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Light-Controlled Gap-Type TFT Used for Large-Area Under-Screen Fingerprint Sensor

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ABSTRACT In the fierce market competition of different biometric methods in smartphones, where consumers are pursuing a high screen ratio, optical fingerprint recognition under OLED screen is a well-established approach. However, using thin-film transistor (TFT) technology to make large-area optical sensors generally has the issue of low sensitivity, which will make the signal difficult to be read out. In this paper, we propose to use gap-type TFT with high photosensitivity current and process compatible with display panels as the sensing device to build the sensing array. The pixel circuit can be simplified to structure containing only of two thin-film transistors (TFTs). Using this gap-type TFT sensing array under OLED panel for fingerprint recognition is proven to be effective by the clear images captured with the readout system.

INDEX TERMS Fingerprint sensor, gap-type, photocurrent, thin film transistor (TFT).

I. INTRODUCTION

Nowadays, smartphone is an indispensable mobile device in human daily life. Many functions and applications require biometrics recognition to ensure personal information security. Biometrics recognition methods include fingerprint and face ID [1]. In comparison, the false rates of fingerprint recognition are relatively low in practical use. Therefore, fingerprint recognition is an indispensable function for smartphone. In addition, consumers want to maximize the screen-to-body ratio of smartphone. Using the optical sensors under screen is a successful approach. Up to now, only the sensing device made in IC can be sensitive and fast enough to fit this application. However, the cost of IC prevents it from being large in area. Users somewhat difficult to find the location of the IC sensor behind display if its area is small. Therefore, the sensor in large-area made on thin-film transistor (TFT) substrate is expected to replace IC sensor by the smartphone makers [2] and [3].

There are several photosensitive devices can be made on the same substrate of TFT, including PIN diode [4], phototransistor [5]–[7], gap-type TFTs [8] and [9]. We consider that gap-type TFT is the best optical device in the under-screen fingerprint sensor for its good sensitivity and low cost owing to the high photocurrent and fully TFT-compatible process [10] and [11]. In this paper, a system with the gap-type TFT for the optical sensing array, the array under OLED panel with collimator in between, and the read-out circuit is built to demonstrate the good performance in fingerprint image capture.

II. GAP-TYPE TFT CHARACTERISTIC AND MECHANISM

The cross-sectional view of gap-type TFT is shown in Fig. 1, and the characteristics are shown in Fig. 2. The size of the device is 10 μm in both channel width (W) and length (L), and the gap length (Li) is 4 μm. Its process is identical to that of the conventional amorphous silicon TFT [10]. As the transfer curves shown in Fig. 2(a), the light response of drain current (I_D) can be observed no matter what the gate voltage (V_G) is biased, but it is preferred to use the much high photocurrent when V_G is positive and large. The curves of I_D versus drain voltage (V_D) shown in Fig. 2(b) give another aspect of this device. Varying light intensity with

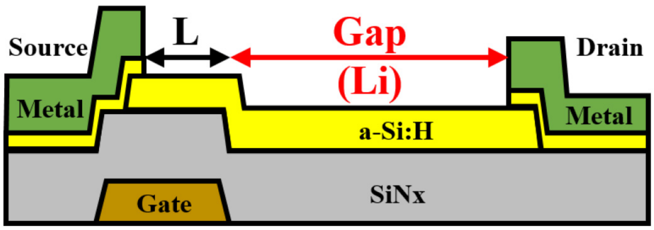

FIGURE 1. Cross-sectional view of gap-type TFT.

V_G fixed at 5V, I_D increases linearly with V_D before it gets a saturation value. This behavior is very similar to a typical I_D-V_D characteristic of a normal transistor. In addition, the trend of photocurrent to light intensity at fixed biases of V_G and V_D is illustrated in Fig. 2(c).

The energy band diagrams shown in Fig. 3 are used to explain the light response of the gap-type TFT. When the device is biased at $V_D > 0$V, the illumination can generate electron-hole pairs in the active layer. As shown in Fig. 3(a), when V_G lower than flat band voltage (V_{FB}), the holes and electrons move to the source and drain electrodes, respectively. The photo effect in this condition resembles that in a photodiode. When V_G is higher than V_{FB}, as shown in Fig. 3(b), the light-generated electrons moves to the drain electrode as well, but the light-generated holes accumulate at the junction of the gate-controlled channel and the gap. The hole accumulation can lower the energy barrier at the junction, which limits the electrons pass through. The higher light intensity can make the barrier lower, which brings about the light-controlled I_D of the gap-type TFT. The first increase in V_D can provide higher horizontal electric field in the gap to separate more photo-induced carriers. When V_D is large enough, the photo-induced carriers is limited by the incident photons, which results in the I_D-V_D characteristics shown in Fig. 2(b).

III. FINGERPRINT SENSING SYSTEM

The configuration of the gap-type TFT sensing array with its readout circuit is shown in Fig. 4. The pixel circuit is composed of two TFTs, including a gap-type TFT and a normal TFT. Gap-type TFT is used as a photosensitive device, while normal TFT is used as a switch to cut off the current from the unselected gap-type TFT. The simple pixel structure is beneficial for high density. The readout circuit includes analog front end (AFE) IC of Texas Instruments AFE0064 to convert the sensing current into an analog voltage by an integrator, and analog-to-digital convertor (ADC) IC of Analog Devices AD7274 to convert analog voltage into digital code. Unlike the conventional operation of TFT sensing array, which needs long integration time (t_{int}) to accumulate enough photo charge as shown in Fig. 5(a), the photocurrent of the gap-type TFT is high enough to be instantly read out in one row-selection time as shown in Fig. 5(b). Thus, the operation of the array is to simply scan the rows, which is implemented by the gate driver on panel. For example, the photocurrent I_{photo} is 1.944×10^{-8}A at the

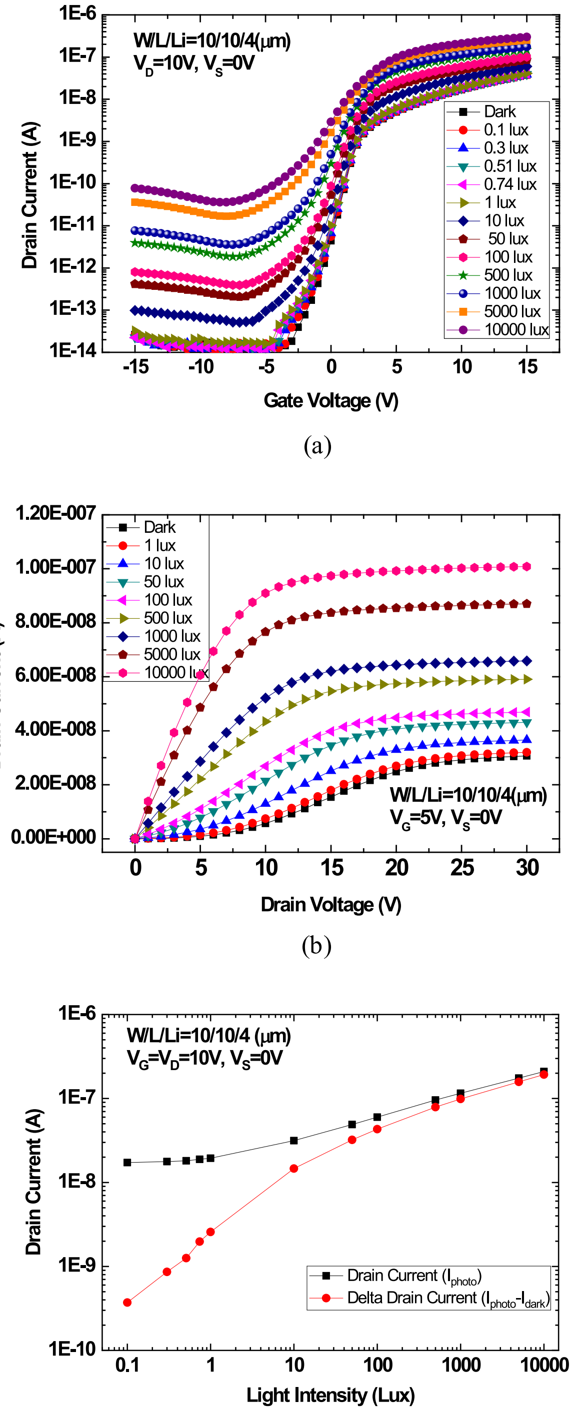

FIGURE 2. Characteristics of gap-type TFT (a) I_D-V_G (b) I_D-V_D (c) I_D-Lux.

light intensity of 1Lux, when the read time t_{read} is set at 200μs, and the integrate capacitance C_{int} is chosen to be 1.7143pF, the output voltage V_{out} is calculated to be 2.268V by (1):

$$|V_{out}| = \frac{I_{photo} \times t_{read}}{C_{int}} \tag{1}$$

The large signal and fast readout brought by the high photocurrent of the gap-type TFT provides the great advantages in the application of fingerprint recognition.

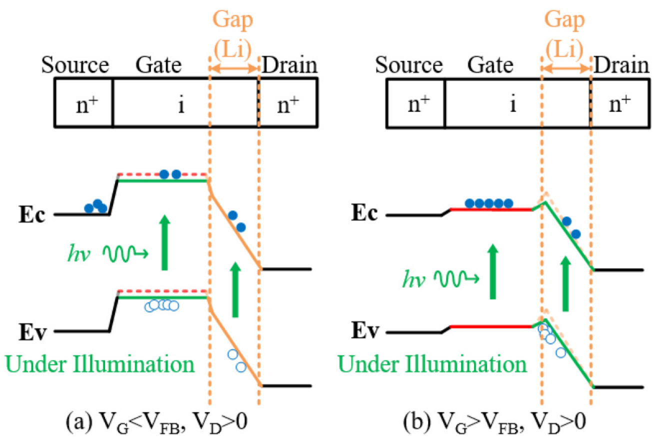

FIGURE 3. Band diagram of gap-type TFT (a) $V_G<V_{FB}$ (b) $V_G>V_{FB}$.

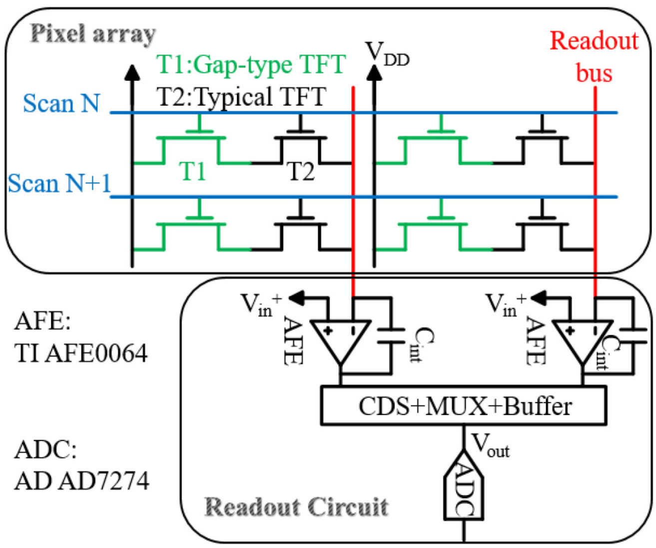

FIGURE 4. Gap-type TFT sensing array with its readout circuit.

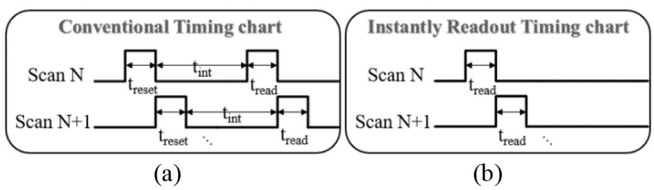

FIGURE 5. Timing chart of (a) conventional (b) instantly readout.

The specifications of the fingerprint sensor array are organized in Table 1. The photograph of the actually built sensing system taken from the front and back sides are shown in Fig. 6(a) and (b) respectively. The collimator is sandwiched between OLED panel and the gap-type TFT sensing array, as shown in Fig. 6(c). The sensing array connects to the readout circuit via flexible printed circuit (FPC). The fingerprint signal is acquired by the readout circuit and fed to control unit. The captured images of some fingerprint are shown in Fig. 6(d), which are processed by background subtraction and image enhancement through algorithms. The ridges and valleys of fingerprint can be clearly seen.

TABLE 1. Fingerprint sensor array specification.

Pixel Per Inch (PPI)	508 PPI
Resolution (H×V)	160 × 160
Fingerprint Sensing Window	26mm × 15mm
Active Area (AA)	8mm × 8mm
Pixel Size	50µm × 50µm
Readout Time (t_{read})	175µs

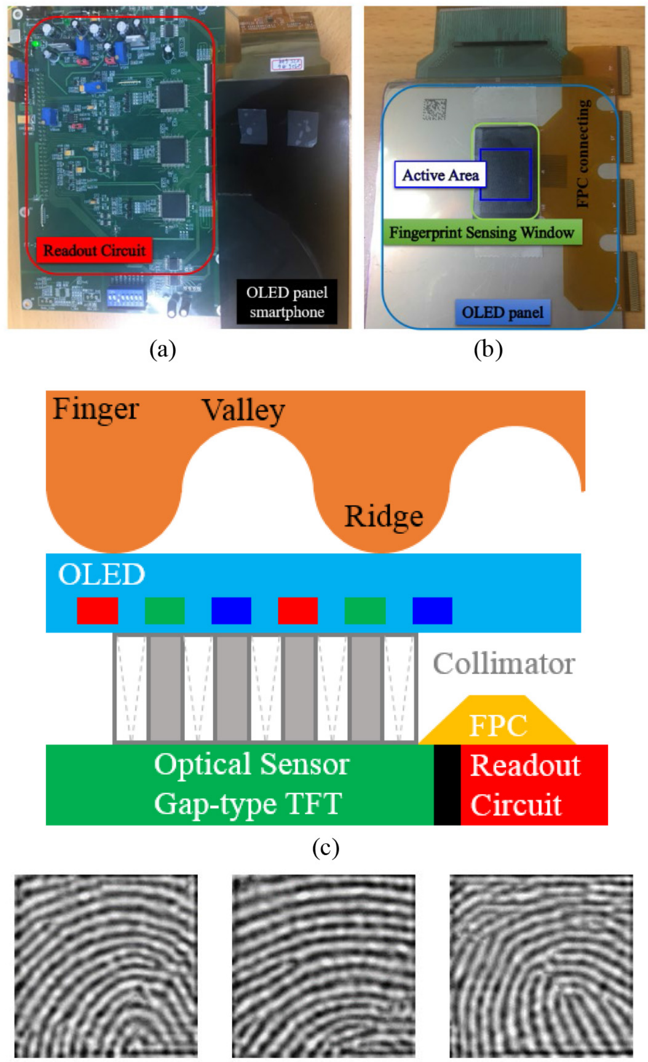

FIGURE 6. Fingerprint sensing system (a) front view (b) back view (c) cross-section view and (d) captured fingerprint images.

IV. CONCLUSION

The high photo-sensing current of the gap-type TFT is suitable for applications in under-screen fingerprint sensing, especially for those requiring fast readout. The common manufacturing process enables the large area and low cost. The simple pixel structure is not only favorable for high-density sensor, but also useful for integrating the sensing function in displays.

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