Structural Effect on Backlight Induced-leakage Current in Amorphous Silicon Thin Film Transistor

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Abstract

Leakage current produced by backside illumination on bottom-gated amorphous silicon thin film transistor has been investigated. The experimental results show that the leakage current of bottom-gated structure is significantly dependent on the shape of amorphous silicon pattern. A proper design of amorphous silicon pattern has been suggested in viewpoint of reducing the leakage current as well as mass production.

1. Introduction

It is well known that the leakage current of amorphous silicon thin-film transistors (a-Si:H TFTs) is severely increased by illumination of light onto the channel [1,2]. Inverted staggered structure, so called bottom-gated structure, is commonly employed when a-Si:H TFTs are utilized for switching elements in active matrix-liquid crystal displays (AM-LCDs). This is because the gate electrode shields the amorphous silicon channel from backside illumination of the assembled backlight system [3]. It has been accepted that the light induced leakage current can be neglected in bottom-gated a-Si:H TFT. However the shielding effect of the bottom-gate is not perfect and the deterioration of image quality related with the light induced leakage current may arise as the brightness of backlight increases for LCD-TV applications.

In this work, bottom-gated a-Si:H TFTs were fabricated in various types of pattern design and the light induced leakage current of each type TFT was measured under backside illumination. The relationship between the detailed design and the magnitude of light induced leakage current was investigated. Dominant mechanism of generation of light induced leakage current in the bottom-gated structure was also discussed. It was verified that the light induced leakage current can be increased when a-Si:H layer protrudes outside the gate electrode and that the generation of the light induced leakage current is concentrated at a specific point. Finally a proper design of amorphous silicon pattern was suggested in viewpoint of reducing the leakage current as well as mass production.

2. Experimental

Bottom-gated a-Si:H TFTs were fabricated on a corning 1737 glass substrate. 200nm-thick chromium (Cr) layer was deposited by DC magnetron sputtering and patterned for the gate electrode. Amorphous SiN_x, a-Si:H and n^+a-Si:H layers were successively deposited by plasma enhanced chemical vapor deposition (PECVD) and patterned to form the active layer. The thickness of each layer was 350nm, 200nm and 50nm respectively. 200nm-thick Cr film was sputtered and patterned to form the source and drain electrodes. And then the n^+a-Si:H layer between the source and drain electrodes was etched out by dry etch method. Finally, passivation layer of 200nm-thick amorphous SiN_x was deposited by PECVD. Holes were opened for the measurement of electrical characteristics of TFTs.

The I-V measurement was carried out using Agilent 4156B with probe position controlling system. Samples were located on the substrate where the backlight system was installed. The light induced leakage current was measured in a shielding box which blocks additional external light.

3. Results and discussion

Firstly, in order to verify the generation of leakage current due to backside illumination, a-Si:H TFTs were fabricated in three types of pattern design as shown in Fig. 1. Type I has conventional bottom-gated structure where a-Si:H layer protrudes outside the gate electrode. Type II has the same bottom-gated structure but a-Si:H layer locates completely inside the gate electrode. Type III has asymmetric a-Si:H pattern employing the design of type I at one of the source and drain electrodes and the design of type II at the other side. All the fabricated TFT has the same channel length of 5μm and width of 40μm.

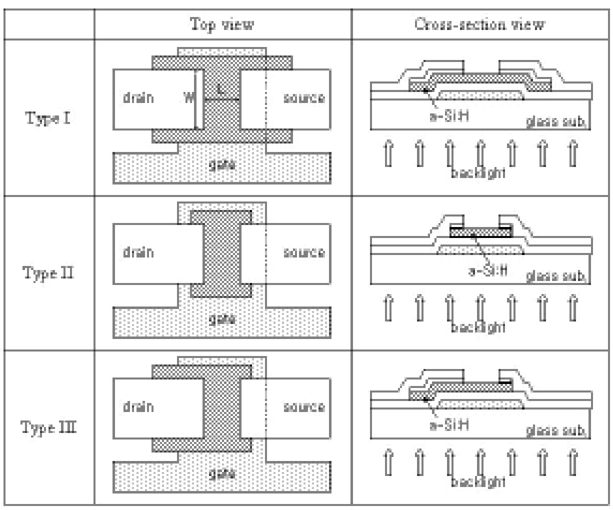
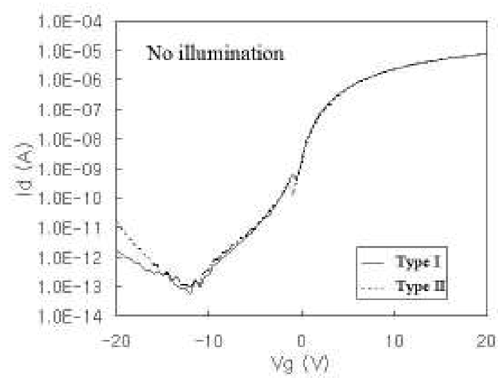
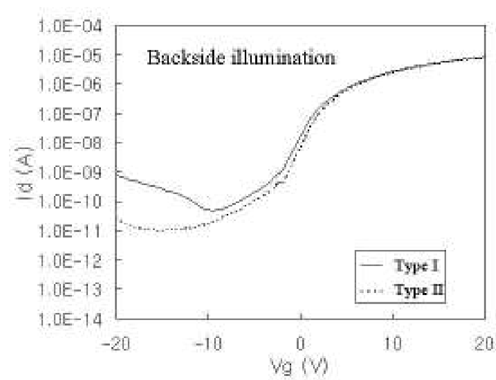


Fig. 1. Three types of bottom-gated a-Si:H TFT design

Figure 2 (a) shows I_d-V_g characteristics of type I and type II in dark state where no backside illumination is applied. The characteristics of each TFT are nearly the same regardless of the pattern design and the dark leakage current shows very low magnitude lower than 1 picoampere. However, when backside illumination is applied, the leakage current of each TFT shows very large difference in magnitude as shown in Fig. 2 (b). The intensity of backlight was about 8000cd/m^2 comparable to that of LCD-TV backlight. The light induced leakage current of type I is much higher than that of the type II. It is clear that the protrusion of a-Si:H layer outside the gate electrode plays a major role in the generation of leakage current due to electron-hole pair generation by absorbing the backlight. The leakage current of type III shows different magnitude by exchanging the source and drain electrodes. When the electrode contacting with the protruding side is assigned as the drain and the other electrode as the source, the leakage current is almost same as type I. However, when the source and drain are exchanged, the leakage current is almost the same as type II. This result implies that the leakage current produced by backlight in bottom-gated structure is related to the reversed-biased drain junction and high electric potential difference between the drain and channel. From the above results the mechanism of generation of leakage current can be considered as follows. Electron-hole pairs are generated in the protruding a-Si:H layer by absorbing the backlight and then some of them near the edge of the gate electrode flow into the reversed-biased drain junction which appears in turn-off state. The electrons are attracted into n$^+$a-Si:H layer by the junction electric field and reach to the drain electrode. The holes are attracted into the channel where holes are accumulated and reach to the source electrode across the channel. Finally closed current loop for the leakage current is obtained.



(a)

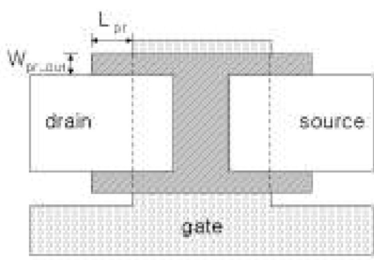


(b)

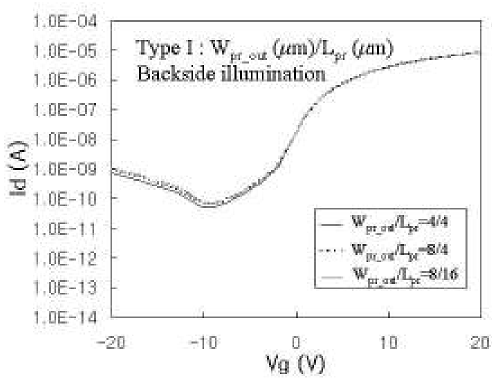
Fig. 2. I_d-V_g characteristics of type I and type II TFTs, (a) in dark state, (b) under backside illumination

The reason for some increase in the leakage current of type II is considered to be due to the light guiding effect of the gate insulator assisted by multi-reflection at the drain and gate electrodes, which delivers some amount of slantly incident backlight to the hidden a-Si:H layer.

In order to investigate the exact location where the leakage current is generated, the design of type I was varied in the protruding length (L_{pr}) and width (W_{pr_out}) as illustrated in Fig. 3 (a). The protruding width (W_{pr_out}) means also the outward distance from the edge of the drain electrode. Figure 3 (b) shows the I_d-V_g characteristics of each TFT which has different values of L_{pr} and W_{pr_out}. Increasing the protruding length has no relationship with the magnitude of the leakage current.



(a)

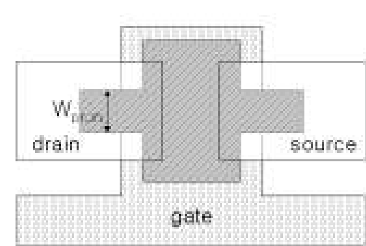


(b)

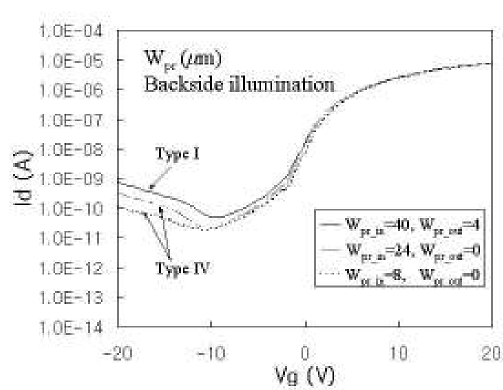
Fig. 3. (a) Variations of the protruding length (L_{pr}) and width (W_{pr_out}) in type I, (b) I_d-V_g characteristics of type I TFTs

Increasing the outside protruding width results in some increase of the leakage current but the increased magnitude is not so much as to the increased width. Therefore the outside protruding width has minor relationship with the magnitude of the leakage current. Electron-hole pairs are generated in overall protruding region and increase as the area of protruding region increases. However most of them cannot move to contribute to the leakage current because the protruding a-Si:H region seems to have equipotential defined by the drain bias. The electron-hole pairs which contribute to the leakage current are only those near the gate electrode. So it is clear that the protruding length is not related to the magnitude of leakage current. The reason for some increase of the leakage current by increasing the outside protruding width is considered as follows. The potential of the channel in turn-off state is not so much different from the source bias. Therefore the potential difference between the outside protruding region and the channel region may result in the movement of electrons and holes near the interface to contribute to the leakage current. But, although holes can move easily into the channel, most of electrons far from the drain electrode may disappear due to recombination before they move to reach the drain electrode. So this component is not also dominant in the total magnitude of leakage current.

From the above results it can be thought that the main component of the light induced leakage current is the electron-hole pairs generated near the edge of the gate electrode under the drain electrode. In order to verify this, type IV TFT where the width of the protruding a-Si:H layer is smaller than that of the source and drain electrodes as illustrated in Fig. 4 (a). The inside protruding width (W_{pr_in}) means the width of the protruding a-Si:H layer. Figure 4 (b) compares I_d-V_g characteristics of type IV TFTs which have different W_{pr_in}s with the reference curve of Type I.



(a)



(b)

Fig. 4. (a) Variation of the inside protruding width

(W_{pr_in}) in type IV, (b) I_d-V_g characteristics of type VI TFTs in comparison with type I TFT

As the inside protruding width gets smaller, the light induced leakage current decreases considerably. By reducing the inside protruding width the leakage current decreases by more than one order. This is due to the upper mentioned mechanism that the main component of the light induced leakage current is the electron-hole pairs generated near the edge of the gate electrode under the drain electrode. Type I has disadvantage in the magnitude of the light induced leakage current, however it has some advantage in viewpoint of mass production. This is because the protruding a-Si:H layer prevents the source and drain electrodes from step-opening, due to smooth step-coverage. Therefore type IV is the most preferable because the leakage current can be minimized and the advantage of preventing the step-open problem can be maintained.

4. Summary

We investigated the relationship between the shape of amorphous silicon pattern and the leakage current produced by backside illumination. The conventional design where the amorphous silicon layer protrudes outside the gate electrode showed considerable increase in leakage current when the brightness of backlight increases. Although the amorphous silicon layer protrudes outside the gate electrode, if the protruding region is completely covered by the source and drain electrodes and the protruding width is minimized, the light induced leakage current can be considerably reduced and the advantage of preventing the step-open problem can be maintained.

5. References

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