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Three-Dimensionally Stacked Analog Retinal Prosthesis Chip

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1. Introduction

More than 10 million people are blind due to end-stage photoreceptor degenerative diseases such as retinitis pigmentosa (RP) and age-related macular degeneration (AMD) in the world. The retinal prosthesis has been proposed to provide visual information to blind patients. Conventional retinal prosthesis consists of photo sensor, LSI chip and electrode array as shown in Fig.1 [1]. In this system, firstly, photo sensor captures a visual scene and converts it into pixel data. Then the LSI chip converts the image data into appropriate pattern of electrical current. The retinal neurons are stimulated by the electrical current via the electrode array positioned closely above the retina. Therefore, the blind patients would percept a dot of light at each stimulation point.

In order to fabricate a single chip implantable device, we propose a high performance retinal prosthesis chip with three-dimensionally stacked structure (3D stacked retinal prosthesis chip) in this paper [2]. We also discuss the analog circuits for 3D stacked retinal prosthesis chip.

2. 3D Stacked Retinal Prosthesis Chip

3D stacked retinal prosthesis chip that consists of thinned and stacked LSI chips is implanted closely above the retina as shown in Fig.2. Photo diodes on the top layer of this 3D chip capture a visual scene and convert it pixel data. Then, the analog circuits on the bottom layer receive the image data via vertical interconnections and convert the image data into appropriate pattern of electrical current. Consequently, the retinal neurons would be stimulated by the electrical current via the stimulus electrodes on the backside of the chip. As described above, 3D stacked retinal prosthesis chip is a single chip implantable device with photo detectors, image processing circuits, stimulating current generators and electrode array.

Depending on the degree of damage in a patient’s retina, the medical doctor must be able to tune the stimulating current waveform in such parameters as amplitude, pulse width, interphase delay and frequency as shown in Fig.3 [1][3]. The stimulating current waveform consists of alternate pulses with either positive (anodic) pulse first followed by negative (cathodic) pulse or vice versa and hence equal amount of charge is provided by both anodic and cathodic pulses to maintain charge balance.

3. Analog Circuit for 3D Stacked Retinal Prosthesis

We designed the analog circuits with the functions of light detection and stimulating current pulse generation as shown in Figs.4, 5 and 6. The light detection circuit as shown in Fig.4 was designed so as to have a large time constant at C1 in order to generate the appropriate current pulse frequency by decreasing the voltage of the output terminal “PHOTO” as gradually as possible. Figure 7 shows the dependence of the stimulating pulse current frequency on the input light current obtained by the spice simulation. Figure 8 also shows the spice simulation result of the stimulating current pulse output.

The photodiode (PD) acts as a variable current source controlled by the input light intensity in the circuit shown in Fig.4. The voltage of PHOTO gradually decreases to “Low” voltage according to the photo current. Once the voltage reaches the threshold voltage of INV1, the voltage of CATHODIC_OUT increases to “High” voltage immediately and the voltage of N1 gradually increases to “High” voltage. After that, once the voltage of N1 reaches the threshold voltage of INV2, M1 charges C1 immediately and the voltages of N1 and CATHODIC_OUT decrease to “Low” voltage. Thus, photo detection and cathodic pulse control circuit in Fig.4 detects the light and converts the light signal into the output pulses. In addition, we confirmed by the spice simulation that the pulse width is tuned by controlling the voltage of BIAS2 as shown in Fig.9 (a).

Anodic pulse control circuit shown in Fig.5 receives the output pulses of the cathodic pulse control circuit and generates the output pulses, ANODIC_OUT, in the same way. Figure 9 (b) shows the dependence of the pulse width on the voltage of BIAS5 which was obtained by the spice simulation. It was also confirmed that we can tune the interphase delay between the output pulses of cathodic pulse and anodic pulse by controlling the voltage of BIAS4 as shown in Fig.10.

Stimulating current generator circuit shown in Fig.6 receives the output pulses of the cathodic and anodic pulse control circuit and generates the stimulating current pulses as shown in Fig.8.

4. Conclusions

We proposed a new 3D stacked retinal prosthesis chip and designed the analog circuits with the functions of light detection and stimulating current pulse generation for 3D stacked retinal prosthesis chip. As the result of spice simulation, the stimulating current pulse frequency shows a linear dependence on the input photo current in a range of about three decades and we confirmed that the width of the stimulating current pulse can be tuned from about 0.5ms to 4ms and the interphase delay between the cathodic and anodic pulses also can be tuned from about 0.5ms to 5ms.

Acknowledgements

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The VLSI circuit in this study has been fabricated in the chip fabrication program of VLSI Design and Education Center (VDEC), the University of Tokyo in collaboration with Rohm Corporation and Toppan Printing Corporation.

References

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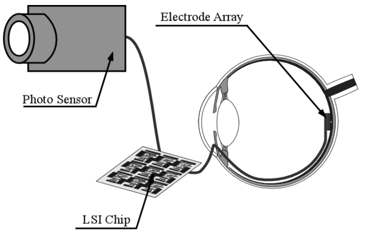


Fig. 1 Configuration of conventional retinal prosthesis.

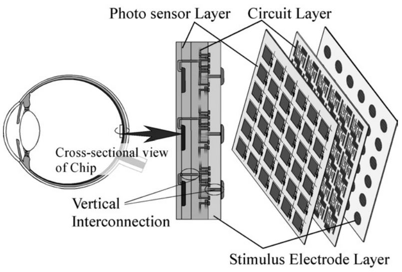


Fig. 2 Configuration of 3D stacked retinal prosthesis.

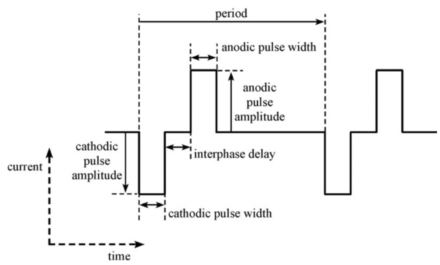


Fig.3 Diagram of stimulating current waveform.

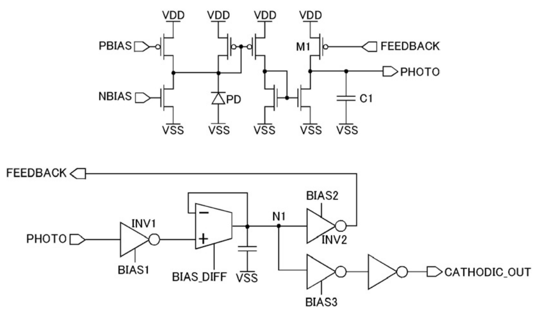


Fig.4 Schematic diagram of the photo detection and the cathodic pulse control circuits.

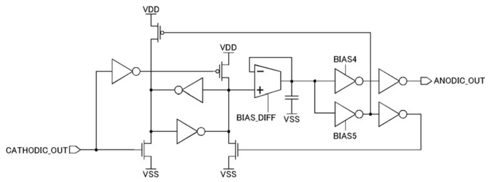


Fig.5 Schematic diagram of the interphase delay and the anodic pulse width control circuit.

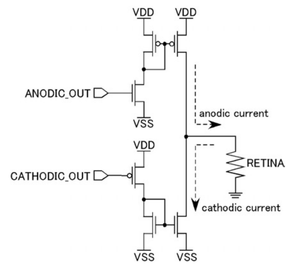


Fig.6 Schematic diagram of the stimulating current generator circuit.

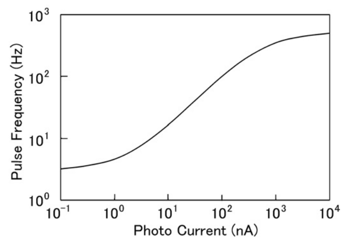


Fig.7 Spice simulation result of the dependence of the stimulating current pulse frequency on the input light current.

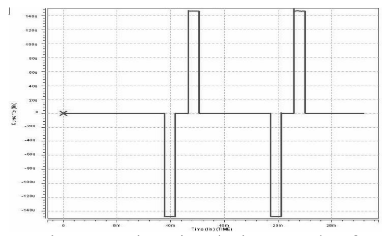
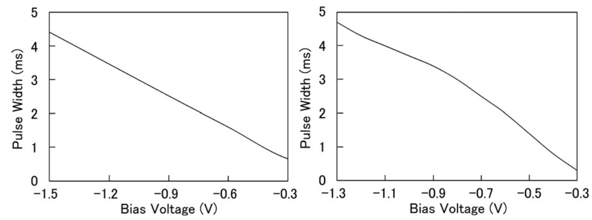


Fig.8 Spice simulation result of the stimulating current pulses output.



(a) Cathodic pulse width (b)Anodic pulse width

Fig.9 Spice simulation results of the dependence of (a) cathodic and (b)anodic pulse width on bias voltage (BIAS2, BIAS5).

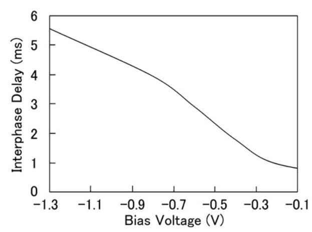


Fig.10 Spice simulation result of the dependence of the interphase delay on bias voltage (BIAS4).