VIVO STUDY OF MECHANICAL PROPERTIES OF THE MONOLITHIC SILICON PROBES WITH FLEXIBLE PARYLENE CABLES FOR NEURAL PROSTHESES

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Abstract

This work presents the new experimental results for a new monolithic silicon probes array with flexible parylene cables used for neural prostheses. A new technology developed in the Caltech micromachining lab provides great flexibility to fabricate silicon probes with large range of geometries. Instead of the brittle inorganic materials (e.g. SiO_2 or Si_3N_4), parylene is used as the insulating/protecting material on silicon substrate. Parylene is biocompatible and at the same time improves mechanical properties of the silicon probes. Animal tests have been done to validate the mechanical properties of the new silicon probes with different geometries. The results show that the probes have great improvements than other current silicon probes in mechanical properties. Successful chronic implantation shows that the probes are able to penetrate monkey's pia by hand insertion.

Keywords: Neural probes, silicon probes, parylene, neural prostheses

1. Introduction

An important common goal is to achieve cortex prostheses using implanted probes to interface with robotics by pure thoughts. The first beneficiaries are likely to be patients with spinal-cord injuries, peripheral nerve disease, or amyotrophic lateral sclerosis [1]. To achieve this, researchers are racing to make 3-D neural probes that can record cortex cognitive signals. Unfortunately, there are two major challenges toward the ideal devices. The first is the lack of long-term insulating/protecting biocompatible materials. The commonly used materials such as SiO_2 and Si_3N_4 are useful but they are brittle and have reliability issues for chronic use.

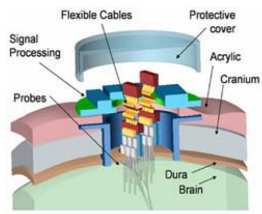

Figure 1. Schematic of cortical implantation using parylene cables.

The second problem is related to through-skull interconnect. Signals obtained by probes have to be cabled out of skull (Shown in Fig. 1). Flexible and biocompatible cables are simply crucial. Facing these two new aspects of research, a new 3-D silicon probes array with monolithic flexible parylene cables has been developed in the Caltech micromachining lab (Shown in Fig. 2) [2]. Firstly, the electrodes on the new probes are completely insulated by parylene, instead of the conventional SiO_2 and/or Si_3N_4. Here, Parylene is highly desirable because only parylene has been proven to have the longest durability for over 3 years for implant insulation [3]. Secondly, this new probe technology allows the integration of monolithic flexible parylene cables, which further enable functional through-skull interconnect. At the same time, unlike other current silicon probes, for example, Michigan probes made by wet etching can only reach limited probe thickness, and need to open pia and even special guide tools for insertion because of mechanical weakness of the probes. This may cause bigger damage to the brain. Our new double side DRIE etching fabrication technology allows us to make the silicon probes strong enough to penetrate primates' pia. Animal tests have been done to validate the mechanical properties of our new silicon probes.

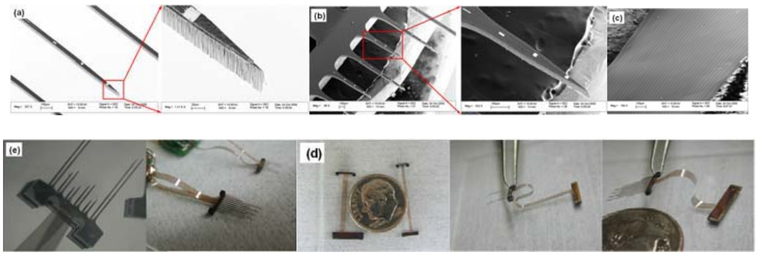

Figure 2. Pictures of the fabricated probes. (a) SEM pictures of the long shank probes; (b) SEM pictures of the short shank probes; (c) SEM picture of the parylene cable; (d) optical pictures of the 2-D probe arrays with parylene cables; (e) optical pictures of the 3-D probe arrays (4×2 with 32 electrodes and 8×2 with 64 electrodes) stacked by two 2-D probes plates.

2. Devices design and fabrication

In order to test the mechanical properties of the new silicon probes. Testing silicon probes are designed for vivo tests. The design parameters are shown in Fig. 3. The testing silicon probes are the same as the complete device except metal electrodes and parylene cables. A 10μm parylene layer is on top of the silicon probe's shank, so that the testing probes perform the same mechanical properties as the complete device. A fabricated testing silicon probe is shown in Fig. 4.

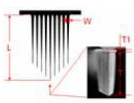

Figure 3. Parameters of the silicon probes for rigidity test.

Figure 4. A fabricated silicon probe for rigidity test.

3. Testing results and discussions

The testing silicon probes with different geometries are tested to penetrate rat's dura by hand insertion. The test results are shown in Table 1. The probes without top parylene layer are very brittle and all failed in the vivo tests. The results prove that parylene insulating/protecting layer makes greatly improvement of the probe mechanical properties. A chronic implantation of the testing silicon probe in rat's brain has been done to test the probe biocompatibility. The animal recovered very well after 7 days. As a common knowledge, rat's dura is a little bit thicker than primates' pia. A successful chronic implantation in monkey's cortex by penetrating monkey's pia is done using a complete device with metal electrodes and flexible parylene cables.

Table 1. Silicon probes rigidity vivo test results

Probe No.	Probe shank length L (mm)	Probe shank base width W (μm)	Probe shank thickness T (μm)	Top parylene layer thickness T1 (μm)	Testing results (penetrating rat's dura)
1	1.0, 1.5	75	150	10	successful
2	6.0, 6.5, 7.0, 7.5, 8.0	75	150	10	failed
3	8.0	100, 120, 140,160,180,200	200	0	failed
4	6.0, 6.5, 7.0, 7.5, 8.0	200, 250	240	10	successful
5	6.0, 6.5, 7.0, 7.5, 8.0	175	100, 120, 140, 160, 180, 200	10	successful
6	6.0, 6.5, 7.0, 7.5, 8.0	150	100, 120, 140, 160, 180, 200	10	successful
7	6.0, 6.5, 7.0, 7.5, 8.0	125	100, 120, 140, 160, 180, 200	10	failed
8	6.0, 6.5, 7.0, 7.5, 8.0	100	100, 120, 140, 160, 180, 200	10	failed

4. Conclusions

The new parylene-embedded MEMS probes are developed, and the mechanical properties are validated by animal tests.

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