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Ultimate Functional Multi-Electrode System (UFMES) Based on Multi-Chip Bonding Technique

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1. Introduction

Aiming to develop a new information processing system or cure brain diseases, many research programs for revealing cerebral nervous system have been progressing in the world. Most neurophysiologists currently use conventional single neural recording techniques with a electrode made of a electrolytically etched tungsten wire [1]. Therefore simultaneous multipoint recording of neurons in the brain has attracted considerable attention in neurophysiology due to its high measurement efficiency [2]. As opportunity for a more thorough exploration of neural and cellular functions increase, further functionalized systems, which we call as Ultimate Functional Multi-Electrode System (UFMES), are required. In this system, neurophysiologists can always precisely record the electrical response from individual neurons without causing the animals pain.

In order to realize the UFMES based on multi-chip bonding technique, we developed a new multipoint recording Si microelectrode, multi-chip bonding technique with biocompatible resin and biocompatible flexible cable. In this paper, we describe these components, and the measured result of neural activity in the primate premotor cortex using the test Si microelectrode.

2. Concept of Ultimate Functional Multi-Electrode System (UFMES) based on multi-chip bonding technique

Figure 1 illustrates the configuration of UFMES which consists of multi electrode, on-electrode circuit (MUX, AMP, and DAC), flexible cable with secondary coil for inductive link, main control circuit (controller, data link, power recover circuit and so on), and external unit.

In UFMES, low noise amplifiers, multiplexers, D/A converters, should be directly mounted on the multi-electrode array, because neural signals and signal-to-noise (S/N) ratios are extremely low: ~10μV. Therefore we developed multi-chip bonding technique with biocompatible resin. As shown in Fig. 2, a LSI chip is connected with microelectrodes via bumps by highly accurate alignment techniques. Then good *I-V* characteristics are obtained and the resistance of the bump is about 3Ω.

Most studies of neural recording have primarily focused on monkeys with their head and arm bound to the chair, which restricts the precise and real-time neural data acquisition under their natural environment. To solve such a problem, we will utilize an inductive data link for data transmission between the implant and external unit. Furthermore the external units wirelessly transmit data to the storage apparatus. Once the implant has been embedded in the brain, recording with unstrained monkeys would be achieved.

3. Fabrication of multi-electrode array

The overall structure of our test microelectrode is shown in Fig. 3. This needle-shaped electrode is 4cm long, 200μm wide, and 200μm in thickness. The tip of the electrode has an angle of 11.4 degree. The recording sites located 1mm behind the tip are made of tungsten/aluminum with circular pattern of 15μm radius and with separation of 100μm, center to center. This electrode is fabricated by combining standard photolithography with bulk micromachining techniques: Chemical Vapor Deposition (CVD), sputtering, Chemical Mechanical Polishing (CMP), and wet- and deep dry-etching. Figure 4 shows the photograph of 8-channel patterned microelectrode covered with a stainless steel pipe to support penetration of the microelectrode into the closed dura mater. We also developed fully parallel microelectrode array having 200 recording sites (5 by 5 electrodes and 8 channels) and biocompatible flexible cables connected to the electrodes as shown in Fig. 5.

4. Results and Discussions

Figure 6 shows the photograph of our assembled single microelectrode test system consisting of a stainless steel pipe for a puncture through the dura, a manipulator for control in positioning, and stainless steel lead wires for connection to amplifiers. With this microelectrode, we monitored the somatosensory response from the monkey premotor cortex contributed to lower limb under ketamine anesthesia. A performance test of the single microelectrode in a prepared monkey shows that it was strong enough to penetrate dura matter to desired depth. As shown in Fig. 7, we successfully observed neural signals (impedance ~40kΩ) with our fabricated microelectrode system; the amplitude of noise is approximately 10μV. The intensity of the signals greatly changes at two second intervals, which shows collective action of neurons in sub-millimeter-scale premotor regions. Observation of further intense neural spikes can be expected using our newly designing electrodes having high impedance ranging from 1MΩ to 2MΩ.

5. Summary

We proposed Ultimate Functional Multi-Electrode System (UFMES) in which wireless implantable multi microelectrodes with electric circuits and a flexible cable are formed by multi-chip bonding techniques. In order to realize the UFMES based on multi-chip bonding technique, we developed a new multipoint recording Si electrode, multi-chip bonding technique with biocompatible resin and biocompatible flexible cable. Microelectrode array was successfully fabricated by Si technology, and neural response was clearly detected with a test microelectrode.

References

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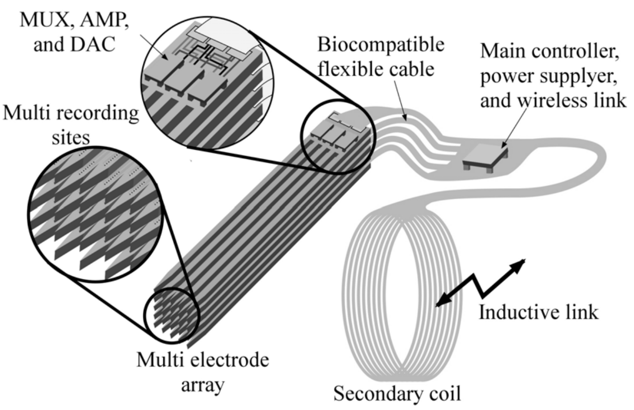

Fig. 1 Configuration of UFMES.

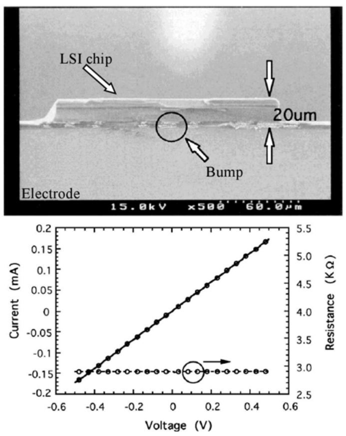

Fig. 2 SEM cross-sectional view of LSI chip on electrode using multi-chip bonding technique, and *I-V* characteristics and bump contact resistance measured using chain patterns.

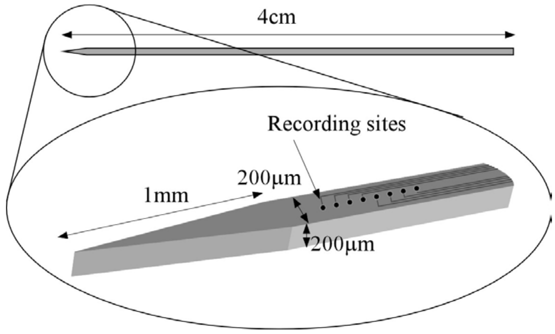

Fig. 3 The design of the microelectrode with 8 channels.

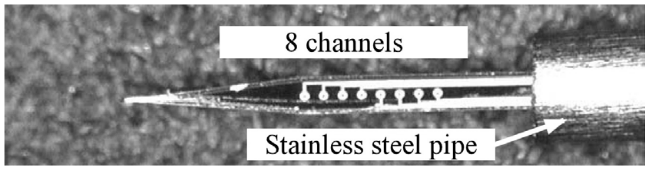

Fig. 4 Photograph of the microelectrode with 8 channels.

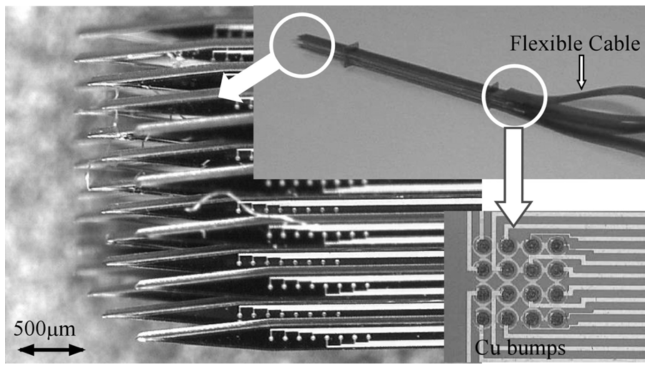

Fig. 5 Photograph of the fabricated multi-electrode array with biocompatible flexible cables.

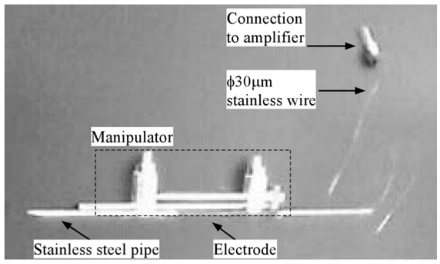

Fig. 6 Photograph of the assembled single microelectrode.

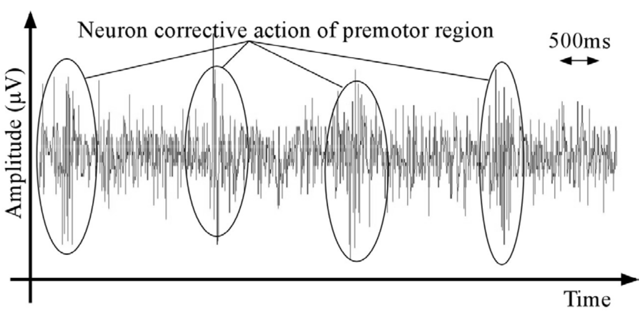

Fig. 7 Somatosensory response from neural premotor cortex in a Japanese monkey.