Highly Stable High Mobility Top-gate Structured Oxide TFT by Supplying Optimized Oxygen and Hydrogen to Semiconductors

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ABSTRACT

Top-gate self-aligned structured TFT is appropriate for the high-end display. However, it is hard to realize highly stable high mobility characteristics, because GI deposition affects active surface in top-gate structure. Here we realize highly stable high mobility oxide TFTs by using thermal-ALD and oxygen sourcing plasma treatment for GI process.

1 INTRODUCTION

Amorphous oxide semiconductor (AOS) materials are appropriate candidates for the active layer of thin-film transistors (TFTs) due to their several advantages such as high electron mobility, reasonable stability, good uniformity in a large area and easy fabrication. [1-3] However, there are many important issues that need to be addressed in order to drive high resolution, large sized AMOLED and micro-light emitting diode (micro-LED) that are drawing attention nowadays. The top-gate self-aligned structured oxide TFT is the appropriate candidate for the backplane device of the high-resolution and large-sized display due to their negligible parasitic capacitance. And also, in order to reach a fast frame rate, researches on the various kinds of high mobility materials such as indium zinc oxide (IZO) [4] and Al-doped ITZO (Al:ITZO) [5] were also been actively conducted. However, the quality of gate insulator (GI) and its process environment should be carefully concerned, especially in high mobility case, because the GI is deposited on top of the active layer. In particular H at the interfaces between the active layer and the GI acts as a shallow donor and increases the carrier density. However, H also acts as a passivator for the defects, thus improving stability [6]. Therefore, to realize a high-mobility oxide TFT with good stability, it is important to finely regulate the amount of H so that it behaves as a defect passivator rather than a shallow donor in the high mobility channel region.

In here, to realize highly stable high mobility oxide TFTs, we applied thermal atomic-layer deposition (T-ALD) process for GI. During the T-ALD process, H from H_2O reactant can incorporate into the channel region and degraded on/off characteristics. Therefore, we applied O_2 or N_2O plasma treatment just before the T-ALD process so that the H from the H_2O would act as a passivator for the charge trapping defects generated by the subsequent processes, including plasma treatment. Here, we realize a highly stable, high-mobility top-gate bottom-contact (TGBC) structured oxide TFT that mimics a SA-structured TFT. The AlOx thin layer for 1st GI is deposited by T-ALD using an H_2O oxygen source, and the second GI, of SiNx, is deposited by PE-CVD. To investigate the effect of the plasma treatment, reference TFTs were fabricated, with the T-ALD or PE-ALD for 1st GI, using H_2O and O_2 plasma as oxygen sources, respectively, without any plasma treatment.

2 EXPERIMENT

The TGBC TFTs were fabricated with different kinds of GI deposition process conditions. First, ITO was patterned as source and drain. Then, 20nm of high mobility Al doped ITZO was deposited by sputtering, followed by patterning as the active layer. Before the deposition of GI, the O_2 and N_2O plasma treatment were carried out, separately in ALD reaction chamber. For the GI, the stack of 20nm AlO_x / 180nm SiN_x was used. The AlO_x layer was deposited by T-ALD using H_2O as an oxygen source right after the plasma treatment. In order to investigate the effect of the plasma treatment, reference TFTs were prepared with first GI deposited consecutively on top of the active layer by T-ALD or PE-ALD using H_2O and O_2 plasma as oxygen source, respectively, without any further plasma treatment. As the second GI, thick layer of SiN_x was deposited by means of PECVD. Silane (SiH_4), ammonia (NH_3) and hydrogen gas were used as reaction elements for the deposition of SiN_x. Finally, the molybdenum was deposited as gate electrode. The schematic diagram of the fabricated oxide TFTs are shown in figure 1. The fabricated TFTs were annealed at 300^{o}C under vacuum condition. To investigate the origin of the differences among the TFTs, we analyzed the elements by means of secondary ion mass spectroscopy (SIMS) and X-ray photoelectron spectroscopy (XPS).

3 RESULTS AND DISCUSSION

3.1 Transfer characteristics

The transfer characteristics of the TGBC TFTs with various kinds of GI deposition environments were investigated and shown in Fig. 1. The applied drain voltage (V_d) was 0.1V and the dimension of the measured TFTs were 40 and 20 μm in width and length, respectively. The TFT exhibited conductive characteristic in the case of the GI processed by means of T-ALD without any plasma-treatment before and after thermal annealing. On the other hand, on/off characteristics were shown when the GI processed by using T-ALD with O_2 or N_2O plasma treatment. The both O_2 and N_2O plasma-treated TFTs showed hysteresis, however, it fully recovered after thermal annealing. Except for the TFT with T-ALD processed GI without plasma-treatment, all of the devices exhibited high mobility characteristics over 25 cm^2/Vs.

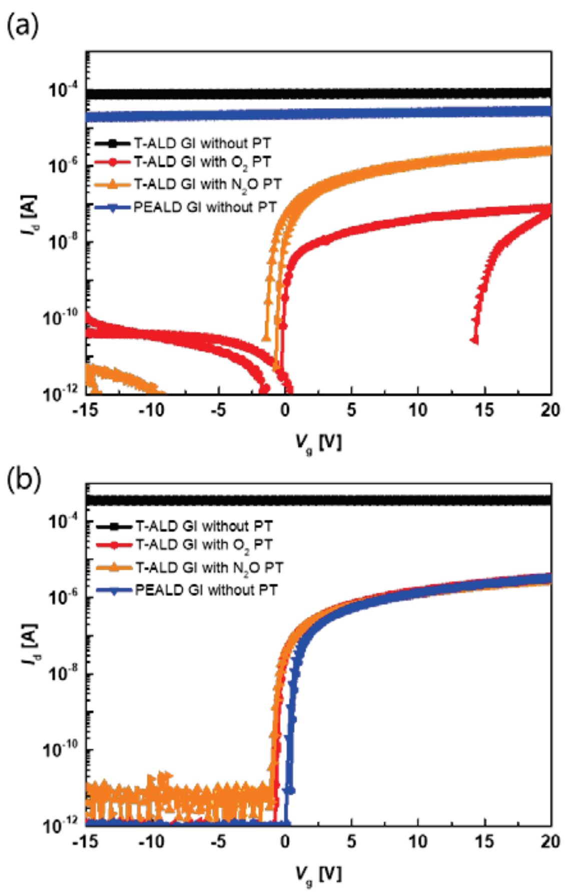

Fig. 1 Transfer curve of the devices with differen kinds of GI process (a) before and (b) after thermal annealing

3.2 Carrier concentrations

From the Hall measurement analysis, we investigate the carrier density of the active layer covered by each GI, which were processed as they would be in devices as shown in Fig. 2. The active layer with 1st GI deposited by using T-ALD without plasma-treatment shows a large value of carrier density before and after thermal-annealing. In contrast, when active layers were O_2 or N_2O plasma-treated, they show dramatically reduced carrier density values. In addition, a significant increase of the carrier density did not found after thermal annealing. We expect O_2 and N_2O plasma treatments to be able to induce the generation of an oxygen interstitial (O-O_i) in an oxide semiconductor and channel interface, which plays the role of a charge trap center. The thermal annealing induced H diffusion from the T-ALD AlOx film into the interface and the oxide semiconductor, thereby passivating these charge trapping defects and leading to an appropriate carrier concentration, and in turn to reasonable on/off characteristics. The active layer covered by 1st GI with PE-ALD also shows moderate carrier concentration, because PE-ALD use O_2 plasma for oxygen source and free from the H incorporation issue. Therefore, the TFT with PE-ALD processed GI exhibit good transfer characteristics even without any plasma-treatment.

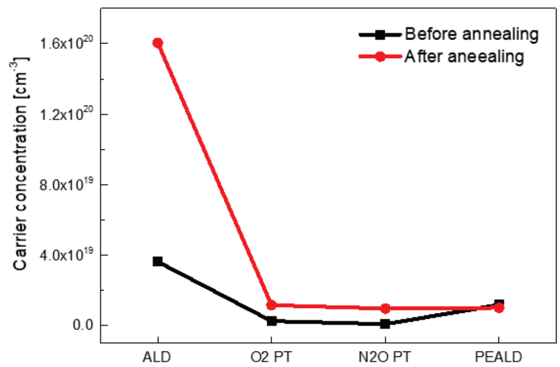

Fig. 2 Carrier concentration of active layer covered by different kinds of GI process before and after thermal annealing.

3.3 XPS results

XPS analysis was carried out to investigate the effects of the plasma treatment on active surface composition and bonding state. We scrutinized the O1s peaks, because the electrical characteristics of the oxide semiconductor is strongly related to the oxygen bonding states. The peaks of O1s near 530eV were measured as shown in Fig. 3. It is well known that binding energies of the O vacancies and –OC or –OH related bonding states are relatively larger than the M-O bonding state. From the graph, it can be easily noticed that the portions of the O vacancies and –OC or –OH related bonding were dramatically decreased after the plasma treatment. It is well known that O vacancies act as shallow donor, therefore, oxygen-containing plasma treatment results in a suppression of intrinsic carrier density. These results are in good agreement with the previously explained carrier concentration results.

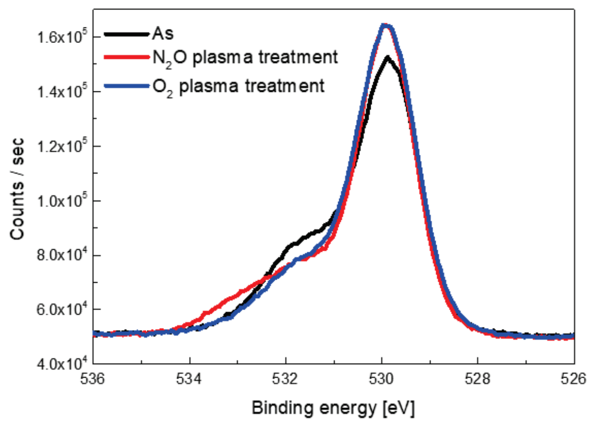

Fig. 3 XPS results of O1s peaks before and after plasma treatment

3.4 PBTS stability

The biggest difference in electrical properties was found in the stability results. The transfer-curve were obtained during the positive-bias temperature stress (PBTS) condition. The stressed gate-bias and temperature were 20 V (1MV/cm) and 60 ^{o}C, respectively. The transfer-curve was shifted to the positive direction significantly when the device's GI was deposited by using PEALD without plasma treatment. However, when the GI was deposited by using T-ALD with plasma treatment, the devices shown improved stability characteristics. Especially, the device with O_2 plasma treatment shown outstanding PBTS stability characteristics, which only shifted about 0.03V after 10000 sec. The transfer-curves of the devices with GI deposited by PEALD without plasma-treatment and GI deposited by thermal-ALD with N_2O plasma-treatment were shifted 7.49V and 1.23V, respectively.

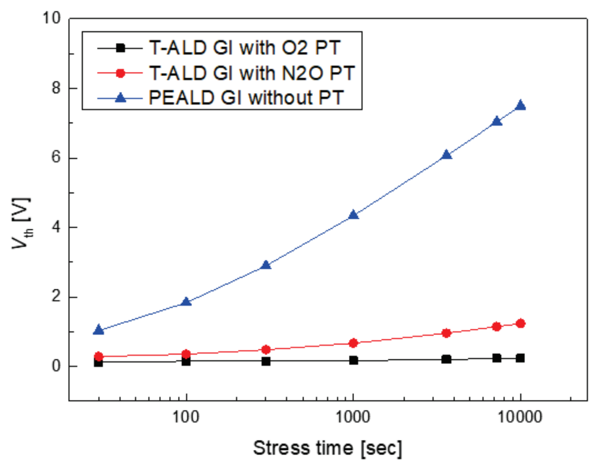

Fig. 4 V_{th} change during the PBTS.

4 CONCLUSIONS

The high mobility SA oxide TFT is a promising device which can realize high-end large area display such as AM-OLED and AM-LED due to their low RC delay characteristics. For the good stability characteristics, the T-ALD, in which no reactive oxygen plasma source is generated, resulting in the suppression of the generation of charge trapping centers in the interface, was used to deposit AlO_x as a first GI. To tailoring the amounts of shallow donor of H and carrier-killer defect of interstitial oxygen in the active and/or interface, we adopted the O_2 and N_2O plasma treatment to yield TFTs with improved on/off characteristics. From the XPS and SIMS results, we inferred that the both O_2 and N_2O plasma treatment increase the portion of M-O bonding and reduce the donor elements which from the H incorporation. The TFT with PE-ALD GI showed also good on/off characteristics even without any plasma treatment. The V_{th} of the TFT was about 3.06 V. The O_2 plasma-treated TFTs with T-ALD GI gave high field-effect mobility over the 35.3 $cm^2/V{\cdot}s$. In addition, the TFTs with T-ALD GI treated by O-containing plasma showed improved bias stability compared with that of TFT of which AlO_x, the first GI, deposited by PE-ALD. Therefore, we conclude that the T-ALD process for the thin GI deposition can be applied to fabricate even high mobility top-gate structured oxide TFTs by using O_2 or N_2O plasma treatment. The AlO_x deposited by T-ALD contains proper amounts of H depending on its deposition temperature, and it can passivate extra trap sites generated during the supply of the oxygen for the carrier control process of high mobility oxide TFT. This makes it possible to obtain high mobility TFTs with high stability.

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