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Development of Si Long Microprobe (SiLM) for Platform of Intelligent Neural Implant Microsystem

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1. Introduction

Recently, in order to develop new information processing systems or to cure brain diseases such as paralysis, epilepsy, and Parkinson's disease, many research programs for cerebral nervous system are in progress worldwide. In these researches, various types of Si microprobe have been developed to record neuronal signals from the brain of animals [1]. The conventional Si microprobes are used only for analysis of small animals. This is because its length is very short, that is, 10mm or less. Therefore, to achieve the neuronal signal recording for not only small animals but also big animals like primates, we proposed the novel Si long microprobe (SiLM) with the length of sub-100 mm in 2004 [2]. Our SiLM can be also used for the analysis of deep part of brain such as substantia nigra in basal ganglia where Parkinson's disease originates. In addition, as opportunities for a thorough exploration of neural functions increase, further functional systems with the SiLM array, which we call intelligent neural implant microsystem, are required. Figure 1 shows the configuration of intelligent neural implant microsystem which consists of the SiLM array, processing circuits, flexible cables with secondary coil for inductive link, main control circuits, and various kinds of sensors. In this system, low noise amplifiers, multiplexers, and D/A converters are directly mounted on the SiLM array, because the neuronal signal is as extremely low as 10μV and the resultant signal-to-noise (S/N) ratio is very small [3]. By using this system, neurophysiologists can precisely record the neuronal activity from any animal's brain without restriction of animal.

In this work, we optimize structural parameters of the SiLM using equivalent circuit analysis, and fabricate the carefully-designed SiLM, which is the platform of intelligent neural implant microsystem. Furthermore, we perform animal experiments of recording the neuronal signal from CA1 region in a hippocampal slice.

2. Equivalent Circuit Analysis of SiLM

In general, a long microprobe has large wiring area and the resultant large insulating film capacitance, which leads to an attenuation of output signal. In order to solve this problem, we developed and analyzed an equivalent circuit model for optimization of structure of SiLM, as shown in Fig. 2. By using this model, we changed parameter values and performed mathematical calculations to determine the optimum thickness of insulating films over and under the wiring. As the result of calculation, we employed the film thickness of 1.5μm and 1μm, respectively. We also optimized width of the wiring from the viewpoint of resistance and capacitance.

The overall structure of the optimized SiLM is shown in Fig. 3. This needle-shaped SiLM has the length of 40mm, the width of 120μm, and the thickness of 140μm. At the tip of this SiLM, the round shape was employed to prevent injury to the neurons. The recording sites made of W/Al are located in 40μm behind the tip and have 4 circular patterns of 20μm diameter and 100μm pitch.

Our SiLM was fabricated by combining standard photolithography with bulk micromachining techniques. Figure 4 shows the photograph of fabricated SiLM with 4 recording sites mounted on the extension board to connect with the recoding apparatuses. The SiLM was covered with a stainless steel pipe to reduce a noise and to improve a mechanical strength. Figure 5 shows the impedance characteristics of the fabricated SiLM in a saline solution. Our SiLM has the appropriate impedance value of about 2MΩ at 1kHz, because the microprobes usually requires impedance values of several MΩ at 1kHz to record the neuronal signal [4]. As results, the large output signal can be obtained with this SiLM.

3. Neuronal spike potentials recording using SiLM

We measured the neuronal spike potentials with hippocampal slice obtained from the brain of guinea pigs (200-250g). Animal experiments were authorized by the committee for experiment on animal of Graduate School of Information Sciences, Tohoku University. As shown in Fig. 6, a neuronal signal was recorded extracellularly in the pyramidal cell layer of CA1 area in 400-μm-thick hippocampal slice. We successfully recorded neuronal spike potentials from the individual neuron by using the SiLM, as shown in Fig. 7. Since we achieved the noise amplitude as low as 20μV with the SiLM, we can detect small neuronal spike potentials.

4. Summary

We performed the equivalent circuit analysis to optimize structural parameters of SiLM, and determined optimum thicknesses of insulating films and width of the wiring. The SiLM was fabricated and had an impedance of 2MΩ at 1kHz, which was suitable for the neuronal signal recording. Using our carefully-designed SiLM, we successfully recorded neuronal spike potentials of hippocampal slice. We will develop the intelligent neural implant microsystem with SiLM array.

Acknowledgment

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References

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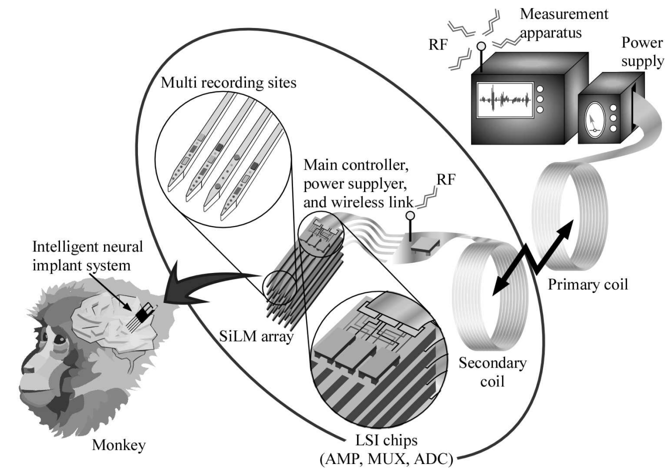
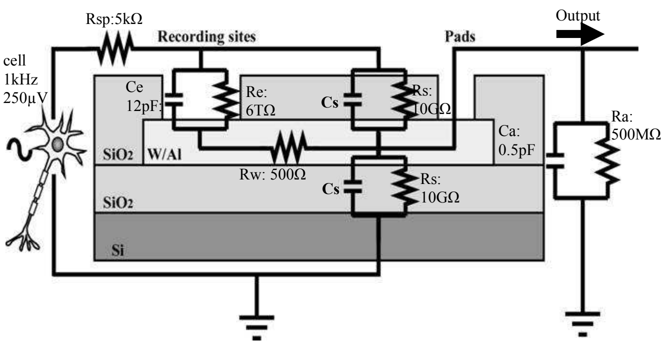


Fig. 1. Configuration of intelligent neural implant microsystem.



Rsp: Resistance of cell fluid
Ce: Capacitance of recording site
Re: Resistance of recording site
Rw: Resistance of wiring
Cs: Capacitance of insulating film
Rs: Resistance of insulating film

Fig. 2. Equivalent circuit of the SiLM.

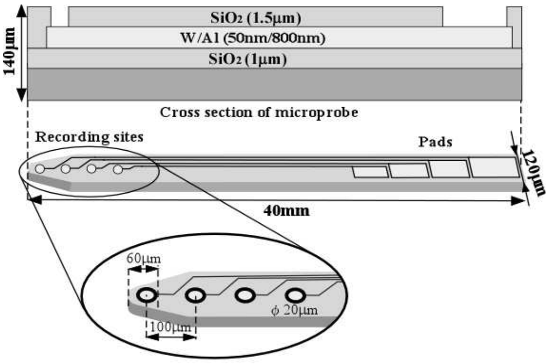


Fig. 3. Optimized structure of the SiLM.

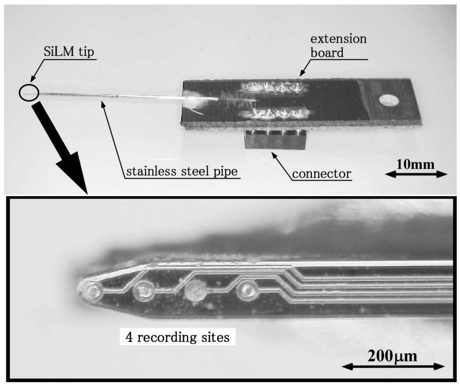


Fig. 4. Photographs of the SiLM mounted on extension board.

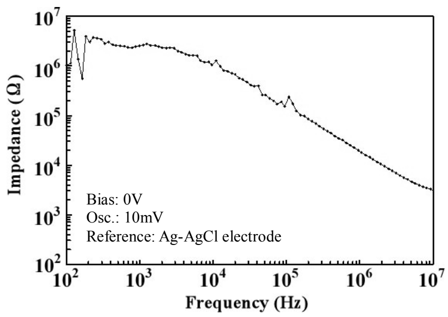


Fig. 5. Impedance spectra of the fabricated SiLM.

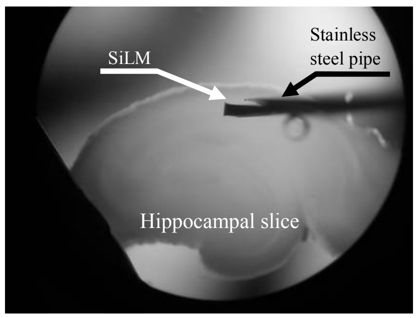


Fig. 6. Photograph of the SiLM inserted into hippocampal slice.

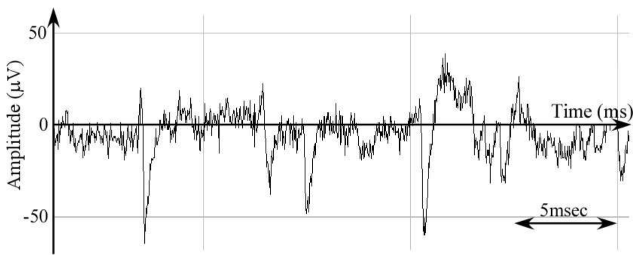


Fig. 7. Recorded neuronal spike potentials of hippocampal slice.