An integrated photodiode fabricated by low temperature poly-Si TFT process

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Abstract

We have simultaneously fabricated LTPS TFTs and integrated photodiodes on the same glass substrates without any additional LTPS process. The structure of an integrated photodiode is a lateral p-i-n diode with a gate. The performances of a photodiode were improved at a negative gate voltage.

1. Introduction

Recently, mobile displays have been focused on input functions such as image capturing[1,2], touch screen[1,3], finger printing[4], and ambient light sensor[5]. To implement these techniques, many researchers have investigated various methods for the input functional displays. One of the dominant techniques is a sensor technique integrating photo sensors in pixels. There are several benefits in these sensor techniques. First, it is unnecessary to have peripherals which performed functions in besides of a display. Second, it is easy to integrate photo sensors in pixels as the circuit integrating technology developed. Finally, mobile displays with functions can be thin, light, and durable.

Two different kinds of photo sensors[1-8] have been investigated in research groups. One is a TFT-type[6-8] and the other is a diode-type[1-5].

Low temperature poly-Si (LTPS) TFT-LCD has chosen a diode-type of photo sensor because it is easy to make a diode structure with the LTPS TFT fabrication method. The diode structure is mainly a lateral p-i-n diode unlike the conventional vertical p-i-n diode. Also, the lateral structure can solve the problem of poly-Si whose film thickness is optimized to maximize the TFT performance, as controlling the intrinsic region of p-i-n diodes[9].

In this paper, we propose an integrated photodiode with an advanced structure, which is a lateral p-i-n diode with a gate electrode. The performances of a lateral p-i-n diode with a gate were analyzed with respect to a gate voltage and a photo-sensitivity

2. Fabrication and Experiment

We have simultaneously fabricated LTPS TFTs and integrated photodiodes on the same glass substrates. Figure 1 represented the fabrication process of an LTPS TFT and an integrated LTPS photodiode. In figure 1 (a), a conventional LTPS TFT process was shown. On glass substrates, 6000 Å-thick SiO_2 was deposited as buffer layer followed by 500 Å-thick a-Si deposition. Using an excimer laser annealing (ELA), a-Si was recrystallized. 1000 Å-thick SiO_2 was deposited on the active layer as a gate insulator. 3000 Å-thick Mo as a gate electrode was sputtered and patterned. For ion doping, ions were doped for p+, n+, and n- as a lightly doped drain (LDD). 1 μm-length LDD structure was optimized to increase the stability of TFTs and decrease a thermal leakage current. 6000 Å-thick SiO_2 was deposited as a passivation layer, followed by the deposition and patterning of source and drain electrodes.

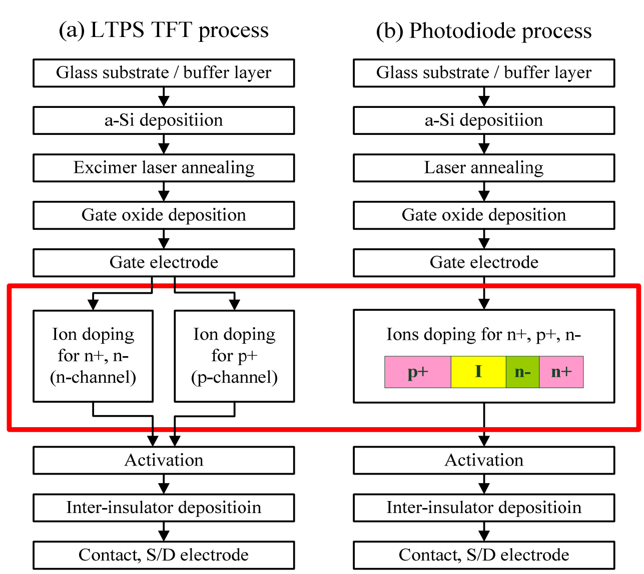
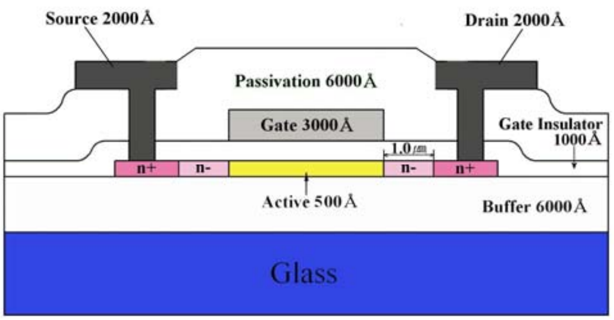
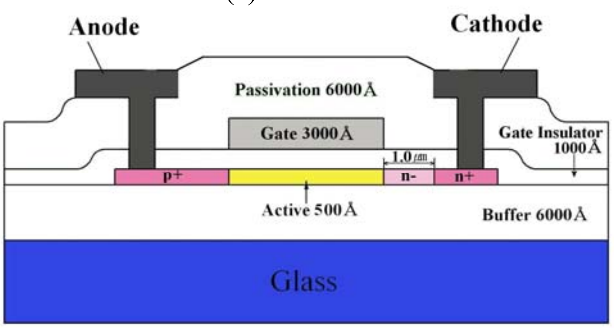


Fig. 1. The fabrication process of (a) LTPS TFT and (b) photodiode.



(a) LTPS TFT



(b) Photodiode

Fig. 2. The cross-sectional view of (a) an LTPS TFT and (b) a photodiode.

In figure 1 (b), an integrated photodiode was fabricated by the same LTPS TFT process simultaneously. The difference between the process of LTPS TFTs and that of photodiodes is only an ion doping process (see a box in figure 1). The integration of a photodiode does not require additional manufacturing process and adding costs. Therefore, the advantage of this structure is that a unique photodiode can be incorporated in the LTPS process without any additional steps.

The cross-sectional structure of an LTPS TFT and an integrated photodiode is shown schematically in figure 2. The LTPS TFT was designed as a top gate structure and the photodiode consisted of a unique lateral p-i-n structure with a gate electrode like an LTPS structure. Figure 3 is the top-viewing image of fabricated samples, which are (a) an LTPS TFT with W/L = 20/15 μm and (b) an integrated photodiode with W/L = 200/12 μm.

To confirm the LTPS process, the characteristics of LTPS TFT was analyzed. Figure 4 is the electrical characteristics of the LTPS TFT with W/L = 20/15 μm. The field-effect mobility, on/off current ratio, and threshold voltage of n-channel TFT exhibited 209 $cm^2/V{\cdot}s$, 1.7×10^9, and -2.05 V at V_{DS} = 10.1 V, respectively.

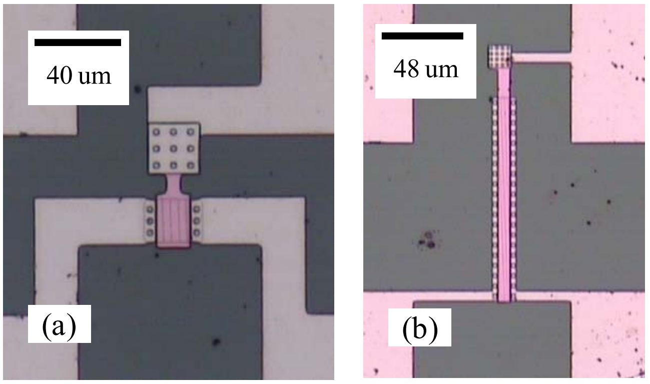


Fig. 3. The plane-view of (a) an LTPS TFT and (b) a photodiode taken by optical microscope.

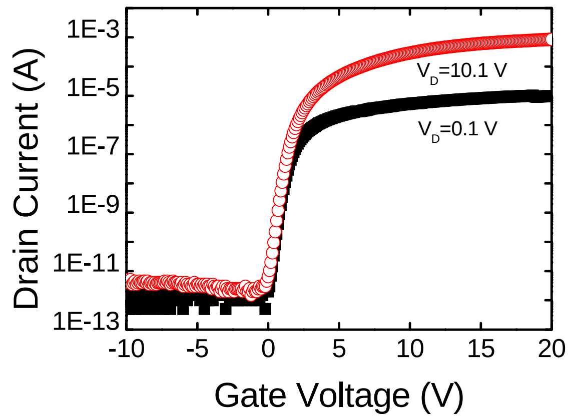


Fig. 4. The transfer characteristic of LTPS TFT.

3. Results and discussion

The lateral p-i-n photodiode was controlled by a gate voltage (V_g). The gate voltages varied from -10 V to +10 V. Generally, a photodiode is operated in reverse bias conditions. The fabricated lateral p-i-n photodiode did not generate break-down to anode-cathode voltage (V_{ac}) = -10 V. From V_{ac} = 0 V to V_{ac} = -10 V, the diode current was saturated. As the light was irradiated, a photo leakage current (I_{photo}) occurred.

A gate electrode causes a vertical electric field to the intrinsic region (i-region) of the lateral p-i-n diode. Appling a positive gate voltage, an electron channel was formed. On the contrary, a hole channel was formed at a negative voltage. Namely, the gate electrode can control the conductivity of i-region by varying voltages.

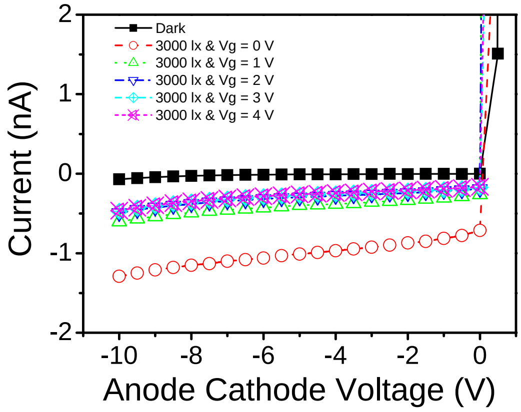


Fig. 5. The I-V_{ac} characteristic of a lateral p-i-n photodiode for a positive gate voltage.

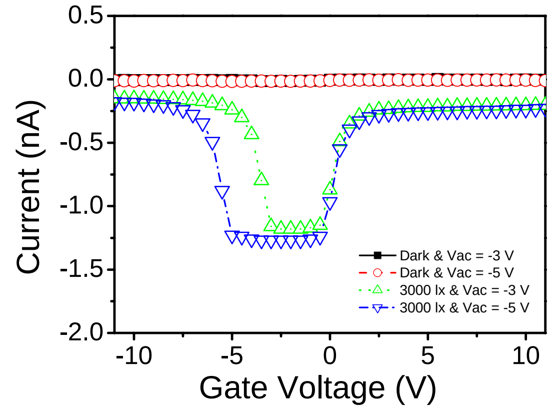


Fig. 7. The I-V_g characteristic of a lateral p-i-n photodiode.

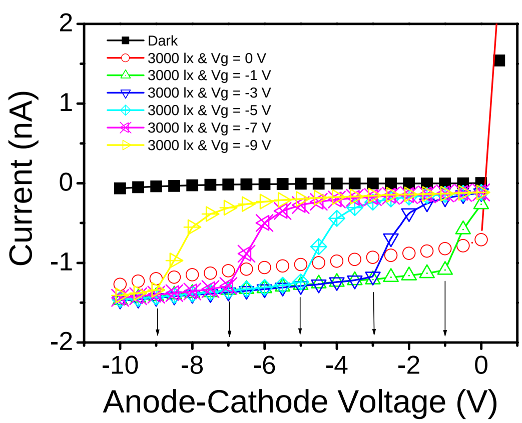


Fig. 6. The I-V_{ac} characteristic of a lateral p-i-n photodiode for a negative gate voltage.

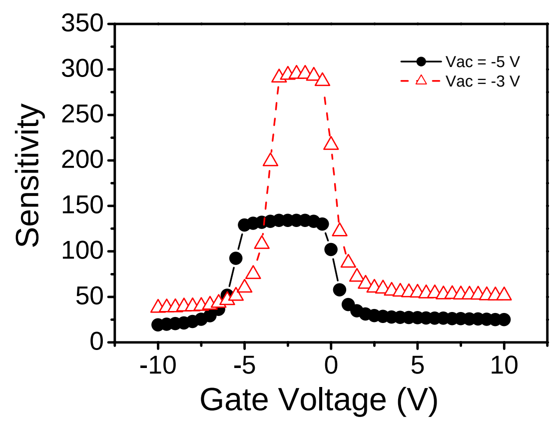


Fig. 8. The sensitivity of a lateral p-i-n photodiode.

Figure 5 and figure 6 shows the I-V_{ac} characteristic of a photodiode applying gate voltages. The photodiode was illuminated by using an LED back light. At dark condition, gate voltages hardly influenced a photodiode because of little photo leakage currents. On the other hand, there were significant differences between a negative gate voltage and a positive gate voltage at bright condition.

Applying a positive gate voltage, the photo current was decreased. In figure 5, a gate voltage varied from 0 V to 4 V. Increasing a positive gate voltage induced decreasing the photo current. This result is due to form an electron channel in an intrinsic region (i-region).

For a negative gate voltage in figure 6, there is a distinctive feature in the curve. Without a gate voltage, the photo leakage currents began at V_{ac} = 0 V in a reverse bias. With a negative gate voltage, from V_{ac} = 0V to V_{ac} = V_g, the leakage currents increased slowly. At V_{ac} = V_g, the photo leakage currents fully flows.

Figure 7 represented a gate voltage effect. The current of a lateral p-i-n photodiode has a maximum value from V_g = 0 V to V_g = V_{ac} in a negative gate voltage region. The photocurrent in negative voltage regions (0 V < V_g < V_{ac}) was larger than that at V_g = 0 V.

In figure 8, the sensitivity was defined that the photo current applying a gate voltage was divided by the dark current at V_g = 0 V. From V_g = 0 V to V_g =

V_{ac} in a negative gate voltage region, the lateral p-i-n photodiode can operate with the maximum sensitivity.

In these results, the lateral p-i-n photodiode with a gate showed significant characteristics. First, to control gate voltages can induce to increase the photo current at a negative gate voltage. Moreover, the sensitivity is increased. Second, at specific negative voltage, the lateral p-i-n photodiode can be operated stably.

4. Summary

We have simultaneously fabricated LTPS TFTs and integrated photodiodes on the same glass substrates. The photodiode can be incorporated in the LTPS process without any additional steps. The advanced photodiode consisted of a unique lateral p-i-n structure with a gate electrode like an LTPS structure. The gate electrode can control the conductivity of i-region by varying voltages. Specially, at a negative gate voltage, the sensitivity of a lateral p-i-n photodiode can be increased by forming a hole channel. At specific negative voltage, the lateral p-i-n photodiode can be operated stably with the maximum sensitivity.

5. Acknowledgements

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