Ultralow Power Operation of 3-D Stacked Retinal Prosthesis Chip with Edge Enhancement Function

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Abstract

To restore visual sensation of blind patients suffering from age-related macular degeneration (AMD) and retinitis pigmentosa (RP), retinal prostheses have been developed by several institutes. Since the retinal cells would be damaged by heating, the power consumption of the retinal prosthesis chip should be kept less than 19 mW/mm^2 . In this work, to reduce the power consumption of retinal prosthesis chip, effects of edge enhancement function implemented in retinal prosthesis chip were investigated in detail, and ultralow power operation of the chip was clearly demonstrated.

1. Introduction

More than several millions people in the world become blind due to retinal diseases such as AMD and RP. Effective medical treatments for these diseases have not been established yet. In order to restore visual sensation of blind patients, we have been developing a 3-D stacked retinal prosthesis chip for fully implantable retinal prosthesis [1]. The 3-D stacked retinal prosthesis chip consists of a photoreceptor chip for converting incident light into electrical current and stimulus current generator chip with visual information processing function for edge enhancement and generating appropriate electrical stimulus patterns, as shown in Fig. 1. These chips are vertically stacked and electrically connected by through silicon vias (TSVs).

Until now, we designed and fabricated a photoreceptor chip using 0.35-µm CMOS image sensor technology and a stimulus current generator chip with edge enhancement function using 0.25-µm CMOS standard technology [2]. From evaluation results of these chips, it was confirmed that the 3-D stacked retinal prosthesis chip can be achieved by stacking a photoreceptor chip and a stimulus current generator chip with edge enhancement function. However, we have not evaluated power consumption of the 3-D stacked retinal prosthesis chip with edge enhancement function yet. When the power consumption of the chip in the eyeball becomes more than 19 mW/mm^2 , the retinal cells will be thermally damaged [3]. Therefore, lower power of the retinal prosthesis chip is strongly required to ensure highly safe retinal prostheses. Generally, the power of more than 90% is consumed in the stimulus current generator for evoking phosphenes in the retinal cells. For

achieving a retinal prosthesis with higher quality of life (QOL), we have proposed the retinal prosthesis chip having edge enhancement function. The edge enhancement function will be also effective to reduce the power consumption because the only pixel circuits corresponding to edges of the visual information generate stimulus current pulses and consume the power. In this study, we investigated the power characteristics of 3-D stacked retinal prosthesis chip with edge enhancement function.

2. Design of edge enhancement circuit

For the edge enhancement processing, we have used a four-neighbor Laplacian filtering. Fig. 2 shows a schematic diagram of edge enhancement circuit. The output current of a photoreceptor, I_{vd}, flows in nMOS transistor, Ma, and the same current flows in Mb, because a current mirror ratio is set to 1. Additionally, the $0.25 \times I_{pd}$ flows in four nMOS transistors, M1-M4. These nMOS transistors are connected to neighbor pixel circuits via P_T, P_L, P_B, and P_R. The current mirror ratio among Ma and M1-M4 are 1 to 0.25. Consequently, I_{tot} , which is equal to $0.25(I_T + I_L + I_B + I_R)$, flows in pMOS transistor, M5, via terminal P_{in} . I_T , I_L , I_B , and I_R are the output current of four-neighbor pixels, respectively. The current mirror ratio between M5 and M6 is set to 1. Therefore, the same current as I_{tot} flows toward node nlfrom M6. I_o , which is equal to $I_{tot} - I_{pd}$, flows into the stimulus current generator via Pout. The retinal prosthesis chip consists of 37×37 pixels. A pixel size is 75 μ m \times 75 μ m.

3. Evaluation of power characteristics of retinal prosthesis chip with edge enhancement function

We evaluated power consumption of a pixel circuit with edge enhancement function using SPICE simulation combined with measurement results of photoreceptor chip. Fig. 3 shows the waveform of stimulus current pulses. Cathodic pulse width, interphase delay, and anodic pulse width were all set to 1 msec. Supply voltage was ± 1.25 V, and current amplitude was 110 μ A. Fig. 4 shows a relationship between incident light intensity and stimulus current pulse frequency of the retinal prosthesis chip. For this simulation, the incident light intensity was converted to the input current of the pixel circuit based on the measured result of the photoreceptor chip. The frequency of stimulus current pulses changes accordingly with the incident light intensity. Fig. 5 shows a relationship between incident light intensity and power consumption of the retinal prosthesis chip having 37 \times 37 pixels without edge enhancement function. The maximum power consumption reached 23 mW/mm².

To evaluate power consumption of the retinal prosthesis chip with edge enhancement function, three kinds of grav scale images composed of 37×37 pixels have been processed in the retinal prosthesis chip. Input image A is an image of six gradations, where incident lights are set to 1, 4, 16, 63, 251, 1000 lx for every six columns, respectively. Since this input image has five edge lines, stimulus current pulse were generated in the pixels only at edge lines. Therefore, the power reduction of 41% was achieved by using edge enhancement function. As for an input image B, what is called a checkered flag, the power consumption didn't decrease with the edge enhancement. For the input image C, the power reduction of 60% was achieved with edge enhancement function in the retinal prosthesis chip because no edge existed and all pixels didn't generate the stimulus current. Table I summarizes and compares power consumptions for different input images.

4. Conclusions

We evaluated the power consumption characteristics of the retinal prosthesis chip with edge enhancement function in detail. For evaluation results, we confirmed the effects of the edge enhancement function to achieve ultralow power operation of the 3-D stacked retinal prosthesis chip. With the edge enhancement function, the 3-D stacked retinal prosthesis chip realizes highly safe artificial retina with higher QOL.

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Fig. 1 Configuration of 3-D stacked retinal prosthesis chip.



Fig. 2 Schematic of the edge enhancement circuit.

References

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Fig. 4 Evaluation result of relationship between incident light intensity and stimulus current pulse frequency of a pixel circuit.



Fig. 5 Evaluation result of relationship between incident light intensity and power consumption of retinal prosthesis chip without edge enhancement function.

Table I. Comparison of power consumption for different input images.

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	Input image A (gradation)	Input image B (checkered flag)	Input image C (fully bright)
without edge enhancement	17 mW/mm ²	16 mW/mm ²	23 mW/mm ²
with edge enhancement	10 mW/mm ²	16 mW/mm ²	9.2 mW/mm ²
Power reduction rate	-41%	0%	-60%
1 1 1x 4 1x 16 1x 63 1x 251 1x 1000 1x			