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A comparison of photo-induced hysteresis between hydrogenated amorphous silicon and amorphous IGZO thin-film transistors

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Abstract

We investigate photo-induced hysteresis characteristics of thin-film transistors (TFTs) consisting of hydrogenated amorphous silicon (a-Si:H) and amorphous indium-gallium-zinc-oxide (a-IGZO) as active semiconducting layers. Even though such materials possess an amorphous phase, each structural system based TFTs exhibit different optical responses and photo stability. We believe that this work can provide a promising approach to understand device physics and charge transport for optical engineering based on transparent electronic applications.

1. Introduction

Metal-oxide semiconductor based thin-film transistors (oxide-TFTs) have attracted the considerable attention for various electronic applications due to good device performance, visible light transparency and potential uniformity at low deposition temperature [1]. Significantly, they are expected to be promising for transparent display applications given light insensitivity and a high field-effect mobility which promote the pixel aperture ratio and driving ability as contrasted with the conventional silicon-based TFTs [2]. The variation of electrical properties caused by light absorption in oxide-TFTs have been extensively investigated because it can lead to failure in device operation although metal-oxide semiconductors are being considered a wide band-gap (>3eV) materials. One of photo instabilities is photo-induced hysteresis which causes very serious residual image sticking problems for transparent displays. We have observed the serious photo-induced hysteresis of TFTs consisting of amorphous indium-gallium-zinc-oxide (a-IGZO) as an active semiconducting layer. The purpose of our work is to investigate the origin of photo-induced hysteresis characteristics in amorphous metal-oxide TFTs by comparing with those in conventional hydrogenated amorphous silicon (a-Si:H) TFTs.

2. Experimental

We fabricated the inverted-staggered bottom gate a-IGZO TFTs by using etch-back process. First, a 250 nm-thick molybdenum (Mo) as a gate electrode was deposited by DC sputtering on a glass substrate. A 450 nm-thick SiNx-SiO_2 bi-layer as a gate dielectric was deposited by using plasma enhanced chemical vapor deposition (PECVD). Then, a 40 nm-thick a-IGZO semiconducting layer was deposited by DC sputtering. After an active island patterned, a 250 nm-thick Mo as source and drain electrodes was deposited by sputtering. A 10 nm-thick a-IGZO was dry-etched in order to form the etch-back-type channel after patterning source and drain electrodes by a wet etching. A 200 nm-thick SiNx-SiO_2 bi-layer as an encapsulation layer was deposited by PECVD. Finally, a 90 nm-thick indium zinc oxide (IZO) electrode as a contact pad was deposited, followed by patterning contact holes. The dimension of a-IGZO TFTs is a channel width of 200 μm and a channel length of 6 μm. All samples were characterized by a semiconductor parameter analyzer and measured *in air*. The magnitude of gate and drain voltage sweeps is 20V and 0.1V, respectively. The light source has an optical power density of 24 mW/cm^2 and the luminance of max 20000 lx with a broad spectrum similar to sun light.

3. Results and Discussion

Figure 1 shows transfer characteristics of a-IGZO and a-Si:H TFTs in both dark and illuminated conditions. A large hysteresis window in a-IGZO was observed while no hysteresis window was observed in the dark condition. On the contrary to this, a hysteresis in a-Si:H was suppressed in the illuminated state compared to that in the dark state. Unlikely in a-IGZO TFTs, charge-carrier generation by absorption of the light illumination in a-Si:H TFTs overwhelms shallow charge trapping/de-trapping induced by electrical gate bias based on the difference of effective mass between electrons and holes.

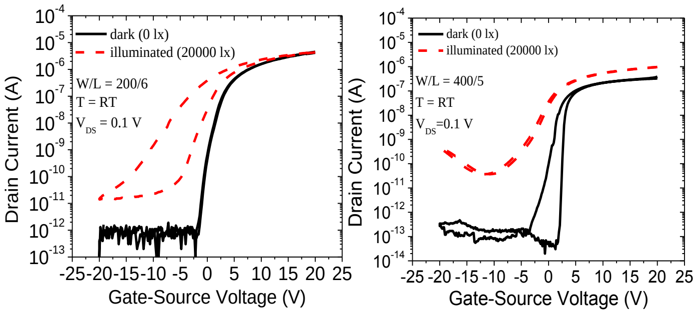

Figure 1. transfer characteristics of a-IGZO and a-Si:H TFTs in both dark and illuminated conditions.

Very little hysteresis means that charge trapping/de-trapping between charge carriers confined in the channel and defect states at the semiconductor/dielectric interface is weak. We calculated the density of trap states by using the following equations [3]:

$$SS = \frac{kTln10}{e}\left[1 + \frac{e^2}{C_{ox}} N_{trap\ density}\right]$$

where k is the Boltzmann constant, T is the temperature and C_{ox} is a capacitance per unit area of gate dielectric. The calculated density of trap states in a-IGZO TFTs is ~ $10^{11}cm^{-2}eV^{-1}$ which is one order lower than the that in a-Si:H TFTs.

Figure 2 shows transfer characteristics of a-IGZO and a-Si:H TFTs measured under the illuminated state with different intensity levels. A negative shift in threshold voltage (V_{th}) of an a-IGZO TFT in the forward sweep of an applied gate voltage was observed along with the illumination intensity, meaning that a hysteresis window was enlarged. However, similar hysteresis window in an a-Si:H TFT was observed regardless of the illumination intensity. It must be noted that the initially trapped charge carriers play a role in a screen effect on the electric field applied by gate voltage.

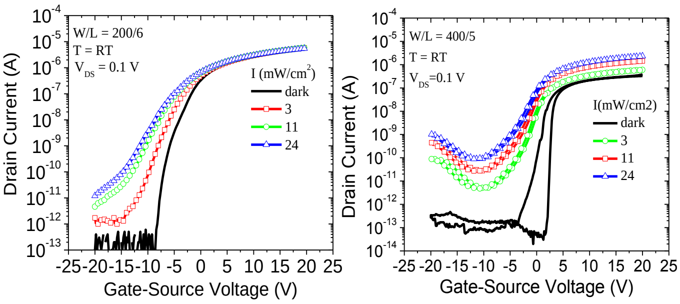

Figure 2. transfer characteristics of a-IGZO and a-Si:H TFTs measured under the illuminated state with different intensity levels.

Figure 3 shows transfer curves of an a-IGZO TFT in the forward sweep of gate voltage under the dark state after the reverse sweep with and without the light illumination. Even though the forward sweep was conducted under same dark state, more negative shift in V_{th} was observed in the reverse sweep under illuminated state than dark state due to the initially trapped charges.

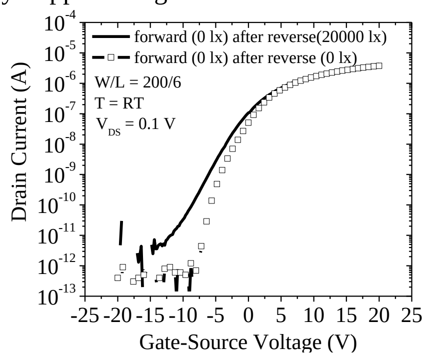

Figure 3. transfer curves of an a-IGZO TFT in the forward sweep of gate voltage under the dark state after the reverse sweep with and without the light illumination.

Such results are in good agreement with CV characteristics of hysteresis, as shown in Figure 4. hysteresis windows of C-V characteristics in an a-IGZO TFT were changed with the different frequencies (1Mz and 50kHz). The result supports that photo-induced hysteresis in a-IGZO TFTs is related to the interfacial trapped charges rather than intrinsic fixed charges [4].

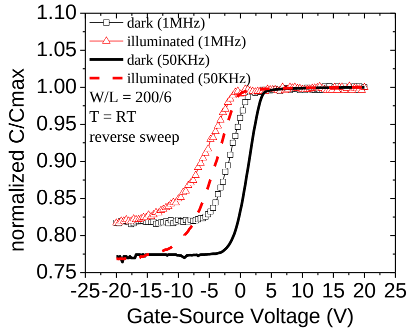

Figure 4. hysteresis windows of C-V characteristics in an a-IGZO TFT with the different frequencies (1Mz and 50kHz)

Figure 5 shows that the V_{th} difference between the reverse and the forward sweeps in the dark condition increased with a measuring temperature in a a-IGZO TFT, resulting in a thermal hysteresis. Such hysteresis looks very similar with photo-induced hysteresis, indicating that the effect of temperature on hysteresis can be expected to that of light illumination.

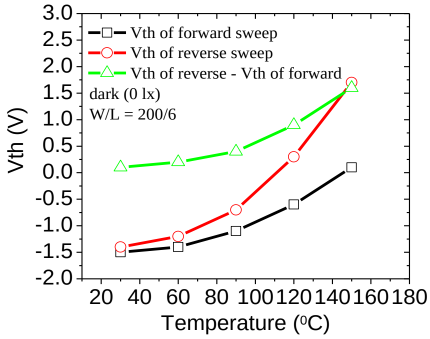

Figure 4. V_{th} difference between the reverse and the forward sweeps in the dark condition increased with a measuring temperature in a a-IGZO TFT

4. Conclusions

We have investigated the origin of hysteresis characteristics in TFTs consisting of amorphous silicon and metal-oxide semiconductors. Photo-induced hysteresis results from initially trapped charges at the interface of semiconductor/dielectric and/or in the gate dielectric which possess absorption energy to interact with trap states. We will demonstrate photo-induced hysteresis-free oxide-TFTs based on transparent display applications.

References

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