Characteristics of ZnO Thin Films by Means of ALD for the Application of Transparent TFT

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Abstract

Zinc oxide thin films were grown at the temperature of 100°C and 150°C by means of plasma enhanced atomic layer deposition (PEALD) and conventional atomic layer deposition for applying to the transparent thin film transistor (TTFT). The growth rate of 1.9Å/cycle with oxygen plasma is similar to that of film grown with water. While the sheet resistivity of ZnO grown with water is 1233 ohm/sq, that of film grown with oxygen plasma was too high to measure with 4 point probe and hall measurement system. The resistivity of the films grown with oxygen plasma estimated to be 10^6 times larger than that of the films grown with water. The difference of electrical property between two films was caused by the O/Zn atomic ratio. We fabricated ZnO-TFT by means of ALD for the first time and the ZnO channel fabricated with water showed saturation mobility of 0.398$cm^2/V \cdot s$ with bottom gate configuration.

1. Introduction

Wurtzite structured wide band gap ZnO thin films have been investigated extensively because of their interesting electrical, optical and piezoelectric properties. They have played an important role in various applications such as transparent conducting electrodes of solar cells and displays [1], surface acoustic wave devices [2], varistors [3], and gas sensors [4]. Recently, their characteristic of wide band gap has intrigued researchers with respect to their application for transparent thin film transistor (TTFT), for substituting amorphous or poly crystalline TFT with transparent ZnO TFT could increase the aperture ratio of pixels [5]. In addition to the transparency, the magnitude of the electron channel mobility of ZnO based TTFT also attracted much attention since it results in higher drive currents and faster device operating speed [6].

Undoped ZnO films behave as n-type due to the defects such as zinc interstitials or oxygen vacancies. Hall effect mobility of polycrystalline ZnO films ranges from 10-50 $cm^2/V \cdot s$ according to the fabrication method and temperature [7]. Especially low temperature fabrication of ZnO made it have good compatibility with various substrates including the plastic.

The devices of ZnO TFT, however, usually exhibit "normally-on characteristic because these materials have excess carriers as large as 10^{17} cm^{-3} in as deposited states. Therefore, one of the main issues in ZnO TFT fabrication is controlling the carrier concentration in the channel.

Recently there have been several reports on the fabrication of ZnO TFT by rf magnetron sputtering [8], chemical solution deposition [9] and pulsed laser deposition [10]. Here, we report the properties of ZnO thin films grown by means of plasma enhanced atomic layer deposition (PEALD) and conventional atomic layer deposition (ALD) at the temperature of 100 and 150°C. We have investigated characteristics of TFT including ZnO films deposited by ALD for the first time.

2. Experiments

ZnO films were deposited on the alumina coated p-type Si(100) substrates at the substrate temperature of 100 and 150°C using diethylzinc (DEZ) as Zn precursor in both deposition methods and oxygen plasma in PEALD and water in ALD as oxygen precursor using shower head typed reactor (Genitech MP-1000). The reactor pressure was 3 Torr. The flow rate of a purge Ar gas was 140 sccm during the deposition for both techniques. In ALD method, the precursors were alternatively injected into the reactor using Ar as a carrier gas with flow rate of 120 sccm. The pulsing times were 0.5 second for the DEZ, 1.5 second for H_2O, and 2 second for Ar purge. In PEALD method, one PEALD cycle of ZnO consisted of the sequential injection of DEZ (0.5 second), Ar (2 second), O_2 gas (60 sccm, 0.5 second), and Ar (0.5 second). Radio frequency pulse was applied during the injection of O_2 gas for 0.5 second with the rf power of 100W. The crystallographic orientation of the ZnO films was determined by an x-ray diffractometer (XRD) with CuK radiation, and the morphologies of the films were observed using a scanning electron microscope (SEM) and an atomic force microscope (AFM). The atomic compositions (O/Zn ratio) of the films were qualitatively investigated by an Auger electron spectroscopy (AES) depth profile using an electron beam energy of 5 keV. Depth profiles of the films were examined by secondary ion mass spectrometry (SIMS). The carrier-type, concentrations and electron mobility were measured using a Hall measurement with the Van der Pauw electrode configuration under a magnetic field of 0.5 T at room temperature.

For the fabrication of TFT, 500-nm thick thermal oxide (SiO_2) coated Si was used for the substrate. After patterning of sputtered

Cr by lithography, ALD-deposited alumina was deposited with the thickness of 150nm at the temperature of 250℃, followed by gate metal pad opening by wet etching of alumina. ALD-deposited ZnO:Al [11] was used as source and drain electrodes and patterned by lithography followed by wet etching. The ZnO semiconductor films were deposited by means of PEALD or ALD by 450 repeated cycles and patterned using lift-off method. Figure 1 shows the structure of TFT.

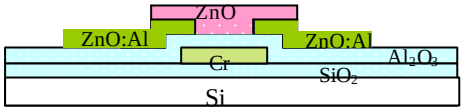

Figure 1. The cross sectional view of the ZnO–TFT.

3. Results and Discussion

We carried out the ZnO film deposition at the temperature below 150°C with the consideration of applying to the plastic substrate. Table 1 shows the variations in the saturated growth rate as a function of the deposition temperature and deposition method. In both deposition methods, the growth rate increased as the temperature increases. The growth rate of 1.9Å/cycle for ZnO films grown using oxygen plasma is lower to that using water at 150°C.

Table 1. the growth rate of ZnO films as a function of temperature and deposition method.

Growth condition	Growth rate (Å/cycle)
100°C w water	1.7
150°C w water	2.1
100°C w O_2 plasma	1.7
150°C w O_2 plasma	1.9

Fig. 2 shows the X-ray diffraction patterns of ZnO thin films grown by PEALD and ALD at different temperature with 350 repeated cycles. The ZnO thin films show more or less a random orientation with (100) and (200) direction. The films grown at 100°C show similar XRD patterns but the PEALD deposited ZnO film rather becomes (200) orientation dominant as temperature increases.

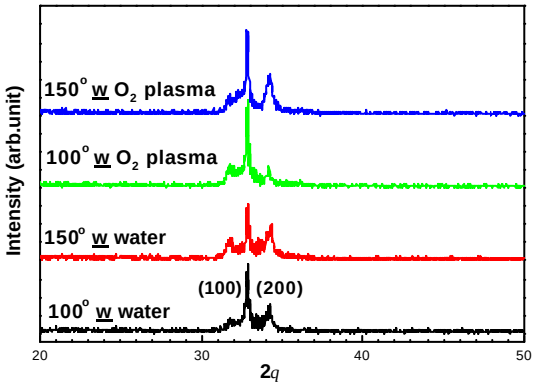

Figure 2. XRD of ZnO films deposited by PEALD and ALD.

This behavior could be confirmed by the surface morphology. The SEM images of ZnO films of (a), (b) and (c) in Figure 3 show early wedge-like shaped crystallites. On the other hand, the increased process temperature in PEALD resulted in a ZnO film consisting of columnar crystallites.

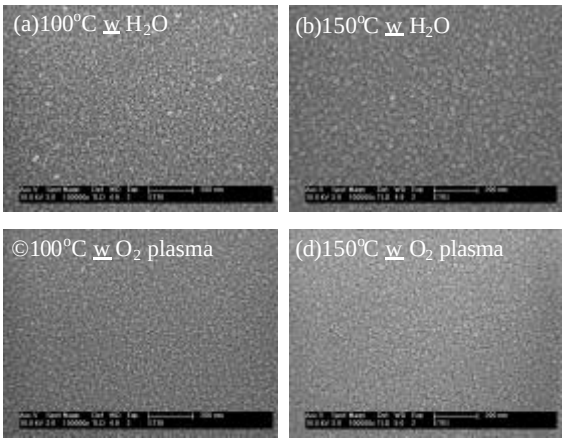

Figure 3. SEM image of ZnO thin films deposited by PEALD and ALD.

Fig.4 shows atomic force micrographs (AFM) of ZnO films grown by different oxygen precursor. The RMS roughness of ZnO films grown at 100°C by oxygen plasma was 8.85Å and peak-to valley of 93.71 Å while that of ZnO film grown by water was 15.47 Å and 144.16 Å respectively. When the temperature increases to 150°C, the RMS roughness of ZnO by plasma decrease as well as peak-to-valley to 8.68 Å and 85.19 Å, respectively, while those for ZnO by water increased to 16.28 Å and 194.49 Å.

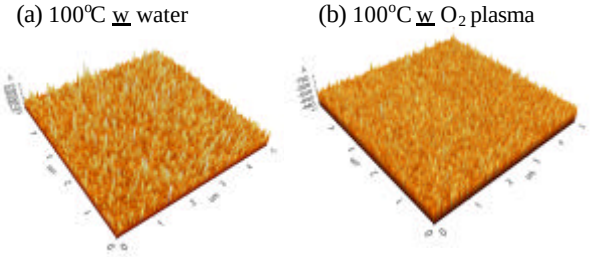

Figure 4. AFM images of ZnO films grown with water and oxygen plasma at 100°C.

The profound difference between ZnO films grown by oxygen plasma and water lies in the electrical properties. While the sheet resistivity of ZnO grown with water at 150°C is 1233 ohm/sq, that of film grown with oxygen plasma was too high to measure with 4 point probe and hall measurement system. The resistivity of the films grown with oxygen plasma estimated to be 10^6 times larger than that of the films grown with H_2O. The difference of electrical

property between two films seemed to be caused by the O/Zn atomic ratio. Fig. 5 shows the O/Zn atomic ratio of ZnO films measured by AES. The film grown by oxygen plasma has higher O/Zn ratio, which results in decreasing carrier density associated with free Zn ion or oxygen vacancy. Since the hydrogen amount can also affect the carrier concentration of ZnO films we investigated relative H amount with SIMS. Unexpectedly, the film grown with water has lower hydrogen amount than that of film with oxygen plasma. This might show that the main factor for the electrical properties of ZnO film comes from the stoichiometry of ZnO.

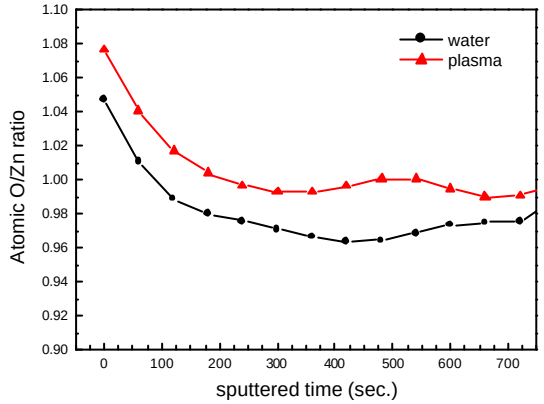

Figure 5. The depth profiles of atomic O/Zn ratio for the films grown with water and oxygen plasma.

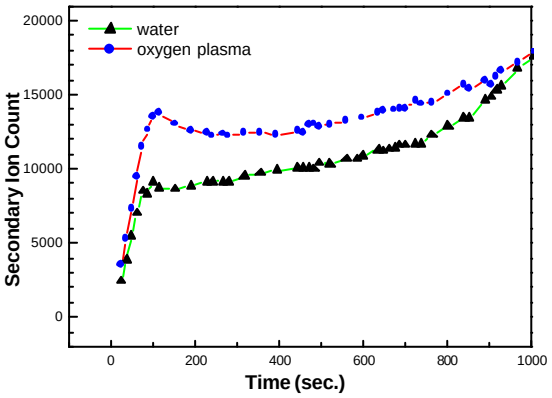

Figure 6. The depth profile of secondary ion count of Hydrogen atom of ZnO films grown with water and oxygen plasma.

The reduction of background electron concentration for the film grown by PEALD led us to evaluate the performance of TFT. We used bottom gate configuration with the W/L ratio of 5 and 10. Unexpectively, ZnO channels with high resistivity (grown by oxygen plasma) and too low resistivity (grown with water at 150°C) did not show the TFT behavior. On the other hand, device with ZnO grown with water at 100°C showed TFT characteristic. The figure 7 (a) shows the source-to-drain current (ID) as a function of the gate voltage (VG). As well established, ZnO-TFT has an n-channel and electrons are generated by the positive VG.

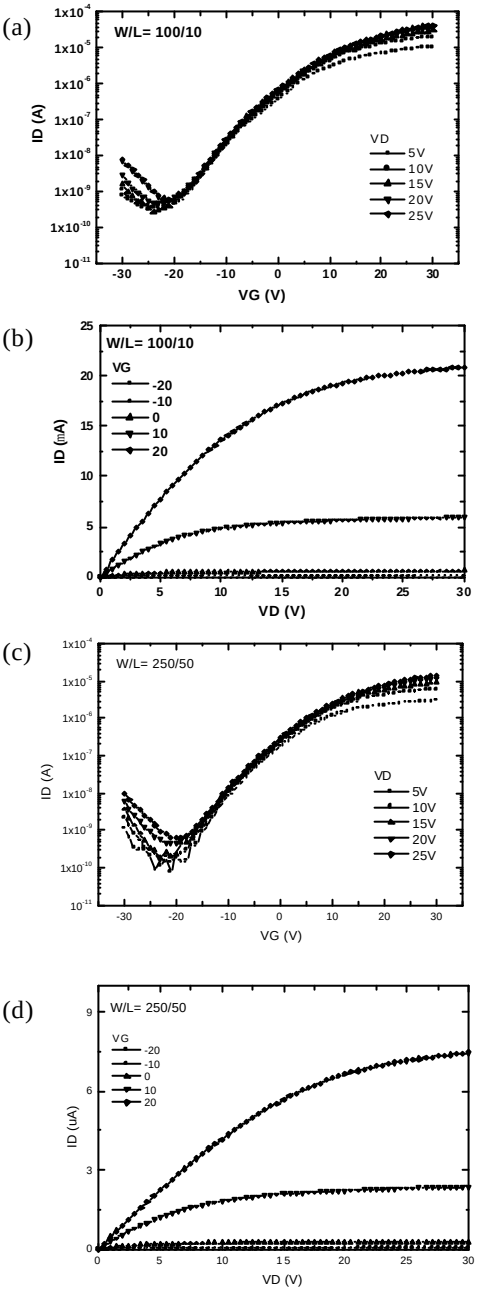

Figure 7. ZnO-TFT characteristics including ZnO film grown with water at 100°C as active layer (a) Transfer characteristics of ZnO-TFT with a W/L=100/10 for V_{DS} varying from 5 to 25V. (b) Output characteristics for a ZnO-TFT with a W/L=100/10 for V_{GS} varying from -20 to 20V (c) Transfer characteristics of ZnO-TFT with a W/L=250/50 for V_{DS} varying from 5 to 25V. (b) Output characteristics for a ZnO-TFT with a W/L=250/50 for V_{GS} varying from -20 to 20V.

The I_D of 20μA is obtained at V_{GS}=20V and V_{DS}=25V with a W/L=10 TFT. The saturation mobility and the threshold voltage are 0.398 $cm^2/V's$ and -2 V, respectively. For the TFT with W/L=5, the saturation mobility and the threshold voltage are 0.117 $cm^2/V's$ and -4 V, respectively.

Although the ZnO channel grown by oxygen plasma did not exhibited TFT action so far, we believe that optimization of deposition process and improvement of interface could show good ZnO-TFT behavior. In addition, the reduction of carrier concentration of ZnO film grown by water could improve the ZnO-TFT characteristics.

4. Conclusion

Zinc oxide thin films were grown at the temperature of 100°C and 150°C by means of plasma enhanced atomic layer deposition (PEALD) and conventional atomic layer deposition for applying to the transparent thin film transistor (TTFT) for the first time. The ZnO films grown with oxygen plasma showed similar characteristics with those of ZnO films grown with water. The electrical properties, however, are quite different and it seemed to be caused by the O/Zn atomic ratio. We fabricated ZnO-TFT by means of ALD for the first time and the ZnO channel fabricated with water showed saturation mobility of 0.398 $cm^2/V's$.

5. Acknowledgements

The Korea ministry of Information and Communications financially supported the accomplishment of present work.

6. References

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