Abstract—We have evaluated an artificial retina using thin-film transistors driven by wireless power supply. It is found that the illumination profile can be correctly detected as the output voltage profile even if it is driven using unstable power source generated by inductive coupling, diode bridge, and Zener diodes. This means the feasibility to implant the artificial retina into human eyeballs.

Index Terms—Artificial retina, implant, thin-film transistor (TFT), wireless power supply.

I. INTRODUCTION

A rtificial retinas have been ardently desired to recover the sight sense for sight-handicapped people [1]. Recently, artificial retinas using external cameras, stimulus electrodes, and three-dimensional large scale integrations (LSIs) have been actively developed for patients suffering from retinitis pigmentosa and age-related macular degeneration [2]–[8]. In these cases, electronic photodevices and circuits substitute for deteriorated photoreceptor cells. The implant methods can be classified to four types: epiretinal implant, subretinal implant, suprachoroidal stimulation, and transretinal stimulation. Among these implant methods, the epiretinal implant has features that the image resolution can be high because the stimulus signal can be directly conducted to neuron cells and that living retinas are not seriously damaged.

In our research, we have proposed an artificial retina using thin-film transistors (TFTs) [9], [10], which can be fabricated on transparent and flexible substrates. The concept model of the artificial retina fabricated on a transparent and flexible substrate and implanted using epiretinal implant is shown in Fig. 1. Electronic photodevices and circuits are integrated on the artificial retina, which is implanted on the inside surface of the living retina at the back part of the human eyeballs. Since the irradiated light comes from one side of the artificial retina and the stimulus signal goes out of the other side, the transparent substrate is preferable. Moreover, since the human eyeballs are curved, the flexible substrate is also preferable. It is possible to make spherical shape by designing a petal-like pattern. As a result, the artificial retina using TFTs are suitable for the epiretinal implant on the curved human eyeballs.

Until now, wired power supply has been used to drive the artificial retina using TFTs to ensure reliable operations. However, the wired power supply harms quality of life of the sight-handicapped people because of bothersome connection wires between the artificial retina and external equipments. Therefore, wireless power supply is requisite to eliminate the connection wires and to realize complete artificial internal organs to improve the quality of life. In this paper, we have evaluated an artificial retina using TFTs driven by wireless power supply. It is found that the illumination profile can be correctly detected as the output voltage profile even if it is driven using unstable wireless power supply.

II. ARTIFICIAL RETINA USING THIN-FILM TRANSISTORS

The artificial retina using TFTs is fabricated using the same fabrication processes as conventional poly-Si TFTs [11]–[13] and encapsulated using SiO₂ in order to perform in corrosive environments. Although the artificial retina is fabricated on the glass substrate here to confirm the elementary functions, it can be fabricated on the plastic substrate [14]. The artificial retina using TFTs is shown in Fig. 2. The retina array includes matrix-like multiple retina pixels. Although large contact pads are located for fundamental evaluation, a principal part is 27 300 µm², which corresponds to 154 ppi. The retina pixel consists of a photo transistor, current mirror, and load resistance. The photo transistor is optimized to achieve high efficiency [15], [16], and the current mirror and load resistance are designed by considering the transistor characteristic of TFTs [17]. The photosensitivity of the reverse-biased p/i/n poly-Si phototransistor is 150 pA at 1000 lx for white light and proper values for all visible color lights [18]. The field effect mobility and the threshold voltage of the n-type and p-type poly-Si TFT were 93 cm²V⁻¹s⁻¹, 3.6 V, 47 cm²V⁻¹s⁻¹ and −2.9 V, respectively. First, the photo transistor perceives the irradiated light (Lphoto) and induce the photo-induced current
(Iphoto). Next, the current mirror amplifies Iphoto to the mirror current (Imirror). Finally, the load resistance converts Imirror to the output voltage (Vout). Consequently, the retina pixels irradiated with bright light output a higher Vout, whereas the retina pixels irradiated with darker light output a lower Vout.

III. WIRELESS POWER SUPPLY USING INDUCTIVE COUPLING

The wireless power supply using inductive coupling is shown in Fig. 3. The right graph in Fig. 3 is a measured stability of the supply voltage. This system includes a power transmitter, power receiver, diode bridge, and Zener diodes. The power transmitter consists of an ac voltage source and induction coil. The Vpp of the ac voltage source is 10 V, and the frequency is 34 kHz, which is a resonance frequency of this system. The material of the induction coil is an enameled copper wire, the diameter is 1.8 cm, and the winding number is 370 times. The power receiver also consists of an induction coil, which is the same as the power transmitter and located face to face. The diode bridge rectifies the ac voltage to the dc voltage, and the Zener diodes regulate the voltage value. The diode bridge and Zener diodes are discrete devices and encapsulated in epoxy resin. Although the current
system should be downsized and bio-compatibility has to be inspected, the supply system is in principle very simple to implant it into human eyeballs. As a result, the generated power is not so stable as shown in Fig. 3, which may be because the artificial retina is fabricated on an insulator substrates, has little parasitic capacitance, and is subject to the influence of noise. Therefore, it is necessary to confirm whether the artificial retina can be correctly operated even using the unstable power source.

IV. DETECTED RESULT OF ILLUMINATION PROFILE

The artificial retina with the wireless power supply system is located in a light-shield chamber, and Vout in each retina pixel is probed by a manual prober and voltage meter. White light from a metal halide lamp is diaphragmed by a pinhole slit, focused through a convex lens, reflected by a triangular prism and irradiated through the glass substrate to the back surfaces of the artificial retina on a rubber spacer. The real image of the pinhole slit is reproduced on the back surface. The detected result of the Lphoto profile versus the Vout profile is shown in Fig. 4. It is found that the Lphoto profile can be correctly detected as the Vout profile even if it is driven using the unstable power source, although shape distortion is slightly observed, which is due to the misalignment of the optical system or characteristic variation of TFTs.

V. CONCLUSION

We have evaluated an artificial retina using TFTs driven by wireless power supply. It was found that the Lphoto profile can be correctly detected as the Vout profile even if it is driven using unstable power source generated by inductive coupling, diode bridge, and Zener diodes. In order to apply the artificial retina to an actual artificial internal organ, we should further develop a pulse signal generator appropriate as photoreceptor cells, consider the interface between the stimulus electrodes and neuron cells, investigate the dependence of Vout on Lphoto, which realizes grayscale sensing, etc. However, we think that the above result means the feasibility to implant the artificial retina into human eyeballs.

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REFERENCES


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