Artificial retina using thin-film photodiode and thin-film transistor

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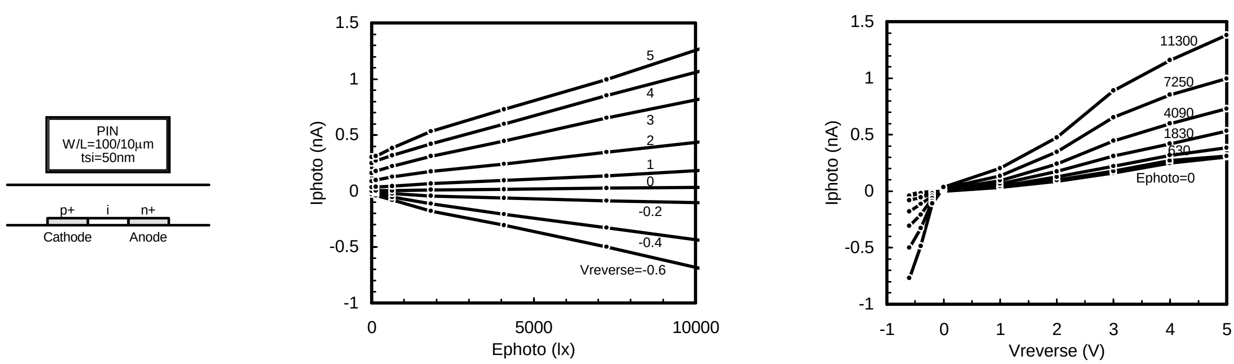
Abstract

An artificial retina using thin-film photodiodes (TFPDs) and thin-film transistors (TFTs) is proposed. The characteristics of a TFPD and TFTs are measured, and the circuits of the retina pixel and retina array are designed. It is confirmed that the artificial retina can achieve edge enhancement and control photo-sensitivity.

1. Introduction

Artificial retinas are promising because they may recover light for the blind [1] and because they provide new applications of information electronics [2]. Until now, bulk Si metal-oxide-semiconductor field-effect transistors (MOSFETs) have been commonly used.

On the other hand, thin-film transistors (TFTs) have been mainly applied in flat panel displays (FPDs) [3-4], and area sensors [5]. In particular, since polycrystalline silicon (poly-Si) TFTs have high performance, they are expected to be applied to the system-on-panel (SOP) devices [6-8] and general electronics [9-11]. Recently, the transfer technology of thin-film devices called surface free technology by

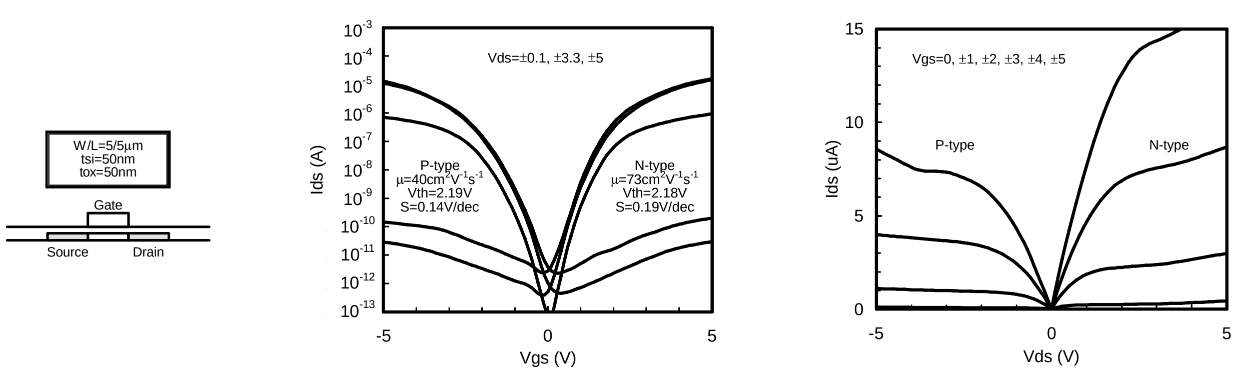


(a) Device structure

(b) Dependence of Iphoto on Ephoto with variation in Vreverse

(c) Dependence of Iphoto on Vreverse with variation in Ephoto

Figure 1 Device structure and characteristics of TFPD



(a) Device structure

(b) Transfer characteristic

(c) Output characteristic

Figure 2 Device structure and characteristics of poly-Si TFTs

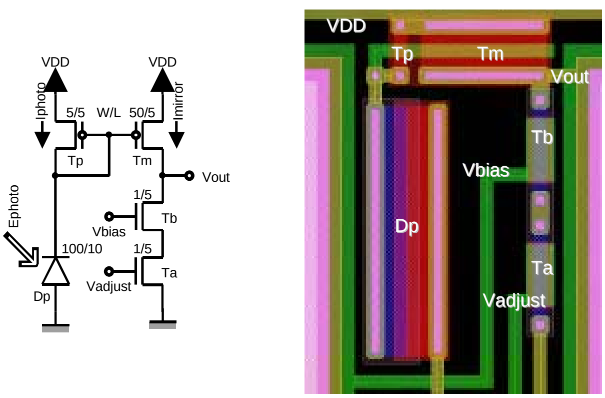
laser ablation / annealing (Suftla) [12] has been developed, enabling poly-Si TFTs and other thin-film devices to be transferred to any flexible, harmless and organic material substrates [13]. Moreover, since the fabrication processes of poly-Si TFTs do not consume much energy and since wafers are recycled after Suftla, it is expected to be low-emitting and cost-effective.

Here, we will propose an artificial retina using thin-film photodiodes (TFPDs) and poly-Si TFTs, which is expected to be suitable for living bodies, low-emitting and cost-effective [14-15]. Especially in this paper, we will design the circuits of the retina pixel and retina array and confirm that the artificial retina can control photo-sensitivity.

2. Thin-film photodiode and Thin-film transistor

The device structure and actual characteristics of the TFPD are shown in Figure 1. It is fabricated using the same fabrication processes as those for poly-Si TFTs and consists of a PIN diode. The actual dependence of photo-induced current (Iphoto) on photo-illuminance from the incandescent lamp (Ephoto) with a variation in reversely applied voltage (Vreverse) is shown in Figure 1(b), and the actual dependence of Iphoto on Vreverse with a variation in Ephoto is shown in Figure 1(c). They are modeled into circuit simulation using the method developed by the authors, which is a numerical fitting using spline interpolation, and utilized for the following circuit simulation [16].

The device structure and actual characteristics of the poly-Si TFTs are shown in Figure 2. It is fabricated as follows. First, an amorphous-Si film is deposited using low-pressure chemical-vapor deposition (LPCVD) of Si_2H_6 and crystallized using XeCl excimer laser to form a poly-Si. Oxygen plasma treatment is performed to improve poly-Si and its interface. Next, SiO_2 is deposited using electron-cyclotron resonance chemical-vapor deposition (ECR-CVD) for a gate-oxide. A gate metal is deposited and patterned. Phosphorous and boron are doped and thermally activated for source-drain regions. Contact holes are opened, and a source-drain metal is deposited and patterned. The actual transfer characteristic is shown in Figure 2(b), and the actual output characteristic is shown in Figure 2(c). They are also modeled into circuit simulation using the method developed by the authors.

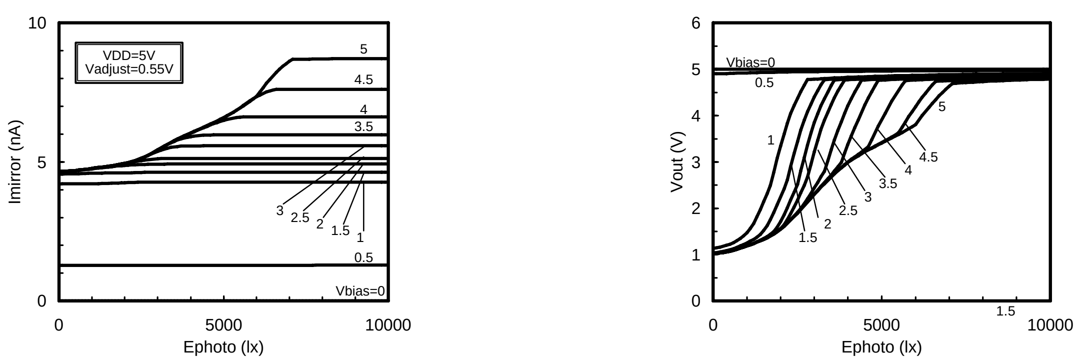


(a) Circuit diagram (b) Design layout

Figure 3 Circuit diagram and design layout of retina pixel

3. Retina pixel

The circuit diagram and design layout of the retina pixel are shown in Figure 3. It is based on an elementary current mirror, but some improvements



(a) Dependence of Imirror on Ephoto with variation in Vbias

(b) Dependence of Vout on Ephoto with variation in Vbias

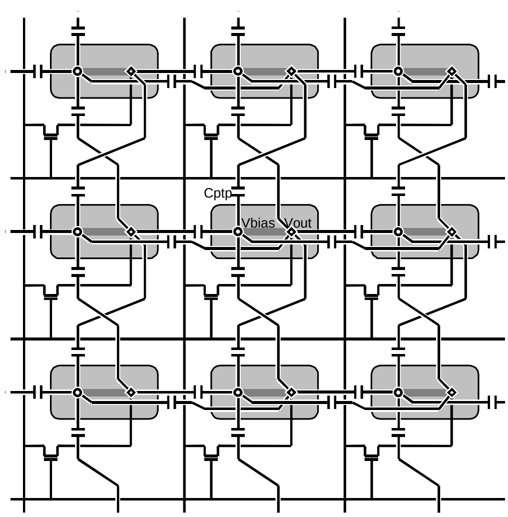
Figure 4 Characteristics of retina pixel

are added by considering the characteristics of the TFPDs and poly-Si TFTs and operation of an artificial retina discussed below. Although the part for the generation of Imirror consists of two p-type TFTs, the part for the load resistance consists of two n-type TFTs. Sensitivity can be controlled by both Vbias and Vadjust. The scales for the TFPD and all poly-Si TFTs are optimized.

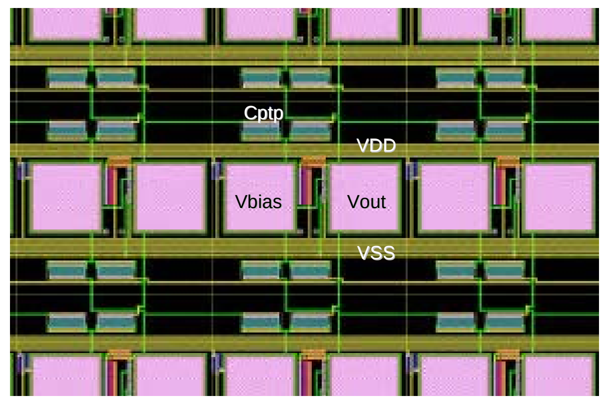
The simulated characteristics of the retina pixel are shown in Figure 4. Circuit simulation is performed using the TFPD model and poly-Si TFT model. The simulated dependence of Imirror on Ephoto with a variation in Vbias is shown in Fig 4(a), and the simulated dependence of Vout on Ephoto with a variation in Vbias is shown in Fig 4(b). It is verified that the retina circuit can correctly produce Imirror and Vout. Sensitivity is controlled by Vbias once a suitable voltage is applied to Vadjust.

4. Retina array

The circuit diagram and design layout of the retina array are shown in Figure 5. Although living retinas have several functions, edge enhancement is achieved using this retina array. Vout is connected to Vbias in

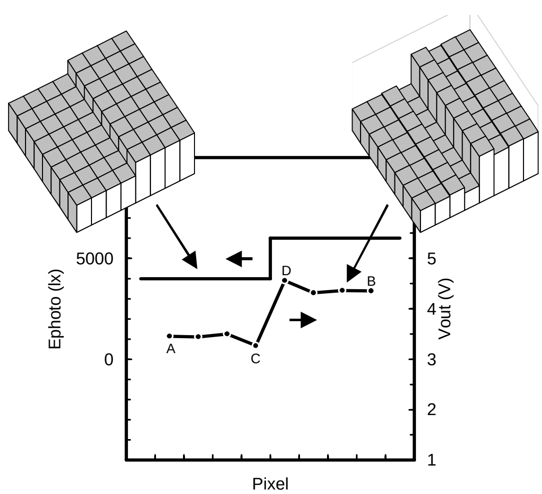


(a) Circuit diagram

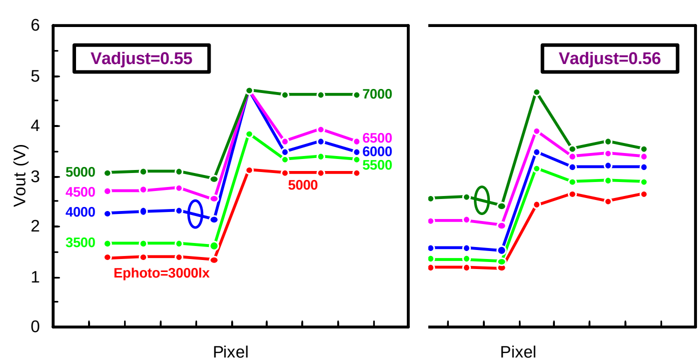


(b) Design layout

Figure 5 Circuit diagram and design layout of retina array



(a) Edge enhancement



(b) Photo-sensitivity control

Figure 6 Characteristics of retina array

adjacent pixels through Cptp. Vout is not only the output signal but is also applied as Vbias in adjacent pixels through Cptp. When a pixel is highly illuminated, its Vout is high. When a high voltage is applied as Vbias in an adjacent pixel, Vout in the adjacent pixel is decreased, and vice versa. As a result, edge enhancement can be achieved. Although large contact pads are located for fundamental evaluation, a principal part is 27300 μm^2, which corresponds to 154 ppi.

The simulated characteristics of the retina array are shown in Figure 6. The simulated edge enhancement is shown in Figure 6(a). The inputted profile of Ephoto and simulated profile of Vout for multiple pixels are shown. Vout whose adjacent pixel is poorly illuminated is increased, and vice versa. The difference in Vout between A and B in Figure 6(a) is 0.90 V, while the difference between C and D is 1.30 V, therefore edge enhancement is defined as (1.30 V - 0.90 V) / 0.90 V = 44 %. The simulated photo-sensitivity control is shown in Figure 6(b). By adjusting Vadjust, Ephoto where the edge enhancement is achieved can be controlled. By applying 0.55 V to Vadjust, 4000 - 6000 lx is most enhanced, while by applying 0.56 V, 5000 - 7000 lx is most enhanced.

5. Conclusion

An artificial retina using thin-film photodiodes (TFPDs) and thin-film transistors (TFTs) is proposed. The characteristics of a TFPD and TFTs are measured, and they are modeled into circuit simulation. The circuits of the retina pixel and retina array are invented with some improvements, and they are designed. It is confirmed that the artificial retina can operate and achieve edge enhancement. It is also confirmed that it can control photo-sensitivity.

6. Acknowledgements

The authors thank Mr. Hiroyuki Hara, Dr. Tomoyuki Okuyama, Dr. Satoshi Inoue, and Dr. Tatsuya Shimoda of Seiko Epson Corporation, Silvaco International, Silvaco Japan, Cadence Design Systems, Cadence Design Systems Japan, Mr. Yoshiki Katsuyama of Cybernet Systems for OrCAD PSpice licenses, Mr. Tsuneo Munakata of Jedat for α-SX licenses. This research is partly supported by collaborative research with Seiko Epson Corporation, a research grant from Ryukoku University Science and Technology Fund, and a research project of the Joint Research Center for Science and Technology at Ryukoku University.

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