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P-11-1 Development of Power Supply System for Three-Dimensionally Staked Retinal Prosthesis Chip

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1. Introduction

Visual sensation carries essential information to lead daily life. In recent years, the number of blind patients due to retinitis pigmentosa (RP) and age-related macular degeneration (AMD) is dramatically increasing with the progress of ageing society. However, medical cures for these diseases have not been established yet. Retinal prostheses can enable such blind patients to restore visual sensation by electrical stimulation to remaining retinal cells via a stimulus electrode array in the engineering field [1]. We have proposed a novel implantable retinal prosthesis system with a three-dimensionally (3D) stacked retinal prosthesis chip with a stimulus electrode array [2]. The retinal prosthesis system includes flexible printed circuit board (FPC) on which the 3D retinal prosthesis chips and a power supply circuit are mounted, as shown in Fig. 1.

We employ electromagnetic induction as a power supply method to prevent eyeball from being infectious. This power supply system is composed of a primary coil, an extraocular power supply circuit, a secondary coil that can be embedded in the surface of the eyeball, and intraocular translation circuits, as shown in Fig. 2. The intraocular translation circuit has three functional parts, such as rectification, smoothing, and stabilization. Both the rectification and smoothing parts convert the induced electromotive force from the secondary coil into the DC voltage, and the stabilization part converts the DC voltage into the appropriate voltages required for the retinal prosthesis chip drive.

There are few papers reporting the power supply system for retinal prosthesis because the human eyeball is very small and there are lots of restrictions on implant. Regarding the power supply system for retinal prostheses, this paper describes the design and fabrication of the secondary coil for power receiving and the schottky barrier diode (SBD) in the rectification circuit.

2. Design and fabrication of the secondary coil

As our retinal prosthesis chip uses a supply voltage of 3.3 V, translation circuit needs a supply voltage of 4.5V. Therefore, it is necessary to optimize several parameters such as an external supply voltage and transmission frequency to supply the voltage of 4.5 V to the translation circuit. Moreover, in accordance with these parameters, structural optimization is also required for the primary and secondary coils.

Figure 3 shows a simplified circuit model of power supply system to design. In order to optimize parameters simply, we use a resistance, R_2, for the translation circuit. To improve transmission efficiency, each capacitor, C_1 and C_2, are designed to resonate with each coil, L_1 and L_2, respectively. Voltage V_2 can be obtained using the following formula.

$$|\mathbf{V_2}| = \frac{\varpi \mathbf{M}|\mathbf{e}|\mathbf{R_2}}{\sqrt{(\mathbf{r_2 r_1} + \varpi^2 \mathbf{M}^2)^2 + (\varpi \mathbf{L_2 r_1} + \varpi^3 \mathbf{C_2 M^2 R_2} + \varpi \mathbf{C_2 r_2 R_2 r_1})^2}}$$

L : inductance of coil C : capacitance
M : mutual inductance r : winding resistance of coil
ω : angular frequency e : supply voltage
R_2 : resistance of the retinal prostheses chip

A large number of turns decrease voltage loss on the secondary coil. However, the number of turns of secondary coil is limited to 20 turns, because the secondary coil needs to be thin and can be implanted in crystalline lens. When we employed 50 and 20 turns for the primary and secondary coils, respectively, it was confirmed that voltage transmission efficiency became maximum at the frequency between 3 MHz and 300 MHz, with the external supply voltage of 2.5 V, as shown in Fig. 4. Our power supply system using electromagnetic induction can supply a sufficient electric power for the translation circuit and the resultant retinal prosthesis chip. We fabricate the secondary coil with appropriate parameters by using copper electroplating and damascene techniques, as shown in Fig. 5.

3. Design and fabrication of the schottky barrier diode

The rectification circuit adopts bridge method including four diodes and rectifiers full-wave. The rectification circuit requires a planer structure due to its packaging on FPC. In this work, we employ a schottky barrier diode as a rectification diode because the schottky barrier diode can operate with frequency more than 3 MHz. The schottky barrier diode also has a high breakdown voltage. Figure 6 shows photograph fabricated schottky barrier diode, and Fig. 7 shows I-V characteristics with the size of 100 μm^2. The N-well concentration at the schottky contact is appropriate 5×10^{16} ion/cm^3. Tungsten was employed for a metal material of schottky contact. The resistance of schottky contact was reduced by annealing after tungsten film deposition. The schottky barrier diode has the high breakdown voltage more than 4.5 V, which is sufficient for our power supply system.

4. Results and Discussion

We confirm that the power supply system can transmit an electric power to the translation circuit by using our calculation results. We also attempt to decrease the weight of the secondary coil by copper electroplating and damascene techniques. To drive the retinal prosthesis chip, it is necessary to transmit 4.5 V to the secondary coil. The breakdown voltage of fabricated schottky barrier diode was 4.6V, as shown in Fig. 7. In order to increase the break down voltage, we need that the N-well concentration of the schottky contact becomes lower. A new schottky barrier diode is fabricated by using this data. We employ smaller area of schottky contact than one we designed and fabricate the schottky barrier diode with low N-well concentration of approximately 1×10^{16} ion/cm^3 at the schottky contact. Additionally, we would employ Platinum for a metal material of schottky contact. Therefore, we can achieve the schottky barrier diode with higher break down voltage and lower resistance of schottky contact.

5. Summary

The design and fabrication of the secondary coil and the schottky barrier diode (SBD) in the rectification circuit were studied in detail. We can fabricate the secondary coil using the parameters derived in this work. We fabricated schottky barrier diode used in the rectification circuit. The schottky barrier diode with the high breakdown voltage was obtained. Our power supply system can supply the sufficient electric power for the retinal prosthesis chip.

Acknowledgments

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References

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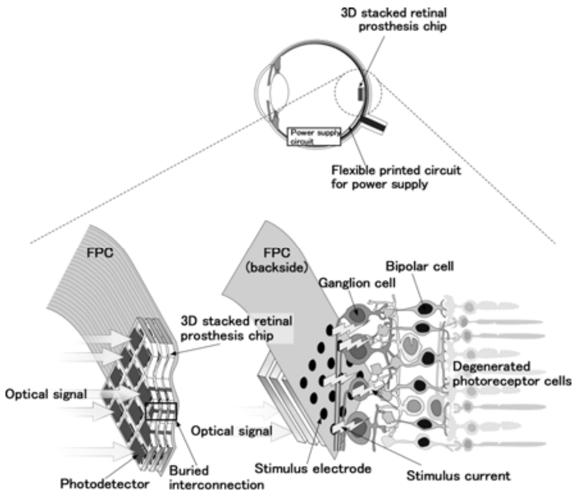

Fig. 1. Configuration of novel retinal prosthesis system with 3D staked retinal prosthesis chip.

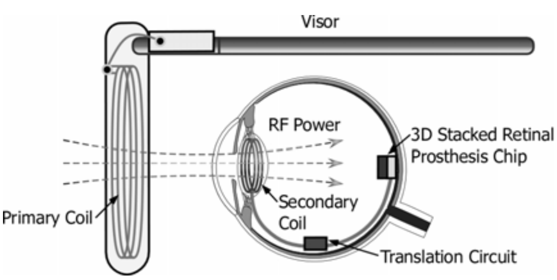

Fig. 2. Concept of the power supply system.

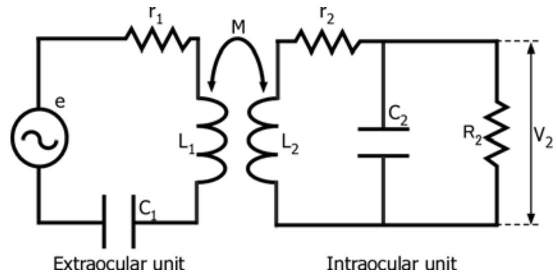

Fig. 3. Simplified circuit model of the inductively coupled system

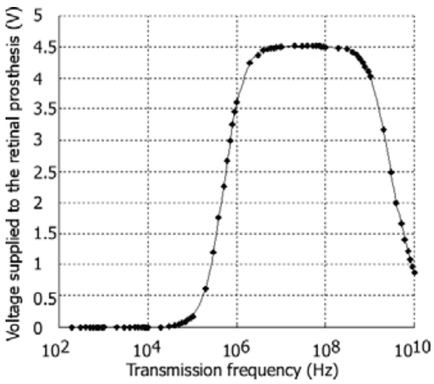

Fig. 4. Relationship between supplied voltage and transmission frequency.

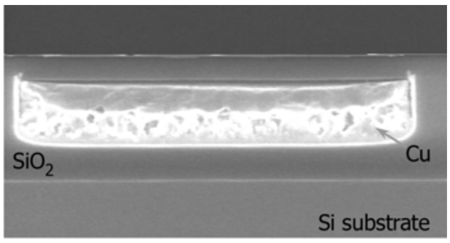

Fig. 5. Cross-sectional view of part of secondary coil fabricated by using copper electroplating and damascene techniques.

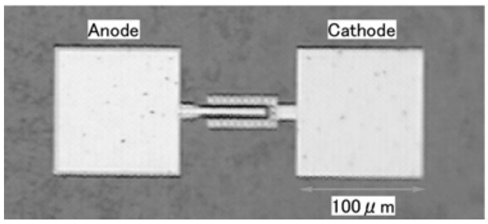

Fig. 6. Photograph of fabricated schottky barrier diode.

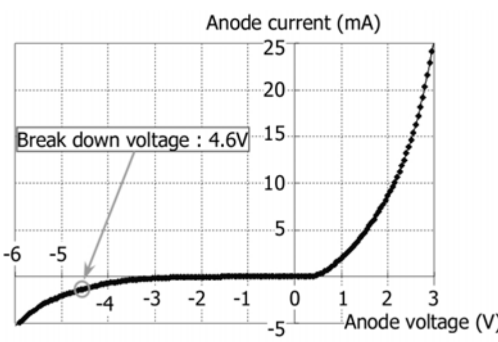

Fig. 7. I-V characteristics of fabricated schottky barrier diode.