Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 890-891

C-9-2

Evaluation of Electrical Stimulus Current to Retina Cells for Retinal Prosthesis by Using Platinum-Black (Pt-b) Stimulus Electrode Array

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1. Introduction

Recently, the number of patients, who lost their vision due to retinitis pigmentosa (RP) and age-related macular degeneration (AMD), has been increasing. However, effective medical treatments for these diseases have not yet been established. Retinal prostheses enable such blind patients to restore visual sensation by electrical stimulation to remaining retinal cells via a stimulus electrode array [1].

We have proposed a novel implantable retinal prosthesis system with a three-dimensionally (3D) stacked retinal prosthesis chip [2]. As shown in Fig. 1, the 3D stacked retinal prosthesis chip is mounted onto a flexible cable with a stimulus electrode array. In the 3D stacked chip, several LSI chips such as a photodetector, an image processor, electrical stimulus current generator are thinned, vertically staked, and electrically connected with each other by short vertical interconnections through the LSI chip. Therefore, the advanced retinal prosthesis chip with small size, light weight, and large fill factor can be realized.

The stimulus current is an essential parameter to design the retinal prosthesis chips and to provide the blind patients with proper visual information. To obtain the optimum stimulus current, it is very important to perform some fundamental animal experiments such as recording of electrically evoked potential (EEP) which represents electrical activities in the primary visual cortex. In our previous paper, we have successfully observed the EEP of a rabbit using an Al stimulus electrode array [3]. This paper describes experimental results of the EEP recording with a rabbit using an array of Platinum-black (Pt-b) stimulus electrode on a flexible cable. Pt-b is inert material and suitable for stimulus electrodes of neural prostheses including the retinal prosthesis. Besides, Pt-b has very low impedance due to the porous surface.

2. Experiments

The structure of the flexible cable with Pt-b stimulus electrode array for retinal stimulation in EEP recording test is shown in Fig. 2. The cable has the length of 140 mm, the width of 2 mm, and the thickness of 30 μm. Biocompatible polyimides are employed as the flexible cable. The array of 4 × 4 Pt-b stimulus electrodes is formed at the end of the cable. The stimulus electrodes are 70 μm in diameter and are placed at a pitch of 200 μm. At the other end of the cable, 16 pads for electrical connection to a stimulus current generator are formed.

The stimulus electrode array on the flexible cable was fabricated on a 2-inch Si wafer by using standard photolithographic techniques. First, a polyimide precursor was spin-coated and cured at 320 ˚C. The resultant polyimide layer with a thickness of ~30 μm was patterned by Reactive Ion Etching (RIE). Then, Al wirings with a thickness of 1 μm were formed by wet etching. After Pt-b formation by a lift-off technique, the Al wirings were covered with a photosensitive polyimide. Finally, the Si wafer was immersed in buffered HF solution for several hours to remove the flexible cable from the Si wafer.

The EEP was measured at the visual cortex of Japanese white rabbits (2-3 kg) upon retinal stimulation with Pt-b or Al stimulus electrode array. All procedures adhered to the Association for Research in Vision and Ophthalmology (ARVO) Resolution on the Use of Animals in Research. The flexible cable with stimulus electrode array, which was connected to the stimulus current generator, was fixed on the surface of the retina by a retinal tack.

3. Results and Discussion

As shown in Fig. 3, the Pt-b stimulus electrode array was fabricated on the flexible cable. Figure 4 shows SEM images of cross-sectional and top view of the fabricated Pt-b stimulus electrode. The porous structure of Pt-b was clearly observed in these figures.

Figure 5 compares the dependence of impedance on frequency for both Pt-b and Al stimulus electrodes. The Pt-b stimulus electrode shows the impedance of 108 kΩ at 1 kHz, whereas the impedance of Al stimulus electrode was 1.55 MΩ. In general, power consumption of more than 100 mW on the retina causes permanent damages of the retinal tissue [4]. Therefore, the power dissipation for our retinal prosthesis system has to be reduced. From the results of impedance measurement using biphasic stimulus current with a pulse width of 500 μs and period of 10 ms, we estimated the relationships between power consumption at 4 × 4 stimulus electrode array and stimulus current, as shown in Fig. 6. As the Pt-b stimulus electrode array shows an 88 % lower power consumption in comparison with the Al stimulus electrode array, Pt-b is suitable for the stimulus electrode array of the retinal prosthesis system.

Stimulus current parameters such as pulse width, amplitude, and period can be optimized by comparing waveforms of the EEP with those of visually evoked potential (VEP) caused by incident light. As a result of animal experiment with Pt-b stimulus electrode array, the EEP response was successfully recorded by stimulating the retina with electrical current of both 200 μA / 50 μs in cathodic amplitude/width, and 100 μA / 100μs in anodic amplitude/width, respectively (Figure 7). This experimental result indicates that the electrical stimulation to the retina with Pt-b stimulus electrode array can restore the visual sensation.

4. Conclusion

We fabricated the Pt-b stimulus electrode array on the flexible cable for the EEP recording. Power consumption of the resultant Pt-b stimulus electrode with the impedance of 108 kΩ at 1 kHz proved to be extremely lower than that of the Al stimulus electrode array. In addition, we successfully recorded the EEP from the brain of rabbits when the retina was stimulated by the Pt-b stimulus electrode array.

Acknowledgments

This work was partially supported by the 21st Century COE Program "Future Medical Engineering based on Bio-nanotechnology", from the ministry of Education, Culture, Sports, Technology and Science, Japan and Venture Business Laboratory, Tohoku University, Japan.

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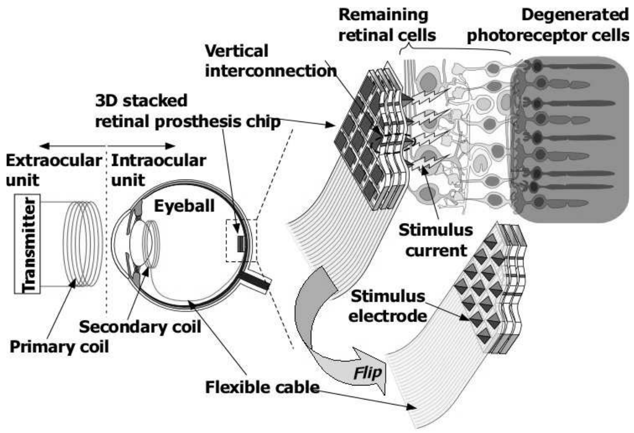


Fig. 1. Configuration of novel retinal prosthesis system with 3D staked retinal prosthesis chip.

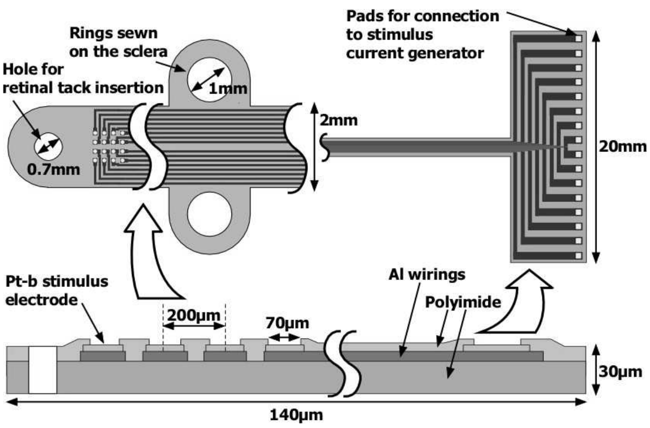


Fig. 2. Structure of flexible cable with Pt-b stimulus electrode array.

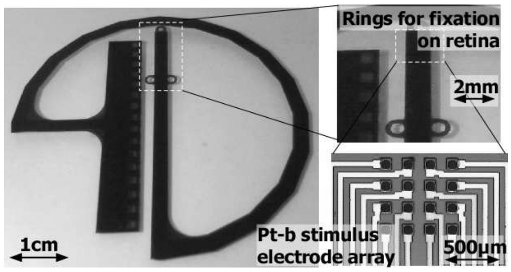
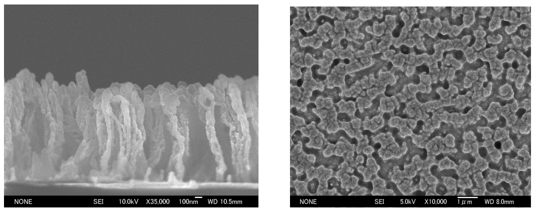


Fig. 3. Photographs of fabricated flexible cable with Pt-b stimulus electrode array.



(a) cross-section (b) top surface

Fig. 4. SEM images of Pt-b stimulus electrode on the cable.

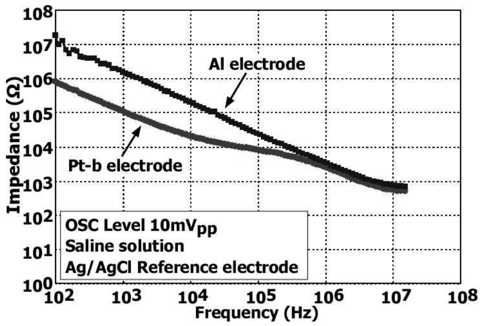


Fig. 5. Impedance spectra of Pt-b and Al stimulus electrodes.

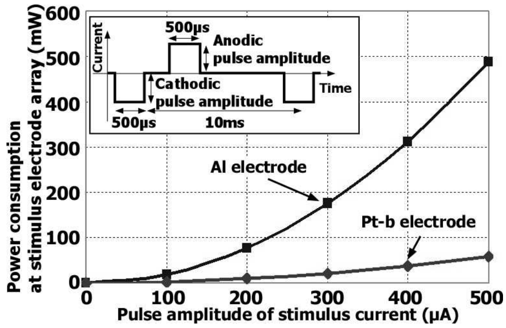


Fig. 6. Relationships between calculated power consumption and stimulus current amplitude.

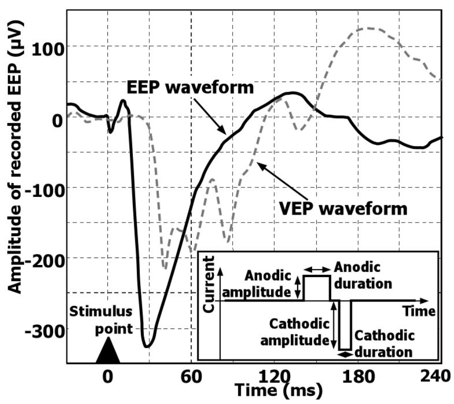


Fig. 7 EEP waveform from the rabbit visual cortex upon retinal stimulation with Pt-b stimulus electrode.