Activation Energy Window-Based Modeling on the NBIS-induced Instability in Amorphous InGaZnO Thin-Film Transistors

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Abstract

The activation energy window (AEW)-based model on the negative bias illumination stress (NBIS)-induced instability in amorphous InGaZnO TFTs. It is found that the influence of either the oxygen content of a-InGaZnO or the energy of incident photons under illumination on the NBIS ΔV_T is successfully explained by combining the proposed model and experimentally extracted subgap density-of-states. Our result suggests that the AEW is physically available concept irrespective of a dominant microscopic mechanism on NBIS instability and thus can be potentially generalized to the instability-ware joint-optimization of the process/material for active film as well as the photo-illumination condition in display backplanes.

Keywords: Negative bias illumination stress (NBIS), instability, activation energy window, amorphous InGaZnO thin film transistors.

1. Introduction

Amorphous indium-gallium-zinc-oxide thin-film transistors (a-InGaZnO TFTs) have been under the active research and development for various applications such as high frame rate, flexible, and mobile displays due to advantageous characteristics with low temperature/low cost process, fair mobility, transparency in visible light range, low off current, and high on/off ratio [1]. In spite of such beneficial aspects, conventional amorphous oxide-based TFTs have challenging issues on reliability, for example, negative bias illumination stress (NBIS) instability. However, the quantitative analysis of the NBIS instability has been rarely researched. In this paper, based on previous work [2], we verify the physical model by using various process and optical conditions.

2. Results and Discussion

The well-known NBIS instability mechanism of the a-InGaZnO TFTs can be classified by following the types: (1) The photo-generated hole followed by charge trapping into gate insulator [3], (2) the defect creation by oxygen vacancy ionization [4], and (3) the hole-mediated metastable peroxide defects [5].

If a-InGaZnO TFTs are under negative gate-source voltage (V_{GS}) condition, the quasi Fermi level (E_{Fn}) will be near valence energy maximum energy level (E_V). In addition, if the devices are illuminated, the threshold voltage shift (ΔV_T) will be triggered by the effect of the light on the subgap traps in an energy range of E_C-E_{ph} < E < E_{Fn} and their density can be described as

$$\int_{E_C-E_{ph}}^{E_{Fn}} g(E)dE , \qquad (1)$$

where E_C, E_{ph}, and g(E) are the conduction band minimum energy level, photon energy, and the density-of-states (DOS).

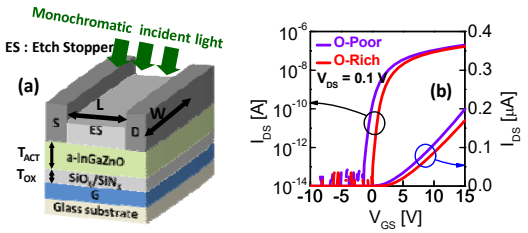

Fig. 1. (a) Schematic illustration of a-InGaZnO TFT with bottom-gate etch stopper layer and (b) transfer characteristics at V_{DS} = 0.1 V with various oxygen contents.

In order to quantitatively analyze the NBIS time (t_{NBIS})-evolution of ΔV_T, the a-InGaZnO TFTs with bottom gate and etch stop layer were fabricated as shown in Fig. 1(a). Molybdenum (Mo) was rf sputter-deposited and patterned for the gate electrode on a glass substrate and the SiN_x/SiO_x (50 nm/400 nm) bilayer was deposited by PECVD as the gate insulator. Then, 50-nm-thick InGaZnO thin films with different oxygen content of 21 sccm (O-Poor) and 63 sccm (O-Rich) with Ar of 35 sccm were dc sputter-deposited and the etch stop layer and source/drain were formed by PECVD and Mo rf sputtering. Respectively. Detailed process was given in [2]. The electrical

parameters of the fabricated TFTs are as follows: threshold voltage (V_T)=0.70 / 1.99 V at I_{DS} = 1 nA and V_{DS} = 0.1 V, field-effect mobility in linear region ($_{FE,lin}$)= 8.74 / 7.81 $cm^2V^{-1}s^{-1}$ at V_{GS}=20 V and V_{DS}=0.1 V in the O-Poor / O-Rich a-InGaZnO TFTs as shown Fig. 1(b), respectively. In addition, the g(E) was extracted by the photo-responsive capacitance-voltage (C-V) spectroscopy [6], where the measurement conditions are the frequency=50 kHz, optical power=5 mW, and photon energy=2.82 eV. The effect of oxygen content on g(E) is shown in Fig. 2.

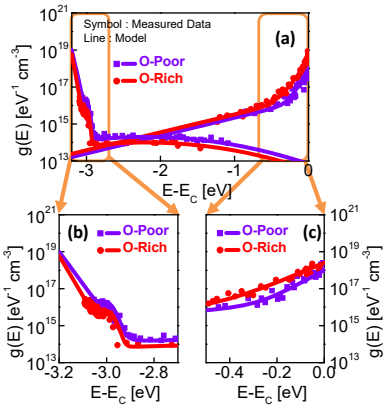

Fig. 2. The g(E) with various oxygen contents (a) in full energy range, (b) near E_V, and (c) near E_C.

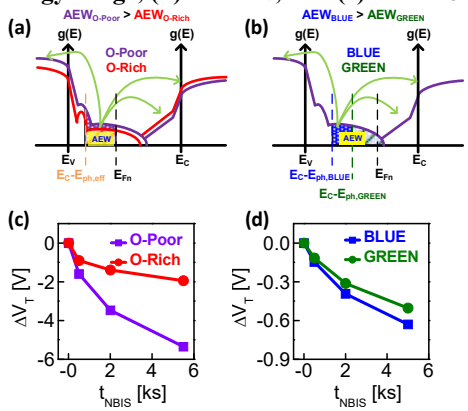

Fig. 3. Schematic illustrations of (a) oxygen content-dependent and (b) E_{ph}-dependent AEWs. The t_{NBIS}-evolution of ΔV_T with different (c) oxygen content and (d) E_{ph}.

To generalize the relationship between AEW and NBIS-induced ΔV_T, the E_{ph}-dependence as well as the oxygen content-dependence of AEW was investigated. Fig. 3(a) and (c) show the oxygen content-dependences of AEW and ΔV_T with the NBIS V_{GS}=-20 V and back light unit of 300 cd/m^2 at a fixed E_{ph}. On the other hand, Fig. 3(b) and (d) show the E_{ph}-dependences of AEW and ΔV_T with the NBIS V_{GS}=-5 V and E_{ph}=2.82/2.33 eV.

It is noteworthy that the device with larger AEW shows larger ΔV_T in terms of the oxygen content as well as E_{ph}. It suggests that the AEW-based model can explain well not only the effect of process condition on the NBIS instability but also the influence of illumination condition on the NBIS instability. It is because the AEW is physically available concept irrespective of a dominant microscopic mechanism on NBIS instability.

3. Conclusion

The AEW-based model is proposed for quantitative analysis on the NBIS-induced instability in a-InGaZnO TFTs. It is found that the influence of either the oxygen content of a-InGaZnO or the energy of incident photons under illumination on the NBIS ΔV_T is successfully explained by using proposed model. Our model is potentially useful for the joint-optimization of the process/material for active film as well as the photo-illumination condition in display backplanes, in perspective of the instability-aware design of highly stable InGaZnO TFTs.

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