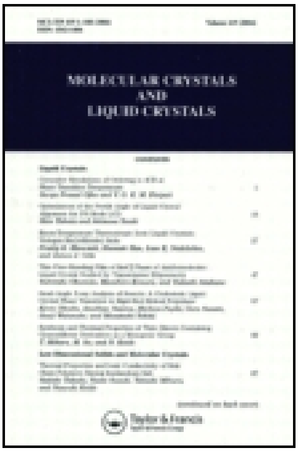

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Oxygen Atom Neutral Beam Assisted Deposited Al_2O_3 and its Application to the Fabrication of Zinc Oxide Thin Film Transistor

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In the fabrication of zinc oxide thin film transistor(ZnO TFT), aluminum oxide(Al_2O_3) was deposited as gate insulator by using an oxygen atom neutral beam assisted deposition(NBAD) during e-beam evaporation. From the thickness of the Al_2O_3 layer evaporated with the oxygen NBAD process and the C-f measurement of metal-insulator-metal(MIM) capacitors fabricated with the NBAD Al_2O_3 layer, it was possible to conclude that the NBAD Al_2O_3 layer has a higher thickness and a higher dielectric constant at an acceleration beam energy of 300 eV as a result of the additional deposition of oxygen atoms during e-beam evaporation. The fabricated ZnO TFT with the NBAD Al_2O_3 gate insulator showed better electrical characteristics, such as a lower subthreshold swing and a higher on-off ratio, than those without any NBAD process.

Keywords zinc oxide TFT; aluminum oxide; neutral beam assisted deposition; e-beam evaporation

Introduction

Many researches and developments about zinc oxide(ZnO) have been carried out to be applied to the devices, such as various sensors, window/buffer layers of solar cells, electronic and optical devices [1–5]. Especially, ZnO has recently been developed as a channel layer of transparent TFT of FPD, such as TFT-LCD or active matrix organic light emitting display(AMOLED), because it has not only a higher mobility than a conventional hydrogenated amorphous silicon thin film transistor(a-Si:H TFT) but also transparent characteristics in a range of wavelengths of visible rays [6–8]. Furthermore, ZnO TFT can be fabricated at a lower temperature than a-Si:H TFT because ZnO layer is deposited by using sputtering or atomic layer deposition(ALD) instead of plasma enhanced chemical vapor deposition(PECVD).

For the low voltage operation of ZnO TFT, it is necessary to reduce the thickness of gate insulator and also to maintain its higher capacitance. Therefore, it is required to find

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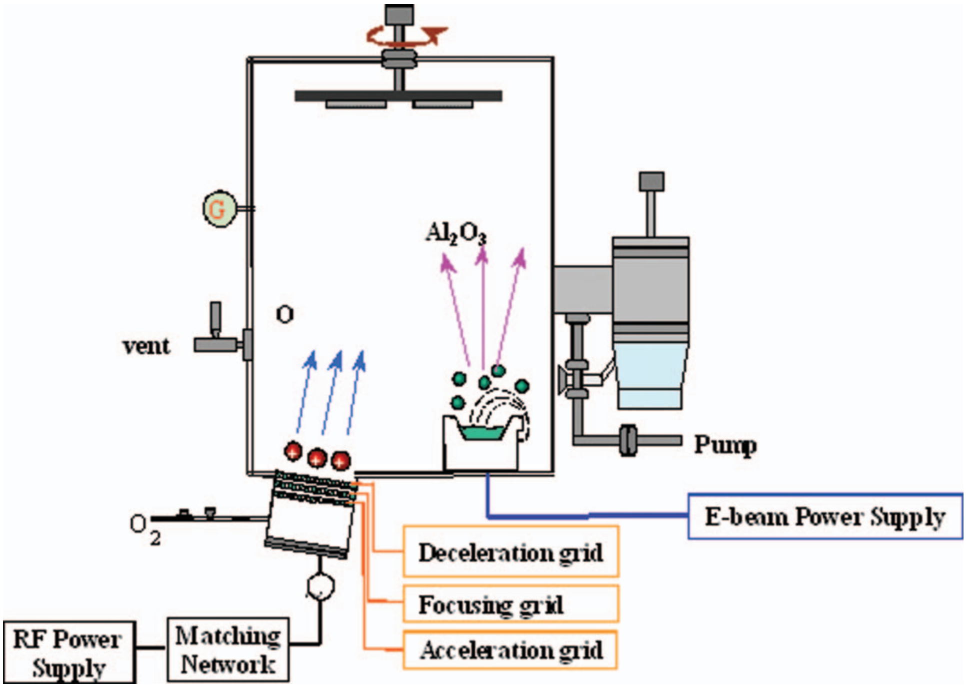

Figure 1. A schematic diagram of the e-beam evaporator with a RF ion source for NBAD process during Al_2O_3 evaporation.

a high k material suitable for the gate insulator [9, 10]. Aluminum oxide(Al_2O_3) is one of the most cost-effective and widely used materials because of its hardness and excellent dielectric properties [11, 12]. When Al_2O_3 layer is deposited by electron-beam (e-beam) evaporation, its structural and electrical characteristics are superior at a lower evaporation rate. However, the evaporation rate is very lower than other processes such as sputtering and it is necessary to improve the characteristics of Al_2O_3 layers at a higher evaporation rate.

In this study, Al_2O_3 layer was evaporated by using an oxygen neutral beam assisted deposition(NBAD). From the structural and electrical results of NBAD Al_2O_3 layers, it is expected to find the optimized process condition of the oxygen NBAD. The optimized NBAD Al_2O_3 layer was applied to the fabrication of ZnO TFT and the fabricated TFT was electrically characterized.

Experimental

Al_2O_3 pellets were evaporated with the oxygen NBAD process as shown in Figure 1. The e-beam evaporation chamber was evacuated to a base pressure of 1×10^{-6} torr and e-beam energy was maintained at 5.5~5.6 keV. The thickness monitor of e-beam evaporator was adjusted to 100 nm and the working pressure was around $1.2{\sim}1.3 \times 10^{-3}$ Torr. The evaporation rate of Al_2O_3 and the temperature of glass substrate were maintained at 0.3 Å/s and 150°C, respectively.

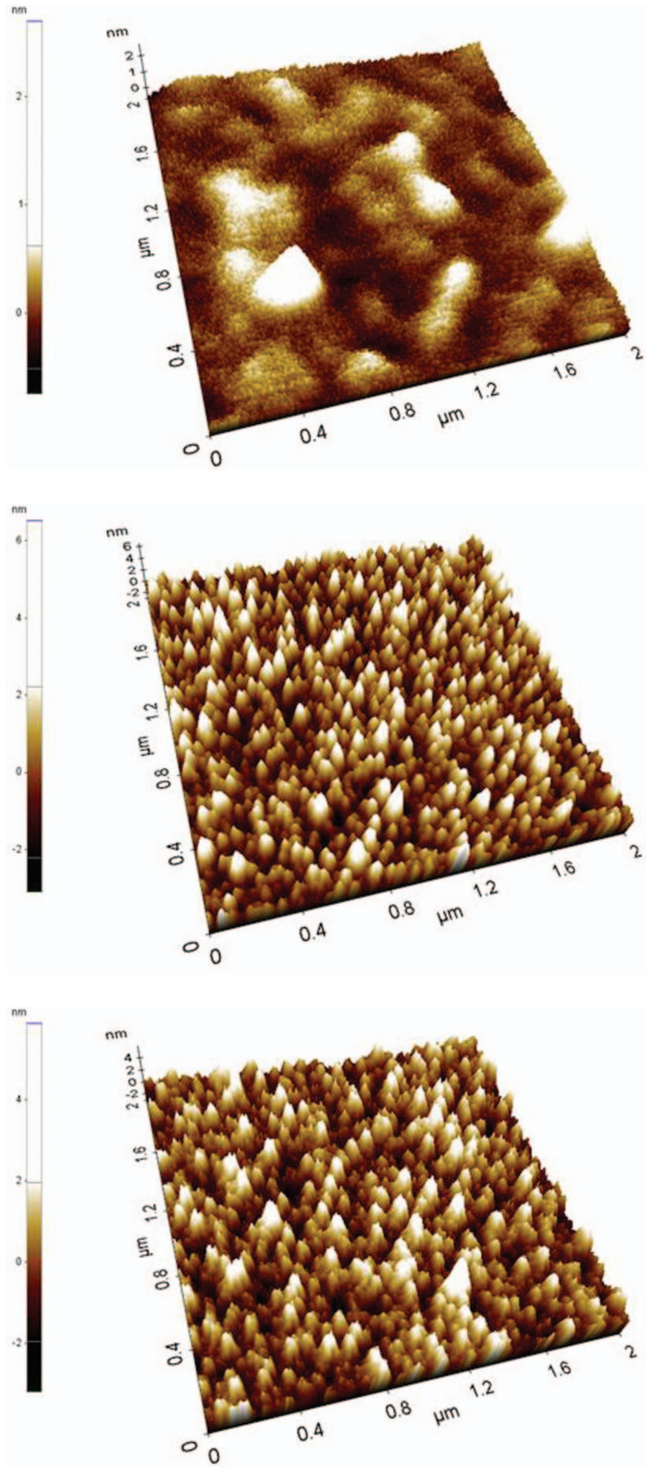

Figure 2. AFM images of Al_2O_3 layers evaporated with NBAD process. The beam energies were (a) 0 eV, (b) 200 eV, (c) 300 eV, and (d) 400 eV, respectively.

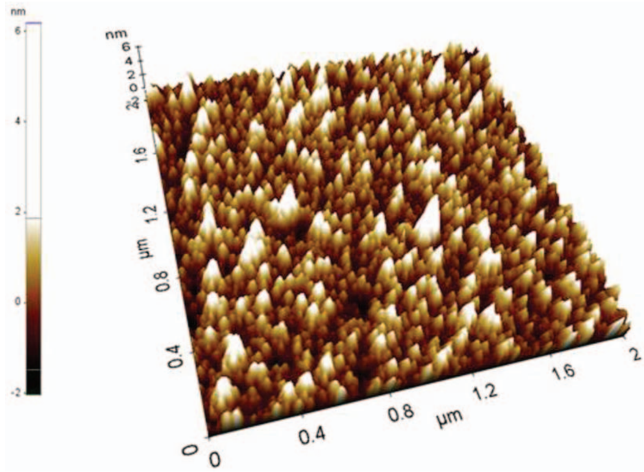

Figure 2. (Continued)

A neutral beam was generated using a RF ion source in Fig. 1 [13, 14]. Plasma was generated in condition of Ar gas and the forward RF power was maintained at 200 W. Then, Ar gas was replaced by O gas for generating O^+ ion and the beam energy was altered by the voltage to the acceleration grid of Fig. 1. The accelerated O^+ ions were neutralized with O^- ions by a resonance neutralization process and an Auger capture process [15]. The acceleration beam energies of neutralized oxygen atoms were 200, 300 and 400 eV.

A bottom gated ZnO TFT was fabricated on glass substrate. As a gate electrode, Al was thermally evaporated with a thickness of 100 nm through a shadow mask. After e-beam evaporation of Al_2O_3 gate insulator with oxygen NBAD, ZnO channel layer was deposited by atomic layer deposition(ALD) process using a shadow mask. During the ALD process

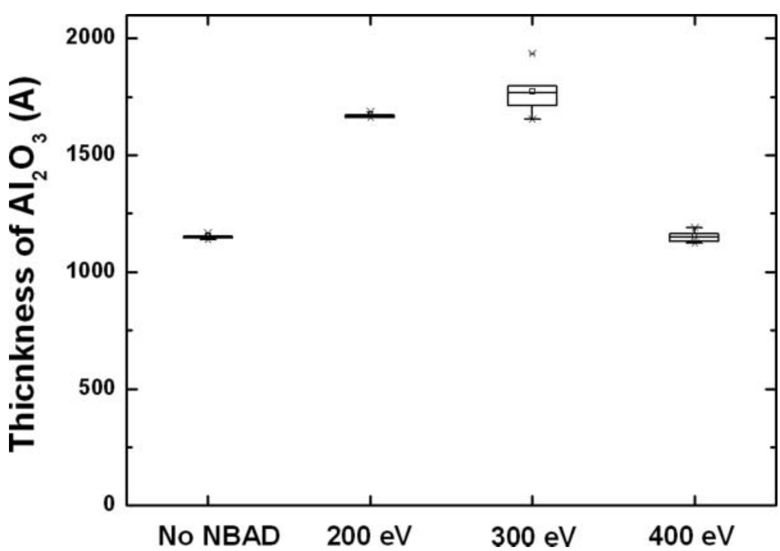

Figure 3. Thickness of the Al_2O_3 layers evaporated with NBAD process of Fig. 2.

of ZnO layer, diethylzinc(DEZn, $Zn(C_2H_5)_2$) and deionized water(H_2O) were used as a zinc precursor and an oxygen precursor, respectively. The DEZn and H_2O were maintained at room temperature and the temperature of glass substrate was 120°C. As a formation of source and drain on 50 nm ZnO active layer, Al was thermally evaporated with a thickness of 60 nm through a shadow mask. The width and length of fabricated TFT were designed as 300 μm and 100 μm, respectively. For the electrical characterization of the fabricated ZnO TFT, a probe station and Agilent 4156C were used in the measurement.

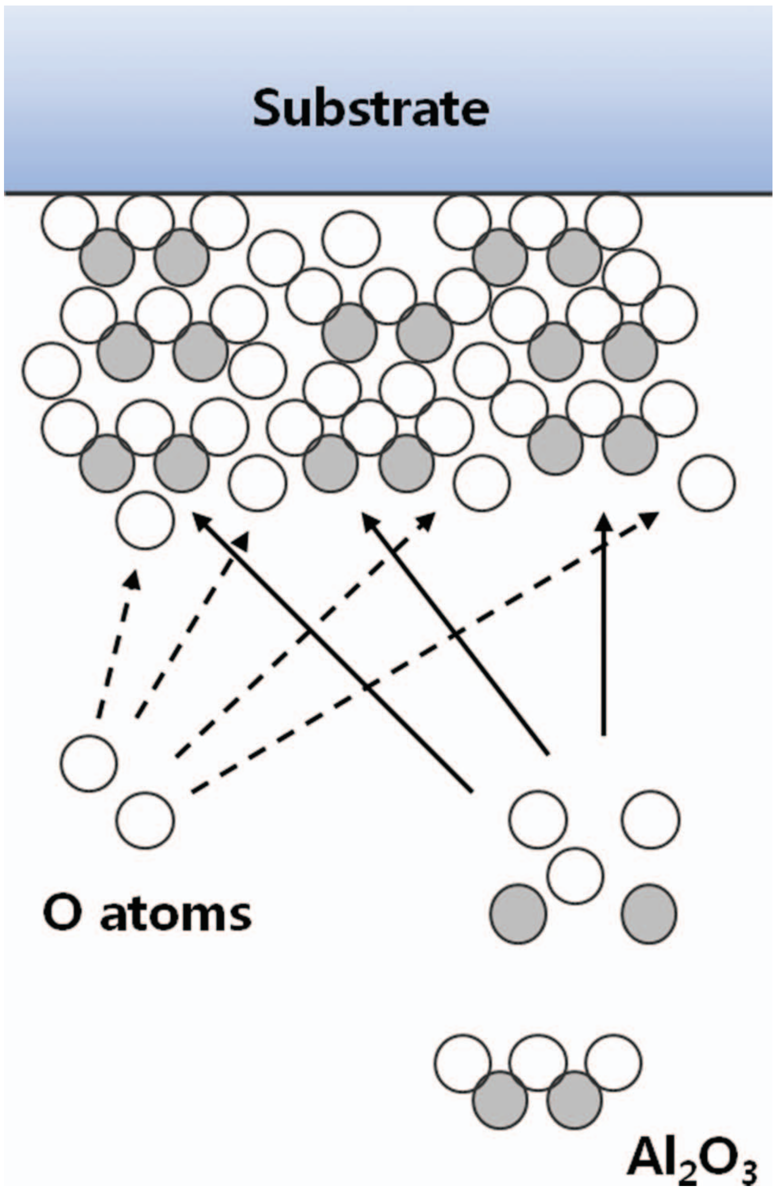

Figure 4. A schematic diagram of the oxygen atom NBAD process (a) for an acceleration beam energy of 200∼300 eV and (b) 400 eV.

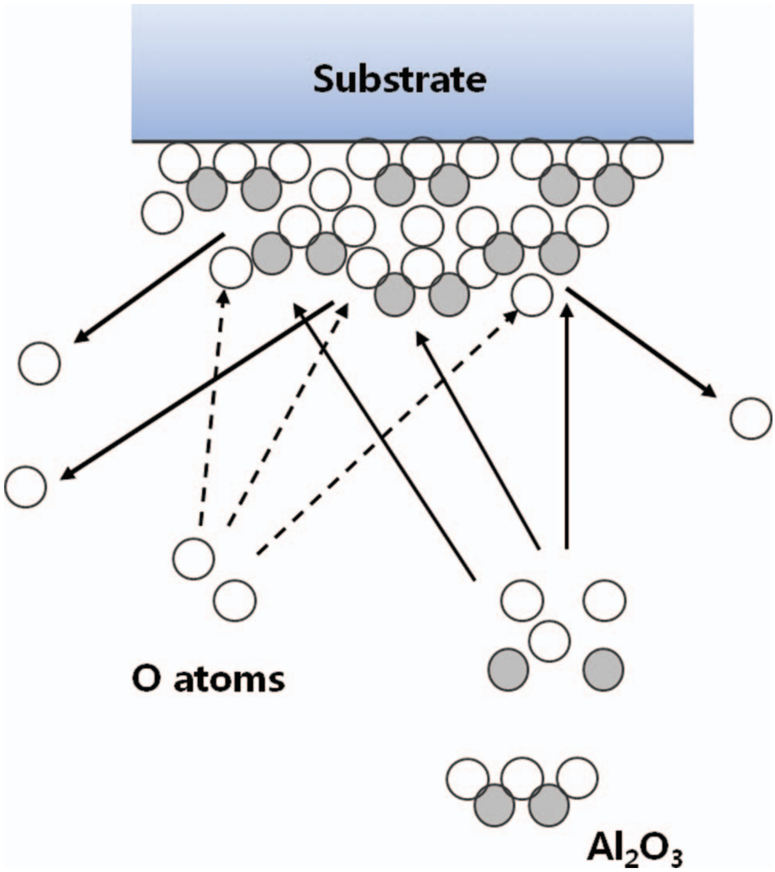

Figure 4. (Continued)

Except for the ZnO channel layer in the fabrication of ZnO TFT, a metal-insulator-metal (MIM) capacitor was fabricated to measure the capacitance of Al_2O_3 layers. The capacitance-frequency (C-f) was measured using HP-4192 impedance analyzer in an ambient condition.

Results and Discussion

Figure 2 shows the atomic force microscope(AFM) images of the Al_2O_3 layers fabricated with oxygen NBAD. Figure 2(a) shows the Al_2O_3 layer without any oxygen NBAD, and Fig. 2(b), (c) and (d) shows the Al_2O_3 layer with oxygen NBAD at acceleration energies of 200 eV, 300 eV and 400 eV, respectively. Figure 2(a) shows that the grain size of Al_2O_3 layer is not uniform. On the other hand, a lot of fine needle-shaped grains uniformly appear on the Al_2O_3 layer when the NBAD process was applied as shown in Fig. 2(b), (c) and (d).

Figure 3 shows the thickness of Al_2O_3 layer with oxygen NBAD process. When the thickness monitor was adjusted to 100 nm, the thickness of Al_2O_3 layer without the oxygen NBAD process was about 115.2 nm. When the acceleration energies were 200 eV and 300 eV, the thicknesses of Al_2O_3 layer were about 167 nm and 177.2 nm, respectively. It is thought that oxygen atoms were additionally deposited on Al_2O_3 layer through NBAD

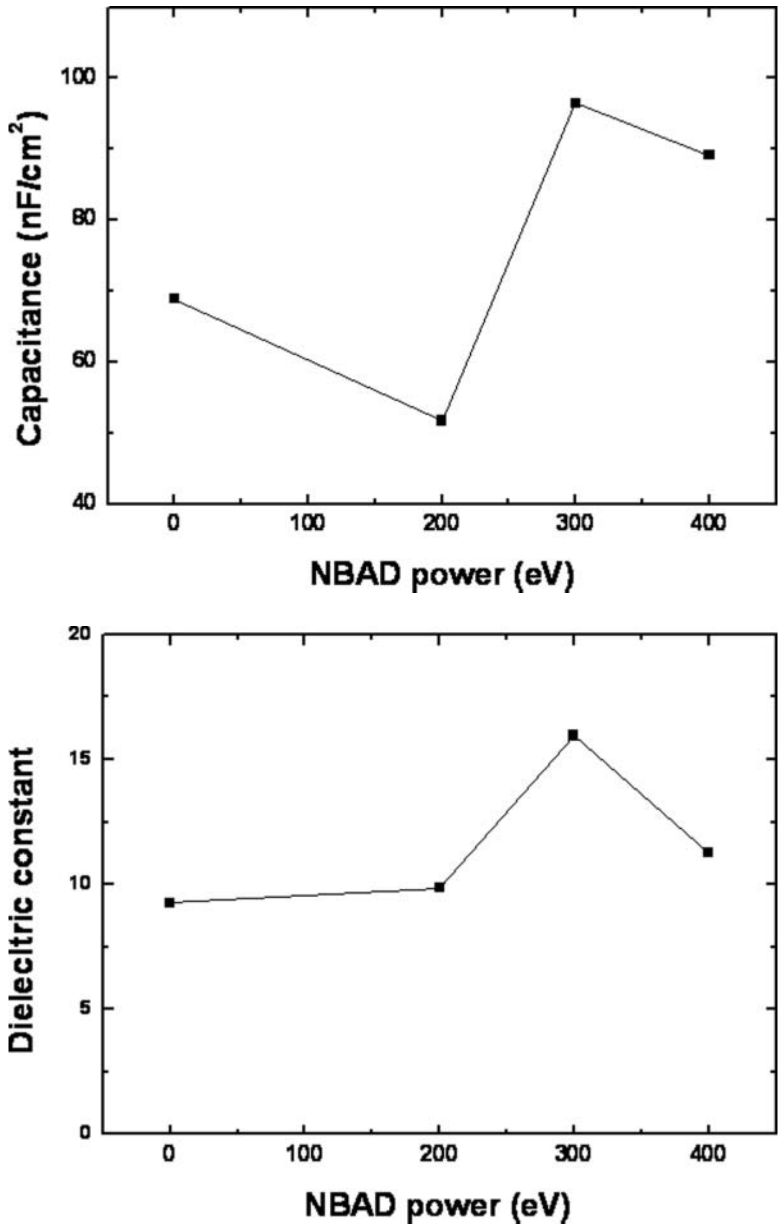

Figure 5. (a) Capacitances of the Al_2O_3 layers evaporated with NBAD process of Fig. 2 (b) Dielectric constant of the Al_2O_3 layers calculated from (a).

process, as shown in Fig. 4(a). The thickness of Al_2O_3 layer was decreased to about 115.1 nm at 400 eV, and the oxygen atoms are expected to be simultaneously deposited and etched on the surface of Al_2O_3 layer, as shown in Fig. 4(b), because the acceleration energy was higher for the additional deposition of oxygen atoms.

For measuring the capacitance of Al_2O_3 layer, Al(100 nm)/Al_2O_3/Al(100 nm) capacitors with a structure of metal-insulator-metal (MIM) were fabricated. Figure 5(a) shows the capacitance of the Al_2O_3 layers of Fig. 2. The capacitors were measured after annealing for

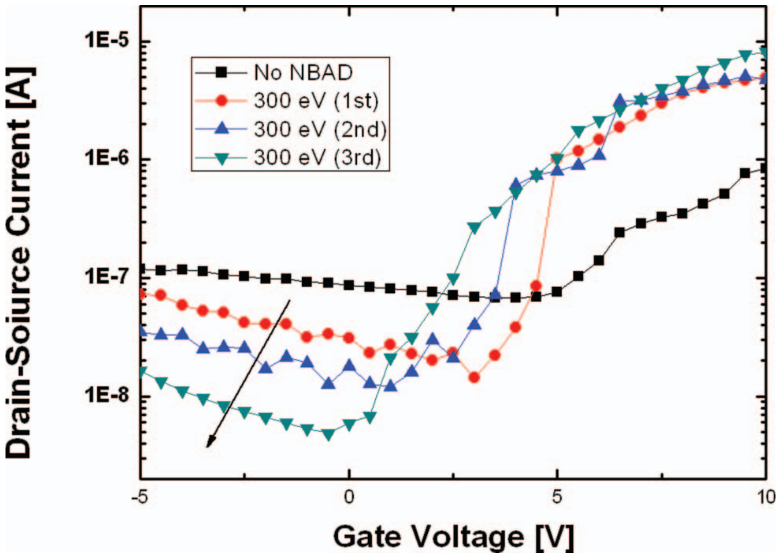

Figure 6. Transfer characteristics of fabricated ZnO-TFT with NBAD Al_2O_3 gate insulator.

2 hrs at 150 °C under an ambient condition. When the acceleration energy was 200 eV, the capacitance decreased as a result of the higher thickness of the Al_2O_3. However, in spite of the higher thickness of Al_2O_3, the capacitance increased when the acceleration energy was 300 eV. The Al_2O_3 layer with 400 eV NBAD also showed higher capacitance. Considering the thickness of Al_2O_3 layers, the dielectric constants were calculated, as shown in Fig. 5(b). From the results, the highest dielectric constant was obtained at 300 eV and the NBAD process condition was applied to the fabrication of gate insulator of ZnO TFT.

Figure 6 shows the transfer characteristics of the fabricated ZnO TFT with oxygen NBAD process at an acceleration energy of 300 eV. From the comparison of the electrical results, it is possible to conclude that a ZnO TFT with an oxygen NBAD Al_2O_3 gate insulator has the lower leakage current of 10^{-8} A, the higher on-off ratio of 1.67×10^3 and the lower subthreshold swing of 0.463. Although the NBAD Al_2O_3 has a higher thickness, it is possible to conclude that the ZnO TFT shows improvements in electrical characteristics with the oxygen NBAD process.

Conclusion

Oxygen atom NBAD was applied to the deposition of Al_2O_3 gate insulator in the fabrication of ZnO TFT. For the various neutral beam energies, the thickness of Al_2O_3 layer increased as a result of the addition of the oxygen atoms during Al_2O_3 e-beam evaporation. Through the C-f measurement of the MIM capacitors fabricated with the Al_2O_3 layers, it was possible to obtain the higher k insulator at the acceleration neutral beam energy of 300 eV. ZnO TFT was fabricated with the optimized O NBAD process condition and showed better transfer characteristics, such as a lower voltage operation and a lower leakage current, than those without any NBAD process. Further investigation and analysis are needed to confirm the stability of the fabricated ZnO TFT.

Acknowledgement

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