UV-Cured Reactive Mesogen-YInZnO Hybrid Materials as Semiconducting Channels in Thin-Film Transistors Using a Solution-Process

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Abstract

The Recently, amorphous oxide semiconductors (AOSs) have been researched extensively for a use as the channel layer in thin-film transistors (TFTs). 1−3 which exhibit superior electrical and optical characteristics to amorphous Si (a-Si) TFTs. a-Si TFTs have a relatively low mobility of approximately 0.5 cm2/Vs because of the angular distortion of the strongly directive sp3 orbital. 1 In contrast, AOSs have a different carrier-path mechanism that permits them to achieve high mobility, as demonstrated by Nomura et al. 1 They proposed a unique mechanism: direct overlapping between neighboring s orbitals that have insensitive angular distortion because of the chemical bonding between heavy-metal ions, such as the In in the InGaZnO (IGZO) system. Thus, despite the amorphous phase, AOSs have mobility that is almost comparable to that of the crystalline phase. 4 Previously, Shin et al. studied using YInZnO (YIZO) for the TFT channels by replacing the Ga in the IGZO system with Y. 5 Y has a lower standardation of heavy-metal ions, such as the In in the InGaZnO (IGZO) system. Thus, despite the amorphous phase, AOSs have mobility that is almost comparable to that of the crystalline phase. 4 Previously, Shin et al. studied using YInZnO (YIZO) for the TFT channels by replacing the Ga in the IGZO system with Y. 5 Y has a lower standard

The amorphous oxide semiconductors (AOSs) can be aligned to a specific direction and this alignment is the key to obtaining high electrical performance. 6−8 Therefore, reactive mesogen (RM) was added to the YIZO system to obtain high electrical performance by inducing the channel material to become positioned along the source-drain direction. When a hybrid YIZO film is irradiated with UV radiation, the channel material is further densified 12,13 and the oxygen loosely bonded to stoichiometric oxygen in the hybrid YIZO films (O1) and the oxygen loosely bonded to the surfaces of the hybrid YIZO films (O3). 12 The O2/O1 ratio indicates the relative number of oxygen vacancies, and the values of this ratio are 24.65% and 51.86% for the hybrid YIZO films with and without UV irradiation, respectively. These values can be explained by the fact that the oxygen vacancies, which are the origin of the low mobility, were decreased by the application of UV irradiation in the hybrid YIZO system because the UV-cured film affects the channel alignment and densifies the channel. 12,13

We used [120 nm SiO2] substrates fabricated on a p+−Si wafer, and we spin-coated the hybrid YIZO solution onto these substrates to form the channels of the TFTs. After the channel deposition, the samples were pre-annealed at 300 °C for 5 min, and then annealed at 500 °C for 2 h on a hot plate. To investigate the role of the aligned RM, the hybrid YIZO film was irradiated with UV for 20 min via a 436-nm filter and a polarizer in the source-drain direction. We deposited Al for the sources and drains of TFTs via evaporation using a 150-μm shadow mask.

Figures 1a and 1b show field-emission scanning electron microscope (FE-SEM) images of the hybrid YIZO films with and without UV irradiation, respectively. Figures 1c and 1d show an atomic force microscope (AFM) images. In the case of the hybrid YIZO film that was cured under UV irradiation, the crystal size is larger than that of the other film. This difference indicates that the UV irradiation affects the alignment of the film surface by reacting to the RM in the YIZO system. The surface roughness was measured using an AFM, and the corresponding values for the hybrid YIZO films with and without UV treatment were found to be 5.779 nm and 6.034 nm, respectively. This result implies that the application of UV radiation makes the film smoother.

To investigate the role of the UV-irradiated RM in the YIZO system, X-ray photoelectron spectroscopy (XPS) measurements were performed. Figures 2a and 2b show the O 1s peaks of the hybrid YIZO films with and without UV irradiation, respectively. These spectra consist of three main peaks centered at 530.1 eV, 531.2 eV, and 532.1 eV, as determined via Gaussian fitting. These peaks correspond to stoichiometric oxygen in the hybrid YIZO films (O1), oxygen vacancies in the hybrid YIZO films (O2), and the oxygen loosely bonded at the surfaces of the hybrid YIZO films (O3). 12 The ratio of these oxygen vacancies, and the values of this ratio are 24.65% and 51.86% for the hybrid YIZO films with and without UV irradiation, respectively. These values can be explained by the fact that the oxygen vacancies, which are the origin of the low mobility, were decreased by the application of UV irradiation in the hybrid YIZO system because the UV-cured film affects the channel alignment and densifies the channel. 12,13

We then measured the optical retardation of the hybrid YIZO films with and without UV irradiation to trace the aligned channel material, as shown in Figure 3. Optical-retardation measurements can evaluate and be used to determine the anisotropy of hybrid YIZO films with and without UV irradiation. 14,15 The films are not crystalline, but involved reactive mesogen can be aligned to a specific direction and this
Figure 1. FE-SEM (a), (b) and AFM (c), (d) images of solution-processed RM-included YIZO films deposited on Si substrates (a), (c) with and (b), (d) without UV irradiation.

Figure 2. XPS spectra that show the O 1s peaks of solution-processed RM-included YIZO films deposited on Si substrates (a) with and (b) without UV irradiation. O1, O2, and O3 denote the stoichiometric oxygen in the hybrid YIZO films, the oxygen vacancies, and the oxygen loosely bonded at the surfaces of the hybrid films, respectively.

Figure 3. Optical-retardation measurements of solution-processed RM-included YIZO films deposited on Si substrates with and without UV irradiation. The red line represents the UV-cured RM-included YIZO film, whose anisotropy is greater than that of the RM-included YIZO film with no UV treatment, which is represented by the blue line.

Figure 4. Transfer characteristics of solution-processed RM-included YIZO TFTs. The red line represents the RM-included YIZO TFT that was cured under UV irradiation, and the blue line represents the RM-included YIZO TFT that was given no UV treatment.
Figure 5. Mechanism of the alignment of the channel structures of RM-included YIZO TFTs (a) with and (b) without UV irradiation. (a) Electrons can easily pass through the aligned channel because of UV-reacted RM. (b) RM acts as a carrier suppressor in the channel material, which prevents the electrons from passing through the channel.

gives the film the anisotropy. The results of the optical-retardation measurements indicate that the retardation was increased by UV irradiation of the film. Consequently, the UV-cured films exhibited enhanced anisotropy, which can lead to high electrical performance of the hybrid TFTs.

Figure 4 shows the transfer characteristics of the hybrid YIZO TFTs with and without UV irradiation. Both TFTs were prepared as n-channel TFTs. When no UV irradiation was applied to the hybrid YIZO TFT, the $V_{TH}$ was shifted from 10.96 V to 5.51 V, and the mobility was decreased because of the large reduction in the on current and its random direction in the channel material. These results indicate that UV-irradiated RM affects the channel structure by inducing the electrons to move along the direction from the source to the drain. The saturated mobility ($\mu_{SAT}$) of each hybrid YIZO TFT with and without UV irradiation were found to be 1.26 cm$^2$/Vs and 0.15 cm$^2$/Vs, respectively, and the values of the S.S for the hybrid YIZO TFTs with and without UV irradiation were found to be 0.88 V/decade and 0.94 V/decade, respectively. We obtained each value using the following equations:

$$\mu_{SAT} = \frac{2L}{C W} \frac{I_{DS}}{V_{GS} - V_{TH}^2}$$  \[1\]

where $I_{DS}$, $V_{GS}$, C, L, and W are the drain current, gate voltage, capacitor, channel length, and channel width of the hybrid YIZO TFTs, respectively.

$$V_{TH} = \frac{\sqrt{I_{DS}}}{\text{Grad}}$$  \[2\]

where Grad is $\frac{\partial \sqrt{I_{DS}}}{\partial V_{GS}} = \sqrt{\mu_{SAT} C W} \frac{2L}{2L}$

$$S.S = \frac{dV_{GS}}{d \log(I_{DS})}$$  \[3\]

Equations 1, 2, and 3 were used to determine the $\mu_{SAT}$, $V_{TH}$, and S.S values, respectively.

Figures 5a and 5b show the mechanism of the UV-cured hybrid YIZO TFT and that of hybrid YIZO TFT that was not UV treated, respectively. In the case of the UV-cured hybrid YIZO TFT, the UV-irradiated RM makes the electrons flow along the source-drain direction. Therefore, the value of $V_{TH}$, which is related to the charge trapping in the channel, gate insulator, or the interface between them, is low. Under the UV irradiation, the RM-included channel material was aligned along the source-drain direction, thereby allowing the electrons to pass through the channel more easily than in the other TFT. The S.S value is strongly related to the interface trap density. If the S.S value is high, it implies that the interface trap density is also high, and it causes the degradation of certain aspects of the TFT performance, such as mobility. As the hybrid YIZO system was UV irradiated, the structure of the channel was densified, and the trap density was reduced compared with that of just-deposited hybrid YIZO TFT.

In conclusion, Y can serve as a substitute for Ga in the IZO system (as a carrier suppressor) because of its low electronegativity and low SEP. When RM is added to this system under UV irradiation, the surface roughness is lowered because of the high film density. As a result, the S.S value becomes small because the electrons are less frequently trapped in the hybrid YIZO channel, the SiO$_2$ gate insulator, or the interface between them.

References