Multifunctional Laminated Organic Passivation Layer on InSnZnO Thin-Film Transistors for enhanced performance

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***Abstract*—To enhance the performance and stable electrical characteristics for ZnO-based thin-film transistors (TFTs), we propose a new passivation structure consisting of a self-assembled monolayer and a UV absorber-modified polydimethylsiloxane (PDMS) layer. This multifunctional laminated organic (MLO) passivation layer combined the benefits of each film, improving the electrical properties and reliability of InSnZnO (ITZO) TFTs under bias stress UV light illumination.**

Introduction

To address the demands of the next-generation display, TFTs with InSnZnO (ITZO) semiconductors as the active layer have garnered considerable attention because of their low cost, good electrical characteristics, and high field effect mobility [1]. However, the ZnO-based semiconductor TFTs are unstable in various environments [2], such as in humid or UV light environments. Therefore, it is necessary to add a passivation layer or protective layer to improve the stability of the ZnO-based TFTs in multiple environments. Conventional passivation layer materials such as SiNx, SiOx, and AlOx, unfortunately, inevitably degrade the electrical performance of the device due to plasma damage. The newly proposed self-assembly monolayer (SAM) passivation process can effectively avoid plasma damage, but the ability of a SAM to suppress the absorption of external sensitive molecules is limited due to its thinness [3].

In this work, a multifunctional laminated organic (MLO) passivation layer (PVL) for ITZO TFTs was prepared. This MLO PVL consisting of a self-assembled monolayer (SAM) and a polydimethylsiloxane (PDMS) layer modified with UV absorbers could improve the performance of ITZO TFTs. After adding this passivation layer, the ITZO TFTs demonstrated excellent reliability in various environments, especially the light stress stability.

Experiment

To construct the bottom-gate ITZO TFT, first, Al-Nd alloy films of 100 nm thickness were prepared on a Corning glass substrate of 0.5 mm thickness using DC magnetron sputtering and photolithography to form the gate electrode. A 200 nm-thick AlO_x: Nd layer was then prepared as a gate dielectric layer by an anodic oxidation process. Subsequently, ZnO targets and ITO targets (In_2O_3:SnO_2 =90:10 wt%) were used to deposit 60 nm ITZO films by co-sputtering in an $Ar+O_2$ atmosphere, followed by sputtering of 200 nm-thick ITO films as source/drain electrodes, resulting in a channel with a width and length of 300 μm. The devices were then post-annealed for 3 hours at 350℃.

To construct the MLO PVL, we first inverted the devices onto a tungsten boat with n-octyltriethoxysilane (OTES). This process was conducted at 120℃ for 2 hours to create a hydrophobic barrier layer on the back-channel surface of the devices. Subsequently, the PDMS solution modified by the UV absorber was spin-coated onto the surface of the device with a hydrophobic barrier layer, forming a functionalized PDMS layer [4-5].

Fig. 1(c). displays a schematic of the manufactured ITZO TFTs with the MLO PVL. This passivation consists of two layers, a n-octyltriethoxysilane self-assembled monolayer (OTES-SAM) and a UV absorber-modified PDMS layer, prepared by vapor-phase processing and spin-coating, respectively.

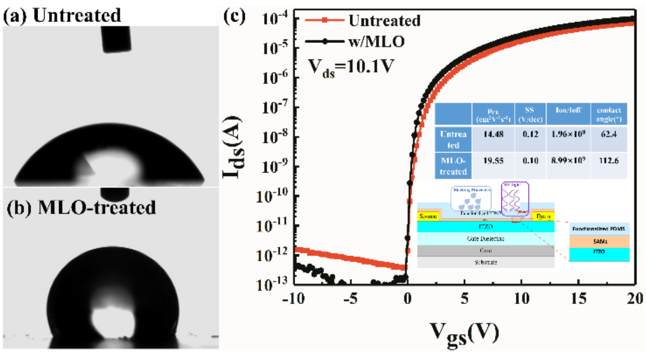

Fig. 1. Contact angle images of (a) untreated and (b) MLO-treated ITZO films, and (c) the transfer curves of untreated and MLO-treated ITZO TFT.

Results and Discussion

Surface energy estimations of the untreated and MLO-treated ITZO films were carried out by performing contact angle measurements, as shown in Fig. 1(a) and (b). On the MLO-treated ITZO surfaces, the contact angle increased noticeable (from 62.4° to 112.6°), and the surface became hydrophilic, whereas the untreated ITZO surface showed a relatively hydrophilic surface. Surface energy was calculated from the contact angle estimated by Young's equation. The values of the surface energy of the untreated and MLO-treated ITZO film were determined to be 41.72 and 7.55 mJ/m^2, respectively. Therefore, the MLO treatment could reduce the reactivity of back-channel surface of ITZO film, which could suppress the absorption of external sensitive molecules [6].

Moreover, the MLO-treated ITZO TFTs exhibit excellent electrical performance, with an on-off current ratio (I_{on}/I_{off}) of up to 8.99×10^9, a field-effect mobility as high as

19.55 $cm^2V^{-1}s^{-1}$, and a subthreshold swing (SS) down to 100 mV/dec.

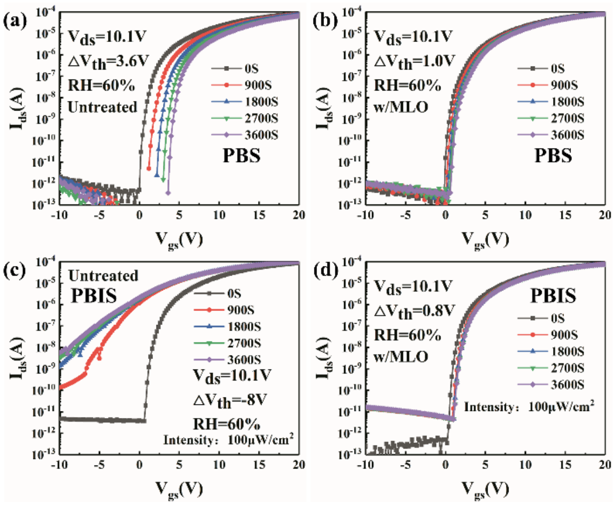

Fig. 2. The variations of time-dependent transfer curve of untreated and MLO-treated ITZO TFTs under positive bias stress (part a and b) and positive bias illumination stress (part c and d). Stress condition: V_{gs}=10V, V_{ds}= 0V, UV light wavelength=365nm.

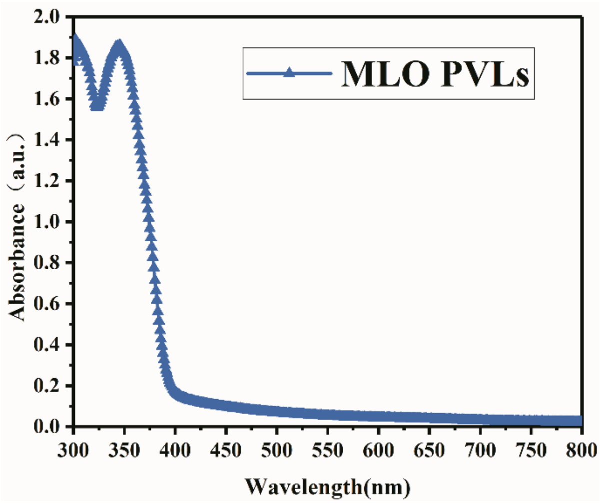

Fig. 3. The absorbance as a function of wavelength for MLO films.

The stability of the untreated and MLO-treated TFTs under positive bias stress (PBS) and the positive bias illumination stress (PBIS) tests for 3600 s at a 10V positive gate bias and a 60% relative humidity was investigated. In the PBIS test, the light stress was provided by a 365nm UV light with 100 μW/cm^2. The transfer curves were recorded every 15 minutes, as shown in Fig. 2. It can be seen that the shift of the threshold voltage (ΔV_{th}) for untreated ITZO TFTs reached 3.6V and -8V in the PBS and PBIS test, respectively, which indicates a poor bias and light stability. After MLO-treatment, the stability of the ITZO TFTs was greatly improved, and the ΔV_{th} decreased to 1V/0.8V in the PBS/PBIS. The bias stress improvement is attributed to the OTES-SAM film's ability to eliminate weak absorption of sensitive molecules, such as water and oxygen [7], on the back-channel surface of the ITZO films. Moreover, the electrical properties of the unpassivated ITZO TFTs showed a significant degradation in the PBIS test. Because the band-to-band photoexcitation generates a large amount of the light-induced carriers, which increased the off-state current and the V_{th} showed a substantial negative shift [8-10]. In contrast, the MLO film absorbed external UV light to protect ITZO film from light stress, as shown in Fig. 3. Therefore, the MLO-treated ITZO TFTs had excellent stability even under UV light illumination.

Conclusions

In conclusion, we proposed a new multifunctional laminated organic (MLO) passivation structure. The MLO-treated ITZO TFTs have a threshold voltage offset of just 1V and 0.8V in the positive bias stress and the positive bias illumination stress tests, respectively. the ITZO TFTs with this MLO passivation layer exhibited considerable stability. This new passivation layer offers a potential strategy for enhancing the performance of ITZO TFTs.

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