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CMOS-based smart-electrode-type retinal stimulator with bullet-shaped bulk Pt electrodes

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***Abstract*— A CMOS-based flexible retinal stimulator equipped with bullet-shaped bulk Pt electrodes was fabricated and demonstrated. We designed a new CMOS unit chip with an on-chip stimulator, single- and multi- site stimulation modes, and monitoring functions. We have developed a new structure and packaging process of flexible retinal stimulator with bullet-type bulk Pt electrode. We have confirmed the retinal stimulation functionality in an *in vivo* stimulation trial on rabbit's retina.**

I. Introduction

RETINAL prosthesis has been attracting a lot of scientific and technological interest [1-5]. We have developed and demonstrated a series of CMOS-based flexible neural stimulators based on multi-chip architecture [6-10]. We have successfully demonstrated features of the CMOS-based retinal stimulators such as flexibility and functionality. In the prototypes that have been reported previously [6-10], we have used on-chip Pt bump electrodes fabricated with conventional ball bonding technique. Typical diameter of the on-chip Pt bump electrode was 100 µm. Although it is acceptable to demonstrate the functionality of the retinal stimulator in *in vivo* tials, the size of the Pt electrodes limits the stimulation strength [10]. To apply the CMOS-based flexible retinal stimulator for further *in vivo* feasibility study, electrode with larger stimulation capability should be implemented. It means that we have to shift the configuration of the stimulation electrode from on-chip to off-chip, thus "smart-electrode" type. To implement off-chip stimulation electrode, we have to design a new device structure and packaging process that is compatible with an off-chip electrode. However, changing the electrode configuration, we obtain a wide option in material, size and shape of the stimulation electrode. A bullet-shaped bulk Pt electrode is one of the most promising candidates for the stimulation electrode [11]. The typical size of the bullet-shaped bulk Pt electrode is 500 µm in both diameter and height, and we expect a drastic improvement of the current injection performance from the on-chip Pt bump electrode.

In this work, we developed a CMOS-based smart-electrode-type retinal stimulator with bullet-shaped bulk Pt electrodes. A CMOS unit chip equipped with on-chip biphasic current generator was designed, and packaging structure and process were developed. An *in vivo* retinal stimulation on rabbit's retina was successfully performed.

Fig.1 shows the concept of the CMOS-based flexible retinal stimulator, and implementation of the bullet-shaped bulk Pt electrode.

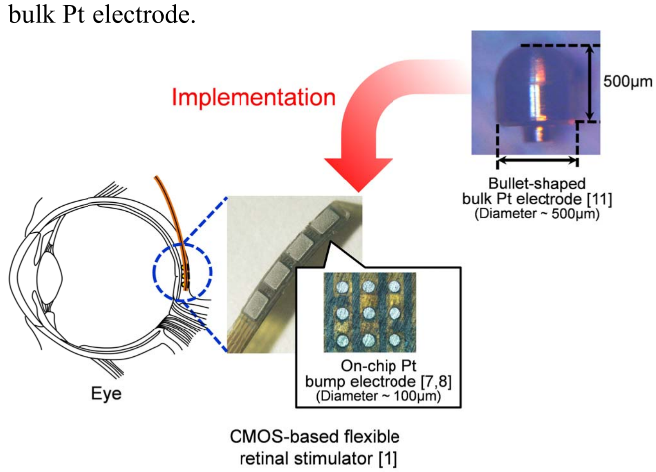

Fig. 1. Concept of the CMOS-based flexible retinal stimulator and implementation of the bullet-shaped bulk Pt electrode.

II. Design and Functions of CMOS Unit Chip for Smart-Electrode-Type Retinal Stimulator

In the multi-chip architecture, we realize a flexible neural stimulator with an array of small-sized CMOS intelligent neural stimulator chips. We called is as "unit chip". In the present work, we designed a smart-electrode-type retinal stimulator in which each bullet-shaped bulk Pt electrode is accompanied with individual CMOS unit chip.

Fig.2 shows layout of the CMOS unit chip designed in this work. Specifications of the unit chip are summarized in Table I. The unit chip was designed using 0.35 µm standard CMOS technology. The operation voltage is 5V. It has a footprint of 400 µm × 400 µm, which is smaller than that of bullet-shaped bulk Pt electrode used in this work.

The unit chip has four inputs; VDD, GND, CONT1, and CONT2. VDD (5V) and GND (0V) are power supply lines, and CONT1 and CONT2 are 5V digital lines to control the

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unit chips. All the unit chips on a multi-chip retinal stimulator are connected in parallel on one set of VDD, GND, CONT1, and CON2. Thus, we can control the multi-chip retinal stimulator using four lines. Maximum number of the unit chips on one retinal stimulator is 256.

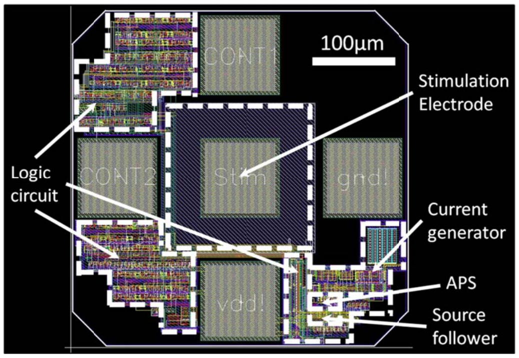

Fig. 2. Layout of the CMOS unit chip.

TABLE I
SPECIFICATIONS OF THE UNIT CHIP

Technology	0.35 µm 2-poly 4-metal Standard CMOS
Chip size	400 µm×400 µm
Input	4 (Vdd,gnd,CONT1,CONT2)
Output	1 (Stimulation)
Drive voltage	5V
Chip ID	8bit (Max. 256 unit chips)
Current output	50 ~ 1000 µA, 50 µA step

Fig. 3 shows a block diagram of the unit chip. A digital control circuitry for addressing and commanding the unit chip, and a current-generator are implemented. A voltage sensing circuit was also implemented to monitor the situation around the stimulation electrode. Two digital inputs named as CONT1 and CONT2 are used to control the unit chip. Number of the pulses applied on CONT2 is used as the command value. Pulses on CONT1 are used as delimiter, thus, to separate the pulses on CONT2 into command values. The command system for the CMOS unit chip was described our previous reports [10, 11].

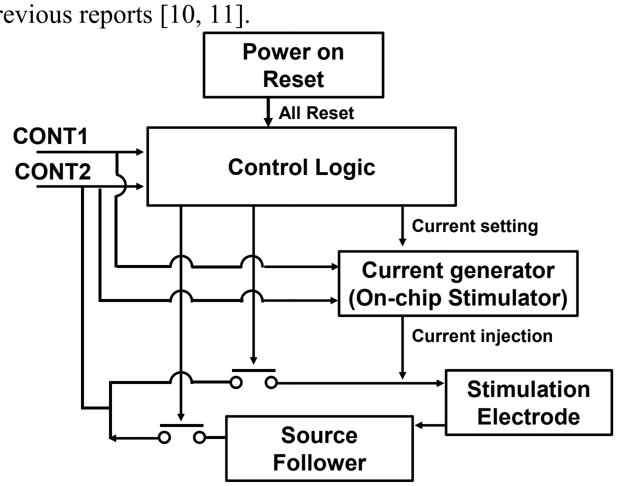

Fig. 3. Block diagram of the unit chip.

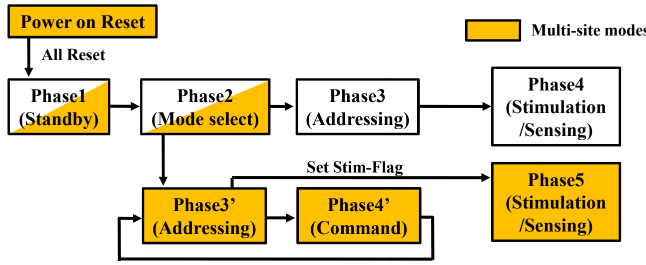

Fig. 4. Operation phase diagram of the unit chip.

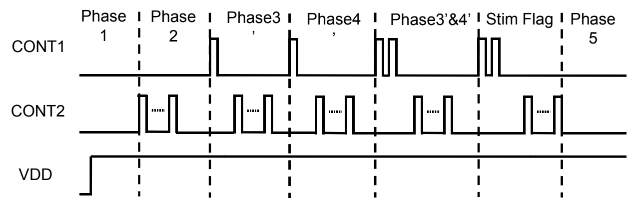

Fig. 5. Typical control sequence (multi-site stimulation).

TABLE II
OPERATION MODES

Bit of mode buffer	Operation mode
Bit 1	Single site relay stimulation (default)
Bit 2	Single site sensing
Bit 3	Multi-site biphasic on-chip stimulator
Bit 4	Multi-site monophasic on-chip stimulator (positive) with single site sensing
Bit 5	Multi-site monophasic on-chip stimulator (negative) with single site sensing

Fig. 4, and Fig. 5 show phase diagram and typical control sequence for the multi-chip retinal stimulator. All the unit chips are reset and restarted at the power supply (VDD 0V to 5V). At first, we choose an operation mode to be used (phase 2). The implemented operation modes are listed in Table II. The operation mode is stored in an asynchronous counter (mode buffer) whose bits show the operation mode. After we selected the operation mode, we can set stimulation conditions on the unit chips.

In single-site relay stimulation mode, we can directly connect CONT2 to one of the stimulation electrode accompanied with the selected unit chip, and we can perform direct stimulation using external stimulation generator such as biphasic current source (phase 4).

In multi-site stimulation modes, we use on-chip biphasic current generator as stimulation source. We can set different stimulation conditions by repeating addressing (phase3') and commanding (phase 4') loop. After we set the conditions on all the unit chips to be used, we change the operation phase into stimulation phase (Phase 5).

We also implemented a monitoring circuitry that can be used during stimulation. Voltage on one of the electrodes can be monitored with this function, which will help us to understand the situation around the electrode.

Fig. 6 shows schematic of the biphasic current generator for stimulation. The circuit is configured with two sets of MOS current sources. One is a PMOS source for positive current injection and the other is a NMOS source for negative injection. Each source was configured as parallel-connected five current lines. Choosing the lines to be used, stimulation strength can be set for each unit chip.

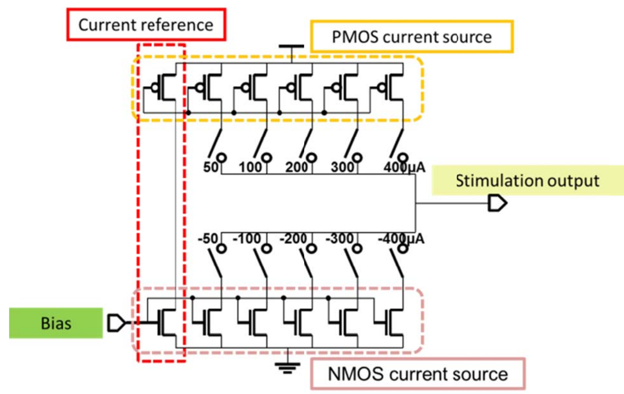

Fig. 6. Schematic of the biphasic current generator for stimulation.

TABLE III
COMMAND TABLE

Bit of command buffer	Operation mode
Bit 1	Enable 50μA
Bit 2	Enable 100μA
Bit 3	Enable 200μA
Bit 4	Enable 300μA
Bit 5	Enable 400μA
Bit 6	Enable light-controlled stimulation Using on-chip stimulator
Bit 7	Enable unconditional relaying stimulation Using external stimulator
Bit 8	Enable light-controlled relaying stimulation Using external stimulator
Bit 9	Enable monitor mode

Table III shows the commands assignable for the unit chip operation. As same as the mode buffer, the command for each unit chip is stored in an asynchronous counter (command buffer). Bits on the command buffer are used to identify the operation condition as shown in TABLE III.

III. STRUCTURE AND PACKAGING OF THE SMART-ELECTRODE-TYPE RETINAL STIMULATOR

In this work, we adopted a bullet-shaped bulk Pt electrode [11] and fabricated smart-electrode-type retinal stimulator. The electrode has a size of 500 μm in diameter and height. We designed a flexible substrate with printed wiring pattern and mounting holes for bullet-shaped bulk Pt electrodes. The unit chips are bonded onto the lands prepared near the Pt electrodes using flip-chip bonding technique.

Fig. 7 shows packaging process and structure of the smart-electrode-type retinal stimulator, and Fig. 8 show appearances of the fabricated stimulator. This device was designed for *in vivo* demonstration using rabbit, and 3 x 3 -electrodes configuration was adopted.

After confirming the waterproofness and current injection capability were confirmed in saline solution, we performed an *in vivo* stimulation experiment on rabbit's retina.

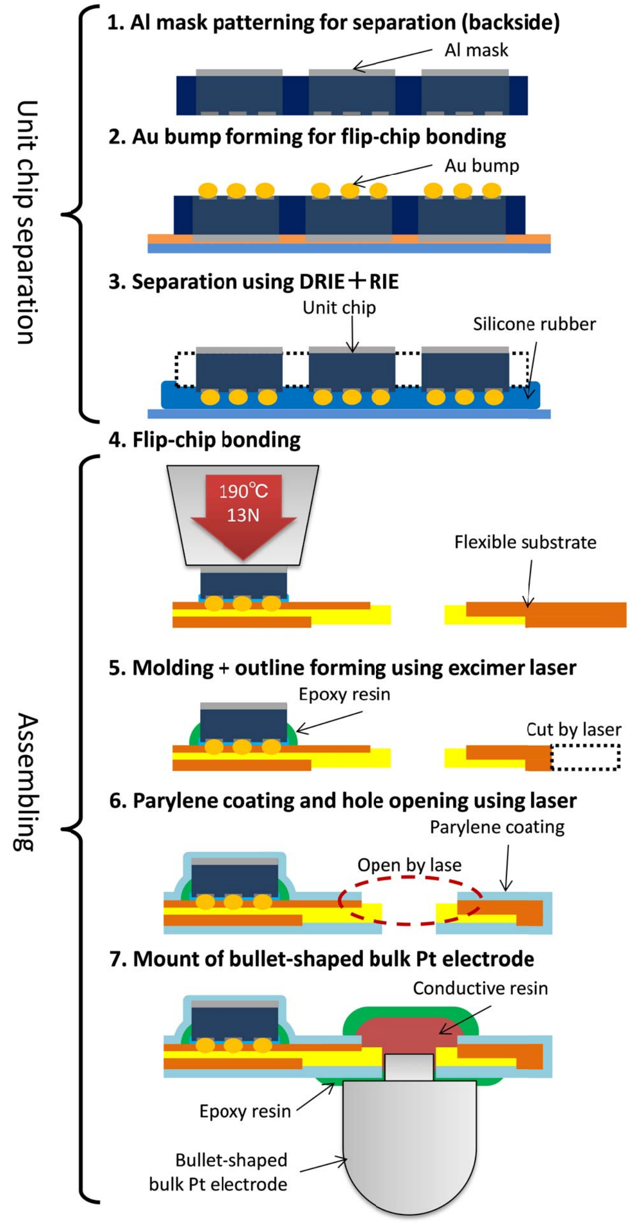

Fig. 7. Packaging process and structure of the smart-electrode-type retinal stimulator.

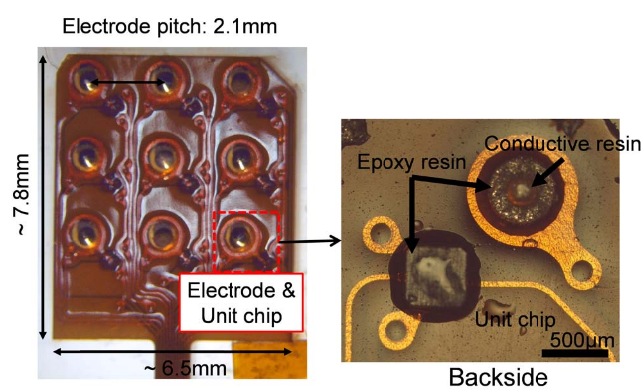

Fig. 8. Appearances of the smart-electrode-type retinal stimulator in 3 x3 configuration.

IV. *IN VIVO* FUNCTIONAL DEMONSTRATION USING RABBIT

The function of the fabricated smart-electrode-type retinal stimulator was demonstrated in an *in vivo* experiment. Fig. 9 schematically shows the experimental setup. The retinal stimulator was implanted on rabbit's retina in STS (suprachoroidal ransretinal stimulation) configuration [12] and stimulation was performed. The response (EEP: electrically evoked potential) on visual cortex was measured. Detailed experimental setup and protocol are described in the previous reports [9, 10]. All the experiments were carried out following the ARVO Resolution on the Use of Animals in Ophthalmic Research.

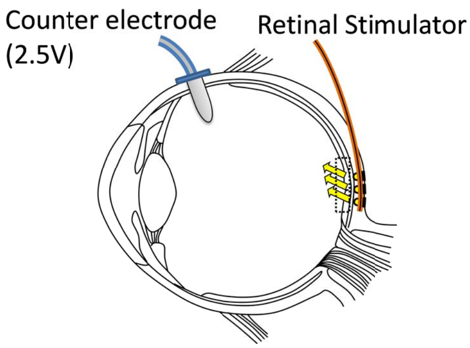

Fig. 9. Experimental setup for *in vivo* trials.

Biphasic stimulation was applied on the rabbit's retina in single-site, relay stimulation mode. The setting condition was: cathodic-first, 1mA/1ms biphasic pulse with inter-pulse duration of 0.5ms. Fig. 10 shows observed EEP response evoked using the present retinal stimulator. A response peaks which show the retinal stimulator was correctly working were observed 15-30ms after the stimulation.

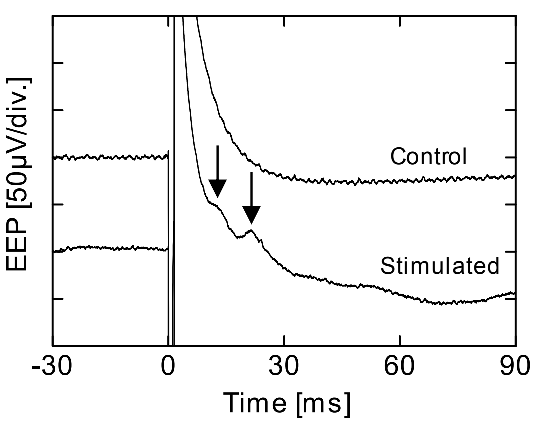

Fig.10. EEP response evoked by a stimulation using the present retinal stimulator.

V. CONCLUSION

A new type of CMOS-based flexible retinal stimulator equipped with bullet-shaped bulk Pt electrodes was fabricated and demonstrated. A new CMOS unit chip was designed and we have implemented on-chip stimulator, and single- and multi- site stimulation modes, and monitoring functions on the unit chip. We have developed a new structure and packaging process of flexible retinal stimulator with bullet-type bulk Pt electrode accompanied with CMOS unit chip. We have confirmed the retinal stimulation functionality in an *in vivo* stimulation trial on rabbit's retina. We are evaluating the detailed performance and durability of the retinal stimulator, which will be presented at the conference, too.

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