Amorphous Silicon Top-Gate-Gap TFTs for Front-illuminated Optical Sensors

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Abstract

The amorphous silicon top gate-gap TFTs are proposed for front-illuminated optical sensors in this work, which is identical to the process of standard VA TFT-LCD arrays. The proposed top gate-gap TFT exhibits distinct photocurrent in both the on and off regions of Id-Vg curve under different front-illuminated intensities, remaining theoretically undisturbed by the bottom backlight. The length of gap has an impact on the photocurrent of top gate-gap TFTs, where even with a real W/L of only 40μm/9μm, and the maximum dynamic range and photocurrent can achieve 128 dB and 1.86E-7A, respectively. The photocurrent and dynamic range could be taken into account by optimized size of top gate-gap TFTs, which could provide a new development idea for front optical sensors.

Author Keywords

Top gate; gap gate; a-Si TFT; front-illuminated optical sensors; wide dynamic range; high photosensitive current.

1. Introduction

Hydrogenated amorphous silicon (a-Si:H) thin-film transistors (TFTs) have received widespread application in TFT-LCDs, electronic paper displays (EPDs), X-ray detectors, and various other fields [1-2]. This is attributed to their advantages of cost-effective fabrication, high maturity, excellent yield rates, and compatibility with large-scale, medium-scale, and small-scale production lines over the past few decades. In particular, compared with monocrystalline silicon, amorphous silicon film possess an optical band gap of approximately 1.7 eV and exhibit greater sensitivity to illumination, which is conducive to being used as an optical sensor. Therefore, a-Si:H TFT-based optical sensors have be used to perform value-added functions such as ambient light sensor (ALS), fingerprint identification, remote light touch for large displays or interactive whiteboards.

Furthermore, increasing a-Si:H TFT-based optical sensors integrated into the interactive display device can realize multi-functional integration without external complex components, which is inconsistent with the high screen-to-body ratio and civilianize prices. According to the above, integrating a-Si:H TFT-based optical sensor in screen, which could be manufactured as the standard a-Si:H TFT processes synchronously, becomes the competitive choice currently.

In previous research, the optical characteristic advantages and photosensitivity of so called gap-type or bias TFT and ambipolar Gap-Type a-Si TFT have been paid attentions, and the high-level photocurrent at on-region makes it a potential candidate for optical sensor [3-6]. The influence of gap-type TFT size, bias length and TFT shape on photosensitivity has also been studied [7]. Nevertheless, as shown in Figure 1, according to the structural characteristics of gap type TFT, the gap of gate does not prevent the illumination emitted by the backlight from reaching the a-Si:H semiconductor layer [8], which is not suitable for LCD displays that must be equipped with backlight.

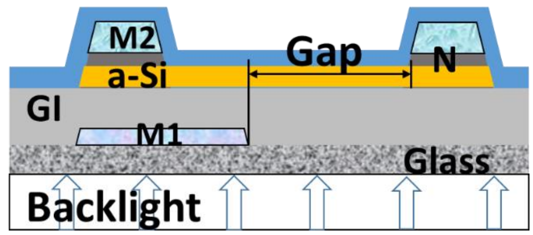

Figure 1. Cross section view of conventional gap-type TFT with backlight

In this work, to address the aforementioned challenges, the top gate a-Si:H TFT with gap was proposed as a front-illuminated optical sensor. The TFT was fabricated using the identical process as the VA TFT-LCD array. For the top gate-gap a-Si:H TFTs, PV and PFA serve as the gate insulation layer, ITO serves as the gate, bottom metal can serve as the backlight shielding layer, and the TFT channel can receive front illumination from the outside through the transparent ITO layer.

2. Process and Structures

Process: The a-Si top gate TFT-based optical sensors was described as follows. First of all, a Mo/Al film (M1) was sputtered and patterned on the glass substrate to form gate electrodes. After GIN (SiNx, a-Si:H and N films) and Mo/Al/Mo (M2) were successively deposited by plasma-enhanced chemical vapor deposition (PECVD) and sputter system respectively, two wet two dry process (2W2D) technology was followed to form a-Si TFT source and drain electrodes and channel pattern. Subsequently, a SiNx layer was deposited to passivate the TFTs and PFA (polymer on array) was coated and partly patterned for planarization, respectively. Finally, transparent conducting ITO film was deposited and patterned to form pixel electrodes and top gate electrode. The cross section view of standard and top gate-gap structure TFTs are compared in Figure 2, the gate insulation layer of sensor TFT_1 and 2 are PV and PV&PFA respectively.

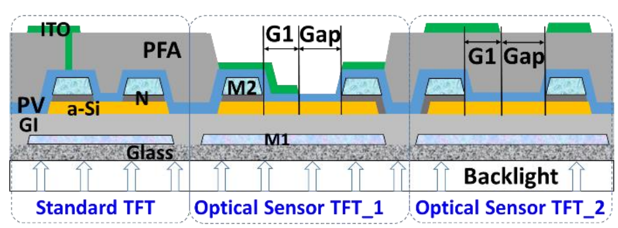

Figure 2. Cross section view of standard and top gate structure a-Si:H TFTs with gap

The influence of top gate-gap on photosensitivity was investigated by fixing the length of G1 at 4μm and varying the gap length from 5 to 30μm, as demonstrated structure of TFT_1

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and TFT_2 in Figure 2. Just as a basic comparison of photosensitivity, the width of the top gate TFT was defined as 40μm.

The optical sensor TFT was measured in the front illuminance range of 0 to 70000 lux, encompassing the vast majority of application scenarios.

3. Results and Discussion

3.1 Photosensitivity of different TFT structures: Figure 3(a), (b) and (c) show the transfer characteristics of standard TFT, optical sensor TFT_1 and TFT_2 with gap=5μm under different front illuminance intensities, respectively. The measured Vds is 10V and Vgs is -30V~30V with step 1V. It is obviously seen that the standard and optical sensor TFT_1 have photocurrent only in the off-state current, while the TFT_2 has distinct photocurrent on the entire Id-Vg curve. When the photosensitivity was investigated at the current of Vgs=-5V, all the TFTs exhibit excellent photo-response, even at illuminance intensity as low as 1.5 lux.

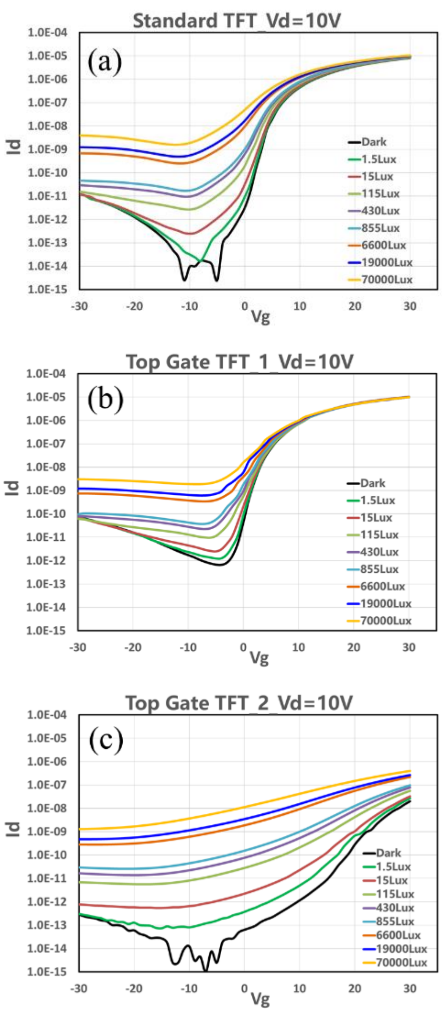


Figure 3. Transfer characteristics of (a) standard TFT, (b) TFT_1 and (c) TFT_2 under different front-illuminated intensities

As shown in table 1, at the illuminance of 70000 lux, the dynamic range [9] of TFT_2 is up to 128 dB, while the standard as well as TFT_1 are 71 dB and 127 dB, respectively. The higher I_{photo}/I_{dark} ratio (wide dynamic range) implies the better resolution of illuminance intensity. Nevertheless, the photocurrent at low illuminance intensity is as low as 1E-12A, resulting in diminished precision and increased costs for the current sensing signal and integrated operational amplifier.

Table 1. Dynamic range of three different TFT structures under 70000 lux.

TFT structure	Standard TFT	TFT_1	TFT_2
Dynamic range (dB)	127	71	128

The proposed optical sensor TFT_2 also exhibits a notable photo-response in the on region. Furthermore, as the Vgs increases, so does the current. The thickness of GI in standard TFT and TFT_1 is only about 4000Å. By contrast, the film thickness of the GI in TFT_2 reaches up to 2.8μm (PV and PFA), resulting in a weak control electric field of the gate voltage on the top gate channel carriers. The higher the illuminance intensity, the greater the number of photo-generated carriers and the lower the resistance of the gap. Consequently, photo-generated carrier emerges as the predominant in TFT_2 on region.

Since the PV layer serves as the gate insulation for the top gate, the characteristics of the thin-film transistor (TFT) are influenced. Hence, film thickness of 3500Å, 4200Å and 4500Å obtained by different deposition recipes is expected to improve the photosensitivity of TFT_1. However, as illustrated in Figure 4, varying conditions have no significant effect on the photosensitivity of TFT_1. The dynamic range of PV with thickness of 3500Å, 4200Å and 4500Å under illuminance of 70000 lux are 71dB, 67 dB and 79 dB, respectively.

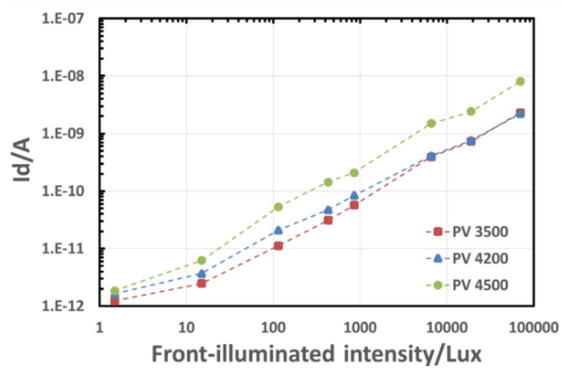


Figure 4. The photocurrent of TFT_1 with different PV conditions at varying illuminance intensities

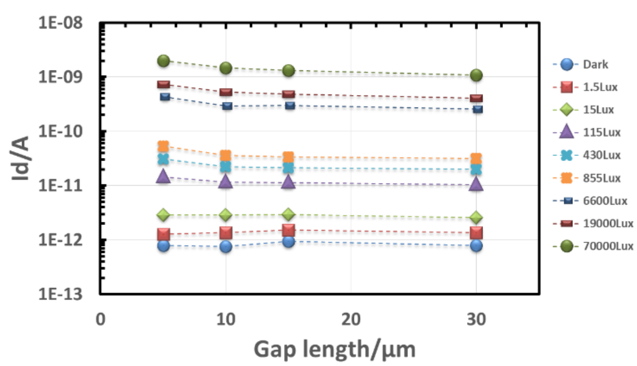


Figure 5. The photocurrent of TFT_1 with different gap lengths at varying illuminance intensities

3.2 Photosensitivity of different gap lengths: The photosensitivity of the top gate-gap TFT is further investigated by applying different gap lengths to the top gate, namely 5μm, 10μm, 15μm, and 30μm respectively. TFT_1 has a photo-response only in the off region, so the current at Vgs=-5V is still chosen for different gap lengths and varying illuminance intensities. As illustrated in Figure 5, the current exhibits a significant increase with rising illuminance intensity levels, but shows a slight decrease overall as the gap length increases.

The transfer characteristic curves of TFT_2 at various gap lengths are presented in Figure 6, revealing significant photosensitive responses in the on and off region. Further analysis is presented in Figure 7(a), it is evident that the dynamic ranges of the four gap lengths under 70000 lux are all the widest near Vg=0V, and narrows as the gate voltage increases to 30V. This phenomenon occurs due to the elevated current approaching the on region in dark. The longer the gap lengths, the greater the channel resistance. Therefore, in the on region, the overall current diminishes as the length of the gap increases. Simultaneously, to ensure a higher light sensing current, we conduct this study with gate voltages set at Vg = 22V. The photocurrent under all illuminance intensities obviously decreases with an increase of the gap length of TFT_2, as shown in Fig. 7(b). The most significant reduction in photocurrent is observed between the gap lengths of 5 and 10μm, whereas the decrease is less pronounced between the gap lengths of 15 and 30μm.

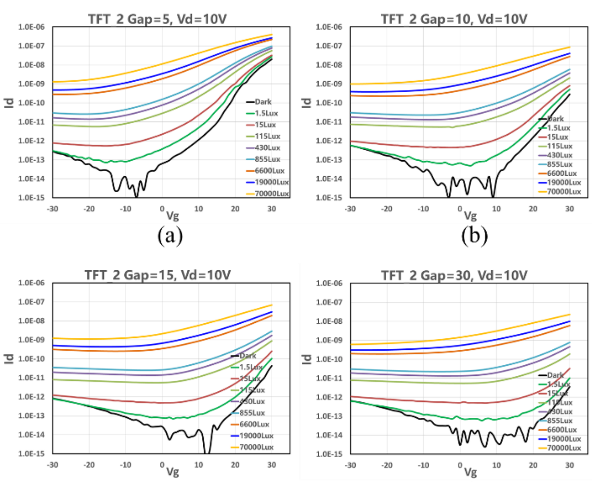
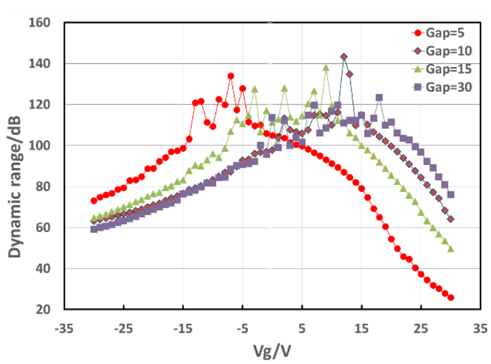
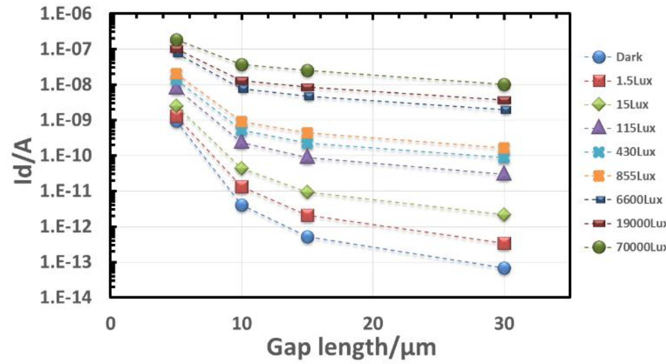


Figure 6. Transfer characteristics of TFT_2 with (a) gap=5, (b) gap=10, (c) gap=15 and (d) gap=30 under different front-illuminated intensities



(a) Under 70000 lux



(b) At Vg=22V and Vd=10V

Figure 7. (a) Dynamic range at different Vgs and (b) photocurrent at varying illuminance intensities of TFT_2 with varying gap lengths

When the gap is 5μm, the current at Vg=22V with Vd=10V under all illuminance intensities can exceed 1E-9A. Therefore, by optimizing the size of the top gate a-Si TFT and adjusting the top gate-gap length, in conjunction with selecting an appropriate voltage, we can achieve the desired photocurrent and dynamic range.

4. Conclusion

This work introduces a-Si top gate-gap TFT, which employs the same process and structure as VA TFT-LCD arrays, serves as a front-illuminated optical sensor. The differences of film thicknesses, film qualities, and gap lengths do not have a significant impact on the photosensitive reaction and dynamic range for TFT_1. The proposed top gate-gap TFT_2 exhibits a significant photocurrent response in both the on and off regions of Id-Vg curve under different front-illuminated intensities. In addition, as the gap length increases, the photocurrent of top gate-gap TFT_2 diminishes while the dynamic range expands. The current of TFT_2 with W/L=40μm/9μm can achieve 1E-9A under all illuminance intensities. The suitable size of top gate-gap a-Si TFT is anticipated to be utilized across all scenarios involving front-illuminated optical sensors, and it theoretically remains unaffected by backlight.

5. Acknowledgements

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6. References

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