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RIE-Lag Reduction by NH_3 Addition in Aluminum Alloy Etching under BCl_3/Cl_2 Chemistry

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The effect of NH_3 addition in Al alloy etching under BCl_3/Cl_2 chemistry is investigated. Optical emission spectral analysis and Auger electron spectroscopy analysis suggest that Al-N layer on Al alloy surface is formed by the reaction between Al and NH_3. This Al-N layer reduces the reaction between Al and Cl radicals. The addition of NH_3 is effective not only in RIE-lag reduction but also in achieving anisotropic profile.

Introduction

In recent sub-quarter-micrometer aluminum alloy dry etching, RIE-lag reduction and anisotropic etched profile formation are strongly required. Here, RIE-lag is the phenomena that the etch rate depends on the space pattern width.

The reason why RIE-lag reduction is required is as follows. For the patterning less than 0.25 μm, KrF excimer laser lithography is necessary. However, the resist thickness is thinner compared with i-line lithography from the depth of focus point of view, and the etching selectivity of photoresist to Al alloy is smaller than about 3. From this consideration, overetching time should be decreased.

An anisotropic profile of Al alloy etching is also required in order to prevent the void formation in subsequent filling process of dielectric material.

On Al alloy etching under BCl_3/Cl_2 chemistry, there have been several reports for RIE-lag reduction under BCl_3/Cl_2 gas chemistry (1), (2). However, they are restricted to phenomenological speculation and do not refer to the surface reaction between Al alloy and Cl radicals.

In this paper, we focus on the Al alloy surface reaction and propose a new gas chemistry of $BCl_3/Cl_2/NH_3$ to meet the requirements of both anisotropic profile and low RIE-lag. Discussion is made on the RIE-lag reduction mechanism by using an optical emission spectral analysis (OES) and an Auger electron spectroscopy analysis (AES).

Experimental

Experiments were made on a conventional RIE apparatus with 13.56MHz RF discharge. Etching samples were 6 inch Si wafers with TiN/Al-Si (1%) -Cu (0.5%) /Ti films sputtered on a 700 nm thick CVD SiO_2 film. The thicknesses of TiN, Al-Si-Cu and Ti layers were 40 nm, 600 nm and 25 nm, respectively. The sample wafers were patterned with the 1.0 μm thick photoresist using i-line photolithography. Three kinds of gas chemistry, *i.e.*, $BCl_3/Cl_2/NH_3$, $BCl_3/Cl_2/N_2$ and BCl_3/Cl_2 were studied. The degree of the RIE-lag was measured from the photograph of scanning electron microscopy (SEM). Table 1 summarizes other etching conditions in this work.

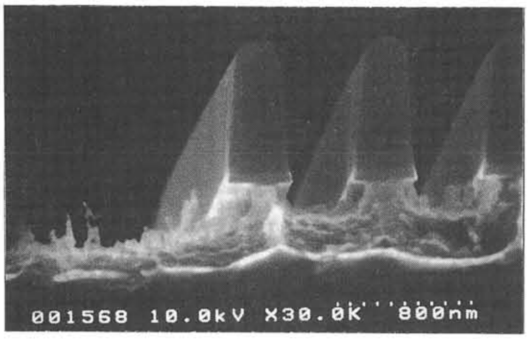
Table 1	Etching Conditions
BCl_3 Flow	50sccm
Cl_2 Flow	50sccm
Pressure	200mtorr
RF Power	250W

Results and Discussion

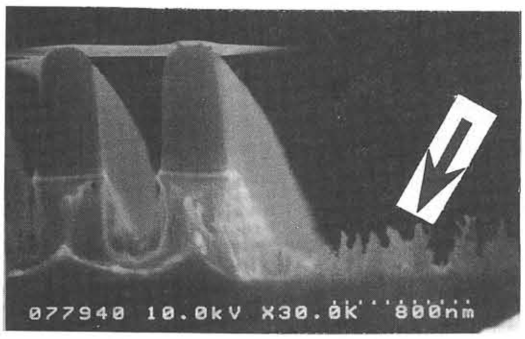
Figure 1 shows SEM photographs of Al-Si-Cu etched profiles by 0.4 μm line and 0.4 μm space patterns. The addition of N_2 or NH_3 in BCl_3/Cl_2 gas chemistry brings about an anisotropic profile, where gas flow rate of N_2 or NH_3 is 50sccm, while BCl_3/Cl_2 gas chemistry without N_2 or NH_3 addition results in an isotropic profile. It is also shown that the addition of NH_3 is effective in reducing the residues (see arrows in Figs. 1 (b) and (c)).

Figure 2 shows a comparison of the etch rate as a function of the pattern width W in line & space (L&S) configuration among four kinds of gas mixtures. When W=1.0 μm, the etch rate for $BCl_3/Cl_2/NH_3$ (50sccm) case is about the half of the etch rate for BCl_3/Cl_2 case and two third of the etch rate for $BCl_3/Cl_2/N_2$ case. The etch rate is sensitive to the NH_3 addition. The etch rate decreases much as W is smaller for W less than 1.0 μm in BCl_3/Cl_2 case.

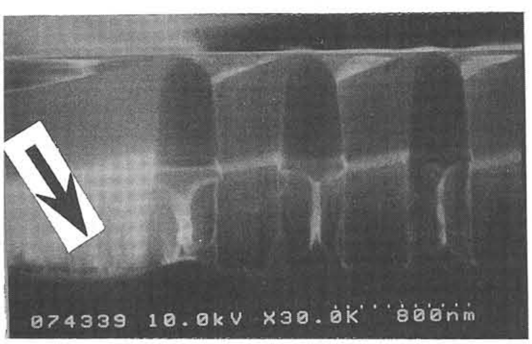
Figure 3 shows the comparison of normalized etch rate as a function of W among four kinds of gas mixtures. Etch rate of each pattern is normalized by that of W=1 μm space pattern. In BCl_3/Cl_2 case, the etch rate decreases to 60% of W=0.4 μm patterns. In N_2 addition case, the RIE-lag is reduced to some extent for W greater than 0.6 μm, compared with BCl_3/Cl_2 case. In NH_3 addition case, the RIE-lag is greatly reduced. The normalized etch rate reduction is kept less than 20% even when W=0.4 μm.



(a) BCl_3/Cl_2 only



(b) N_2 addition



(c) NH_3 addition

Figure 1 Comparison of Al alloy etching profile of 0.4 μm L & S patterns

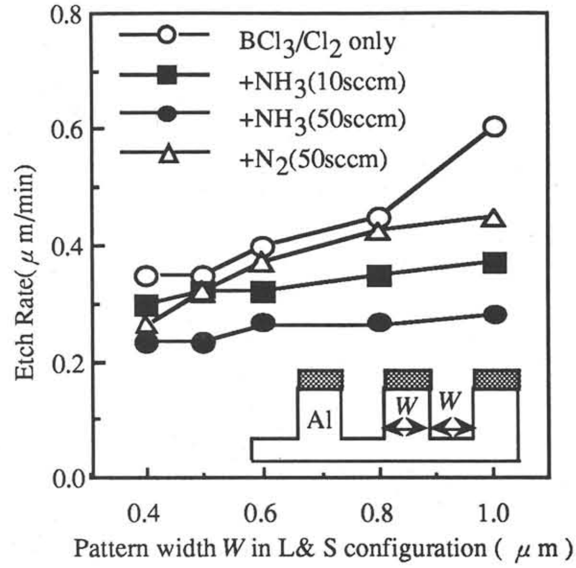


Figure 2 Comparison of Al alloy etch rate among four kinds of gas mixtures

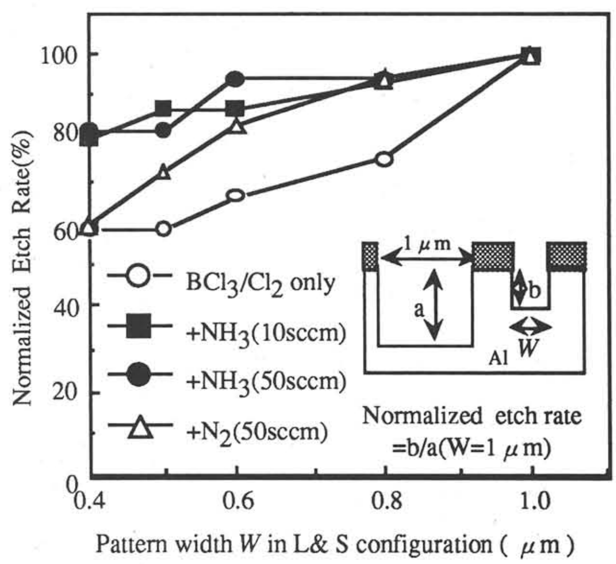


Figure 3 Comparison of normalized etch rate among four kinds of gas mixtures

OES is made in order to examine the effect of NH_3 addition. Figure 4 shows the comparison of the emission intensity of Cl radical (775nm) which is a main etchant species. The emission intensity of Cl radicals in NH_3 addition case and N_2 addition case is normalized by that in BCl_3/Cl_2 case. By NH_3 addition, Cl radical is increased about 1.8 times of BCl_3/Cl_2 case. Also, by N_2 addition, Cl radical is increased about 1.3 times of BCl_3/Cl_2 case. This result shows that the addition of NH_3 gas increases the main etchant radical of Cl. This seems to contradict the result of Fig. 2 where the addition of NH_3 gas decreases the etch rate.

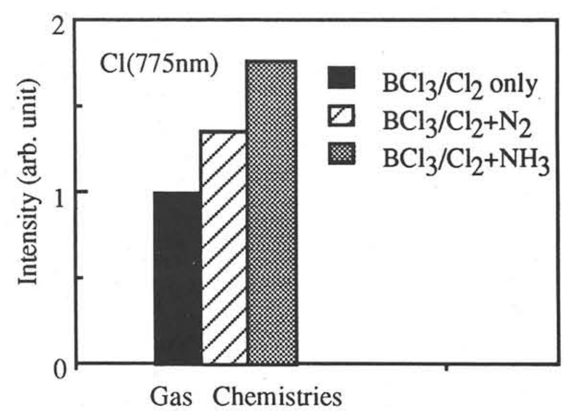


Figure 4 Comparison of the emission intensity of Cl radical among three kinds of gas mixtures

AES is used for the Al-Si-Cu surface analysis. Figure 5 shows the result of AES depth profile. Samples (a) and (b) are exposed by 50sccm NH_3 added plasma and 50sccm N_2 added plasma after the native oxide film removal, respectively. Pressure is 200mtorr, RF power is 250W and treatment time is 300s. It is observed that nitrogen concentration near the surface in NH_3 treatment sample is larger than that in N_2 treatment sample. It is considered that Al-N layer is formed near the Al alloy surface by the reaction between NH_3 and Al.

Figure 6 shows the schematic of the mechanism for the RIE-lag reduction. In BCl_3/Cl_2 gas chemistry, higher rate etching for wide patterns and lower rate etching for narrow patterns occur. This is because the amount of Cl radicals in wide patterns is larger than that in narrow patterns. On the other hand, in NH_3 addition plasma, Al-N layer is formed on the Al alloy surface by the reaction between NH_3 and Al. The chemical reaction probability between Al-N layer and Cl radical is reported to be small (3). Therefore, Al-N layer plays a role of the sidewall protection against Cl radicals. As a result, the reaction between Al-N layer and Cl radicals is not progressive without the ion bombardment. It is considered that the reduction of the RIE-lag is owing to the increase of the relative percentage of ion assist etching.

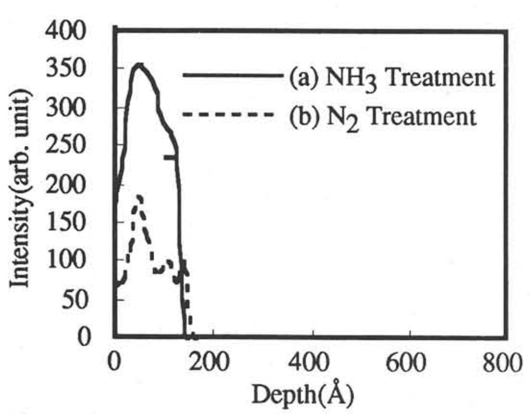


Figure 5 Auger electron spectroscopy measurement for nitrogen depth profile of samples after N_2 and NH_3 plasma exposure

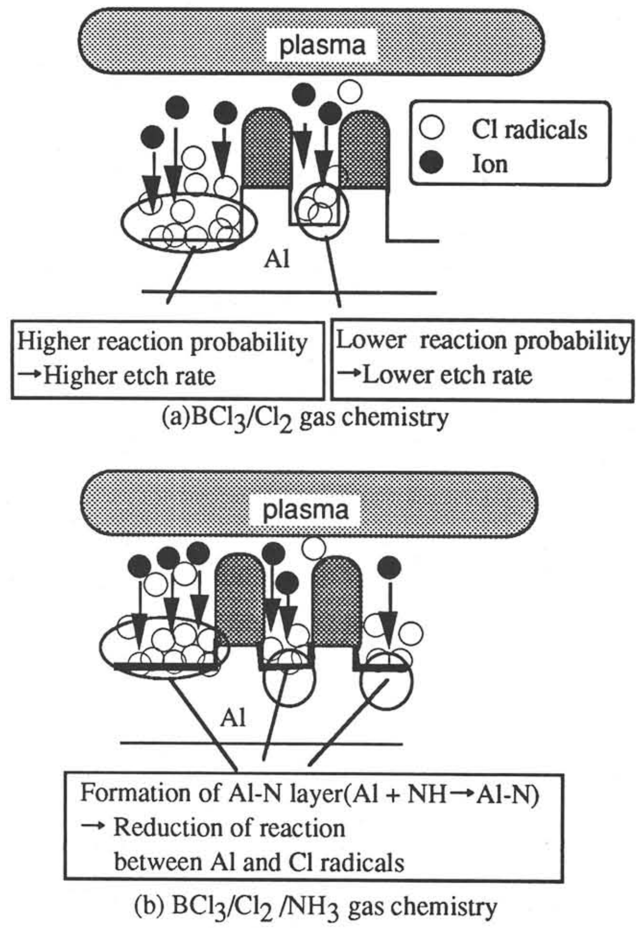


Figure 6 Schematic of mechanism for RIE-lag reduction

Conclusion

The effect of NH_3 addition under BCl_3/Cl_2 gas chemistry on both RIE-lag and etched profile is studied in Al alloy etching. Optical emission spectral analysis and Auger electron spectroscopy analysis suggest that Al-N layer on Al alloy surface is formed by the reaction between Al and NH_3. It is considered that this Al-N layer reduces the reaction between Al and Cl radicals. The addition of NH_3 is effective not only in RIE-lag reduction but also in achieving anisotropic profile.

Acknowledgments

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