Study of Power Supply System for Fully Implantable Retinal Prosthesis Chip

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Abstract

Recently, with the progress of an aging society, the number of people who have suffered from retinal diseases such as retinitis pigmentosa (RP) and age-related macular degeneration (AMD) has been remarkably increasing. However, the proper medical treatments for such diseases have not been established yet. Due to strong demands on alternative medical treatments to restore visual sensation for blind people, several retinal prostheses have been reported [1-2].

We have proposed a fully implantable three-dimensional (3-D) retinal prosthesis system which is composed of 3-D stacked retinal prosthesis chip and a power supply system for realizing the high quality of life (QOL) to blind patients. In this research, we studied a flexible electromagnetic thin film inductor to realize inductive power delivery system for the 3-D retinal prosthesis chip.

1. Introduction

Figure 1 shows a configuration of the fully implantable retinal prosthesis system with 3-D retinal prosthesis chip we proposed. In the 3-D retinal prosthesis chip, photodetectors, which are formed in the top layer of the 3-D retinal prosthesis chip, receive visual scenes and convert them into image data. The image data is converted into appropriate patterns of electrical current by image processing circuits formed under photodetector layer through vertically connected wires. Survival retinal cells are then activated by the stimulation of this electrical current via stimulus electrode array. As a result, blind patients can restore their visual sensation because the visual information is sent to the primary visual cortex [3].

In our fully implantable retinal prosthesis system, we employ electromagnetic induction as a power delivery method, which means an inductive type power supply to the 3-D retinal prosthesis chip, to prevent the eyeball from being infected. This power delivery system is composed of a primary coil, an extraocular power supply circuit, a secondary coil, and an RF/DC voltage conversion chip for converting AC voltage to DC voltage, as shown in Fig. 2. Several papers have been reported the power supply system, which were used a copper wire for second inductive coil in the eyeball. However, these approaches have possibility to infect the eyeball during and after the surgical operation, if the copper wired inductor size is larger to increase power transmission.

In this paper, we proposed new power delivery method using a flexible thin film inductor as a second coil, which can extremely minimize risks of the eyeball being infection diseases. This can be realized as the second coil replaced a conventional implantable type inductor with flexible thin film inductor. We also evaluated the frequency characteristics of flexible Cu thin film inductor and the quality factor which determines a power transmission loss of the fabricated inductor.
2. Fabrication of Flexible Electromagnetic Inductor

In order to operate the 3-D retinal prosthesis chip properly, it is necessary for the second coil to have high inductive performance. Figure 2 shows a circuit diagram of power delivery including two electromagnetic inductors in both extra- and intraocular unit. With increasing the turn number of second coil, mutual inductance and the resultant transmitted voltages are increasing. We investigated the effective power transmission to operate the 3-D retinal chip by introducing a flexible thin film inductor which can be glued on the eyeball without power transmission loss.

Several types of inductors were fabricated with a line width of 10µm and a line thickness of 1µm. These inductors have various turn numbers of 3.5, 5.5, 7.5, 9.5 and 11.5. At first, the coil pattern was fabricated on SiO2 layer by I-line photolithographic techniques. Figure 3 shows a process flow of the Cu coil inductor to fabricate flexible Cu inductor. To form a coil shape in the SiO2 layer, CF4/H2 etching process was used for the etching SiO2 layer. To improve morphology of the etched pattern in the SiO2 layer, we used a laminate silicon oxide layer which was formed by plasma TEOS CVD and silicon nitride layer by plasma CVD as also role of Chemical Mechanical Polishing (CMP) process stop layer. Then, Cu electroplating and CMP planarization process were performed to make thin Cu coil layer.

- P-TEOS CVD SiO2 deposition
- SiO2 dry etching
- Isolation SiO2 and Si3N4 deposition
- Cu electroplating & CMP
- ILD SiO2 deposition
- Contact formation
- Backside patterning and dry etching

Fig. 3. Process flow of flexible Cu thin film inductor fabrication.

To fabricate a flexible thin film inductor, etching process of silicon substrate was performed by BOSCH method. Then, we measured inductance characteristics under various frequency conditions of the flexible Cu thin film inductors.

3. Results and Discussion

Figure 4 shows the frequency dependence of quality factor. Flexible thin film inductors show quality factors with ranges of 5.5 to 7.5, and inductances with ranges of 10 nH to 40 nH. The maximum peak frequency of quality factor from 1.2 GHz to 4 GHz is presented with high frequency bands compared to other report [4]. It is clearly indicated that a power transmission loss can be reduced by eliminating the substrate loss in overall size inductors. We successfully fabricated the flexible thin film type inductors with high quality factor for the power transmission.

4. Conclusion

We fabricated the flexible Cu thin film inductors with high quality factor for the 3-D retinal prosthesis system. Quality factor of the fabricated inductors can be used a power transmission device with reducing power loss factor in 3-D retinal system. Moreover, inductance values of more than 20nH are proven enough possibility to apply the inductor for a retinal prosthesis system. In addition, we successfully obtained the resonance frequency characteristics in proportion to turn numbers of the copper coil without degradation of quality factor. Based on these results, we assume that the flexible Cu thin film inductor can be applicable as a power delivery system for low power and high data transmission speed.

Fig. 4. Quality factor of flexible Cu thin film inductors. The coils have an inner diameter, d=120 µm.

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