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# Development of Si Neural Probe with Piezoresistive Force Sensor for Insertion Force Monitoring

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## Abstract

**Si neural probe is one of the most important tools for neurophysiology and brain science due to its various functions such as optical stimulation, DDS, and so on. However, the Si neural probe is not robust for mechanical stress caused during insertion to brain. It becomes more useful that the Si neural probe has a stress sensor which can detect mechanical forces applied to the probe before breaking. This paper proposed and successfully fabricated a Si neural probe with piezoresistive force sensor for monitoring of insertion force. The fabricated sensor clearly measured applied forces with sensitivities less than 1mN.**

## 1. Introduction

In the past few decades, various kinds of neural probes have been developed for recording and stimulation of neurons to study brain functions and to cure brain diseases such as Parkinson's disease, and epilepsy, and so on. Particularly, Si neural probes realized with micro/nano fabrication technologies are one of the most important tools because of their various functions such as optical stimulation, DDS, and so on. Meanwhile, a conventional Si neural probe tends to be broken during insertion to brain because Si is brittleness material. Although the Si neural probe with larger cross-sectional area becomes rigid, damages to the brain increase and quality of recording signals decreases simultaneously.

It becomes more useful that the Si neural probe has a mechanical stress sensor which can detect mechanical forces applied to the probe before breaking. Until now, several studies of the Si neural probe with force sensors have been reported [1][2]. However, their force sensors can detect bending and buckling of the Si neural probe, which leads to misplacement of the probe tip and resultant poor recording characteristics [3]. In this paper, we proposed and fabricated a Si neural probe with Piezoresistive force sensor for monitoring of insertion forces, and evaluated sensing characteristics in detail.

## 2. Fabrication of the Si neural probe with piezoresistive force sensor

Figure 1 shows a schematic drawing of the Si neural probe with piezoresistive force sensor. The probe was composed of recording electrodes inserted in the brain and force sensors. As the insertion force was concentrated to the force sensors due to their unique structure, this probe can detect insertion forces with high sensitivity before occurring of bending and buckling in the probe shank.

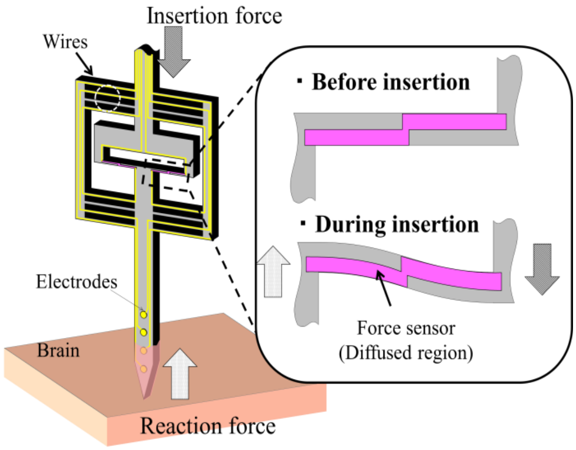


Fig. 1. Schematic drawing of the Si probe with piezoresistive strain sensor during insertion.

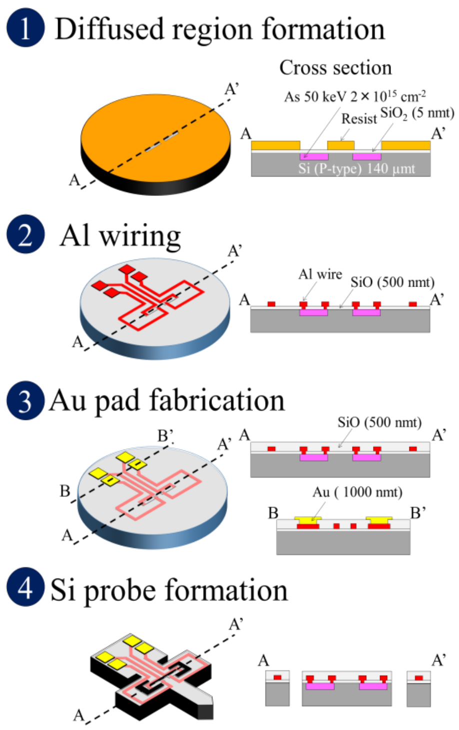


Fig. 2. Fabrication process of the Si neural probe with piezoresistive force sensor.

The Si neural probe with piezoresistive force sensor was fabricated with LSI/MEMS technologies as shown in Fig. 2. A 140-µm-thick 2 inch Si wafers (P-type) were used for probe fabrication. First, a 6-nm-thick $SiO_2$ layer was formed on the Si wafer by pyro-oxidation. Next, ion-implantation pattern was formed on the $SiO_2$ layer using a photolithography process. Arsenic ions were implanted with doses of 2 $\times10^{15}$ $cm^{-2}$ and energy of 50 keV with angle of 7°. After resist removal, rapid thermal annealing (RTA) at 1050 ℃ for 15 seconds was then conducted for the dopant activation. The $SiO_2$ layer was removed with buffered HF solution. A 500-nm-thick $SiO_2$ layer was deposited by PE-CVD. After contact patterning, the $SiO_2$ layer was wet etched with buffered HF solution. After opening of contact holes and Al wiring, a 500-nm-thick $SiO_2$ was also deposited by PEDVD. The $SiO_2$ layer on Al pads was removed for wire bonding, and 1000-nm-thick Au pads was formed on the Al pads. After that, the Si neural probe shape with the force sensors was formed using the DRIE process. Figure 3 shows photographs of the fabricated Si neural probe with piezoresistive force sensors.

## 3. Evaluation results and discussion

Figure 4 shows an experimental setup of the piezoresistive effects measurement with the Si neural probe. The probe was attached to load cell and As diffused regions were connected to a current source with magnitude of 50 µA. The experimental steps are as follows:

Step1: Lower load cell with 100 µm/s until probe tip contacts a rubber and a measured force reaches 1 mN.
Step2: Lower load cell with 1 µm/s until a force of 10 mN .
Step3: Pause for 30 seconds.
Step4: Raise load cell at 1 µm/s.

V1 and V2 were recorded between step 2 and step 4. Resistance values were calculated in the next expression:

$$R = \frac{V1 - V2}{I} \qquad (1)$$

Figure 5 shows the piezoresistive effects of fabricated force sensor integrated in the Si neural probe. A linear relationship can be successfully obtained between resistance changes and forces up to 30 mN with the fabricated force sensor. And this probe did not break with applied forces more than 100 mN. As an insertion force of 10 mN was necessary to penetrate a dura matter of mouse, the Si neural probe can penetrate the dura matter and can precisely predict breaking point for the probe. In addition, this linear relationship with resolution less than 1 mN will estimate precise positions of the Si neural probe during insertion into the brain.

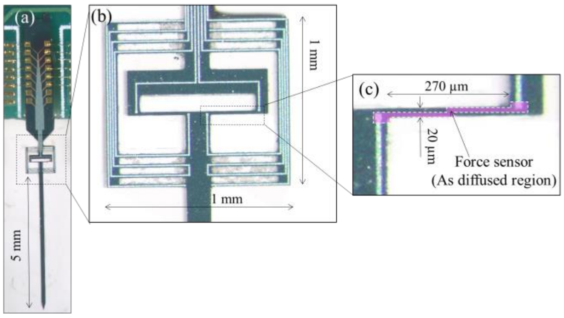


Fig. 3. Photographs of the Si neural probe with piezoresistive force sensors. (a) Whole probe (b) Sensing area (c) As diffused region

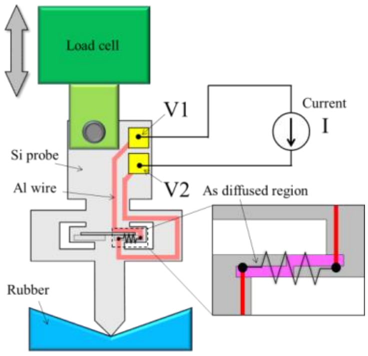


Fig. 4. Measurement setup for piezoresistive effect of fabricated force sensor in the Si neural probe.

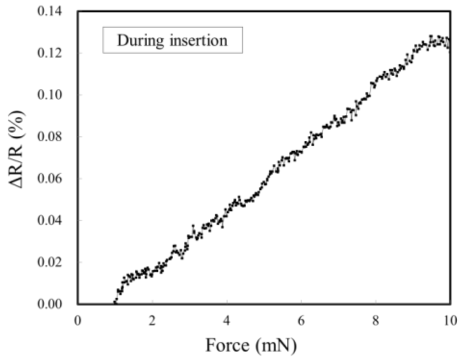


Fig. 5. Measurement results for piezoresistive effect of fabricated force sensor in the Si neural probe.

## 4. Conclusions

The Si neural probe with piezoresistive force sensor was proposed and successfully fabricated for insertion force monitoring. The proposed Si neural probe was composed of recording electrodes and unique structured insertion force sensors. As the insertion force was concentrated to the force sensors, this probe can measure insertion forces with high sensitivity. Furthermore, as this probe had a sufficient strength and the linear relationship between resistance changes and forces, precise positions of the probe tip can be predicted without the probe breaking during insertion. This Si neural probe with piezoresistive force sensor becomes one of the most versatile tools for studying of neurophysiology and brain science.

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