer was formed on the Si wafer by PECVD. Next, Au wires were fabricated by spattering and photolithography process. A 500-nm-thick SiO_2 layer was then deposited by PECVD. After opening of contact holes, 500-nm-thick Au electrodes and bonding pads were formed. After front-side process, a backside SiO_2 layer was patterned. Cu/Sn bumps were formed with electrolytic plating. After that, the multi-shank Si neural probes and Si spacers were formed using the DRIE process. The multi-shank Si neural

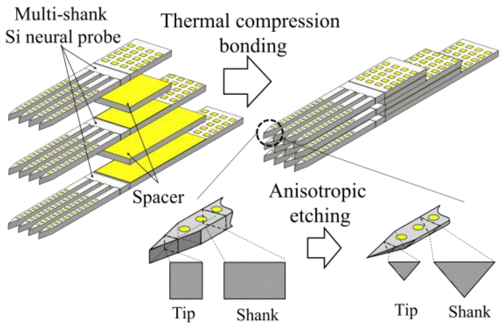

Fig. 1 Vertically-stacked Si Neural Probe Array with Sharpened Tip.

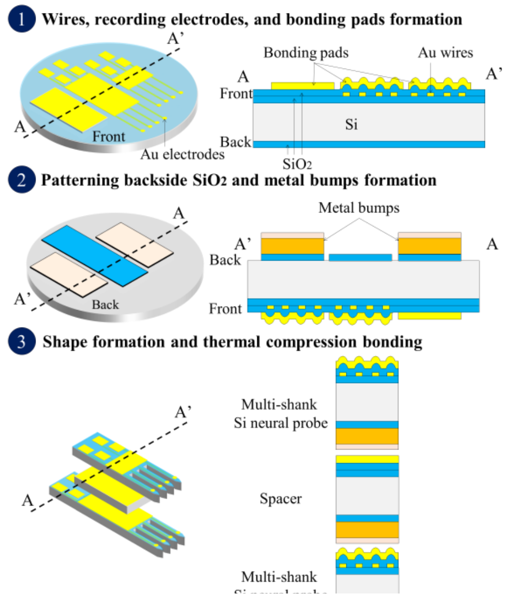

Fig. 2 Fabrication process of vertically-stacked Si neural probe array.

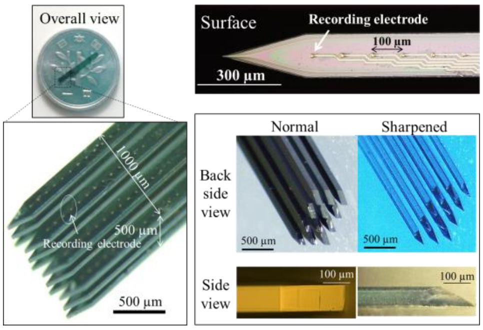

Fig. 3 Fabricated vertically-stacked Si neural probe array.

probes and Si spacers were bonded with thermal compression. After stacking, the vertically-stacked Si neural probe array was sharpened by anisotropic etching. Fig. 3 shows photographs of the fabricated vertically-stacked multi-shank Si neural probe array with sharpened tip. Electrochemical properties of the recording electrodes were evaluated. The impedance values were 0.23-5.4 MΩ at a frequency of 1 kHz. It was obvious that the fabricated Si neural probe had sufficient characteristics for neural recording.

Insertion characteristics measurement

The insertion characteristics of the vertically-stacked Si neural probe array were carefully evaluated. The vertically-stacked Si neural probe arrays were inserted into a 0.6 wt% agarose. The experimental steps are as flows:

Step 1: Move down the probe array at a speed of 5 µm/s until the probe tips come into contact with an agarose and the measured force reaches 0.1 mN.

Step 2: Move down the probe array to 2mm at a speed of 10, 100 or 1000 µm/s.

Step 3: Pause 180 sec.

Step 4: Move up the probe array at a speed of 10 µm/s.

The force applied to the vertically-stacked Si neural probe array was measured between steps 2 and 4 using the load cell. Fig. 4 shows the comparison of insertion characteristics for the vertically-stacked Si neural probe array with normal and sharpened tip at speeds of 10, 100, and 1000 µm/s. As a result, the forces applied to the vertically-stacked Si neural probe array with sharpened tip were smaller than those with the normal tip for all the insertion speeds during insertion. The measured force was compared between the sharpened tip and the normal tip at the insertion distance of 2mm in Table I. It was clearly demonstrated that the sharpened probe definitely reduced the insertion forces. In addition, this result indicated that the effects of the probe tip sharpening increased in accordance with the insertion speed.

Table I Measured force comparison for the insertion distance of 2mm.

	Insertion speed (µm/s)		
	10	*100*	*1000*
$\frac{Force\ (sharpened)}{Force\ (normal)} \times 100\ \%$	66	59	43

In vivo insertion experiment

To confirm insertion behaviors of the vertically-stacked Si neural probe array, the probe array with sharpened tip was inserted into a mouse brain. All experimental procedures conformed to "Regulations for Animal Experiments and Related Activities at Tohoku University", and were reviewed by the Institutional Laboratory Animal Care and Use Committee of Tohoku University, and approved by the President of University. A hole in the skull was made with a drill and a dura mater was not removed. The vertically-stacked Si neural probe array was inserted through the dura mater by a manipulator. Fig. 5 shows a photograph of the vertically-stacked Si neural probe array during insertion. From this result, it was clearly observed that vertically-stacked multi-shank Si neural probe array with sharpened tip was inserted into the brain through the dura mater. In addition, LFP signals were successfully recorded from the mouse brain.

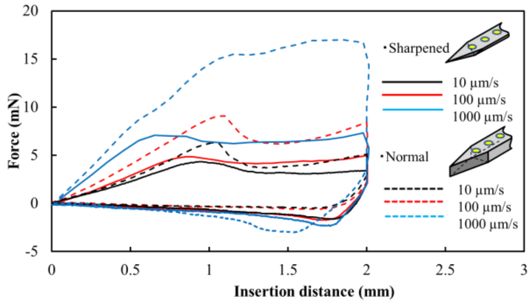

Fig. 4 Insertion characteristics comparison for the vertically-stacked Si neural probe arrays having different tips and shank shapes.

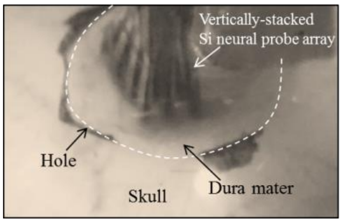

Fig. 5 In vivo insertion experiment of vertically-stacked Si neural probe array.

3. Conclusions

The vertically-stacked multi-shank Si neural probe array with sharpened tip was proposed and successfully fabricated for minimally invasive and cubic spatial recording. 3 multi-shank Si neural probes and 2 spacers were vertically stacked by thermal compression bonding. The sharpened tip by anisotropic etching enabled smooth insertions with smaller forces compared to the normal tip probes for all the insertion conditions, which leads to less damages to the brain. The proposed Si neural probe array will realize the cubic spatial neuronal recording and becomes versatile tools for advanced neurophysiology

Acknowledgments

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