Dry Etching Behaviors of ZnO and Al_2O_3 Films in the Fabrication of Transparent Oxide TFT for AMOLED Display Application

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Abstract

We provide a newly developed dry etching process for the fabrication of ZnO-based oxide TFTs. The etching characteristics of ZnO (active layer) and Al_2O_3 (gate insulator) thin films were systematically investigated when the etching gas mixtures and their mixing ratios were varied in the helicon-plasma etching system.

1. Introduction

A recent advent of transparent oxide TFT has brought a kind of bright prospects for the next-generation fully-transparent information displays, in which the TFT loaded with transparent ZnO thin films can provide the driving back-plane for the transparent OLEDs [1]. ZnO is considered to be one of the most promising materials of active channel layer for realizing the transparent and/or flexible TFTs [2-5].

ZnO-based TFTs can be fabricated by patterning the ZnO active layers using a wet chemical etching [4-5]. However, these wet etching processes may limit the device structure and size due to their isotropic etching behavior and poor etching selectivity between ZnO and other oxide materials of gate insulators and electrodes. Therefore, it is required to guarantee the reliable dry etching processes for the oxide TFTs. Several results have been reported on the dry etching characteristics of ZnO thin films [6-8], in which hydrogen-based (CH_4-H_2) or BCl_3-based gas mixtures were mainly employed to obtain a high etch rate for the optoelectronic applications using ZnO. However, these proposed etching conditions cannot be expected to be suitable for the fabrication of the ZnO TFT, considering that H_2 may have critical impact on the electrical behaviors of ZnO thin film, and that the film thickness of active layer employed in oxide TFT is in the range of several tens-of-nm. In other words, in the dry etching processes for TFT applications using ZnO, the minimization of etching damage and the optimization scheme to obtain a sufficient etch selectivity between a ZnO and other oxide materials used in oxide TFTs.

There are few reports on fabricating the oxide TFT using the optimized dry etching process. In this work, the dry etching behaviors of ZnO and Al_2O_3 films were investigated when the process conditions such as etching gases and their mixing ratios were varied. Then, using the obtained etching conditions, we fabricated the oxide TFTs and characterized their device properties.

2. Experimental

In this study, we used the etching apparatus using high-density helicon plasma, which provides an ultimate high-density helicon wave plasma (e.g., $1 \times 10^{11}/cm^3$ at the input power of 500 W and the chamber pressure of 2 mTorr). The details of system configuration and structure can be referred in another publication [9]. For the investigation on the etching rates of ZnO and Al_2O_3 films, they were prepared on Si substrate by atomic layer deposition (ALD) method, in which the helicon source and RF chuck were operated at 60 MHz and 13.56 MHz, respectively. The temperature of the sample holder was controlled by He gas and held at 35°C. The etching parameters of RF main power and RF bias power, and chamber pressure were fixed at 800 W, 600 W, and 5 mTorr, respectively. In this work, gas mixtures of Ar/Cl_2 and $Ar/Cl_2/CHF_3$ with various mixing ratios were employed for the dry etching of ZnO and Al_2O_3, where the etch rates (ER) and etch selectivities (ES) in given gas mixtures were investigated.

3. Dry etching behaviors of ZnO and Al_2O_3

Figure 1 shows the ER's of ZnO and Al_2O_3 as a function of gas mixing ratio in the gas mixtures of

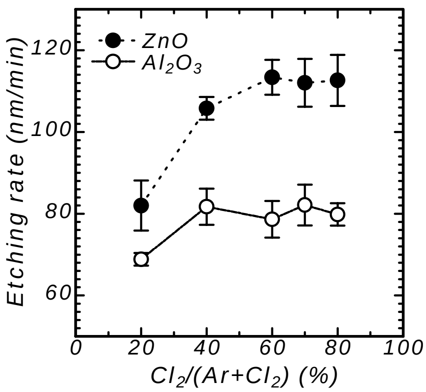

Fig. 1. Etch rates of ZnO and Al_2O_3 in Ar/Cl_2 etch gas mixtures.

Ar/Cl_2. An ER of ZnO increased from 80 nm/min to 110 nm/min when the Cl_2 ratio increased from 20% to 60%. When the Cl_2 ratio was more than 60%, the ER of ZnO did not increase any more and was observed to be saturated. These results indicate that ion-assisted chemical etching is effective for ZnO etching. The increased Cl_2^+ ions will increase the chemical reactivity and/or physical sputtering effect during the ZnO etching until the Cl_2 gas ratio increased to 60%.

Figure 2 shows the ER's of ZnO and Al_2O_3 when Ar ratio was set to 30% and the Cl_2 ratio was varied from 10% to 70% in $Ar/Cl_2/CHF_3$ gas mixtures. At the gas mixing ratio of 30/45/25, the maximum ER of ZnO (140 nm/min) was obtained. On the contrary, the ER of ZnO sharply deceased with the excessive increase of CHF_3 ratio of more than 25% in the gas mixture. In other words, the ER of ZnO was observed to be very low in the CHF_3-based etching gas mixture, even though the addition of a small amount of CHF_3 enhances the ER of ZnO. On the other hand, the ER's

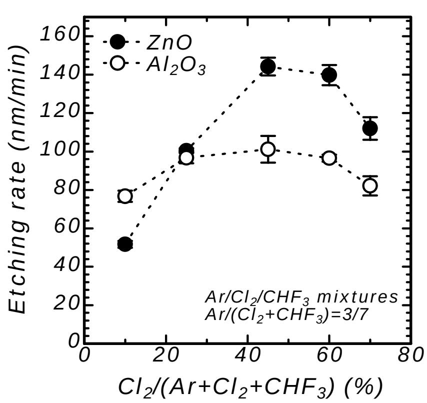

Fig. 2. Etch rates of ZnO and Al_2O_3 in $Ar/Cl_2/CHF_3$ etch gas mixtures.

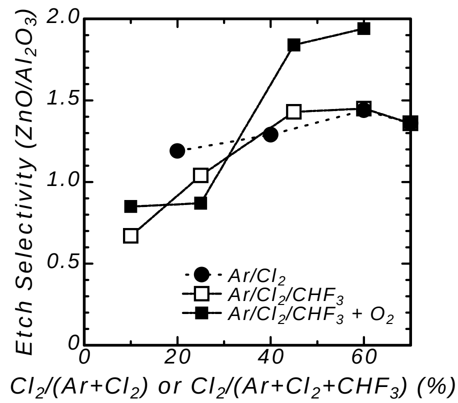

Fig. 3. Etch selectivities of ZnO to Al_2O_3 as a function of the gas mixing ratio of Ar/Cl_2, $Ar/Cl_2/CHF_3$, and $Ar/Cl_2/CHF_3/O_2$.

of Al_2O_3 were varied from 70 nm/min to 80 nm/min and from 80 nm/min to 100 nm/min with the change of Cl_2 ratio in the Ar/Cl_2 gas mixtures and $Ar/Cl_2/CHF_3$ gas mixtures, respectively. It is interesting to note that the ER of Al_2O_3 did not show a significant change with the variation of gas blending ratio, which suggests that the physical mode by ion bombardment is more dominant factor for the Al_2O_3 etching.

For the fabrication of ZnO TFT, it is also important to guarantee the selectivity for dry etching process. As shown in Fig. 3, in the gas mixtures of Ar/Cl_2, the ES of ZnO to Al_2O_3 was obtained to be about 1.4, which is not a sufficient margin especially for the device structure demanding a high ES. When the CHF_3 was added to the etch gas mixtures of Ar/Cl_2 (30/70), the ES of ZnO to Al_2O_3 was widened to be in the range from 0.67 to 1.45. In this study, we newly proposed that the blending of a small volume of O_2 gas into the $Ar/Cl_2/CHF_3$ gas mixtures could improve the ES

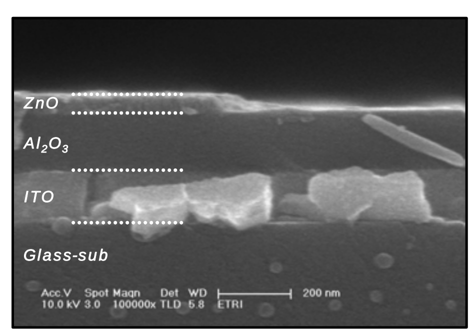

Fig. 4. A SEM view of ZnO/Al_2O_3/ITO/Glass structure after the etching process. The gas mixing ratio was set to be 80/20 in Ar/Cl_2.

between ZnO and Al_2O_3. It is noticeable that the ES increased up to approximately 2 when an O_2 gas of less than 10 sccm was added to the $Ar/Cl_2/CHF_3$ (30/45/25) gas mixture, as shown in Fig. 3 (black square), which is because of the fact that the ER of Al_2O_3 was decreased by adding the O_2. Figure 4 shows a typical SEM view of a ZnO/Al_2O_3/ITO structure after etching process when the conditions of gas mixing ratio were chosen as 80/20 in Ar/Cl_2. As can be seen in this figure, the end point between ZnO and Al_2O_3 was clearly exposed after the etching process.

4. Fabrication and Characterization of ZnO TFT using Dry Etching Method

Then, the top-gate oxide TFT was fabricated by employing the obtained etching condition, in which ITO, ZnO and Al_2O_3, Al films were used as source/drain electrodes, a active channel layer, a gate insulator, and a gate electrode, respectively. Commercial ITO glass was used as a substrate. The device fabrication procedures are as follows. First, the ITO layer was patterned to form source/drain electrodes using wet etching process. Then, a ZnO (20 nm) and an Al_2O_3 were deposited by PEALD method at 150°C in a successive manner. A thin Al_2O_3 prepared on ZnO was expected to act as a protection layer (PL) for protecting the ZnO active material from the following lithography process using several organic solvents. For the formation of Al_2O_3/ZnO gate stack, the dry etching process developed in this work was employed, in which the etching gas mixture of Ar/Cl_2 was chosen to carry out a one-step etch for the Al_2O_3/ZnO gate stack. An etching time was carefully determined by considering the etching rates of Al_2O_3 and ZnO in a given process condition. On the patterned gate stack structure, 160-nm-thick Al_2O_3 was formed by ALD at 150°C, which was verified to have good properties for the gate insulator, such as a low leakage current even at a relatively low deposition temperature and a very smooth film surface. Finally, Al gate electrode was deposited by sputtering method and patterned using a wet etchant after via contacts on the source/drain electrodes were formed. Figure 5 shows a schematic cross-sectional diagram and a photograph of the fabricated ZnO TFT.

Figures 6 (a) and (b) show the output and transfer characteristics of the fabricated ZnO TFT with the gate width (W)/length (L) of 40 um/10 um, which shows good TFT behaviors. The field effect mobility and the threshold voltage were estimated to be about

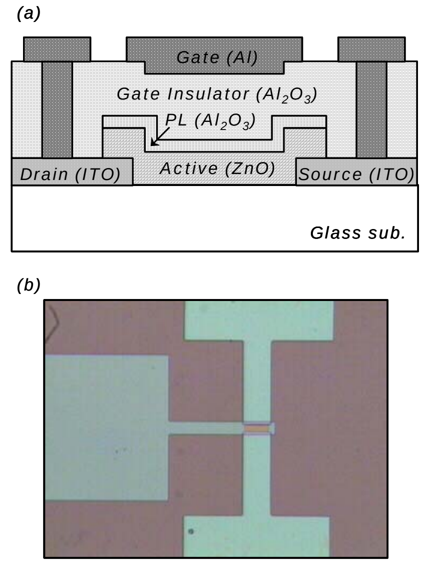

Fig. 5. (a) A Schematic cross-sectional diagram and (b) a photograph of the fabricated device.

0.8 cm^2/Vs and 8 V, respectively. The obtained field effect mobility is comparable to that for the device fabricated by the conventional wet etching method. The ratio of On/Off drain currents in transfer characteristics was approximately 10^7, and the Off currents were sufficiently low for the TFT actions. Furthermore, the undesirable increase of the gate leakage currents was not observed for the fabricated TFT. From these obtained results, it can be concluded that the TFT was successfully fabricated by employing the developed dry etching process. Therefore, the dry etching techniques with a high uniformity and a process reliability can be effectively used for the formation of a large-scale ZnO TFT array to apply for the active-matrix OLED applications. The device behaviors can be expected to be improved by carefully optimizing the etching conditions for ZnO and Al_2O_3 films for the future works.

5. Summary

Dry etching behaviors of the ZnO and Al_2O_3 thin films were investigated under the various etching gas conditions using the high-density helicon plasma etching system. The etch rates and etch selectivities were derived as a function of gas mixing ratio in the gas mixtures of Ar/Cl_2, $Ar/Cl_2/CHF_3$, and $Ar/Cl_2/CHF_3$ /O_2. Consequently, using these obtained results, we can design the etching process in a systematic way according to given cell structures with ZnO active layer and Al_2O_3 gate insulator for oxide TFT

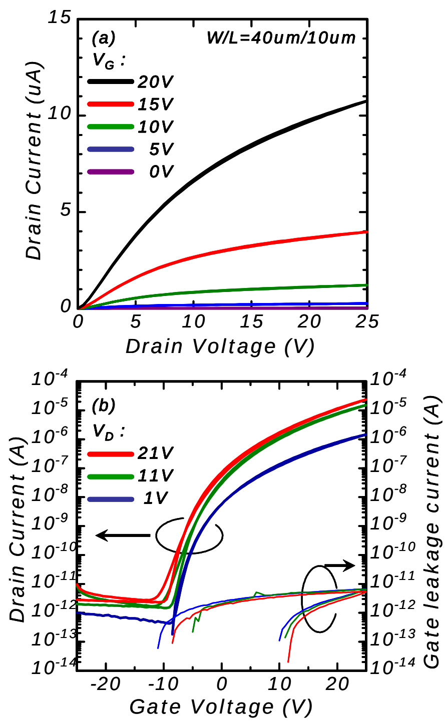

Fig. 6. (a) The output characteristics and (b) the transfer characteristics of the fabricated ZnO TFT using a dry etching method.

fabrications. Actually, a transparent ZnO thin film transistor was fabricated by using the dry etching process, in which good TFT behaviors were successfully confirmed.

Acknowledgement

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6. References

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