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Low Temperature Processed Zinc Oxide Thin Film Transistors 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. While TFTs with poly-Si channel layer have high mobility, the high temperature process is needed for their fabrication. In addition, poly-Si is difficult to fabricate over large areas. These issues make them incompatible with flexible substrate. In the case of a-Si:H, which is readily used in large area flat panel displays, there are some limitations, such as a low channel mobility (~1 cm^2/Vs) and the issues of degradation.[1] In recent years, the application of zinc oxide (ZnO) thin films as an active channel layer in TFTs 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. It has been demonstrated that the channel mobility of ZnO TFTs is higher than that of a-Si:H TFTs.[2] However, there are still issues that have to be solved such as high temperature annealing is employed in TFT fabrication process.

An atomic layer deposition (ALD) method is one of the thin film preparation technologies, which attracts much attention in LSI industry. The ALD thin film is deposited with alternating exposures of a source gas and an oxidant. The ALD method keeps the fabrication temperature of ZnO TFTs low. We have reported that the fabrication of ZnO TFTs at low temperature is possible by using plasma assisted ALD (PA-ALD).[3] The ALD film has additional features of accurate thickness control, high conformity, and uniformity over large areas, because of the alternating gas supply. [4]

In this study, we prepared ZnO thin films for channel layer and Al_2O_3 for gate insulator using PA-ALD, and fabricated the bottom-gate type TFTs. It can be expected that the improvement of the ZnO film quality with the Al_2O_3 films at low temperature because of continuous deposition by ALD. We investigated the effect of preparation condition of ZnO and Al_2O_3 films on the electrical properties to improve the ZnO TFT performance.

2. Experimental Detail

2.1 Film preparation

We prepared ZnO and Al_2O_3 thin films at 100 or 300°C on p-type Si (100) substrates by PA-ALD. The charts of the time sequence in PA-ALD are shown in Fig. 1. The plasma was triggered after oxygen gas pressure became stable. The Al_2O_3 films were deposited with two different oxidizers, O_3 for the conventional ALD (O_3-ALD) and oxygen radical for PA-ALD. For the dependence of the preparation conditions for ZnO and Al2O3 films, the plasma ignition time for the deposition of each layer was 0.1-1.0 s. For the TFTs with Al_2O_3 gate insulator, the plasma ignition time was 1.0 second for the ZnO film deposition.[5]

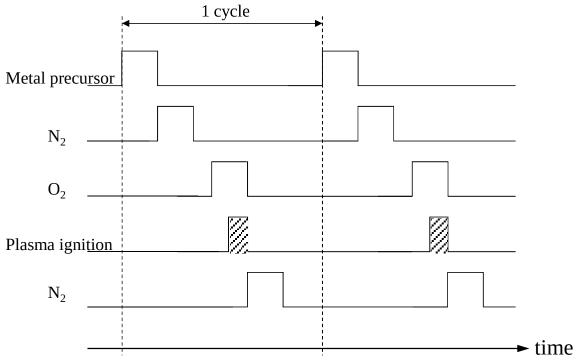

Fig. 1 Charts of the time sequence of PA-ALD gas supplying.

2.2 TFT fabrication

A schematic structure of the bottom-gate-type ZnO TFTs fabricated in this study is shown in Fig. 2. Fifty nanometers thick SiO_2 gate insulator was prepared by thermal oxidation, and Al_2O_3 gate insulator was deposited by ALD. Thirty nanometers thick ZnO thin films were deposited on Si substrates with SiO_2 or Al_2O_3 at 100 or 300°C. Ti metal was deposited and patterned by a lift-off technique to serve as the source/drain electrodes. The Si

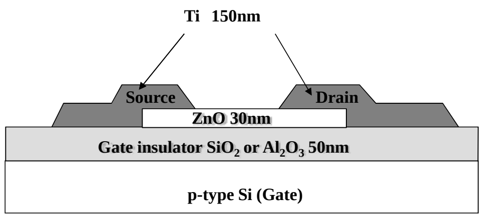

Fig. 2. Schematics of a bottom-gate type TFT

substrate was used as the gate electrode.

The channel length and width 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) = 20 V at a drain voltage (V_d) = 5 V. The field effect mobility (μ) was calculated from the maximum value of the transconductance in the measured voltage range.

3. Results and discussion

3.1 The effect of the plasma ignition time on ZnO film deposition

We deposited a ZnO channel layer at 100°C on Si substrate with an SiO_2 gate insulator. Figure 3(a) shows the variation with the plasma ignition time in the transfer characteristics of the 300°C-annealed ZnO TFTs with SiO_2 gate insulator. The I_{d_on} of the TFTs annealed at 300°C as a function of the plasma ignition time is shown in Fig. 3(b). Both of the TFTs with 0.1 and 1.0 s plasma ignition time exhibited a switching characteristic without annealing. For the 300°C-annealed ZnO TFTs, the TFTs with 0.1 s plasma ignition time exhibited poor TFT device characteristics, such as low I_{d_on} and low μ (< 0.1 $cm^2V^{-1}s^{-1}$). On the other hand, the ZnO TFTs prepared with 1.0 s plasma ignition time exhibited higher TFT characteristics than that of 0.1 s plasma ignition time. The on/off current ratio was > 1×10^8, the μ was 3.2 $cm^2V^{-1}s^{-1}$, and the subthreshold swing was 0.3 V/decade. From the measurement of the electrical properties of the fabricated TFTs, the TFT device performances were improved with increasing plasma ignition time, that is, high μ and high on/off current ratio were observed.

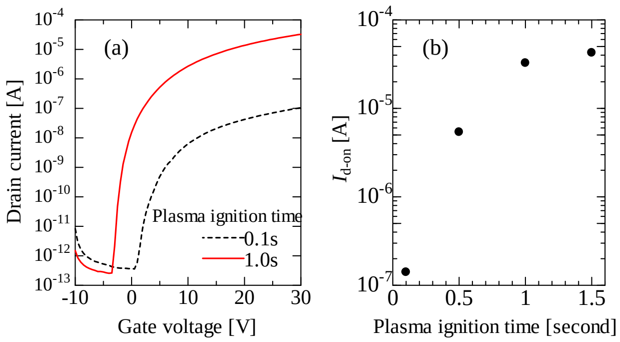

Fig. 3 (a) Transfer characteristics of the ZnO TFTs annealed at 300°C, (b) dependence of I_{d_on} on plasma ignition time.

3.2 The effect of the plasma ignition time on Al_2O_3 film deposition

We fabricated ZnO TFTs with an Al_2O_3 gate insulator. The Al_2O_3 gate insulator was deposited at 100°C, and the ZnO channel layer was deposited at 300°C. Figure 4 shows the variation of transfer characteristics of the TFTs with the plasma ignition time.

The V_{th} of the TFT with Al_2O_3 gate insulator deposited by O_3-ALD largely shifted toward negative. This shift was improved by introduction of plasma for deposition of Al_2O_3 gate insulator. Based on these results, the V_{th} of the ZnO TFT can be controlled by optimization of the Al_2O_3 gate insulator property.

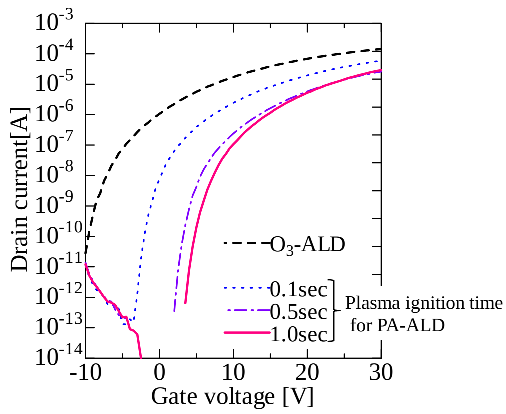

Fig. 4 Transfer characteristics of ZnO TFT with Al_2O_3 gate insulator.

4. Summary

We prepared ZnO and Al_2O_3 thin films deposited by plasma assisted atomic layer deposition as application to an active channel layer and a gate insulator in TFTs. The ZnO TFTs prepared by PA-ALD clearly exhibit TFT behavior without annealing. The electrical characteristics of ZnO TFTs improved with increasing plasma ignition time. Furthermore, we investigated the effect of the deposition condition of the Al_2O_3 gate insulator for ZnO TFT characteristics. The threshold voltage shifted toward positive with increasing plasma ignition time for deposition of the Al_2O_3 gate insulator. Through this study, we found that the improvement of the ZnO TFT performance is possible by optimization of the plasma conditions.

Acknowledgements

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