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Effects of Plasma Treatment on the Reliability of a-IGZO TFT

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Abstract: High reliability thin film transistors are important factors for next-generation displays. The reliability of transparent a-IGZO semiconductors is being actively studied for display applications. A plasma treatment can fill the oxygen vacancies in the channel layer and the channel layer/insulating layer interface so that the device can work stably under a bias voltage. This paper studies the effect of plasma treatment on the performance of a-IGZO TFT devices. The influence of different plasma gases on the electrical parameters of device and its working reliability are reviewed. The article mentions argon, fluorine, hydrogen and several ways of processing in the atmosphere. Among these methods, F (fluorine) plasma treatment can maximize equipment reliability. It is expected that the presented results will form a basis for further research to improve the reliability of a-IGZO TFT.

Keywords: a-IGZO, Plasma treatment, Reliability, Oxygen vacancies, TFT

1. INTRODUCTION

In recent years, high-performance AOS (amorphous oxide semiconductor) materials have attracted wide attention in the field of flat panel display. As a representative material, a-IGZO TFT (amorphous indium gallium zinc oxide thin film transistor) has the advantages of low power consumption, good bias reliability and good uniformity. Fabrication is simple, compare with poly-Si. It is under strong consideration as the main channel material for the next generation of transparent flexible display devices [1,2]. In the actual application of a-IGZO TFT, the long-term reliability of the device is very important for the effect of the device. When the transistor runs for a long time, the V_{TH} changes, which will cause the brightness of the screen pixels to change [3]. In order to improve the performance and life time of a-IGZO TFT, it is a very necessary and critical issue to ensure the reliability of the device [4]. Plasma surface treatment is one of the methods that can effectively fill defects and can improve the reliability of the device. The main reason of instability in TFT devices is the oxygen vacancies existing in the channel layer and the channel layer/insulating layer interface. The plasma treatment can control the oxygen vacancies existing in the device to achieve the purpose of increasing the reliability [5].

Plasma is divided into source/drain region plasma treatment, channel layer plasma treatment, and channel layer/insulation layer plasma treatment based on different positions of the device. When plasma treatment is applied to the source/drain region, it can effectively reduce the contact resistance between the source/drain and a-IGZO channel layer [6]. In this article, we will summarize and analyze the effects of plasma surface treatment on the performance

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of a-IGZO TFT and the mechanism of action in combination with related documents in recent years.

2. EXPERIMENT

In the case of plasma treatment applying to the source/drain regions, after depositing the a-IGZO channel layer on the insulating layer, only processed source/drain regions. Then, the electrodes are deposited and measured. The electrical characteristics of the device are measured by the transfer curve of the device. When plasma treatment used as the channel layer surface and the interface of channel layer/insulating layer, plasma directly acts on the insulating layer or the channel layer.

3. RESULTS AND DISCUSSION

Ensuring the reliability of the device under the working condition of a-IGZO TFT is a key condition for maintaining normal working conditions and service life time. There are two main reasons for the instability of the device under the gate bias voltage: defects generated in the channel layer and trapped charges trapped in the insulating layer or the interface between the channel layer and the insulating layer [7,8]. The instability may be caused by the injection of electrons from the channel layer into the gate insulating layer or the defect traps at the interface between the insulating layer and the channel layer [9]. The defects generated in the channel layer are mainly oxygen vacancy defects. The reasons affecting reliability is that compared with the formation energy of other defects in the a-IGZO film, the formation energy of oxygen vacancies (Vo) is the smallest, so it is most easily formed in the a-IGZO film [10]. The other is that the trapping of the interface state of the carrier at the interface or between the channel layer in the gate bias voltage causes the threshold voltage to drift, resulting in instability [11]. We believe that, these oxygen vacancies can be replaced the plasma ions and improve the device reliability. The basic principle behind this mechanism is as follows:

In the plasma surface treatment process, most of the gas ions in the working gas are used to approximate the ion radius of oxygen. Therefore, gas ions can replace oxygen or gas ions can occupy oxygen vacancies to replace doping, thereby reducing defect density, improve film quality as summarized in Fig. 1 [12]. When the plasma treatment is excessive, the reliability of the device will be degraded. Excess gas ions will form interface defects, which will change the performance of the device again [13].

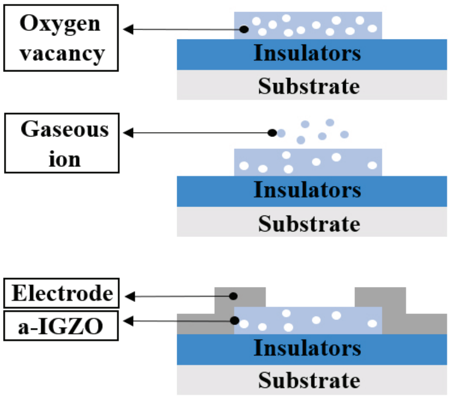

Fig. 1. The plasma treatment is applied to the channel layer.

Using O_2, Ar (argon) plasma treatment is an effective way to improve the contact resistance of a-IGZO TFT. The ion bombardment of high-energy argon ions during the argon plasma treatment can cause preferential sputtering of lighter atoms on the surface of Ⅱ-Ⅵ or Ⅲ-Ⅴ semiconductors. Therefore, the oxygen on the surface of a-IGZO is preferentially dissociated by ion bombardment, increasing the oxygen vacancy concentration. At the same time, the net electron concentration increases. The formation of oxygen-deficient surfaces and the increase in net electron concentration are the main When the contact resistance is too large, it will affect the performance of the device [6]. As shown in Fig. 2, The overall treatment of the source/drain region plasma treatment can reduce the contact resistance compared with only the source/drain region, the source/drain region alone has almost no effect on the reliability of the device [14].

F (fluorine) plasma treatment can improve the mobility of the device and reduce the defect concentration in the channel layer/insulating layer interface by filling the oxygen vacancies on the surface. The ionic radii of F and O (oxygen) are very similar, and the bond between

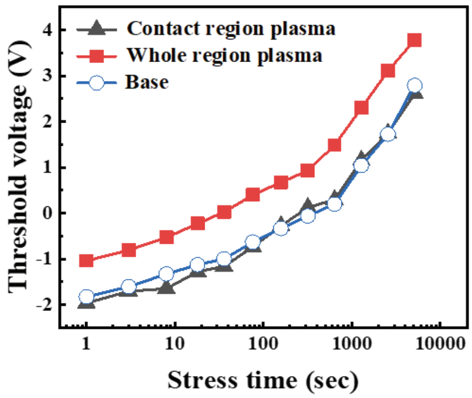

Fig. 2. V_{TH} shift under the different region plasma treatment.

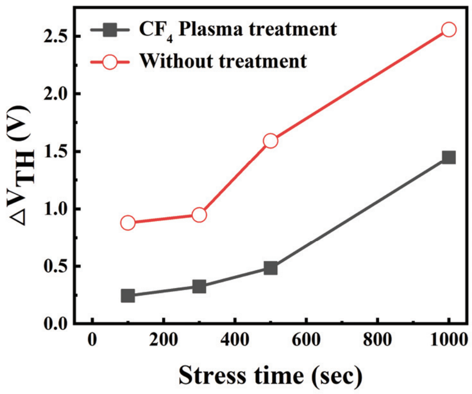

Fig. 3. $\triangle V_{TH}$ of CF_4 plasma treatment and without plasma treatment under PBS condition (V_{GS}=6 V).

F and Zn (zinc) is more stable than the bond between O and Zn during the action. Excess free electrons are generated when F fills the oxygen vacancies, and these free electrons have a positive effect on improving device performance [15]. The data also confirm the change of oxygen vacancy, SS (sub-threshold swing) were slightly decreased from 0.17 V/dec to 0.14 V/dec. As shown in Fig. 3, the threshold voltage after F plasma treatment is obviously much more stable than that of the device before treatment [16].

$$Dit = \frac{C_{OX}}{q}\left(\frac{SS\log(e)}{k_B T/q} - 1\right) \tag{1}$$

As shown in Fig. 4, H can also improve the electrical properties of the device, such as improving reliability and reducing interface defect density.

Further research shows that compared with heavy hydrogen doping, proper hydrogen doping can significantly improve the electrical performance of the device. During the action, the oxygen vacancy and H combine to become a stable shallow donor. The treated SS was also reduced from 0.65 V/dec to 0.25 V/dec. It can be seen from the Table 1 that the conduction band energy level shift becomes smaller due to the doping of H, it makes the electrons easier to be excited, so that the Ne in the a-IGZO film increases and the performance of the device is improved [17].

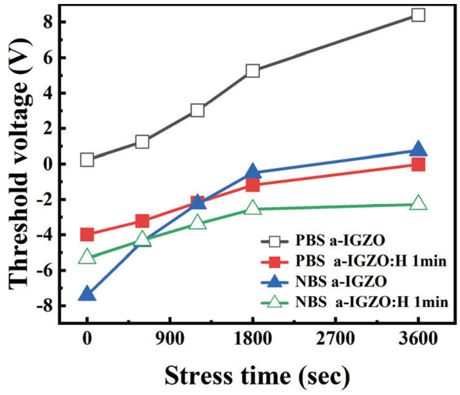

Fig. 4. V_{TH} shift of hydrogen doping and without treatment under PBS and NBS for various stress time.

Table 1. The energy band shift variation of a-IGZO devices with different H plasma treatment time.

	a-IGZO	H doped 1 min	H doped 5 min
$\triangle E_{VB}$ (eV)	2.31	2.63	2.81
$\triangle E_{CB}$ (eV)	1.05	0.73	0.55

APP (atmospheric pressure plasma) treatment can generate high-energy free radicals in the air and directly act on the surface. It does not require a vacuum system, so it has certain potential in the industrial field. APP processing the front channel will change the chemical state of a-IGZO, which can control the electrical performance of the device. During the back channel treatment, due to the passivation effect, the device is less affected by the external environment [18]. Figure 5 and Table 2. shows the effect of APP treatment on reliability. According to the

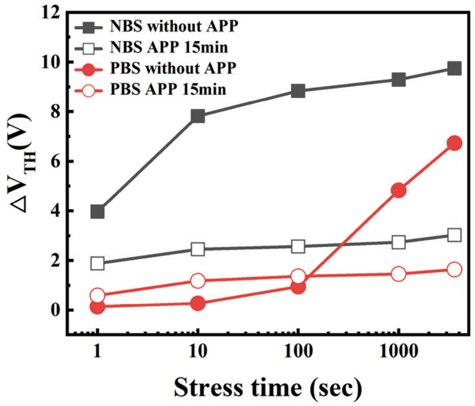

Fig. 5. The V_{TH} shift of APP treatment and without treatment under NBS and PBS, respectively.

Table 2. The energy band shift variation of a-IGZO devices with different APP plasma treatment time.

	Without APP	APP 15 min
$\triangle E_{VB}$ (eV)	2.22	2.4
$\triangle E_{CB}$ (eV)	0.975	0.79

calculation of Eq. (1) after being processed by the APP, interface trap state density (D_{it}) was also reduced from 3.55×10^{11} cm^{-2}/eV to 2.3×10^{11} cm^{-2}/eV.

4. CONCLUSION

The effects of different plasma gases on the performance of a-IGZO TFT are reviewed. Plasma surface treatment has a great influence on TFT devices and the reliability. For different working gases, surface plasma treatment can control the oxygen vacancy. The main mechanism uses plasma ions to fill the oxygen vacancy defects, so as to achieve the purpose of improving the reliability of the device under positive and negative biases, and at the same time, it can effectively improve the electrical performance of the device. As an effective treatment method for a-IGZO TFT, plasma treatment brings benefits to the future research and development of a-IGZO TFT.

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