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Multichannel 5 × 5-site 3D Si Micro-Probe Electrode Array for Neural Activity Recording System

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1. Introduction

Multichannel penetrating electrodes with a few microns in the diameter will accelerate the neural research. The electrodes with same size as neurons can be used for recording of neural-activity potentials in the neural tissue. For the electrode, we have proposed 3D Si micro-probe array on integrated circuit chip instead of etching method using Au-Si_2H_6 vapor-liquid-solid (VLS) Si growth on a Si (111) wafer [1]. The position and diameter of the Si micro-probe can be determined successfully by photolithography, and probe length more than a few hundred microns can be fabricated. Moreover the conductive-Si probe can be controlled by phosphorous diffusion. In this paper, we show a multichannel 5 × 5 Si micro-probe array with space of 40 μm each other, and discuss the mechanical properties of the VLS grown Si probe and signal recording experiment using the micro-probe array chip.

2. Fabrication

In the VLS Si growth [2], a Si (111) wafer was used, because the VLS Si probes can be grown with <111> direction. Epitaxial Si probes was fabricated at pre-determined positions, where Au dots were formed using SiO_2 window mask and Au lift-off after Si integrated circuit process as shown in Fig. 1. In the wiring of the chip, WSi_2 instead of Al was used for high temperature process of Si probe fabrication. The Si probe was grown under growth temperatures of 500 - 700 °C [3]. In our applications, the Si probe must be conductive-probe for recording of neural activity with about 100 mV in amplitude. As-grown Si probe with high-resistance due to non-doping growth, was changed to a conductive-probe by phosphorous diffusion [3].

Figure 2 shows the photograph of a 5 × 5 sites Si probe array chip with the dimensions of 2.5 mm × 5 mm. In this design, probes with WSi_2 wiring were fabricated with space of 40 μm each other, as shown in Fig. 3. The SEM view shows the grown Si probe with 2 μm-diameter and about 10 μm-length at the probe site. The VLS growth temperature was 600 °C.

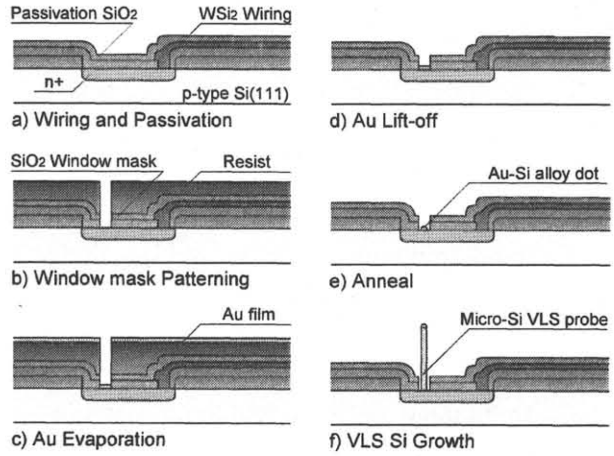

Fig. 1 Process sequence of VLS Si probe array chip.

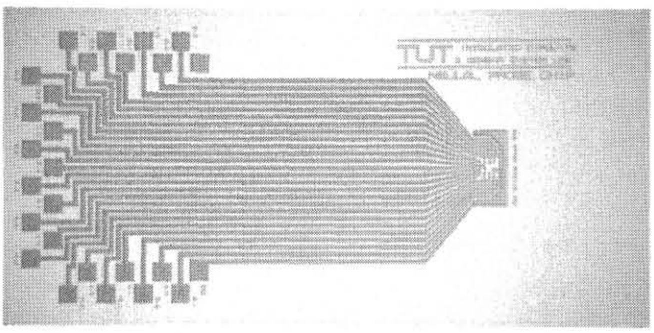

Fig. 2 Photograph of a fabricated 5 × 5 Si probe array chip. These Si probes were connected with wiring. Chip dimension was 2.5 mm × 5 mm.

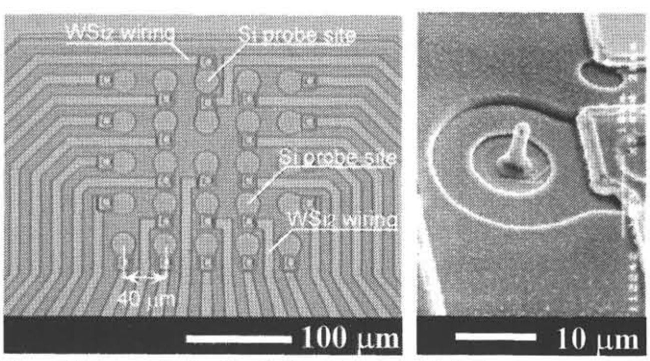

Fig. 3 Photograph of a 5 × 5 Si probe array with site spacings of 40 μm and a SEM image of VLS grown Si probe with 2 μm in diameter and 10 μm in length.

3. Evaluation

3.1 Mechanical properties

It is well known that the single crystalline Si is reliable strength. For the tough probe, the probe shape with circular cone type was realized by changing of Si_2H_6 gas condition in the VLS Si growth. In this study, the circular cone probe was evaluated. Used Si probe was 270 μm in length, and the diameter of the tip and the bottom were 3.5 μm and 22 μm, respectively (Fig. 4).

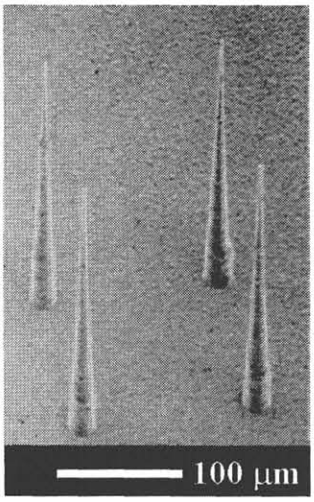

Fig. 4 SEM view shows VLS grown Si probes with 270 μm in length and the diameter of 3.5 μm at the tip and 22 μm at the bottom.

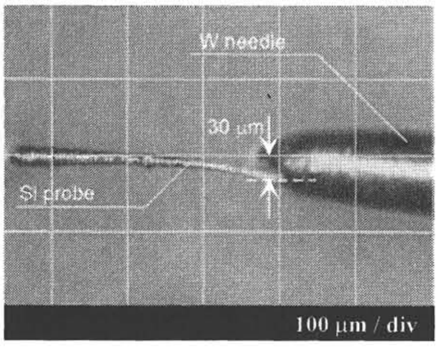

Fig. 5 The VLS grown Si probe was tough enough to endure deflection of 30 μm without fracturing.

Under the external force using manipulatable W needle as shown in Fig. 5, the bending of the Si probe was observed. This observation showed deflections of about 30 μm at the tip of the Si probe without fracture.

In the recording of neural activity in the neural tissue, the Si probe will be punctured and penetrated through the neural tissue, which causes the compressive force. For reliability of the probe electrode, a penetration experiment was also performed using a gelatin membrane as neural tissue. In this penetration, the Si probe penetrated easily without a vibration system. During the continuous penetration, no fracture of the probe was observed.

3.2 Signal recording experiment

The Si probe electrode array was evaluated using a signals with 1 mV in amplitude and 10 kHz in frequency as same as neural activity. Figure 6 shows the results of the signal recording with the Si probe array chip. The input signal was stimulated potentials at the Si probe tip. The output signal was recorded through the Si probe chip, and showed satisfactory results. The stimulated amplitude of 1 mV was 10^{-2} times of the theoretical neural-activity amplitude.

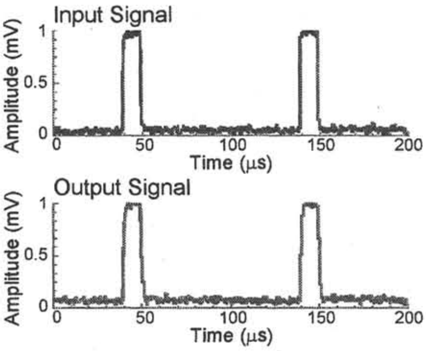

Fig. 6 Signals recorded with Si probe array chip. Input signal with 1 mV in amplitude and 10 kHz. Output signals from a conductive-Si probe.

4. Conclusions

The VLS Si growth method allows to fabricate 3D probe array on Si (111) wafer. For recording neural activity, a 5 × 5 array Si probes were fabricated with 40 μm in space each other. And the VLS Si probe was evaluated in mechanical and electrical properties. The Si probe must be tough enough to ensure that these probes can penetrate into the cell. The mechanical strength of the probe indicated excellent result. And the recoding capability was also evaluated, which showed the satisfactory results. From these experimental results, it is found that the VLS probe is useful electrode for neural activity recording.

Acknowledgments

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