Sensor phenomena

Using Amorphous Silicon Gap-Type Thin Film Transistor as Ambient Light Sensors and Proximity Sensors for Smartphones

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Abstract—In the smartphone industry, there is a clear trend of developing high screen-to-body ratio display. In order to achieve this demand, we proposed the idea of integrating photo sensing devices into display panels. The photosensitive characteristic of amorphous silicon (a-Si) gap-type thin-film transistors is reviewed and the applicability is examined from the viewpoints of ambient light sensor and proximity sensor. The advantages and feasibility of this idea are fully investigated.

Index Terms—Sensor phenomena, ambient light sensor (ALS), amorphous Silicon (a-Si), gap-type, proximity, sensor, thin-film transistors (TFTs).

I. INTRODUCTION

Nowadays, smartphones are almost a must-have communication device for everyone. The popularity of the usage drives the thriving development of smartphone displays. When it comes to choose a smartphone, the proper body size for the individual's hand to hold is essential. With fixed body size, everyone likes the display area to be maximum. Thus, pursing high screen-to-body ratio is a clear trend [1].

Some necessary functions of smartphones must be implemented on the front side of the smartphone by some discrete components, which can occupy the upper and lower parts, as shown in Fig. 1. Cellphone designers would like to get the components away to obtain the high screen-to-body ratio. For example, the former phone has a home button embedded with fingerprint sensor in the lower part, but the new one gets rid of it by putting the fingerprint sensor to the backside or under screen. Other than that, there are still features not dealt with, such as ambient light sensor (ALS), proximity sensor, front camera, sound receiver, etc. ALS is for measuring ambient light intensity and then adjusts the appropriate screen backlight intensity [2]–[4]. Proximity sensor is for detecting the intensity of the reflection of infrared (IR) and determining whether the object is in close range [5], [6]. Front camera is for self-taken photograph and video. Sound receiver is for listening to the call. In the modern phones, these functions are collectively put in the upper part area called notch, which makes irregular shaped display, as shown in Fig. 2 [1]. The notch area is not so welcome by users and the driving force to hide the components away continues.

Among the functions, both ALS and proximity receiver are basically light sensors. According to previous research, amorphous silicon (a-Si) gap-type thin-film transistors (TFTs) are good light sensing devices with high photosensitivity [7]–[8]. More importantly, their fabrication process is fully compatible to that of the conventional a-Si TFTs. Thus, they can be integrated into the display panel in the border area with no extra charge. In this article, the possibility of using gap-type TFTs as ALS and proximity receiver for smartphones is demonstrated.

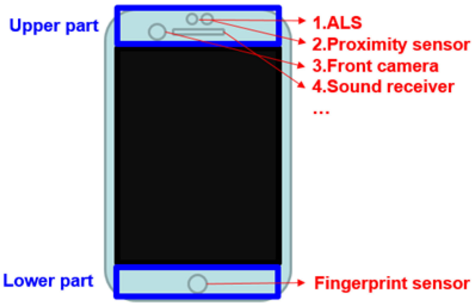

Fig. 1. Smartphone block diagram.

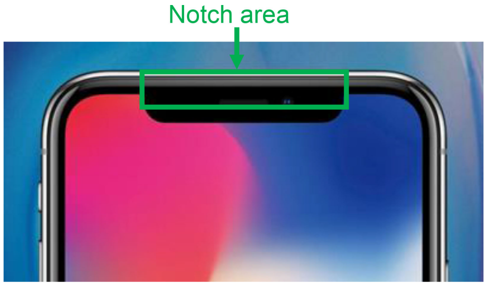

Fig. 2. Notch area of smartphone.

II. A-SI GAP-TYPE TFT

A. Device Process Flow

Fig. 3(a) and (b), respectively, shows the process flows of conventional and gap-type a-Si TFTs. In the identical flow, the only difference between these two devices is source and drain metal layer in pattern definition. The gap length (G_L) is the distance between the edges of drain electrode to gate metal. Using the same process, the a-Si TFTs as switches and light sensors can be monolithically fabricated on the same substrate in the display panel.

B. Device Characteristic

In this article, the device channel width, length, and gap length of the device are all 10 μm. In the measurement, the device is biased at

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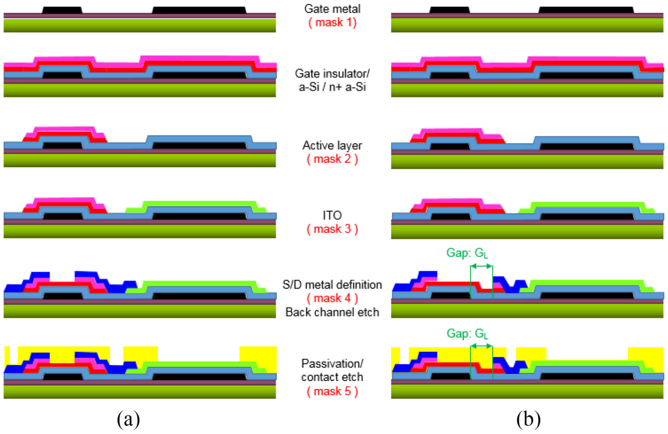
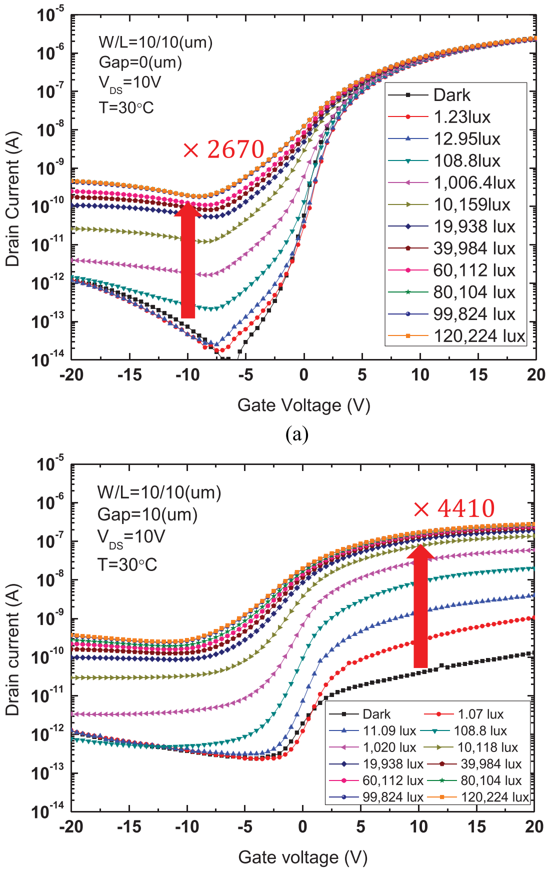


(a) (b)

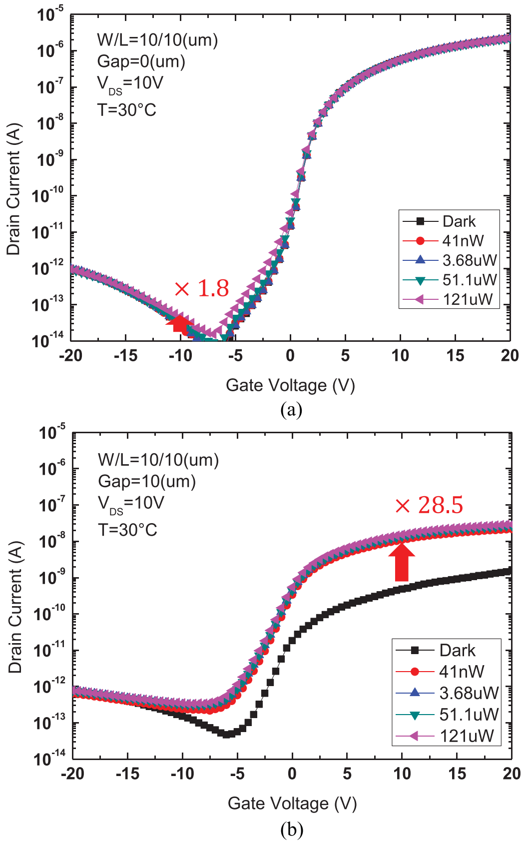
Fig. 3. Process flow of (a) conventional and (b) gap-type a-Si TFT.



(a)

(b)

Fig. 4. I_D–V_G curves of (a) conventional TFT and (b) gap-type TFT under ambient light illumination.



(a)

(b)

Fig. 5. I_D–V_G curves of (a) conventional TFT and (b) gap-type TFT under IR illumination.

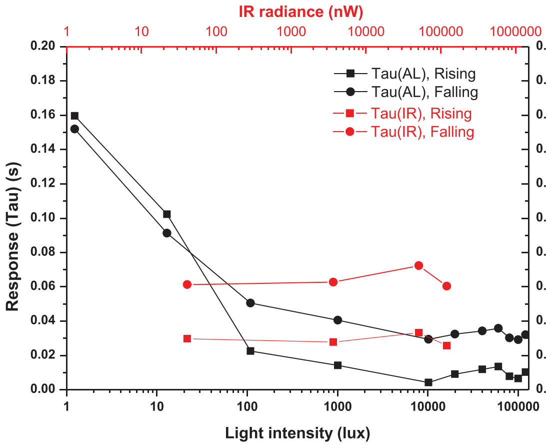


Fig. 6. Response time (tau to lux, tau to IR radiance).

$V_D = 10\,\text{V}$ and $V_S = 0\,\text{V}$, and gate voltage is sweeping from –20 to 20 V, and the illuminating direction is front. The drain current versus gate voltage (I_D–V_G) characteristic curves of conventional TFT and gap-type TFT under ambient light illumination are shown in Fig. 4(a) and (b), correspondingly. The conventional TFT only responds to the light in the off region, while the gap-type one reacts in both on and off regions. The gap-type TFTs' $\mathrm{I_{Don\_120224lux}/I_{Don\_Dark}}$ ratio is 4410, which is higher than that of conventional TFTs' 2670. The other case is device under illumination of IR ray with a wavelength of 940 nm. The I_D–V_G characteristic curves of conventional TFT and gap-type TFT are shown in Fig. 5(a) and (b), correspondingly. The conventional TFT is almost no response to the IR in both on and off regions, while the gap-type one reacts in on region. The gap-type TFTs' $\mathrm{I_{Don\_120224lux}/I_{Don\_Dark}}$ ratio is 28.5, which is higher than that of conventional TFTs' 1.8. The light sensitivity in the on region makes the gap-type TFT more suitable for sensing applications because of the higher current level. Besides, as indicated by the red arrows in Figs. 4 and 5, the dynamic range of gap-type TFT is even better than that of conventional TFT. The response time of gap-type TFT is also examined. The response time (tau) versus lux and radiance are shown

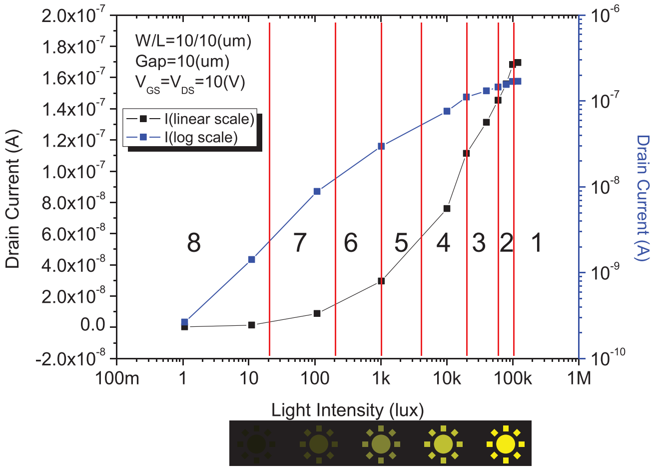


Fig. 7. I_D–lux curve from 0 to 120 000 lux.

in Fig. 6. Under ambient light illumination, the rising time of reaching saturation current is within 0.1 s except the case of light intensity below 20 lux. As the intensity of illumination increases, the rising time is shorter. As shown in Fig. 7, we can see that when the light intensity is too weak, it needs relative longer rising time. The trend of falling time is the same as that of rising time. The results show that the device can be operated at scan frequency 1–10 Hz, which is sufficient for the application in ALS and proximity sensors.

In the following sections, we will demonstrate how to take advantage of the high current level and high light/dark ratios in current to make good sensors for smartphones.

III. EXAMINATION OF APPLICABILITY

A. Ambient Light Sensor

The drain current versus light intensity curve is extracted from Fig. 4(b) and plotted in Fig. 7. As shown in Fig. 7, the linearity of the curve is not perfect, but we can still divide the wide range in ambiance to several levels from dark to bright and use them as the basis to accordingly adjust the backlight intensity level. For example, light intensity higher than 100 000 lux is the first level. Light intensity between 60 000 and 100 000 lux is the second level. And so on, the light intensity below 20 lux is the eighth level. Gap-type TFT sense current, which induced from variant ambient light. The readout current determines backlight level.

B. Proximity

The drain current versus IR intensity is extracted from Fig. 5(b) and plotted in Fig. 8. We can set a critical point as threshold point to define the proximity, as shown in Fig. 8. When the current level is greater than the critical point, it indicates that object is close enough to reflect considerable intensity of IR. The specific IR comes from emitter on smartphone, not the weak spontaneous IR in the natural environment. The screen is set to be off to avoid unintended error in touch. Otherwise, the screen is kept on.

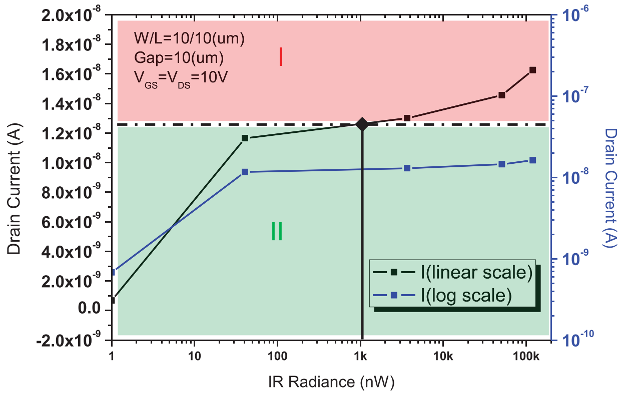
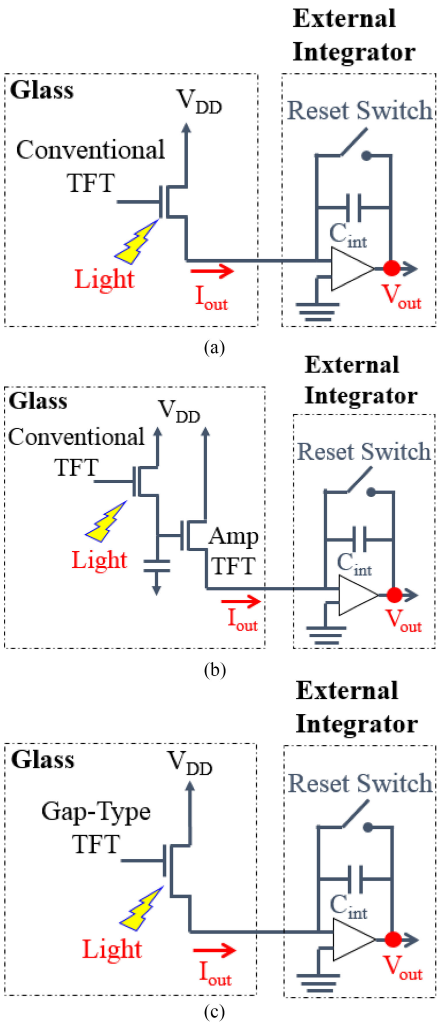


Fig. 8. I_D–IR radiance curve.



(a)

(b)

(c)

Fig. 9. Photo-sensing circuit and block diagram (a) Conventional TFT (b) Conventional TFT and amplifying TFT (c) Gap-type TFT.

IV. ADVANTAGES OF HIGH CURRENT LEVEL

In fact, the off current of conventional TFT can also be used for light sensing. The photocurrent is used to charge the capacitor in an external integrator, and thus the output voltage signal is obtained, as shown in Fig. 9(a). However, either the long charge time is required to charge the external integrator capacitor (C_{int}) and get a readable output voltage, or the output voltage is too small to be read by the external readout IC. For example, it takes 0.1 s for the 0.1 nA photocurrent to charge the C_{int} of 10 pF to 1 V. In order to solve this problem, an amplified TFT can be added to amplify the voltage signal in the pixel, as shown in Fig. 9(b). It is worth noting that using gap-type TFT as sensing device can intrinsically provide the photocurrent level to charge C_{int} several hundred times faster without using the amplifying TFT, as shown in Fig. 9(c).

V. CONCLUSION

In order to pursue high screen-to-body ratio smartphone, the idea of using gap-type TFTs as the integrated ALS and proximity sensing devices is proposed and verified. By virtue of compatible process, the gap-type TFTs can be fabricated on display panels with no extra charge. Therefore, the area on screen occupied by discrete sensors can be omitted. Gap-type TFT has the advantages of good photosensitivity, large dynamic range, and high sensing current level. Even though the linearity of the sensors is not perfect, it is good enough to be applied as the ALS and proximity sensors for smartphones.

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