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ZnO thin film fabricated by plasma assisted atomic layer deposition

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1. Introduction

The most commonly used materials for the active channel layer in thin film transistors (TFTs) have been amorphous silicon (a-Si:H) and polycrystalline silicon (poly-Si). However, there are a number of drawbacks for these materials, such as their high-temperature process needed for their production or limited application to large substrates.[1] In recent years, the application of zinc oxide (ZnO) thin film as an active channel layer in TFT has become of great interest owing to their specific characteristics. ZnO is transparent to visible wavelengths because of its wide band gap (~3.37eV), and the ability to fabricate high-quality films over large areas at low temperature suggests the compatibility of these films with plastic or flexible substrates [2-4]. It has been demonstrated that the field-effect mobility of ZnO TFTs is higher than that of a-Si:H TFTs. However, there is still critical issue that has to be solved. Reliability for electrical stress is serious problem in their mass production.

An atomic layer deposition (ALD) method is one of the thin film preparation technologies, which attracts much attention in LSI industry. In this method, thin film is deposited with alternating exposures of a source gas and an oxidant. The film deposited by ALD has additional features of accurate thickness control, high conformity, and uniformity over large areas, because of the alternating gas supply [5]. Furthermore, it is reported that the TFTs fabricated by ALD as the channel layer achieved high mobility. However, undoped ZnO films grown by ALD have a high carrier concentration. It has been well known that the high carrier concentration of undoped ZnO films resulted from defects such as oxygen vacancies.

In this study, we prepared ZnO thin films using plasma assisted ALD (PA-ALD) to control the residual carrier concentration in the films. The effects of preparation condition on the electrical properties were evaluated, and the effect of plasma condition on the quality of ZnO film was also investigated.

2. Experiment

2.1 ZnO film deposition

We prepared ZnO thin films at 100 °C on Si substrate by ALD using two different oxidizers, water (H_2O-ALD) and plasma oxygen (PA-ALD). In the series of deposition, we used Diethyl-zinc (DEZ) as a metal precursor. The charts of the time sequence of PA-ALD are shown in Fig. 1. The plasma was triggered after oxygen gas pressure became stable. The time for plasma (plasma time) was 0.1~1.5 seconds. The thickness and the refractive index were measured by spectroscopic ellipsometer. Further, depth profiles of the films were examined by secondary ion mass spectrometry (SIMS).

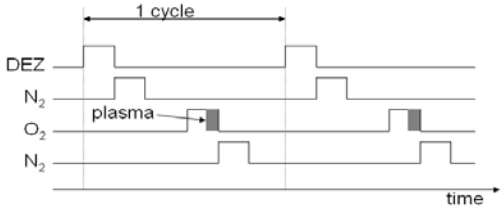

Fig. 1 Charts of the time sequence of PA-ALD gas supplying.

2.2 TFT preperation

A schematic structure of the bottom-gate-type ZnO TFTs fabricated in this study is shown in Fig. 2. 50-nm-thick SiO_2 gate insulator was prepared by thermal oxidation. 30-nm-thick ZnO thin films were deposited on p-type Si (100) substrates at 100 °C. Ti metal was deposited and patterned by a lift-off technique to serve as the source/drain (S/D) electrodes. The Si substrate was used as the gate electrode.

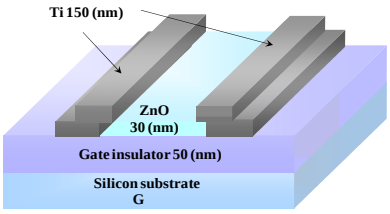

Fig. 2. Bottom-gate type TFT

The fabricated TFTs were annealed at 300 °C for 1 h in O_2 (O_2 = 20 %, N_2 = 80 %) ambient. [6] The electrical properties were measured using a semiconductor parameter analyser (Agilent 4156C).

The channel length (L) and width (W) used in this study were 10 and 20 µm, respectively. The on-current (I_{d_on}) was defined as the drain current measured with gate voltage (V_g)= 30V at a drain voltage (V_d)= 5 V. The field effect mobility was defined by the maximum value calculated using the conventional measurement of I_d.

3. Result and discussion

3.1 TFT characteristics

3.1.1 The effect of oxidizers

The transfer characteristics of the fabricated TFTs were measured in a single-sweep mode of the gate voltage with V_d = 5 V. The variation of the transfer characteristics

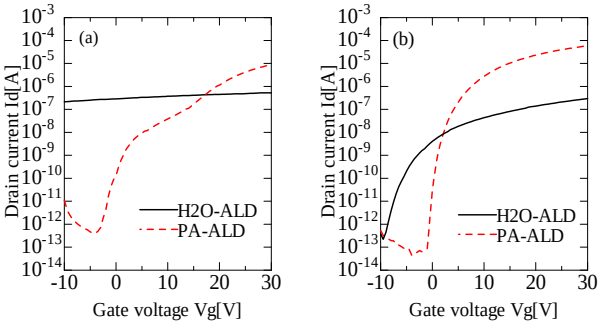

Fig. 3 Transfer characteristics of ZnO TFTs (a) non-annealed and (b) annealed at 300℃. (V_d=5 V)

of the TFTs non-annealed and annealed at 300 ℃ in O_2 ambient is shown in Figs. 3 (a) and (b), respectively. The TFTs with H_2O-ALD ZnO film did not exhibit the switching characteristics before the annealing as shown in Fig. 3(a). After the annealing above 300 ℃, the switching characteristics were obtained as shown in Fig. 3(b). However, insufficient TFT device characteristics such as low I_{d_on} and low mobility were observed. On the other hand, the TFTs with PA-ALD ZnO films exhibited the TFT behaviours even in the case of without annealing as shown in Fig. 3(a). Furthermore, excellent property was obtained after annealing as shown in Fig.3 (b). For the ZnO TFTs annealed at 300 ℃ in O_2 ambient, the on/off current ratio and the threshold voltage were 1×10^9 and 1.0 V, respectively.

3.1.2 The effect of plasma time

The variation of the transfer characteristics and $I_{d\ on}$ as a function of the plasma time are shown in Figs. 4(a) and (b).

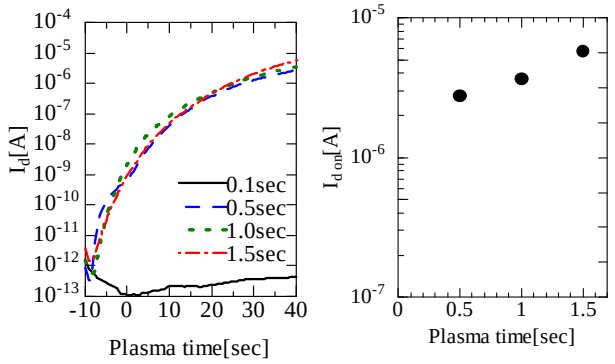

Fig. 4 (a) I_d-V_g characteristics, and (b) $I_{d\ on}$ of ZnO-TFTs as a function of plasma time. (V_d=5 V)

The switching characteristic of ZnO TFT with 0.1second plasma time was not obtained. However, $I_{d\ on}$ increased with the increasing of the plasma time. To investigate the influence of plasma time, we evaluated the refractive index and impurity profile by SIMS.

3.2 ZnO film properties

The changes of the refractive index and growth rate as a function of plasma time are shown in Fig. 5. Both of the refractive index and the growth rate are increased with

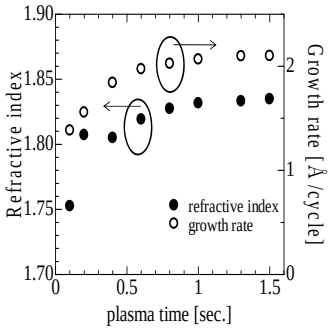

Fig. 5 The refractive index and growth rate of ZnO films

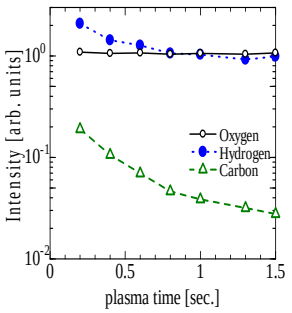

Fig. 6 Depth profiles of the ZnO films

the increasing plasma time. The growth rate of the film prepared with 0.1 second and over 1.0 second plasma time were approximately 1.4 and 2.1 Å/cycle, respectively.

The thickness of an atomic layer of ZnO is 2.2~2.5Å. Further, characteristic value of the refractive index of ZnO is 1.9~2.0, however, that of the prepared ZnO film with 0.1 second plasma time is lower than 1.8. These results suggest that the oxidation of the ZnO films prepared with plasma time shorter than 1.0 second is insufficient.

Figure 6 shows the SIMS profile as a function of plasma time. Hydrogen and carbon concentrations were decreased with increase in plasma time as shown in this figure. It is considered that the residual hydrogen and carbon are caused by insufficient oxidation.

4. Summary

We prepared ZnO thin films deposited by atomic layer deposition using two different oxidizers, water and oxygen radical as application to an active channel layer in TFT. The TFTs with PA-ALD ZnO film exhibited excellent properties. Furthermore, The dependences of their electrical and chemical properties on the plasma time were measured. The ZnO TFT with 0.1 second plasma time did not exhibit the switching characteristics. The TFTs with over 0.5 second plasma time exhibit the TFT behaviors, and the $I_{d\ on}$ increased with the plasma time. Further, the refractive index and growth rate of the ZnO films were increased, and the hydrogen and carbon in the films were decreased with the plasma time. Compared the analysis of ZnO films with the electrical properties, the residual carbon and hydrogen in the ZnO films caused by insufficiency of oxidation degrade the TFT properties.

Acknowledgement

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