유도결합 플라즈마를 이용한 Al_2O_3 식각 특성

구성모, 김동표, 김경태, 김창일*
중앙대학교*

The etching properties of Al_2O_3 thin films in $N_2/Cl_2/BCl_3$ and $Ar/Cl_2/BCl_3$ gas chemistry

Seong-Mo Koo, Dong-Pyo Kim, Kyoung-Tae Kim, and Chang-Il Kim*
Chung-Ang Univ.*

Abstract - In this study, we used a inductively coupled plasma (ICP) source for etching Al_2O_3 thin films because of its high plasma density, low process pressure and easy control bias power. Al_2O_3 thin films were etched using Cl_2/BCl_3, $N_2/Cl_2/BCl_3$, and $Ar/Cl_2/BCl_3$ plasma. The experiments were carried out measuring the etch rates and the selectivities of Al_2O_3 to SiO_2 as a function of gas mixing ratio, rf power, and chamber pressure. When Cl_2 50% was added to Cl_2/BCl_3 plasma, the etch rate of the Al_2O_3 films was 118 nm/min. We also investigated the effect of gas addition. In case of N_2 addition, the etch rate of the Al_2O_3 films decreased while N_2 was added into Cl_2/BCl_3 plasma. However, the etch rate increased slightly as Ar added into Cl_2/BCl_3 plasma,, and then further increase of Ar decreased the etch rate. The maximum etch rate was 130 nm/min at Ar 20% in Cl_2/BCl_3 plasma, and the highest etch selectivity was 0.81 in N_2 20% in Cl_2/BCl_3 plasma. And, we obtained the results that the etch rate increases as rf power increases and chamber pressure decreases. The characteristics of the plasmas were estimated using optical emission spectroscopy (OES).

I. INTRODUCTION

Aluminum-oxide (Al_2O_3) thin films have a great importance for applications in microelectronics and catalysis. Aluminum-oxide thin films are used in various types of microelectronic devices as dielectric, diffusion, and/or tunneling barrier, because of their specific physical and chemical properties such as large dielectric constant (~10), large barrier height for electron tunneling (~2eV), high corrosion resistance, good thermal and mechanical stability, and good adhesion. [1] Also, because sapphire wafers have excellent optical properties, these were widely used in the optoelectronic industry as substrates for growing epitaxial films of optoelectronic devices such as blue light emitting diodes (LEDs) and laser diodes (LDs) which are produced by GaN-based III-Nitrides, recently. [2-3] However, since single-crystalline $Al_2O_3$is very stable for physical andchemical etchant, the physical and the chemical stability becomes a problem for polishing, etching, device isolations, and fabrication of a device structure such as vertical device. To obtain high sapphire etch rates with high etch selectivities, recently, the various sapphire etching techniques such as chemical wet etching after ion implantation, ion beam etching (IBE), reactive ion etching (RIE), laser-assisted etching and inductively coupled plasma (ICP) have been studied. For etching sapphire, BCl_3, CCl_4, $SiCl_4$, HF, CHF_4, etc. have been used. These gases have been used in the case of aluminum etching to remove native oxide (Al_2O_3) on the aluminum surface:

In this article, Al_2O_3 films were etched with Cl_2/BCl_3 gas mixtures in an ICP,and the effect of N_2 and Ar addition into Cl_2/BCl_3 plasma was investigated. We measured the etch rate of Al_2O_3 films as a function of several etching parameters such as gas mixing ratio, rf power, chamber pressure. Etching characteristics on Al_2O_3 films have been investigated in terms of etch rates and etch selectivities over SiO_2. To understand the etching mechanism, optical emission spectroscopy (OES) analysis was used for plasma diagnostic. OES was performed to analyze the behavior of active species as a function of gas mixing ratio, rf power, and chamber pressure.

II. EXPERIMENTAL

The substrates used were Al_2O_3 films grown on a Si wafer by using sputtering. The thickness of Al_2O_3films was about 150 nm, and it was measured by a cross-sectional scanning electron microscopy (SEM). The Al_2O_3 films were etched by an inductively coupled plasma (ICP) system. The chamber was evacuated to a base pressure below 1.3×10^{-4} Pa and then the etching gases were introduced. The etch characteristics of Al_2O_3 films were investigated as a function of gas combination of Cl_2/BCl_3, $N_2/Cl_2/BCl_3$, and $Ar/Cl_2/BCl_3$. The gas mixing ratio was changed to find the best etching characteristics. For these experiments, the total gas flow, chamber pressure, top rf power, bottom DC-bias voltage, and substrate temperature was 20 sccm, 1.3 Pa, 700 W, -150 V and 30 ℃, respectively. Also, plasma etching of Al_2O_3 films was investigated by variation of the etching parameters including rf power 500 ~ 800 W, gas pressure 0.13 ~ 2 Pa with a fixed gas mixing ratio. If one parameter was changed, the others were fixed. The etch rate was estimated measuring the etched thickness with a surface profiler (KLA Tencor, a-step 500). The emission intensity of Cl atoms was investigated using an optical emission spectroscope (Nanotek NTS-U101) with the wavelength range of 300-800nm in order to understand the effects of the gas chemistry on the etch rate of Al_2O_3.

III. RESULT AND DISCUSSION

For the characterization of Al_2O_3 films etched in an ICP system, the etch rate of Al_2O_3 and SiO_2 as well as the selectivities of Al_2O_3 over and SiO_2 were systematically investigated as a function of gas mixing ratio, rf power and working pressure. Fig. 1(a) shows the etch rate of Al_2O_3, SiO_2, and the selectivities of Al_2O_3 to SiO_2 as a function of Cl_2/BCl_3 gas mixing ratio. The total flow rate of the gases was maintained at 20 sccm, ICP rf power/DC-bias voltage was 700 W/-150 V, chamber pressure was 1.3 Pa, and substrate temperature was 30 °C. The etch rates of Al_2O_3 films in pure Cl_2 and in pure BCl_3 were found to be 69 and 82 nm/min, respectively. The maximum etch rate of the Al_2O_3 films was 118 nm/min when Cl_2 50% was added to Cl_2/BCl_3 plasma. The maximum etch rate of SiO_2 was 157 nm/min when Cl_2 70% was added to a Cl_2/BCl_3 plasma. As the content of Cl_2 into gas mixture increases, the etch selectivity of Al_2O_3 to SiO_2 increases and reaches a maximum at $Cl_2$50% and then decreases, being the etch selectivity equal to 0.79. Fig. 1(b) represents the variation of the emission intensities for Cl atoms (452.6 nm, $4p^1{}_{3/2} \rightarrow 4s_{3/2}$) in Cl_2/BCl_3 plasma. As Cl_2 increased in Cl_2/BCl_3 plasma, the emission intensities ofCl increase. The emission intensity is proportional to the volume density of atoms. Addition of Cl_2 into BCl_3up to 50% lead to an increase on the etch rate while further addition of Cl_2 caused a quick decrease on the etch rate. The etch rate of Al_2O_3 was confirmed by the variation of the volume density of Cl atoms.

In Cl_2 50%/BCl_3 50% gas mixing ratio, the effects of N_2 addition to Cl_2/BCl_3 plasma on the etch rates and selectivities of the Al_2O_3films were measured. As results show in Fig. 2(a), the etch rate of the Al_2O_3films decreased while N_2 was added into Cl_2/BCl_3 plasma, however, the etch selectivities reached the highest value (about 0.81) at N_2 20% and then decreased. When Ar 20% added into Cl_2/BCl_3 plasma, the etch rate increased slightly, and then further increase of Ar decreased the etch rate. The maximum etch rate that could be obtained at the addition of Ar 20% was 124 nm/min. The highest selectivity was almost the same in Cl_2 50%/BCl_3 50%.As these results show, N_2 leads to decrease the etch rate, but Ar can lead to increases the etch rate. We supposed that Ar can increase the Cl radicals and raise the chemical reaction between Al_2O_3 and Cl. Also, it seems that the effect of physical ion bombardment is enhanced because Ar is heavier then N_2.

Figure 3 shows the effect of ICP rf power on the etch rate of Al_2O_3 and SiO_2 under 20% N_2 and 20% Ar in Cl_2/BCl_3 plasma. As rf power applied to the ICP antenna was raised from 500 to 800W, the etch rate of the Al_2O_3 films increased from 46 to 122 nm/min in $N_2/Cl_2/BCl_3$ plasma and from 52 to 130 nm/min in $Ar/Cl_2/BCl_3$ plasma. The selectivity in each points has small difference about 0.1~0.2. Therefore, we considered that the etch rates of Al_2O_3 and SiO_2 are increased at the same rate within an error range. With increasing rf power, the plasma density increases increasing the reactive free radicals and ions enhancing the etch rate of Al_2O_3 and SiO_2. It can be said that the acceleration of chemical reactions as well as physical ion bombardment takes place simultaneously. We supposed that this is the reason why the increase of etch rate for the material was measured. [4]

The effect of chamber pressure on etch rate is illustrated in Fig. 4. As the chamber pressure increases from 0.16 to 2 Pa, the etch rate of Al_2O_3 films decreases from 127 to 60 nm/min in $N_2/Cl_2/BCl_3$ plasma and from 136 to 96 nm/min in $Ar/Cl_2/BCl_3$ plasma, respectively. Since the mean free paths of species are inversely proportional to pressure, the recombination rate of ions decreases, then the number of ion that go toward the substrate surface increases and they have higher energies. [5] That is, low pressure leads to higher ion bombardment energies. It is supposed that the etch rate is affected by the increase of ion bombardment.

Figure 5 illustrates the emission intensities variation for Cl measured using OESas rf power and chamber pressure change. As rf power increases, the Cl radical density is increased. That is, the increase of rf power causes the increase of reactive free radical number, i.e. higher concentration of active species in the plasma made the etch rate increase. In the case of chamber pressure, we suppose that the decrease of pressure and the increase of mean free path reduce the recombination of reactive radical, and the Cl radical density is increased.

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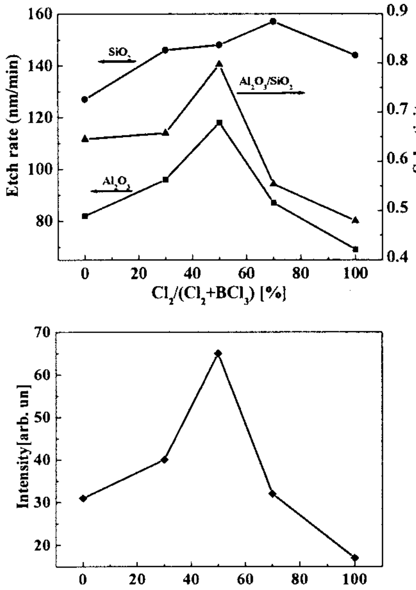

Figure 1. (a) Etch rate and selectivity of Al_2O_3 thin films as a function of Cl_2/BCl_3 gas mixing ratio. (b) The optical emission intensity of Cl radical in Cl_2/BCl_3 plasma.

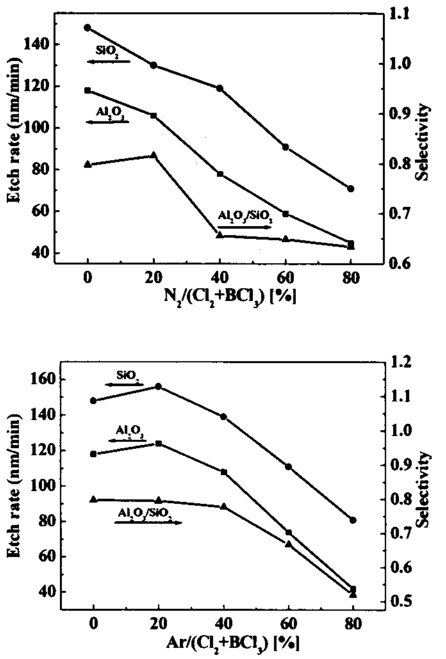

Figure2. Etch rate and selectivity of Al_2O_3 thin films measured for various gas combinations. (a) $N_2/Cl_2/BCl_3$chemistry (b) $Ar/Cl_2/BCl_3$chemistry.

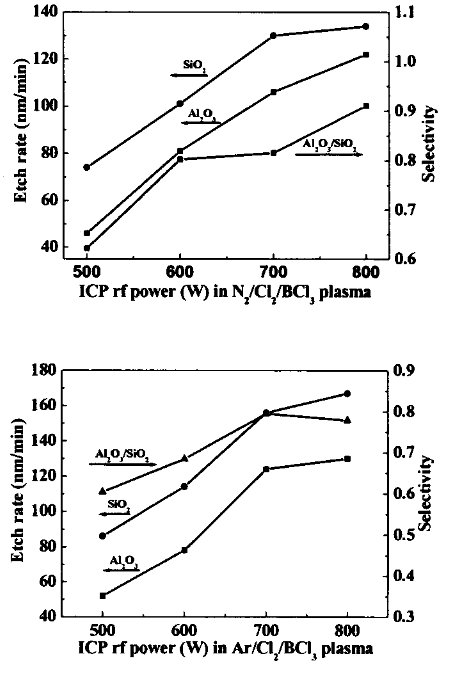

Figure3. Etch rate and selectivity of Al_2O_3 thin films as a function of rf power. (a) $N_2/Cl_2/BCl_3$ chemistry (b) $Ar/Cl_2/BCl_3$chemistry.

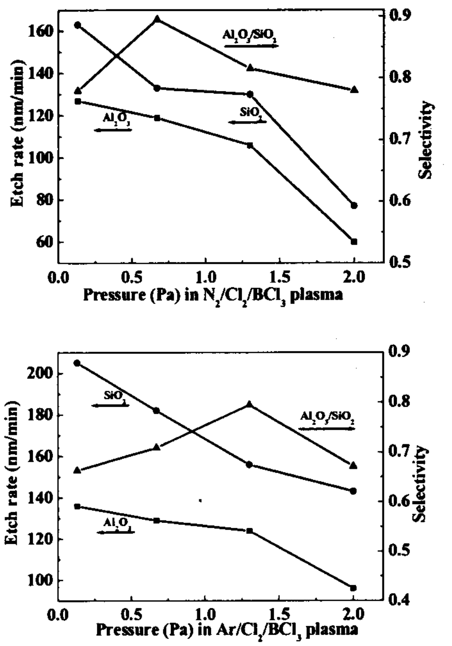

Figure4. Etch rate and selectivity of Al_2O_3 thin films as a function of chamber pressure. (a) $N_2/Cl_2/BCl_3$ chemistry (b) $Ar/Cl_2/BCl_3$chemistry.

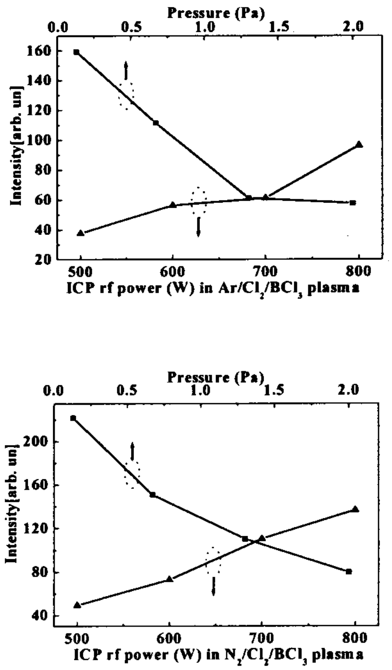

Figure 5. Optical emission intensities measured by OES as a function of rf power and chamberpressure.