

Effect of Hydrogen in the Gate Insulator on the Bottom Gate Oxide TFT

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Abstract

The effect of hydrogen in the alumina gate insulator on the bottom gate oxide thin film transistor (TFT) with an InGaZnO film as the active layer was investigated. TFT with more H-containing alumina films (TFT A) fabricated via atomic layer deposition using a water precursor showed higher stability under positive and negative bias stresses than that with less H-containing alumina deposited using ozone (TFT B). While TFT A was affected by the pre-vacuum annealing of GI, which resulted in V_{th} instability under NBS, TFT B did not show a difference after the pre-vacuum annealing of GI. All the TFTs showed negative-bias-enhanced photo instability.

Keywords: Oxide TFT, H effect, PBS, NBS, NBIS

1. Introduction

Oxide semiconductors, especially multi-component amorphous semiconductors such as InGaZnO (IGZO), AlZnSnO, and ZnInSnO, have attracted much interest as active layers of thin film transistors (TFTs) for the application of active matrix display, thanks to their high mobility and high stability [1-3]. The oxide TFT technology appears to be rapidly approaching the point of being a strong candidate for the backplanes of next-generation displays. During the last couple of years, extraordinarily fast development of oxide TFTs had been accomplished with various active materials in a different device structure [4-6]. Most of all, many factors that affect the oxide TFT stability under electrical stress have been reported. The hydrogen amount in a gate insulator (GI) [7], thermal annealing (including water vapor treatment) [8], the passivation layer [9], and active composition are known to be responsible for the stability under a constant gate bias stress and a constant current stress [10]. Optical stability has recently become a main issue in oxide TFTs [11-13] and the main factors of optical stability are now being investigated [14, 15].

It has been well known that the oxide TFT perform-

ance is dependent on the kind of GI and the amount of hydrogen in the GI [16, 17]. Hydrogen incorporation into the active layer during the TFT fabrication makes the oxide TFT likely to result in a negative V_{th} ; and in the worst case, the TFT would not be modulated by the gate voltage. Furthermore, the deposition process for the same GI material also resulted in different device performance levels. In this study, an attempt was made for the first time to investigate the main effect of hydrogen in the GI of alumina on the characteristics of bottom gate IGZO TFTs in terms of the gate bias stress stability and the optical stability, using the atomic layer deposition (ALD) method for the GI process with a different oxygen precursor.

2. Experiment Details

A bottom gate TFT with an active IGZO layer was fabricated. The schematic diagram of the bottom gate IGZO TFT structure is shown in Fig. 1. An alkaline-free glass was used as a substrate. A gate electrode was formed with a 150nm-thick ITO via photo-patterning. A common GI (the first GI) of Al_2O_3 was formed via ALD using trimethylaluminum (TMA) and water as the Al source and the oxygen source, respectively, at 150°C. The second GIs were deposited using water and ozone as the oxygen sources for TFT A and B, respectively. After the gate pad was opened by wet-etching the GI, the ITO was deposited as a source/drain (S/D) with a 150nm thickness, and was patterned. The 25nm-thick IGZO film was deposited via RF sputtering under the atmosphere of Ar and O_2 mixed gases, with a

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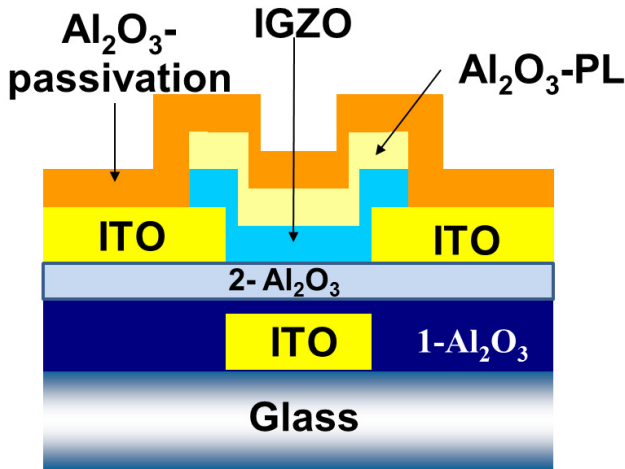


Fig. 1. Schematic cross-section details of the IGZO TFT with a double gate alumina insulator.

chamber pressure of 0.1 Pa. After the 9nm-thick alumina, which played the role of the active protection layer (PL), was deposited by the ALD, the active layer and the PL were patterned via wet-etching, followed by annealing at 250°C for 2 hours under an oxygen atmosphere. The passivation layer of Al₂O₃ was deposited via ALD, using water. All the patterning processes were performed using the photolithographic method and the wet-etching process. The electrical characteristics of the TFTs were measured with a semiconductor parameter analyzer (Agilent B1500A) in darkness. For the light stress test, a halogen lamp with a light intensity of 0.1 mWatt/cm² was used. The light was irradiated onto the active layer side, and the channel dimensions of the measurement were 40 μm / 20 μm.

3. Results and Discussion

To investigate the effect of hydrogen in the alumina GI on the bottom gate IGZO TFT, the Al₂O₃ was deposited using different oxygen precursors--i.e., water and ozone. The alumina deposited with the water precursor contained more hydrogen than that deposited with ozone. According to the results of the authors' previous study [18], Al₂O₃ deposition using water on the active layer induced more n-type carriers than that using ozone. The effect of the difference in the H amounts in each Al₂O₃ on the TFT performance was investigated by using a double GI, as shown in

Fig. 1, in the bottom gate TFT. In addition, vacuum thermal annealing was performed before depositing the active layer to compare the effect of the different H amounts.

The bulk common GI was deposited in Al₂O₃ using water, and the second GIs that formed the interface were deposited using water and ozone. The transfer curves of all the TFTs did not show any hysteresis caused by the slow charge trapping/de-trapping process at or near the interface, or any migration of mobile ions in the GI. TFT A and B had similar mobility performance levels of 16.2 cm²/V.s and 16.5 cm²/V.s, and S.S's of 0.14 V/decade and 0.11 V/decade, respectively. The V_{on} of TFT A was -1.4 V, and that of TFT B was -0.23 V. TFT A showed a more negative V_{on} than TFT B, which implies that the carrier amount in the active layer in Device A was higher than in Device B. This can be explained by the hydrogen migration from the GI that was deposited using water, since hydrogen in an amorphous oxide semiconductor plays the role of a shallow donor [19]. The alumina film from ozone contained less H than that from water. To confirm the effect of the hydrogen amount in each Al₂O₃ deposition process, vacuum annealing of the GIs of TFT A and B was performed at 300°C for 2 hours before the active layer (TFT C for A and TFT D for B) was deposited. While the vacuum annealing of TFT A induced a large V_{on} shift for TFT C to have a V_{on} of -0.4 V, the V_{on} of TFT D shifted less to give a 0 V, as shown in Fig. 2.

In both cases, the V_{on} values shifted to the positive voltage by 1 V for TFT A and 0.23 V for TFT B. The ΔV_{on} between TFT A and C was larger than that between TFT B and D, which supports the possibility of greater H migration

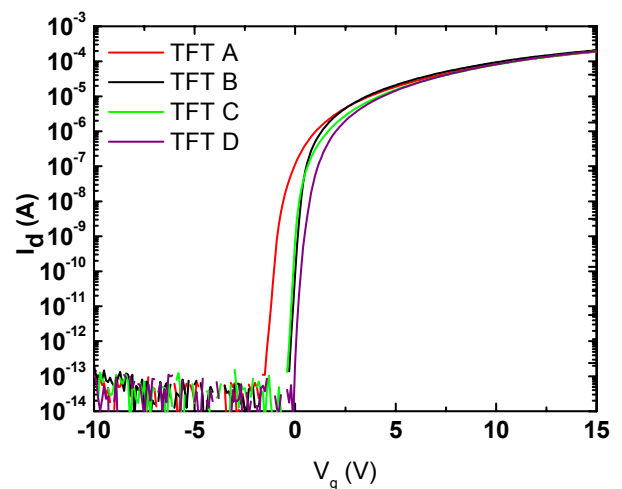


Fig. 2. Variations of the transfer characteristics of TFT A, B, C, and D.

from Al_2O_3 from the water precursor into the active layer in the case of TFT A. The hydrogen was less incorporated into the alumina film during the deposition process using ozone than in the water process. Therefore, the pre-vacuum thermally annealed Al_2O_3 films that were deposited with ozone did not induce a marked change in the H amount in the film, which resulted in only a small change in the transfer curve of TFT B and D.

The hydrogen effect in the GI on the positive bias stress (PBS) of Devices A, B, C, and D was explored, as shown in Fig. 3. TFT A, B, and D showed parallel shifts in the transfer curves as functions of the applied stress time. TFT A, B, and D showed V_{th} shifts of 1.7 V, 8.7 V, and 9.6 V, respectively, under 20 V of PBS for 10^4 seconds. TFT C experienced a change in its transfer curve shape over time and a 4.9V V_{th} shift. It was well established that the positive parallel V_{th} shift of the oxide TFT under the PBS was mostly due to the charge trapping in the gate insulator and/or at the channel/GI interface [20]. Both TFT A and B had identical materials and the same structure, except for their Al_2O_3

process at the interface, which implies material process results of different GI characteristics in terms of the surface and the bulk itself. The alumina deposited with ozone must have many charge trapping centers regardless of the pre-vacuum annealing process. This charge trapping can be attributed to the defect in the Al_2O_3 film that was deposited with ozone at the relatively low temperature of 250°C , since this process needs a higher deposition temperature of 350°C to yield the best electrical performance. Although the transfer characteristics of Device B showed higher mobility and a smaller S.S. than those of Device A, which indicates apparently better TFT performance, the larger V_{th} shift of Device B under a positive V_{gs} bias stress strongly implies the high tendency towards bias-dependent charge injection into Al_2O_3 films deposited with ozone. In the case of the Al_2O_3 GI from water, the TFT with a non-annealed GI showed minimal charge trapping at the interface or in the GI, and the pre-thermal annealing of GI caused an S.S. change of TFT C during the PBS. The change in the S.S. of TFT C can be ascribed to the state creation at the interface.

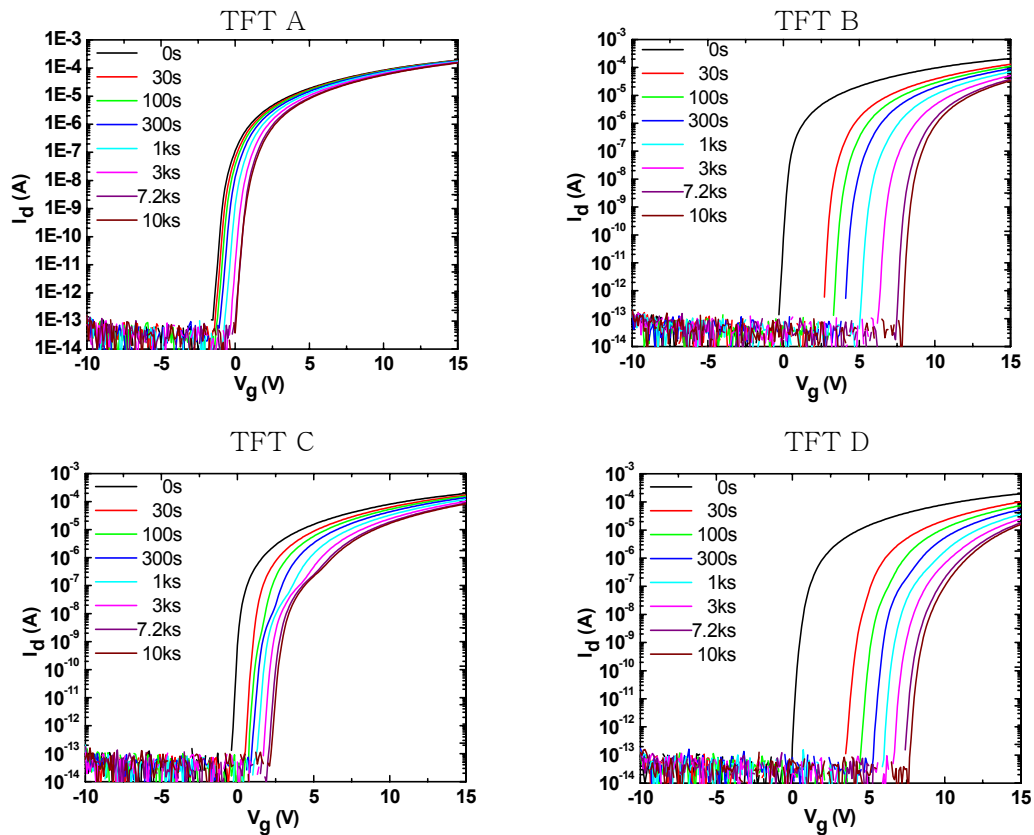


Fig. 3. Evolution of the transfer curves under $V_{\text{gs}} = 20$ V of positive bias stress as a function of the measurement time for TFT A, B, C, and D.

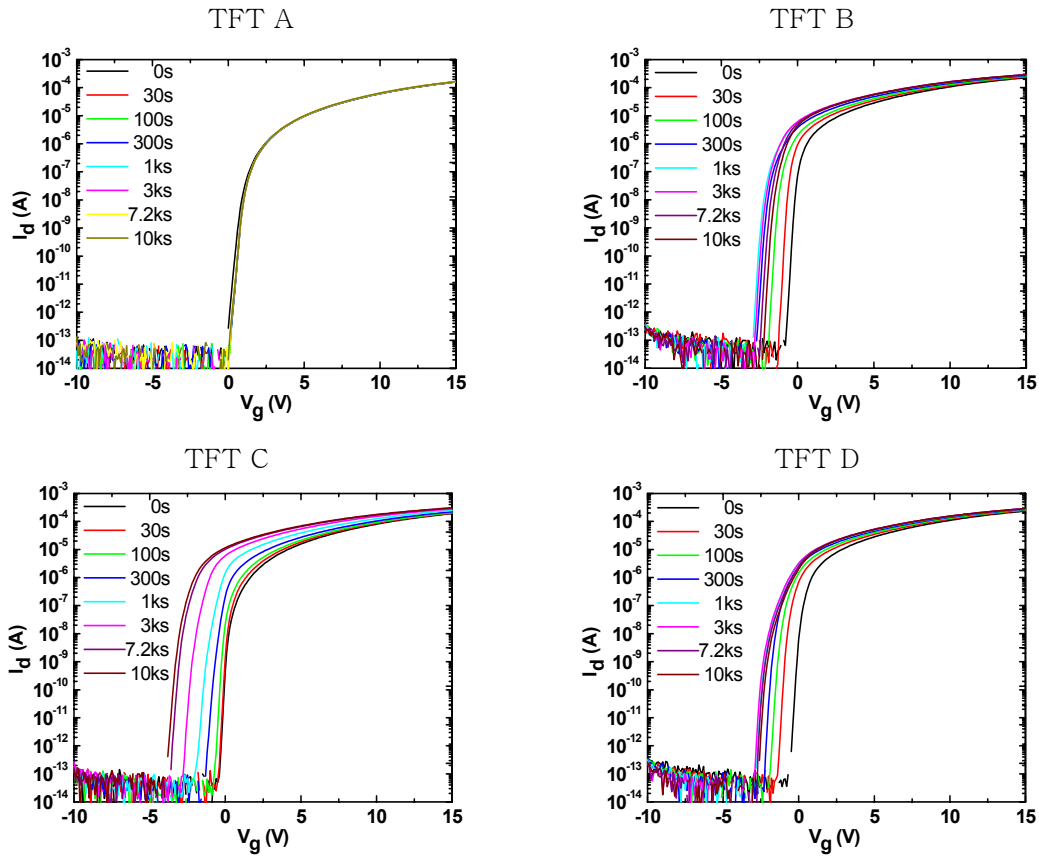


Fig. 4. Evolution of the transfer curves under $V_{gs} = -20$ V of negative bias stress as a function of the measurement time for TFT A, B, C, and D.

The main origin of the S.S. change in TFT C was also investigated. Lee *et al.* earlier reported that the hydrogen in GI may provide a high-density charge trap [7]. According to the results of this study, however, hydrogen rather seems to suppress the V_{th} shift under the PBS. In the case of TFT C, the degree of the V_{th} shift was 4.9 V, which is larger than that of TFT A but smaller than that of TFT B.

The V_{th} instability of each TFT under a negative bias stress (NBS) was noticeable. When a V_{gs} of -20 V was applied, TFT A, B, C, and D showed V_{th} shifts of 0.1 V, -2.2 V, -4.5 V, and -2.36 V, respectively, under the same conditions. Similar to the results for the PBS, the NBS of each TFT showed less V_{th} change in the case of the TFT with more hydrogen in the GI, as in TFT A. Furthermore, the performance of the TFT that consisted of a GI with less hydrogen was not affected by the pre-vacuum annealing of the GI. This implies that as long as the hydrogen in the GI does not make the semiconductor conductive, a proper amount of hydrogen may result in V_{th} stability in the NBS and in the

PBS. The hydrogen in the GI might passivate any defects in the GI and the active layer, to make them stable under the PBS and the NBS at the same time.

It was recently known that most oxide TFTs show negative-bias-enhanced photo instability due to oxygen vacancy and interface charge trapping. The effect of the hydrogen in the GI on the photo stability was examined by measuring the V_{th} shift under the NBS with white light illumination. Fig. 5 shows the evolution of the transfer curves of TFT A, B, C, and D under the NBS and the light illumination as a function of time. The V_{th} change in TFT A, B, C, and D were -6.6 V, -8.2 V, -6.9 V, and -5.4 V, respectively. While the TFTs with water-related GIs showed somewhat smaller negative V_{th} shifts after pre-vacuum annealing, the TFTs with ozone-related GI showed marked differences in their S.S. change and in the degree of their V_{th} shift. The origin of this difference is being investigated with that of other GI materials.

In summary, the effect of hydrogen in the alumina GI

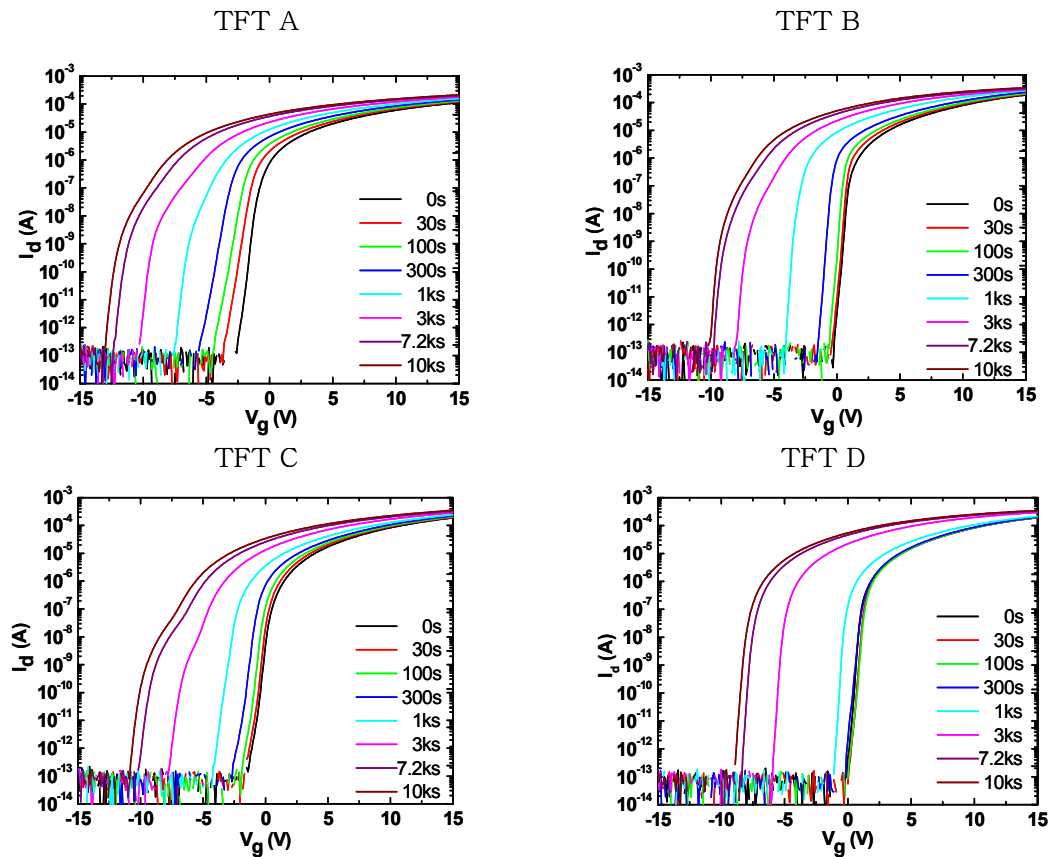


Fig. 5. Evolution of the transfer curves with white light illumination under $V_{gs} = -20$ V of negative bias stress as a function of the measurement time for TFT A, B, C, and D.

deposited by ALD using a different oxygen precursor was studied. The IGZO TFT with its alumina GI deposited using a water precursor (TFT A), which contains much hydrogen, showed stability under both the PBS and the NBS. This TFT showed a large change in its TFT performance, however, especially in terms of the NBS, when pre-vacuum annealing of the GI was performed before the deposition of the active layer. The IGZO TFT with its alumina GI deposited using the ozone precursor, which contains less hydrogen, showed a larger V_{th} shift under the PBS and the NBS than that of the former TFT. The instability of the V_{th} shift of the TFT with the ozone alumina (TFT B) was attributed to the charge trapping centers in the GI. A marked difference between TFT A and B was shown in the NBS, and TFT B was shown as unstable under the NBS. The effect of the pre-vacuum annealing of the GI of each TFT on the TFT performance was noticeable. The TFT with less hydrogen

was not affected by the pre-vacuum annealing, and both TFTs showed V_{th} instability under the PBS and the NBS. All the devices showed negative-bias-enhanced photo instability.

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