Evaluation of Thin-Film Photodevices and Development of Artificial Retina

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Abstract

First, thin-film photodevices are evaluated, and a p/i/n thin-film phototransistor (TFPT) is recommended because the photo-induced current is relatively high and independent of the applied voltage. Next, an artificial retina is developed using the p/i/n TFPTs, and it is found that it can detect photo illuminance profile with sensitivity control.

1. Introduction

Thin-film photodevices are promising for photosensor applications such as ambient light sensors[1], image scanners[2], artificial retinas[3-5], etc. In these applications, since the thin-film photodevices are integrated with low-temperature poly-Si thin-film transistors (LTPS-TFTs), advanced functions can be acquired. Moreover, since the thin-film photodevices are fabricated using the same fabrication processes as LTPS-TFTs, fabrication costs can be saved. However, the thin-film photodevices have not sufficiently been evaluated and presented from the viewpoints of the device structures and driving conditions. In our research, first, a p/i/n thin-film photodiode (TFPD), p/n TFPD and p/i/n thin-film phototransistor (TFPT) are evaluated, and the p/i/n TFPT is recommended because the photo-induced current (Iphoto) is proportional to the photo illuminance (Lphoto), relatively high and independent of the applied voltage (Vapply).

On the other hand, artificial retinas are promising because they may recover light for the blind[6] and provide new applications of information electronics[7]. Until now, bulk Si metal-oxide-semiconductor field-effect transistors (MOSFETs) have commonly been used for artificial retinas. In our research, next, an artificial retina is developed using the p/i/n TFPTs and LTPS-TFTs, and it is found that it can detect the Lphoto profile and correspondingly output the output

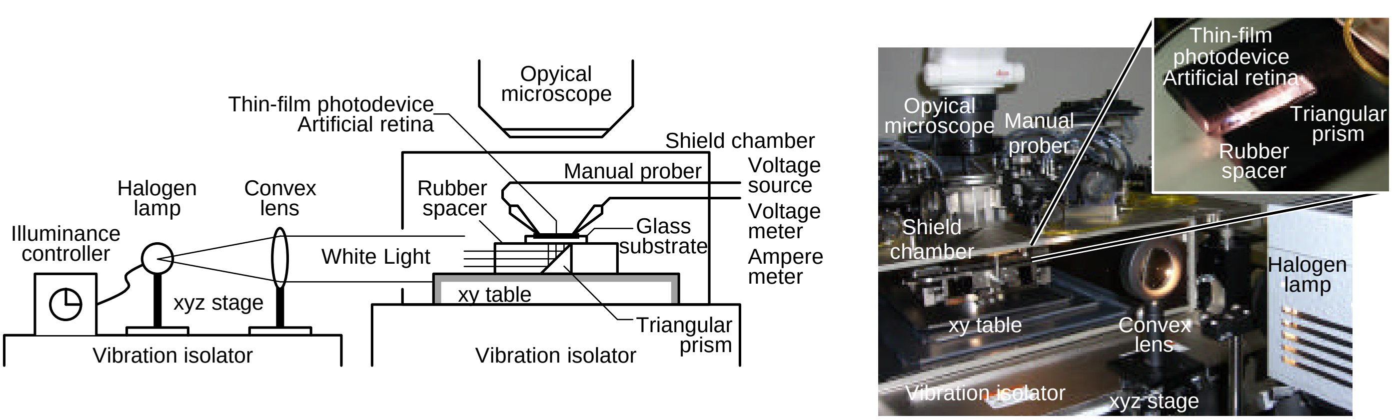

Fig. 1. Measurement system.

voltage (Vout) profile with sensitivity control. This artificial retina is expected to be suitable for living bodies because it can potentially be fabricated on the plastic substrate[8].

2. Experiment

The thin-film photodevices and artificial retina are fabricated on the glass substrate using the same fabrication processes as conventional LTPS-TFTs. First, the amorphous-Si film is deposited using low-pressure chemical-vapor deposition (LPCVD) of Si_2H_6 and crystallized using XeCl excimer laser to form the poly-Si film. Next, SiO_2 film is deposited using plasma-enhanced chemical-vapor deposition (PECVD) of tetraethylorthosilicate (TEOS) for the gate-insulator film. The gate-metal film is deposited and patterned. The phosphorous and boron are implanted and thermally activated for the anode-cathode regions of the thin-film photodevices and source-drain regions of the LTPS-TFTs. The hydrogen plasma treatment, oxygen plasma treatment and water-vapor heat treatment are performed to improve the poly-Si film, SiO_2 film and their interfaces.

The measurement system is shown in Fig. 1. The thin-film photodevices and artificial retina are located on a rubber spacer in a shield chamber and connected via a manual prober to a voltage source, voltage meter and ampere meter. White light from a halogen lamp is formed to be parallel through a convex lens, reflected by a triangular prism and irradiated through the glass substrates to the back surfaces of the thin-film photodevices and artificial retina. The Iphoto is measured with changing the Lphoto and Vapply in the case of the thin-film photodevice. The Vout profile is measured with giving the Lphoto profile in the case of the artificial retina.

3. Thin-film photodevices

Thin-film photodevices generate the Iphoto caused by the generation mechanism of electron-hole pairs at

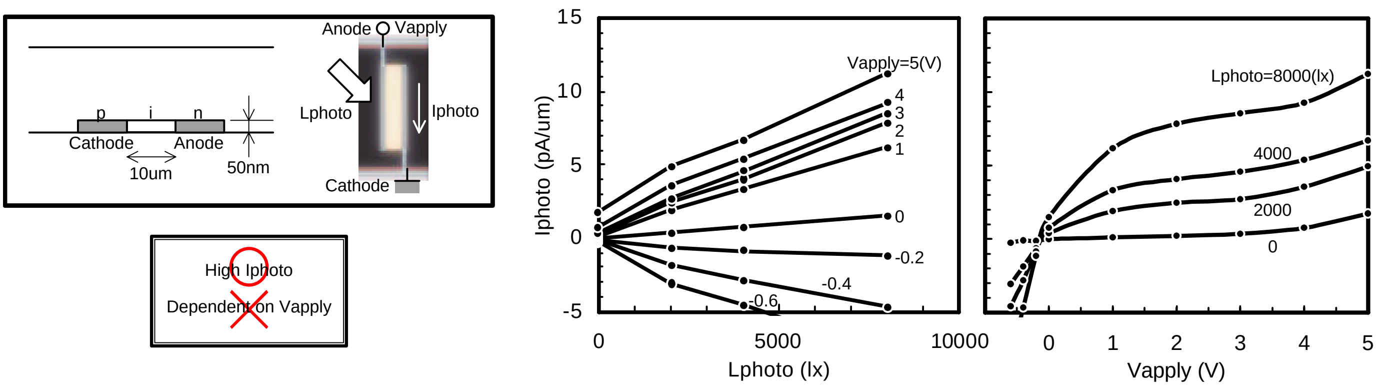

Fig. 2. p/i/n thin-film photodiode.

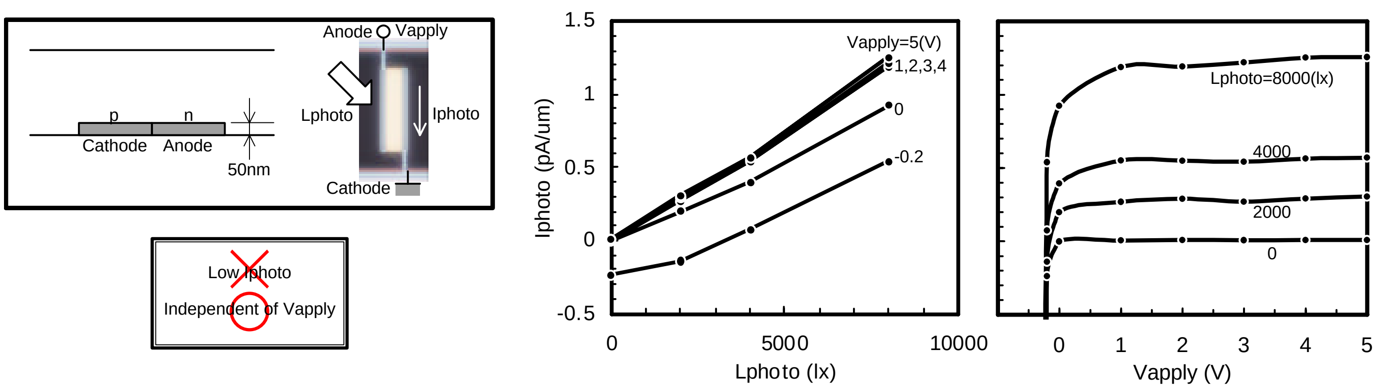

Fig. 3. p/n thin-film photodiode.

semiconductor regions where the Lphoto is irradiated, the depletion layer is formed and the electric field is applied. Since thin-film photodevices are mostly used to detect the Lphoto and the Vapply often unintentionally changes in the circuit configuration, it is preferable that the Iphoto is dependent only on the Lphoto but independent of the Vapply.

First, the characteristic of the p/i/n TFPD is shown in Fig. 2. It is found that the Iphoto is proportional to the Lphoto and relatively high but dependent on the Vapply. This is because: The depletion layer is formed in the whole intrinsic region, which means that the generation volume of electron-hole pairs is large, and the Iphoto is relatively high. However, the electric field increases as the Vapply increases, which means that the generation rate increases, and the Iphoto is dependent on the Vapply.

Next, the characteristic of the p/n TFPD is shown in Fig. 3. It is found that the Iphoto is not high but independent of the Vapply. This is because: The depletion layer is formed only near the p/n junction due to a built-in potential, which means that the generation volume of electron-hole pairs is small, and the Iphoto is not high. However, the electric field is always high, which means the generation rate is constant, and the Iphoto is independent of the Vapply.

Finally, the characteristic of the p/i/n TFPT is shown in Fig. 4, where the gate voltage (Vgate) is optimized. It is found that the Iphoto is simultaneously relatively high and independent of the Vapply. This is because: The depletion layer is formed in the whole intrinsic region, which means that the generation volume of electron-hole pairs is large, and the Iphoto is relatively high. Moreover, the electric field is always high because it is mainly determined by the Vgate, which means that the generation rate is constant, and the Iphoto is independent of the Vapply. Therefore, the the p/i/n TFPT is recommended.

4. Artificial retina

First, the characteristic of the retina pixel is shown in Fig. 5. The retina pixel consists of the p/i/n TFPT, a current mirror and load transistors. It is found that the output voltage (Vout) increases as the Lphoto increases, and its sensitivity can be controlled by the bias voltage (Vbias).

Next, the characteristic of the retina array is also shown in Fig. 5. It is found that this artificial retina can detect the Lphoto profile and correspondingly output the output voltage (Vout) profile. Although some noises occur due to the characteristic deviations of the p/i/n TFPTs and LTPS-TFTs, the shape of the Vout profile is roughly the same as the shape of the Lphoto profile.

5. Conclusion

First, thin-film photodevices were evaluated, and a p/i/n TFPT was recommended because the Iphoto is relatively high and independent of the Vapply. Next, an artificial retina was developed using the p/i/n TFPTs, and it was found that it can detect the Lphoto profile with sensitivity control. This artificial retina is expected to be suitable for living bodies because it can potentially be fabricated on the plastic substrate.

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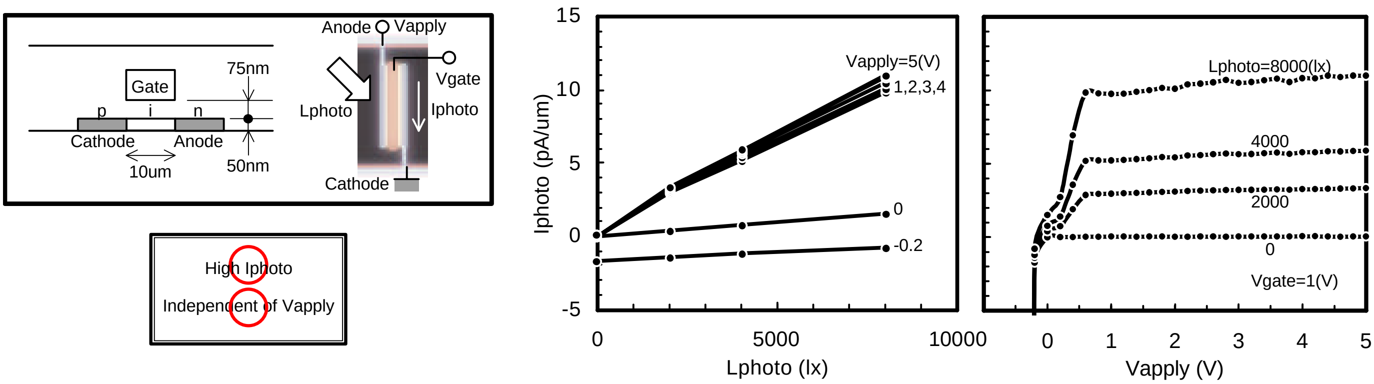

Fig. 4. p/i/n thin-film phototransistor.

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7. References

1. S. Koide, S. Fujita, T. Ito, S. Fujikawa and T. Matsumoto, *IDW '06*, p. 689 (2006).
2. T. Nishibe and H. Nakamura, *AM-FPD '06*, p. 61 (2006).
3. M. Kimura, T. Shima, T. Okuyama, S. Utsunomiya, W. Miyazawa, S. Inoue and T. Shimoda, *Jpn. J. Appl. Phys.*, **45 [5B]**, 4419 (2006).
4 M. Kimura T. Shima, T. Yamashita, Y. Nishizaki, H. Hara and S. Inoue, *IDMC '07*, to be presented (2007).
5 T. Yamashita, T. Shima, Y. Nishizaki, M. Kimura and H. Hara, *AM-FPD '07*, to be presented (2007).
6. T. Yagi, Oyo Buturi 73, 1095 (2004).
7. Y. Nakagawa, ICONIP '00, 636.
8. S. Utsunomiya, T. Kamakura, M. Kasuga, M. Kimura, W. Miyzawa, S. Inoue and T. Shimoda, *Euro Display '02*, pp. 79 (2002).

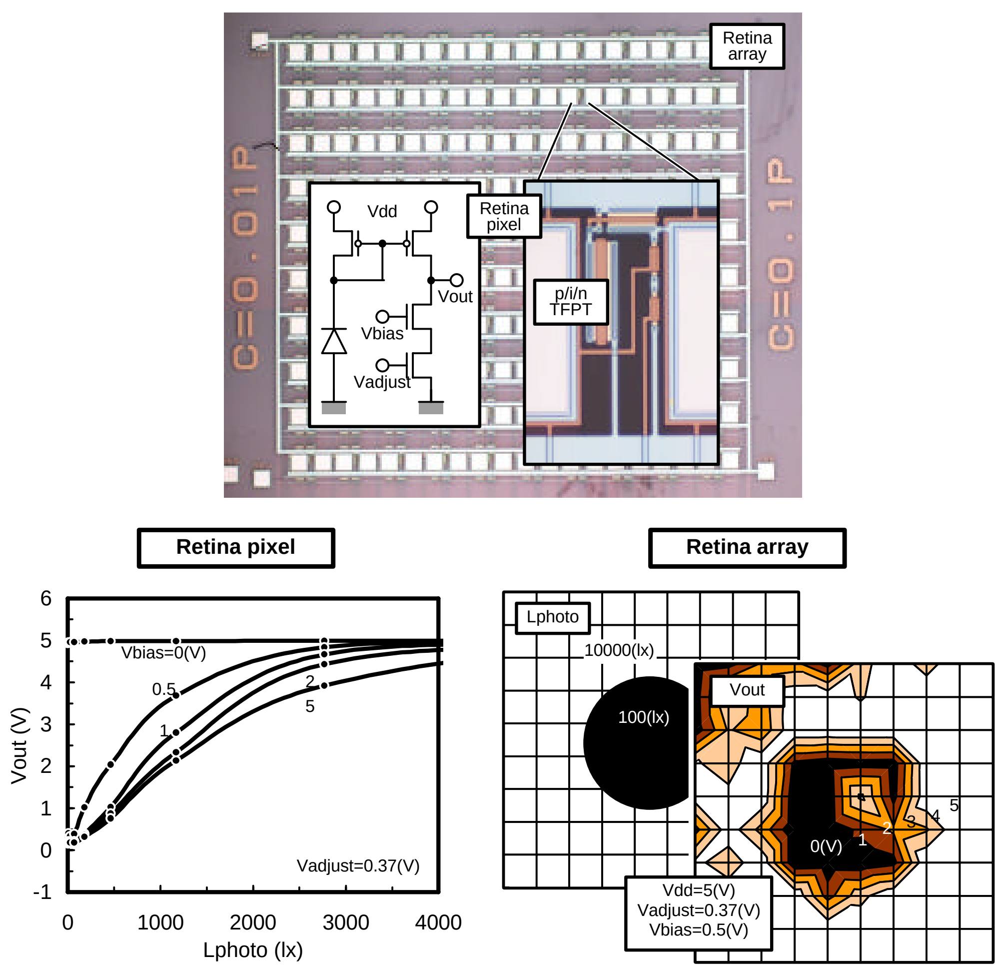

Fig. 5. Artificial retina.