Photoelectric Characteristics of a-IGZO TFT under LED Illumination

Qingru Lu[1,2,a,*], Fan Li[3,b], Xiaodong Huang[3,c], Haiyan Xin[1,d], Hui Huang[1,e]

[1]School of Electron and Computer, Chengxian College, Southeast University, Nanjing, China

[2]State Key Laboratory of Millimeter Waves, Southeast University, Nanjing, China

[3]Laboratory of MEMS of the Ministry of Education, Southeast University, Nanjing, China

[a]121919084@qq.com, [b]2863864200@qq.com, [c]352812402@qq.com, [d]983511889@qq.com,
[e]317707130@qq.com

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Abstract: Amorphous Indium Gallium Zinc Oxide thin film transistor (a-IGZO TFT) with active layer size (length× width) of 300um×100um is fabricated by RF magnetron sputtering. The photoelectric characteristics of the TFT illuminated by LED light of three wavelengths (405 nm, 370 nm and 310 nm) are studied by “probe method”. Results show that the value of the threshold voltage (V_{th}) of the TFT illuminated by LED light is smaller than that without LED illumination, and it decreases when the wavelength of LED decreases. On the contrary, Subthreshold Swing (SS) increases with the decreasing of the wavelength as the result of the increasing of the density of bound states at the interface of the device. In addition, the responsiveness (R) of the device illuminated by LED light is independent of the source-drain voltage (V_{DS}), it is only affected by the illumination light. R decreases when the wavelength of LED light decreases, and it is constant under the illumination of the light with the specific wavelength. It is predictable that a-IGZO TFT has good photoelectric characteristics for LED light, and it has broad application prospects in sensing and photoelectric detection.

1. Introduction

Amorphous indium gallium zinc oxide (a-IGZO) thin film is a new type of transparent oxide semiconductor material. It becomes a research hotspot of display technology nowadays. It is also considered as an important material in the development of flexible display technology, flexible wearable electronic technology and new sensing technology [1]. A-IGZO TFT has many advantages [2] such as higher carrier mobility [3], lower processing temperature [4], better optical transmittance in visible band [5] and so on. It also has good uniformity and high chemical stability. As a result, a-IGZO TFT are the research hotspots at present [6,7].

A-IGZO TFT is exposed directly to visible light when it is used in display field, the display effect is affected as the threshold voltage (V_{th}), Subthreshold Swing (SS) and other parameters change as the result of the photoconductivity effect [8,9]. The changes of photoelectric characteristics of TFT illuminated by light can be used as the detection signal, which can be applied in the field of photoelectric detection and sensing.

Some a-IGZO TFT with a-IGZO as the active layer, La_2O_3 as the insulating layer, Titanium alloy as the source and drain electrode is fabricated in this paper, and its photoelectric characteristics are studied in four cases: without LED light and three kinds of LED light.

2. Structure and preparation

As one of the voltage-controlled devices, a-IGZO TFT has three external contacts: gate (G), source (S) and drain (D), and it has three types: bottom-gate structure, top-gate structure and double-gate structure. Compared with the latter two structures, the bottom-gate structure has the advantages of high effective mobility, large source-drain current and good threshold voltage

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stability [10]. At the same time, a-IGZO TFT with bottom-gate structure can feel illumination light better without the influence of the substrate illumination as a light detection sensor, and it has better stability in sensing and detection applications.

The bottom-gate structure which is shown in Figure 1 is adopted in this paper. A-IGZO TFT with size (length×width) of 300um×100um was deposited on the insulating layer by RF magnetron sputtering as the active layer of TFT. The sputtering power is 100W, the pressure is $1.3\times10^{-3}Pa$, the sputtering gas is the mixture gas of 45 sccm A_r and 5 sccm O_2. Lanthanum oxide (La_2O_3) is used as the insulating layer material of the TFT. Its high dielectric constant can adjust the threshold voltage effectively and it can also increase the driving capacity of the device. The source and drain electrodes are formed by evaporating titanium alloy by electron beam through a mask. It consists of the Ti layer with 20 nm thickness and the Au layer with 80 nm thickness. In addition to high stability and corrosion, the metal work function of Ti/Au is relatively small, and the transistor has high conductivity.

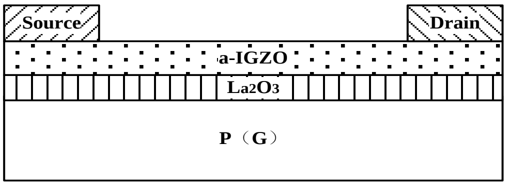

Fig. 1 The structure of a-IGZO TFT

3. Results and discussions

The photoelectric characteristics of the a-IGZO TFT are studied by “probe method” in room temperature and atmospheric environment. And they are measured by Keithley-4200 Semiconductor Parameter Analyzer. Illumination light is up-incident, it is three kinds of LED light with different wavelengths which are 310 nm, 370 nm and 405 nm, respectively. The output optical power is 5 mw.

The transfer characteristic curve of TFT illuminated by LED light is shown in Figure 2. Source maintains grounding during testing, source-drain voltage (V_{DS}) is 5V, gate source voltage (V_{GS}) is gradually increased from 0 V at a 0.2 V interval.

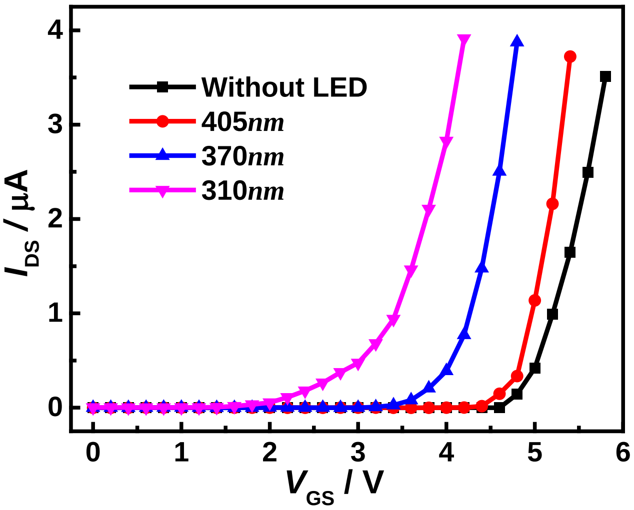

Figure 2 Transfer Characteristic Curve of Device under LED Illumination

The source-drain current (I_{DS}) of the device illuminated by LED light has been significantly increased as shown in Figure 2. The threshold voltage (V_{th}) becomes smaller when the wavelength of illuminated light decreases with the same V_{GS}, and I_{DS} increases meanwhile. It is because the active layer is stimulated by LED light, which produces a lot of photoelectrons, and the conductivity of active layer is greatly improved. That is to say, the photoconductivity effect is produced [11]. When LED light reaches the active layer, the valence electrons absorb photon energy and transfer from the valence band to the conduction band, they become conductive electrons. At the same time, new holes appear in the valence band. The electron generated by the optical excitation accumulates in the conductive channel of the active layer under the influence of V_{GS}. Compared with the case of “without LED”, More conductive electrons accumulate in the conductive channel. Therefore, a conductive channel can be generated at a smaller V_{GS}, thus the source and drain poles are connected and the current is formed, i.e., the V_{th} is smaller. On the other hand, the photon energy is inversely proportional to the wavelength of light, so the smaller the wavelength of light is, the greater the photon energy is, the more photoelectrons generated by excitation are. As a result, V_{th} of the device decreases with the decrease of the optical wavelength, as shown in Table 1.

Table 1 Variation of related parameters in 4 cases

Parameter	Without LED	405nm	370nm	310nm
V_{th} / V	4.3	4.0	2.8	0.9
SS / V/dec	0.21	0.23	0.36	0.51

The Subthreshold Swing (SS) in Table 1 is calculated by the following definition.

$$\mathrm{SS}=\left(\left.\frac{\mathrm{d}\log(I_{\mathrm{DS}})}{\mathrm{d}V_{\mathrm{GS}}}\right|_{\max}\right)^{-1} \tag{1}$$

The theoretical expression of SS can also be expressed as follows

$$\mathrm{SS}=\frac{qk_{\mathrm{B}}\mathrm{T}(N_{\mathrm{t}}t_{\mathrm{C}}+D_{\mathrm{it}})}{C_{\mathrm{i}}\log(e)} \tag{2}$$

In the formula, q is the electronic charge, k_B is the Boltzmann constant, T is the temperature, N_t is the thickness of the active layer, D_{it} is the bound state density of the interface between the insulating layer and the active layer, and C_i is the capacitance of the gate insulating layer per unit area. It is always $N_t << D_{it}$ [12], thus the change of SS is mainly determined by the density of bound states at the interface. On the contrary, we can also know the change of bound state density at the interface by comparing the change of SS. Compared with the case without LED illumination, SS increases after adding LED illumination, and SS increases with the decrease of wavelength. That is to say, the interfacial characteristics of the device are significantly affected by the addition of light. It has been shown that light can excite a certain number of photogenerated carriers. The smaller the wavelength is, the stronger the excitation energy is, and the more photogenerated carriers are excited. Moreover, the excited electrons and holes appear in pairs. Under the positive bias voltage of the gate, photoinduced electrons are captured in the defect of the interface layer under the action of electric field. As a result, on the one hand, the density of bound states increases with the increase of SS; on the other hand, the electric field formed by the interface electrons is superimposed on the electric field generated by V_{GS}, and it makes the device turn on ahead of time, which shows the decrease of threshold voltage.

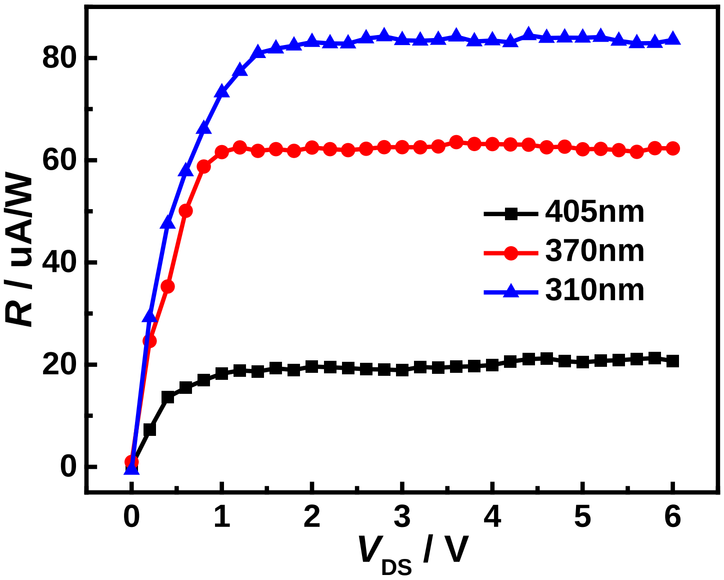

Figure 3 The relationship between R and V_{DS}

The relationship between the responsiveness (R) [13] and V_{DS} of the device irradiated by three different wavelengths of LED light when V_{GS} =5V is shown in Figure 3. The expression of R which is an index of detection sensitivity of the light is as follows: I_{ph} is the photogenerated current between source and drain under illumination, I_{dark} is the source-drain current without illumination, I_{ill} is the source-drain current under illumination, P_{ill} is the power of the LED.

$$R = \frac{I_{ph}}{P_{ill}} = \frac{I_{ill} - I_{dark}}{P_{ill}} \qquad (3)$$

It is shown that R is independent of V_{DS} under the illumination of LED light as shown in Figure 3. R is a constant value when TFT works, and its specific value is related to the wavelength of the light, it increases with the decreases of the wavelength. That the result of I_{ph} which is only controlled by the light. The photon energy provided by the light with certain wavelength is constant, so the photogenerated current generated by the excitation is also constant. On the other hand, more photogenerated carriers are stimulated by LED light with smaller wavelength, then R increases *as* I_{ph} increases. Using these characteristics, a-IGZO TFT can be applied to the fields of photoelectric detection and sensing.

4. Conclusion

IGZO TFT with an active layer size (length× width) of 300um×100um was fabricated by RF magnetron sputtering, and its photoelectric characteristics of the TFT illuminated by LED light are studied. Results show that the value of the threshold voltage (V_{th}) of the TFT illuminated by LED is smaller than that without LED illumination, and it decreases when the wavelength of LED decreases; On the contrary, SS increases with the decreasing of the wavelength as a result of the increasing of the density of bound states at the interface of the device. In addition, R is independent of V_{DS}, it is only affected by the LED light. R decreases when the wavelength of LED decreases, and it is constant when the light with certain wavelength illuminates the TFT. It is shown that a-IGZO TFT has good photoelectric characteristics for LED light, and it has broad application prospects in sensing and photoelectric detection.

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