$BCl_3/Ar/Cl_2$ 유도결합 플라즈마를 이용한 ZnO 박막의 식각특성 연구

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Etch characteristics of ZnO thin films using an inductively coupled plasma

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Abstract : The etching characteristics of Zinc Oxide (ZnO) and etch selectivity of ZnO to SiO_2 in $BCl_3/Ar/Cl_2$ plasma were investigated. It was found that ZnO etch rate shows a non-monotonic behavior with increasing both Ar fraction in BCl_3 plasma, RF power, and gas pressure. The maximum ZnO etch rate of 53 nm/min was obtained for BCl_3(16 sccm) /Ar(4 sccm)/Cl_2(3 sccm) gas mixture. The chemical state of etched surfaces was investigated with X-ray photoelectron spectroscopy (XPS). From these data, the suggestions on the ZnO etch mechanism were made.

Key Words : Etching, ZnO, ICP

1. Introduction

ZnO is a wide bandgap energy of 3.37 eV, it is transparent in visible light and it can operate from UV to blue wavelengths. The exciton binding energy for ZnO (~ 60 meV) is higher than that for GaN (~25 meV). A higher exciton binding energy translates to an enhanced efficiency of luminescence. ZnO also exhibits better (compared to GaN) radiation resistance which is important for devices used in space and nuclear applications [1]. However, there are very few reports detailing the dry etching of ZnO using high density plasma sources favored in modern micro-electronic technology. As a result, the influence of process parameters on the ZnO etch rate has not been explored in detail, and the ZnO etch mechanism is still unclear. In this work, we investigated etching characteristics of ZnO thin films using BCl_3/Ar mixtures in an inductively coupled plasma (ICP) system. The chemical reaction on the surface of the etched ZnO thin film was investigated with XPS.

2. Experimental Details

ZnO thin films were prepared on Si(100) substrate by using Atomic layer deposition reactor(Ever-tek, Plus-100). The final thickness of ZnO films is about 200 nm. The etching experiments were performed in Figure 1. The ZnO thin films were etched in $BCl_3/Ar/Cl_2$ plasmas with the variable process parameters were gas mixing ratio, process pressure (1 - 3 Pa), RF power (500 - 900 W). In all experiments, gas flow rate and DC-bias voltage were fixed at 23 sccm, -150 V. Etch rates were measured by using an a-step surface profiler. Installation of the diagnostic tools was provided through the vertical view port on the chamber's wall-side.

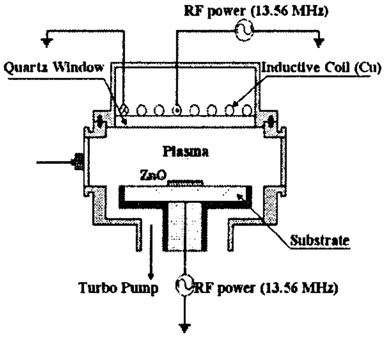

Fig 1. Inductively coupled plasma system

3. Results and Discussion

Figure 2 represents ZnO etch rate and selectivity of ZnO to SiO_2 as a function of $BCl_3/Ar/Cl_2$ mixing ratio at process pressure of 2 Pa and RF Power of 700 W. It can be seen that ZnO etch rate also increases, but then reaches a maximum of 53 nm/min at BCl_3(16 sccm)/Ar(4 sccm)/Cl_2(3 sccm). This fact allows one to assume that, for a given range of experimental condition, the chemical etch pathway is more effective. In our opinion, a domin at ion of chemical etch pathway may be explained by two reasons. The first of the melting point for $ZnCl_2$ is about 290 °C, so that it can not be related to hardly volatile compounds. The second of the strength of Zn-Cl chemical bond (229 kJ/mol) is higher than one for Zn-O (159 kJ/mol). Therefore, Cl atoms formed in plasma can react with ZnO spontaneously and no ion bombardment is needed to support chemical reaction by breaking oxide bonds. It was shown that variation of gas mixing ratio causes monotonic changes of electron density, electron temperature, total ion density and Cl atom density [2].

Figure 3 shows the etch rate of ZnO as a function of RF power for BCl_3(16 sccm)/Ar(4 sccm)/Cl_2(3 sccm) plasma. As RF power increases, the ZnO etch rate also increases, but then reaches a maximum of 53 nm/min at 700 W. It can be seen that an increase in RF power causes a monotonic increase in both dissociation and ionization rates and thus, in densities and fluxes of Cl atoms and positive ions.

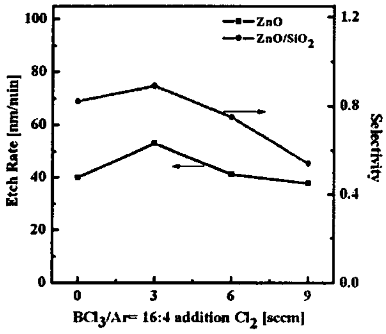

Fig. 2. Etch rate and selectivity of ZnO thin films as a function of $BCl_3/Ar/Cl_2$ gas mixing ratio.

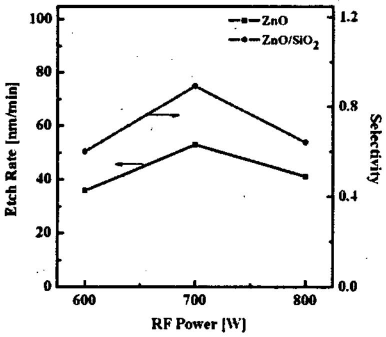

Fig. 3. Etch rate and selectivity of ZnO thin films as a function of RF Power.

Figure 4 shows the etch rate of ZnO as a function of DC-bias voltage for BCl_3(16 sccm)/Ar(4 sccm)/Cl_2(3 sccm) plasma. As DC-bias voltage increases, the ZnO etch rate increased. An increase in etch rate can be related to the increase of mean ion energy resulting in increasing sputtering yields for both ZnO and reaction prooducts.

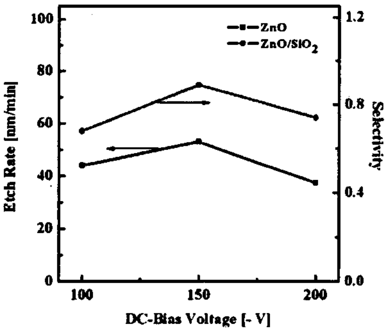

Fig. 4. Etch rate of ZnO thin films as a function of DC-Bias Voltage

The effect of process pressure on etch rate is shown in Figure 5. As process pressures increase in gas pressure increases from 1 to 2 Pa, the etch rates of ZnO increases. However, the furthermore increase in gas pressure up to 3 Pa results in decreasing ZnO etch rate, so that we obtain a simlar non-monotonic behavior as it was mentioned for the effect of gas mixing ration. In our opinion the situation looks as follows. An increase in gas pressure increases the density of neutral chemically active species, but lowers ion mean free path and ion energy.

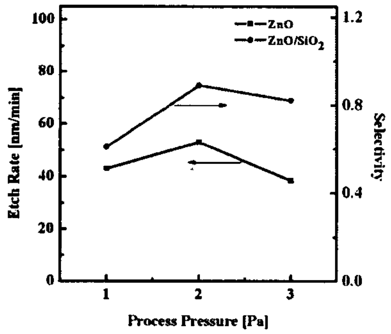

Fig. 5. Etch rate of ZnO thin films as a function of Process Pressure.

4. Conclusion

In this work, we carried out experimental investigations of ZnO etching mechanism in $BCl_3/Ar/Cl_2$ plasma. We have found that an increase of the Cl_2 content in BCl_3/Ar plasma leads to an increase in ZnO etch rate, which reaches a maximum value of 53 nm/min at 3 sccm Cl_2 because a big addition of Cl_2 to in the BCl_3/Ar plasma increased the physical effect. Due to the relatively high volatility of by-products formed during the etching by $BCl_3/Ar/Cl_2$ plasma, ion bombardment in addition to physical sputtering was required to obtain high ZnO etch rates. It was found that the reason for etch rate maximum is the concurrence of physical and chemical pathways in ion-assisted physical reaction.

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