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Active matrix touch sensor detecting time-constant change implemented by dual-gate IGZO TFTs

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ABSTRACT

The dual-gate IGZO TFT is proposed to be used in an active matrix touch sensing circuit. The circuit contains only one TFT with a RC low-pass filter, since the dual-gate IGZO TFT can be controlled by both its top and bottom gates. The simplest structure maximizes the sensing pad area in the pixel. A touch event on the sensing pad forms a capacitance and thus increases the RC time-constant of the scan pulse fed to the gate of TFT. Thus, a significant transient ON current is generated to be the sensing signal. The current is so large that it can be easily read out and thus the power and cost of peripheral ICs can be reduced. In this paper, the robustness of the circuit to environment in operations is discussed.

1. Introduction

Touch screen panels (TSPs) have attracted much attention in various applications, such like personal digital assistants, handheld phones, and tablet PCs [1–5]. With the demands on TSPs increasing, the multi-touch function is developed for adapting in widely applications. Currently, capacitive TSPs are employed in most multi-touch products. Capacitive TSPs sense the capacitance change resulted from human touch. The change gets relatively smaller with panel size increasing and it becomes more difficult in detection. Active matrix is an effective solution to achieve a reliable and large-area multi-touch panel.

For large-area displays, active TSPs are expected to be made as an in-cell (embedded) type because of light weight, good display quality, and reduced production cost [6]. However, the integration of the conventional touch sensing circuit into an in-cell TSP occupies large pixel area, which leads to lower aperture ratio for display. Therefore, an active matrix touch sensing circuit with simple structure is required to maximize the aperture ratio of a display with embedded active TSP.

The top gate of a dual-gate TFT can affect the threshold voltage (V_{th}) [7], and this effect becomes more obvious in the dual-gate IGZO TFTs [8]. Applying this characteristic, we propose a new circuit uses only one dual-gate IGZO TFT. In addition to the merit of small area, the circuit has advantages of high sensitivity, high aperture ratio, low readout cost, and low operating power.

2. Device fabrication and characteristics

The process flow of the dual-gate a-IGZO TFTs is described as following. Shaped Ti/Al/Ti gate electrodes were capped with SiNx gate dielectric which was deposited by plasma enhanced chemical vapor deposition (PECVD). For the S/D metal, Ti/Al/Ti was formed by successive deposition with DC sputtering at room temperature. By patterning and dry etching these layers, the S/D electrode was formed. After that, the active layer of 30-nm-thick a-IGZO film was deposited by DC magnetron sputtering system using a target of In:Ga:Zn = 1:1:1. Then the active layer was defined after etching. Finally, devices were capped by the passivation at 280 °C, and then ITO were patterned and shaped for top gate. The device cross-section and the symbol of a dual-gate TFT are shown in Fig. 1.

Compared to conventional single-gate IGZO TFT, the difference is the top gate layer made by ITO deposited upon the passivation layer. According to Son's paper [8], V_{th} is positively and negatively shifted by the negative and positive bias on the top gate, respectively. We utilize this characteristic to provide alternate ways of turning off the TFT. Fig. 2 illustrates the characteristics of a dual-gate TFT. The bottom gate size is 100 μm in width W and 10 μm in length L, and the top gate length L_{TG} is 6 μm. The normal characteristic of the TFT with V_{BG} equal to V_{TG} is also plotted in Fig. 2. We can keep the TFT off by biasing top gate voltage (V_{TG}) at

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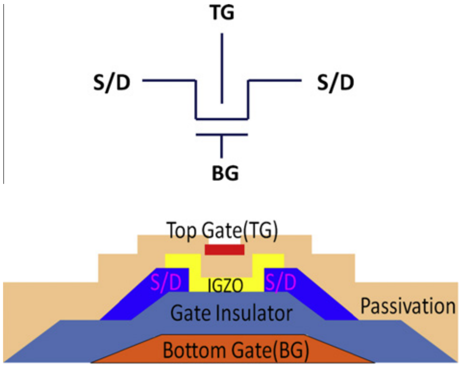

Fig. 1. The cross-section and the symbol of the dual-gate IGZO TFT.

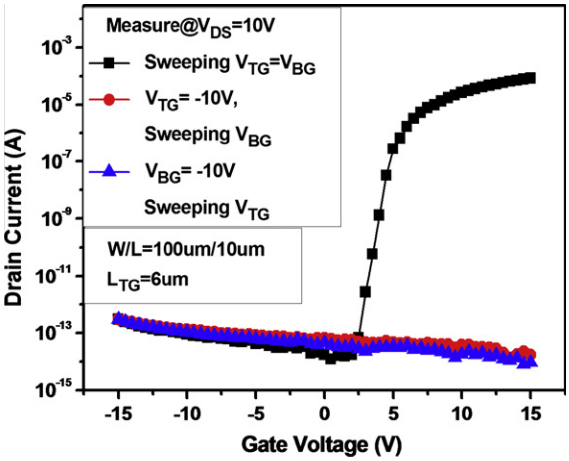

Fig. 2. The transfer characteristics of the dual-gate IGZO TFT: (a) sweeping $V_{TG} = V_{BG}$, (b) $V_{TG} = -10$ V, sweeping V_{BG}, and (c) $V_{BG} = -10$ V, sweeping V_{TG}.

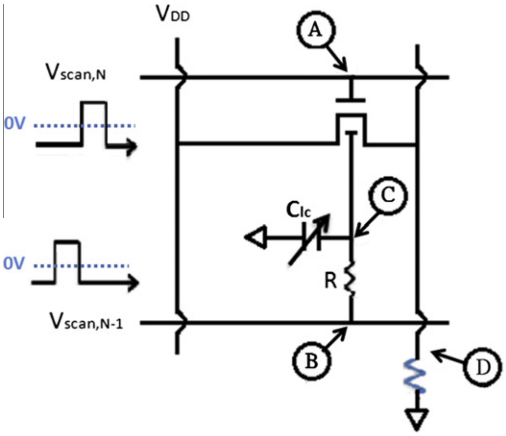

Fig. 3. Schematic drawing of the proposed sensing pixel circuit.

−10 V even when the bottom gate voltage (V_{BG}) is as high as +10 V, and vice versa.

3. Sensing pixel circuit

3.1. Proposed circuit scheme

The proposed sensing circuit is shown in Fig. 3. Only one dual-gate TFT is used to construct the touch sensing circuit. The top and the bottom gates of the TFT are connected to the two successive scan pulses, respectively. The difference is that the scan pulse is fed to the top gate by way of an RC low-pass filter. The capacitor in this RC circuit can be the liquid crystal capacitance (Clc), which is formed by the electrodes made on the TFT substrate and the common electrode on the color filter substrate. Clc can be increased to at least 2 times by the external forcing to compress the gap of the two electrodes [6,9]. Accordingly, the time delay in the RC circuit is increased at the same ratio. By designing the resistance value of the resistor, the degree of distortion in the scan pulse fed to the top gate can be properly adjusted. In our experiment, the pixel circuit is composed of discrete components. In the circuit of Fig. 3, the resistance of the RC circuit is 100 kΩ. Two capacitance, 1nF and 1.6 nF, are used as the untouched and touched capacitor, respectively.

The operation of the sensing circuit is explained hereafter in more detail. For most of the time, both the top and bottom gates of the dual-gate TFT are set at −10 V, and the TFT is turned off. Just before the N^{th} scan pulse ($V_{scan,N}$) coming to the bottom gate, the pulse of the $(N-1)^{th}$ scan ($V_{scan,N-1}$) is sent to the top gate through the RC circuit. If no touch event occurs at this time, the capacitance is low, and thus the slightly distorted gate pulse can fall in time to −10 V to turn off the TFT before $V_{scan,N}$ comes in. On the other hand, if a touch event happens, the Clc is raised due to the compressed cell gap. The larger Clc leads to more serious pulse distortion and prolongs the voltage falling time of $V_{scan,N-1}$. This delay time keeps the TFT from turning off by the time that the bottom-gate switches to +10 V. In such a case, a significant transient ON current flows through the TFT to be the sensing signal. With individual read out channels and sequential scan, the pixel circuit undoubtedly supports multi-touch function.

In an active matrix, the line delay resulting from the row bus must be considered. Generally in TFT LCDs, the RC delay in the gate bus is designed to be small and the gate voltage is switched to off a short period of time ahead the end of the line time correspondingly. It is to assure the row signal falls before its next row signal changes and thus both the pixels at the beginning and at the end capture the right voltage. In the proposed pixel circuit, the resistance value of the resistor R can be carefully chosen according to the change in Clc, making the time constant to be small enough for the untouched case and large enough for the touched case, so that the output signal is generated only when the pixel is touched. In practical fabrication, the resistor R of RC circuit can be made by a TFT with a constant gate voltage to avoid a large occupation of pixel area.

3.2. Measurement results and discussion

To verify the sensing function of the proposed circuit, two values of Clc were used in our experiment. One of the two values is 1.6 times of the other one to simulate the touched and the untouched cases. The measurement result is shown in Fig. 4. The waveforms at node A (V_A) and node C (V_C) are the voltages at the bottom gate and that at the top gate after RC time delay, respectively. To demonstrate the easiness of reading out the sensing current, we simply used a resistor of 1 MΩ to measure the transient current. For the touched case with larger Clc, the spikes in the voltage waveform (V_D) on the readout resistor indicate the touch events. The significant transient currents occur when V_A is high and V_C is not low enough to turn off the TFT. For the untouched case, no current is observed. In addition, the sensing pixel is also measured by applying the gate pulse with distortion time constant set as 20% of the gate pulse width, which corresponds to the reasonable RC distortion at the end of a row line. Fig. 4

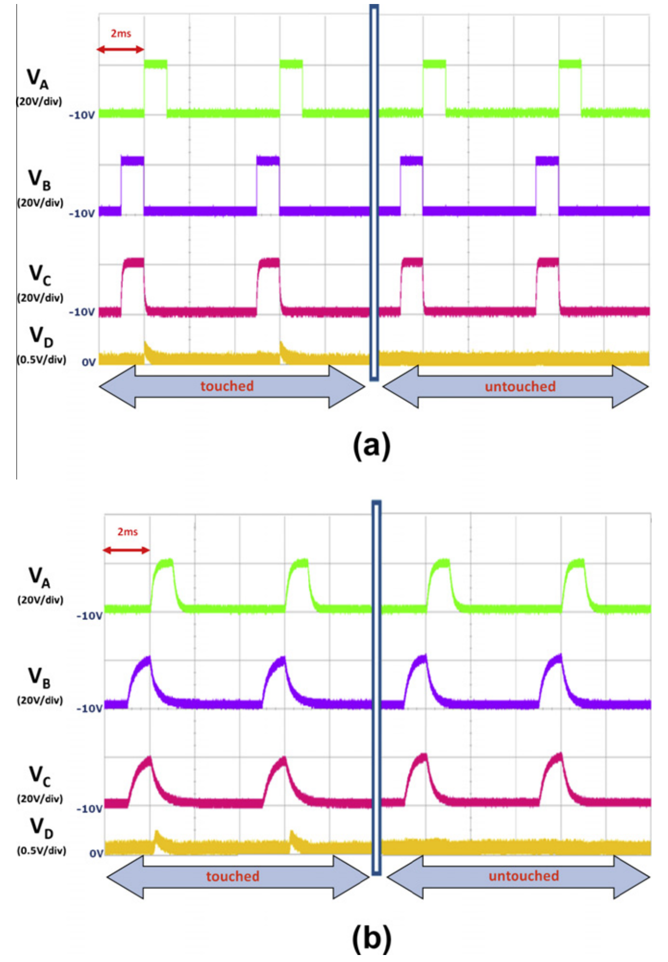

Fig. 4. The measurement results of the proposed circuit: (a) without and (b) with the gate pulse distortion of a row bus.

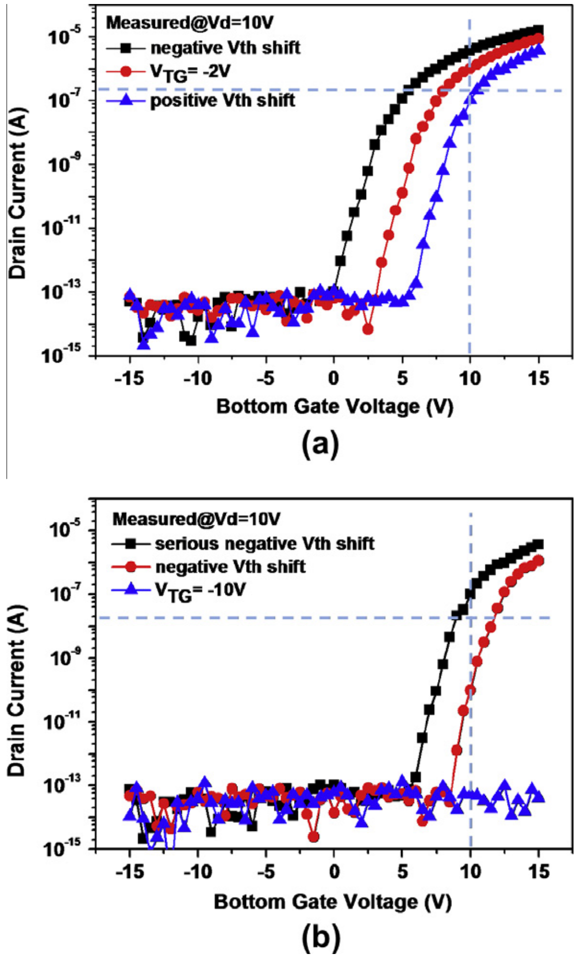

Fig. 5. (a) The transfer characteristics for the dual gate TFT at the $V_{TG} = -2$ V. It also shows the judging criteria for touch case. (b) The transfer characteristics for the dual gate TFT at the $V_{TG} = -10$ V. It also shows the judging criteria for untouched case.

shows that the proposed circuit equips with the same function even in the presentation of gate pulse distortion.

Most of current active matrix TSPs use source followers to output voltage change in Clc as the sensing signals [6,9–11]. These voltage signals can be easily influenced by device variations and distorted by the parasitic resistance and capacitance on the signal bus, which can result in serious errors. Moreover, as a unity-gain buffer, the source follower cannot amplify the voltage change. It depends on the peripheral operational amplifier circuits to differentiate the small signal change, which increases the cost and power of the readout ICs. In addition, to operate the active matrix pixel, whether the touch even occurs or not, the source follower consumes power in every sensing operation. In comparison, our new circuit provides a large change in the output current as the sensing signal, which can be easily picked up by simple read out circuits such as comparators. Meanwhile, the device variation only varies the current level but not the response time that carries the information of touch. Furthermore, this proposed circuit only output currents when the sensing pixel is selected and touched at the same time. The panel equipped with our proposed circuit consumes power only when it is touched. For other touch sensing technologies, the sensing signal is determined by the difference of sensing current so that it always consumes power. Therefore, the proposed circuit can significantly save power differing to other touch sensing technologies. Therefore, the power consumption of the read out IC and the standby power of the sensor are greatly reduced.

4. Stability of the sensing pixel circuit

4.1. Limits of threshold voltage shift

High sensing current ratio between touch and non-touch case of the proposed circuit is expected to provide great tolerance of environmental influences and excellent operating stability. In this section, we further discuss the resistance to environmental and operating conditions for the circuit.

Since only one dual-gate IGZO TFT is used in the proposed sensing pixel circuit, the sensing result is strongly related to the threshold voltage (V_{th}) of dual-gate TFT. The accuracy of the sensing circuit and the limits of V_{th} shift can be acquired by analyzing the device characteristics of the dual-gate IGZO TFT. Based on this concept, we propose the analysis criteria to evaluate the working range of the sensing circuit.

For the touch case, the output current signal should be larger than 200 nA to create a voltage difference of 0.2 V. In the proposed sensing circuit, the touch event can be judged by a comparator. The 0.2 V base is the demarcation for comparator judgment. The current level can be used as our judging criteria for touch events. Fig. 5a shows the transfer characteristics for the dual gate TFT at the top gate bias condition of -2 V, which represents the deteriorated voltage received by top gate with touch. We set the boundary level for the valid output current signal to be 200 nA when V_{BG} is

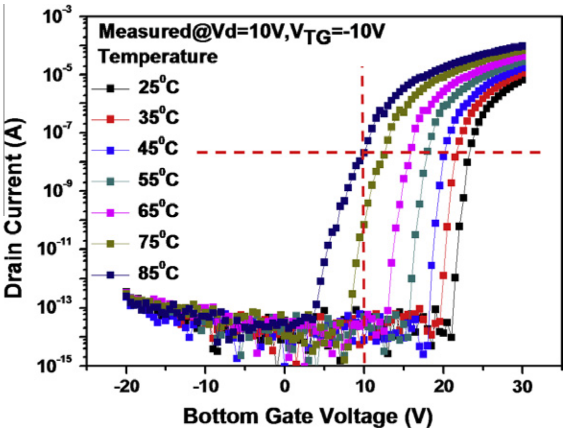

Fig. 6. The transfer characteristics at different temperatures for the dual gate TFT.

set at 10 V. If V_{th} of the sensing transistor shifts negatively, the corresponding output current at V_{BG} of 10 V is surely larger than 200 nA and within boundary. However, if V_{th} shifts to too positive, the corresponding output current will be smaller than 200 nA. In such case, the misjudgment of touch events occurred. Thus, V_{th} shift has a positive limit considering the touch case.

On the other hand, for the untouched case, the output current signal should be smaller than certain current level, for example, a tenth of 200 nA to be the judging criteria for untouched events. Fig. 5b shows the transfer characteristics for the dual gate TFT at the top gate bias condition of -10 V and the horizontal line for the current level of 20 nA is also plotted. The current keeps smaller than 20 nA at $V_{BG} = 10$ V when V_{th} of the sensing transistor positively shifts. However, if V_{th} shifts to too negative, the undesirable output current signal is generated, leading to the misjudgment. Thus, V_{th} shift has a negative limit for considering the untouched case.

4.2. Temperature effect

Fig. 6 shows the transfer characteristics of the TFT at different temperatures from 25 to 85 °C. The trend is clear that the V_{th} decreases with increasing temperature. It implies that the increasing temperature might make V_{th} approaches the negative limit and lead to misjudgment of the untouched case. The maximum operating temperature of the sensing circuit can be estimated from the figure. For our device, the V_{th} of the device at 85 °C reaches the negative limit 20 nA at $V_{BG} = 10$ V. It means an unwanted output current could be detected to be a misjudgment.

The high temperature limit of 85 °C in the previous analysis is extracted from the device characteristics. We now confirm it by measuring the sensing circuit performances at different temperatures. The results are shown in Fig. 7. The sensing circuit works correctly at temperatures up to 75 °C. However, when the operating temperature is raised to 85 °C, the spikes occur in the output voltage waveform (V_{out}) no matter the pixel is touched or not. From these results, we confirm the high range of operating temperature up to 85 °C.

4.3. Illumination effect

As some literatures reported [12–15], the IGZO TFT is affected significantly by illumination. Therefore, the influence of illumination on proposed circuit is subject to examination. Fig. 8 shows the transfer characteristics of the dual-gate TFT at different illumination intensities up to 26,930 lux. From the results, the increasing light intensity causes the V_{th} decreases and results in misjudgment of the untouched case.

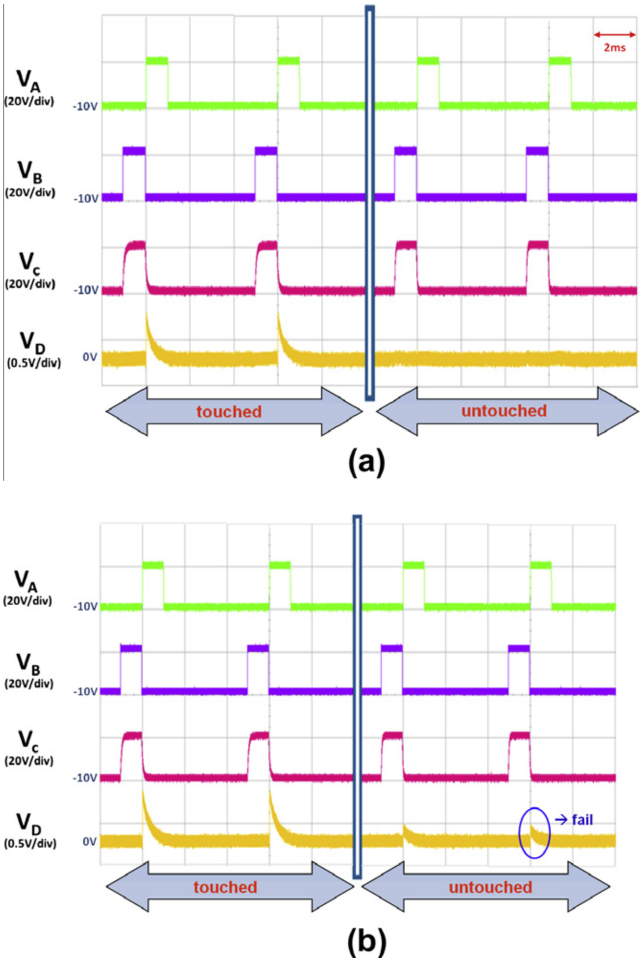

Fig. 7. (a) The measurement result of sensing circuit at 75° and (b) the measurement result of sensing circuit at 85°.

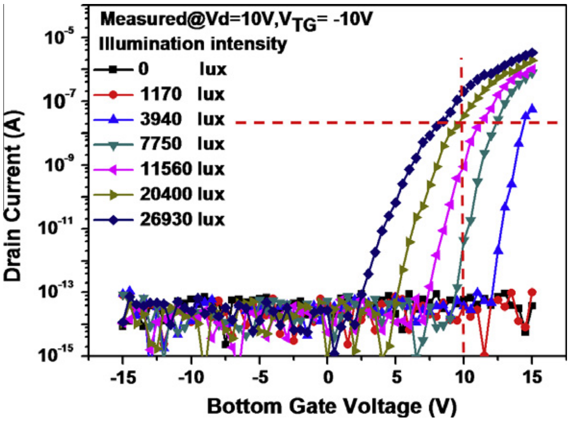

Fig. 8. The transfer characteristics at different illumination intensity for the dual gate TFT.

Experiments of the circuit are also conducted for verification, and the result is shown in Fig. 9. When the illumination intensity is up to 20,400 lux, the unwanted output signal occurs, while the sensing circuit still works correctly at 11,560 lux. The tolerance about the illumination of 20,000 lux should be able to allow the illumination effect on the proposed circuit in general environment. Once again, we confirm that the working range of the proposed sensing circuit can be analyzed based on the device characteristics.

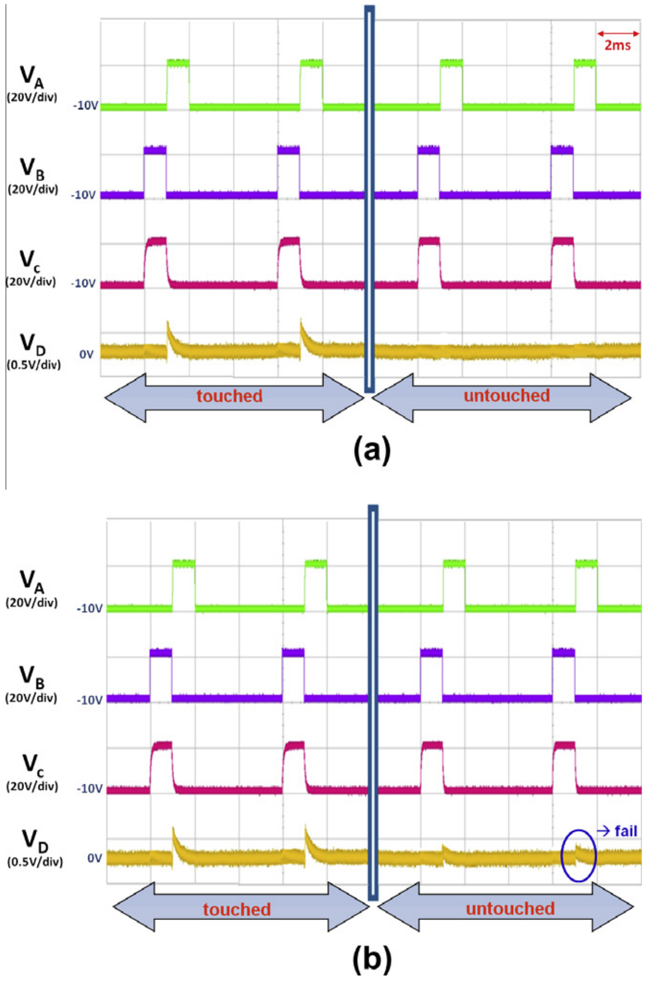

Fig. 9. (a) The measurement result of sensing circuit under illumination of 11,560 lux and (b) the measurement result of sensing circuit under illumination of 20,400 lux.

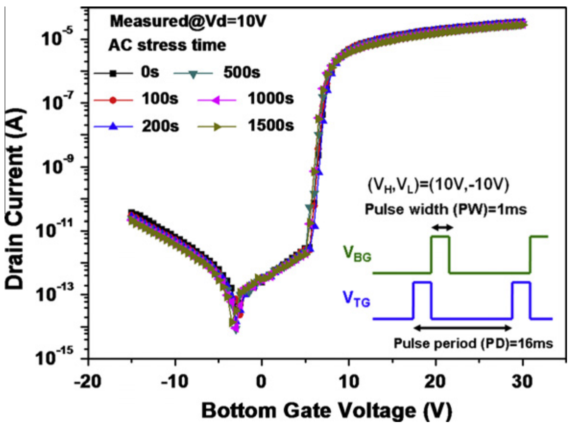

Fig. 10. The evolution of dual gate IGZO TFT transfer characteristics under AC stress.

4.4. Electrical stress stability

In addition to the environmental interferences, the electrical stress also affects the stability of dual-gate IGZO TFT. In our design, the sensing circuit is driven by the pulsed input signal. The stability of the TFT device under AC stress, the periodic pulse signal was applied to the top and bottom gate of dual-gate TFT during the experiment for 1500 s. Fig. 10 shows the evolution of transfer characteristics under AC stress. The pulse period (PD) and pulse width (PW) are 16 ms and 1 ms respectively. The pulse signal is set at a base line of −10 V and the pulse amplitude of 20 V. It can be seen that the transfer curves nearly overlap with each other. Fig. 11 shows the time dependence of the V_{th} shift for dual-gate TFT under AC stress. The result indicates that the dual-gate TFT hardly degrades with time under AC stress. We extrapolate the lifetime of sensing circuit to be much longer than 10^9 s of AC stress, at which time the V_{th} shift is only −3 V and away from the V_{th} limit. The proposed sensing circuit under the AC operation is proven to be robust according to the analysis of device degradation.

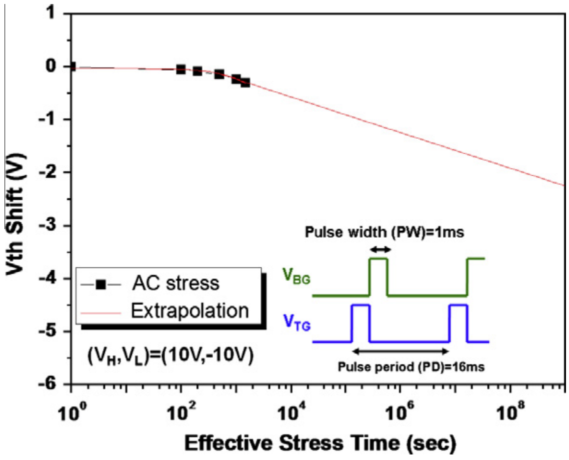

Fig. 11. The threshold voltage (V_{th}) shift versus effective stress time for AC stress. The inset illustrates the pulse waveform for AC experiment.

5. Conclusion

The touch sensing circuit using dual-gate IGZO TFT and the concept that RC time-constant is proposed. The sensing signal is a significant current which can be read out easily by low cost ICs. The advantages of simple structure, along with the low operating power, make the proposed method particularly suitable for in-cell TSPs. Moreover, the high output current ratio of touch and non-touch case provides the excellent stability at raised temperature, under illumination as well as with operation degradation.

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