Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp183-184

Fabrication and *in vivo* Evaluation of High Performance Stimulus Electrodes Employed in a CMOS Chip for Retinal Prosthesis

Toshihiko Noda[1], Shingo Tomimatsu[1], Kiyotaka Sasagawa[1], Takashi Tokuda[1], Yasuo Terasawa[2], Kentaro Nishida[3], Takashi Fujikado[3] and Jun Ohta[1]

[1]Nara Institute of Science and Technology (NAIST), Graduate School of Materials Science
8916-5 Takayama, Ikoma, Nara 630-0192, Japan
Phone: +81-743-72-6054 E-mail: t-noda@ms.naist.jp
[2]NIDEK Co., Ltd., R&D Div., Vision Institute, Hama 73-1, Gamagori, Aichi, Japan
[3]Osaka University, Graduate School of Medicine, 2-15 Yamadaoka, Suita, Osaka 565-0871, Japan

1. Introduction

A large number of research on LSI-based biomedical device, for example Brain Machine Interface (BMI) device [1-2] and intelligent prosthesis [3-5], have been performed increasingly. Retinal prosthesis technology is one of the most expected field on which LSI-based neural interfacing device would play an essential role [3-5]. The retinal prosthesis technology aims to provide a substitutional visual sensation to the patients of retinitis pigmentosa (RP) and age-related macular degeneration (AMD), using a patterned electrical stimulation onto visual nerve system. We have proposed multi-chip architecture to realize a CMOS-based flexible retinal stimulator [6-7]. The proposed stimulator consists of small size (less than a few hundred μm square) unit chip, and each unit chip has stimulus electrode. Thanks to multi-chip architecture, multi-point stimulation of large area and flexibility are realized simultaneously.

However, it becomes difficult by the miniaturization of stimulus electrodes to obtain enough charge delivery capacity (CDC) for stimulation. In this study, high performance stimulus electrodes with high CDC were fabricated. Iridium Oxide (IrOx) was selected as one of the materials with high CDC. Fabrication process parameters were considered. Relationship of process parameter with CDC was evaluated through electrochemical method. *In vivo* evaluation was performed using fabricated high performance stimulus electrodes, and it confirmed that retinal stimulation was possible.

2. Fabrication of high performance stimulus electrodes

The most typical material of stimulus electrode in biomedical field is platinum. We have succeeded in stimulation of retina using platinum stimulus electrode [6-7], however, poor performance of platinum electrode about CDC became clear too. Larger CDC than platinum is required for retinal stimulator with micro electrode. IrOx attracts attention as one of the higher performance material of stimulus electrode in biomedical field [8-9]. IrOx micro electrodes were fabricated and evaluated with electro-chemical method.

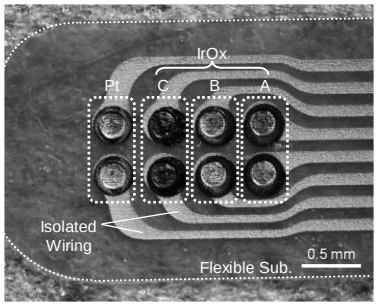

Fig.1 Fabricated stimulus electrodes on flexible substrate.

Circular micro electrodes (ϕ300μm) were fabricated on flexible substrate as shown in Fig. 1. IrOx was deposited by RF reactive sputtering using iridium target and oxygen gas. Properties of deposited film can be controlled with sputtering condition. Partial pressure of oxygen in sputtering gas is related to composition ratio of deposited film, and total pressure of sputtering gas has strong effect about surface morphology. Surface morphology and composition ratio of stimulus electrodes are one of the most important properties to realize high CDC. To optimize sputtering condition, IrOx electrodes were fabricated with different process parameter as shown in Tab. 1. As a standard of performance, Pt electrodes were also fabricated by RF Ar sputtering.

Tab.1 Sputtering process condition

Material	IrOx			Pt
Condition	A	B	C	-
Ar Gas [sccm]	8	8	0	20
O_2 Gas [sccm]	2	2	10	0
Pressure [Pa]	0.2	1.0	1.0	0.35

3. Evaluation of fabricated electrodes

3.1 Electrochemical evaluation

Properties of fabricated electrodes were evaluated through two electrochemical measurement. Cyclic Voltammetry (CV) measurement was performed to estimate fundamental electrochemical characteristic. Fig. 2 shows cyclic voltamogram of IrOx electrode fabricated with condition "C" shown in Tab. 1. From comparison of cyclic voltamogram of IrOx and Pt, closed area of CV curve of IrOx is much larger than Pt. The result means that IrOx has larger CDC than Pt at the voltage range inside of potential window.

CDC measurement by pulse current injection was performed. This measurement is near condition of operating electrode of retinal prosthesis than CV measurement. Pulse current was supplied from stimulus current generator to electrodes steeped in Phosphate Buffered Saline (PBS).

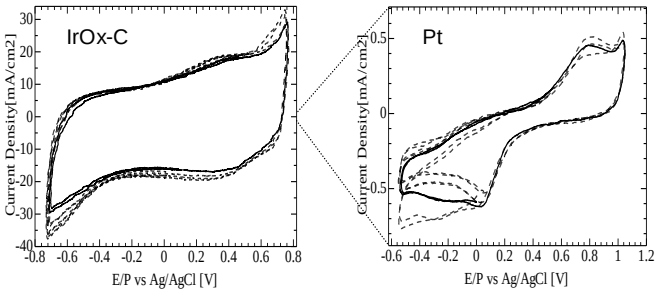

Fig.2 Cyclic voltamogram of fabricated electrodes.

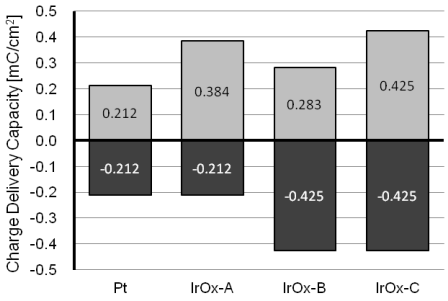

Fig.3 Charge delivery capacity of fabricated electrodes.

Potential of the stimulus electrode versus reference electrode and injection current were observed. From these potential and current data, CDC of the electrode was estimated as shown in Fig. 3. Every IrOx electrodes which were fabricated with different sputtering condition showed larger CDC than Pt. Condition "C" has the best performance as well as CV measurement result.

3.2 *In vivo* evaluation

Fabricated electrodes were *in vivo* evaluated using experimental animal. Experimental setup is shown in Fig. 4. Current controlled retinal stimulations were performed in Suprachoroidal Transretinal Stimulation (STS) configuration [10-11] and electrically evoked potentials (EEPs) were observed on visual cortex of an anesthetized rabbit. Stimulation conditions were cathodic first biphasic pulse with pulse height of 1 mA and pulse width 1 ms. EEP signals were observed using screw electrodes that are commonly used for physiological measurements of field potentials on brains of experimental animals.

Fig. 5 shows typical EEP signals evoked by the stimulation using IrOx and Pt electrodes. Clear EEP responses were successfully obtained with the stimulations. Peak electrical potential of IrOx electrode was lower than Pt, this result was obtained by high CDC of IrOx.

4. Conclusions

IrOx micro stimulus electrodes were fabricated. Sputtering condition of IrOx affects directly CDC of electrode, and that was revealed by electrochemical measurement. *In vivo* retinal stimulation using experimental animal was successfully performed, and EEP responses were obtained clearly. High performance of the IrOx stimulus electrode was clearly demonstrated.

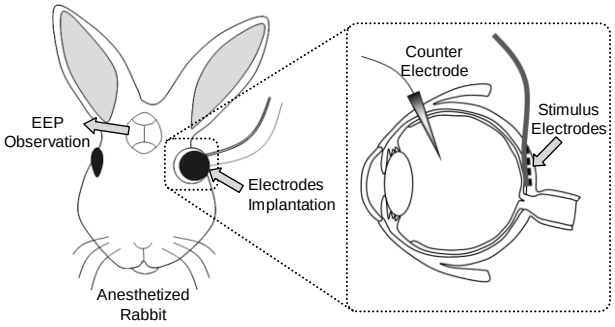

Fig.4 Experimental setup of *in vivo* electrodes evaluation.

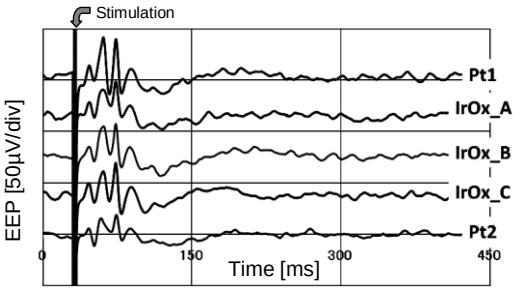

Fig.5 EEP signals evoked by the fabricated electrodes.

Acknowledgements

This work was supported by Health and Labor Sciences Research Grants from Ministry of Health, Labour, and Welfare of Japan, and by the Strategic Research Program for Brain Sciences from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

[1] K. D. Wise and K. Najafi, Science **254** (1991) 1335.

[2] T. Kawano, Y. Kato, R. Tani, H. Takao, K. Sawada, M. Ishida, IEEE Trans. Electron Devices **51** (2004) 415.

[3] W. Liu, K. Vichienchom, M. Clements, S. C. DeMarco, C. Hughes, E. McGucken, M. S. Humayun, E. de Juan, J. D. Weiland, R. Greenberg, IEEE J. Solid-State Circuits **35** (2000) 1487.

[4] J. Ohta, N. Yoshida, K. Kagawa, and M. Nunoshita, Jpn. J. Appl. Phys. **41** (2002) 2322.

[5] J. Deguchi, T. Watanabe, T. Nakamura, Y. Nakagawa, T. Fukushima, S. J.-Chill, H. Kurino, T. Abe, M. Tamai, and M. Koyanagi, Jpn. J. Appl. Phys. **43** (2004) 1685.

[6] T. Tokuda; R. Asano; S. Sugitani; M. Taniyama; Y. Terasawa; M. Nunoshita; K. Nakauchi; T. Fujikado; Y. Tano; J. Ohta, Jpn. J. Appl. Phys. **47** (2008) 3220.

[7] T. Tokuda, K. Hiyama, S. Sawamura, K. Sasagawa,Y. Terasawa, K. Nishida, Y. Kitaguchi, T. Fujikado, Y. Tano, J. Ohta, IEEE Trans. Electron Devices **56** (2009) 2577.

[8] J. D. Weiland and D. J. Anderson, IEEE Trans. Biomedical Eng. **47** (2000) 911.

[9] J. D. Weiland, D. J. Anderson and M. S. Humayun, IEEE Trans. Biomedical Eng. **49** (2002) 1574.

[10] H. Kanda, T. Morimoto, T. Fujikado, Y. Tano, Y. Fukuda, and H. Sawai, Invest. Ophthal. & Vis. Sci., **45** (2004) 560.

[11] T. Fujikado, T. Morimoto, H. Kanda, S. Kusaka, K. Nakauchi, M. Ozawa, K. Matsushita, H. Sakaguchi, Y. Ikuno, M. Kamei and Y. Tano, Graefes Arch. Clin. Exp. Ophthalmol., **245** (2007) 1411.