A Comparative Study of the Etching Behavior of Thin AlN and Al_2O_3 Films

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Abstract

The etching behavior of thin AlN and Al_2O_3 films in RF plasmas was investigated using BCl_3, Cl_2, and HCl as process gases. Under identical process conditions highest etch rates for AlN were obtained in Cl_2 only plasmas, while BCl_3 only plasmas resulted in the highest etch rates for Al_2O_3. The results suggest that pattern transfer in AlN is due to chemical etching while pattern transfer in Al_2O_3 is dominated by physical bombardment with heavy species. This interpretation is supported by the finding that etch rate non-uniformities obtained for Al_2O_3 were substantially higher than those obtained for AlN. An analysis of the optical endpoint signal obtained during pattern transfer allowed a quick assessment of the non-uniformity of the plasma processes.

Introduction

Thin films of AlN and Al_2O_3 are promising candidates for various applications in wireless products, MEMS, advanced DRAMs, MRAMs, and MPUs. For an investigation of the etching behavior of these binary material systems, samples with film thicknesses exceeding those required in most of their future applications were used to allow both, partial etches and a thorough study of the optical emission endpoint signals.

Experimental

All experiments were performed in a metal etcher (MERIE). The temperature of the reactor i. e. of both the chamber lid and the chamber wall was set to 90°C. To minimize mean time of residence for the etch products, the plasma reactor was operated under high flow, low pressure conditions. All processes were magnetic field assisted. In the reactor chamber the wafer was mechanically clamped. Binary mixtures (0-100%) of the feed gases (BCl_3, Cl_2, HCl) were used for processing 150mm diameter silicon substrate wafers. Both, AlN and Al_2O_3 films, were deposited on blanket SiO_2 wafers with PVD and atomic layer CVD, respectively. For pattern transfer an SiO_2 hard mask was used. Endpoint detection was performed with the standard OES system of the etch tool by monitoring an Al emission line (λ=396nm). The etch rates and etch rate non-uniformities for AlN, Al_2O_3, and SiO_2 serving as both mask and underlayer, were determined with thin film measurements, profilometry, and by taking SEM micrographs after partial etches.

Results and Discussion

Leaving all other process parameters unchanged, an increase of the etch rates of AlN was observed when changing from BCl_3 (130nm/min) to HCl (280nm/min) to Cl_2 (650nm/min) plasmas. Thus the lowest rates were obtained with the process gas that provides the highest binding energy /1/ per Cl atom (444kJ/mol) and the heaviest molecular mass (117amu); Cl_2 and HCl exhibit both lower binding energies (Cl_2: 242kJ/mol, HCl: 405kJ/mol) and molecular masses (Cl_2: 71amu, HCl: 36amu) while resulting in higher AlN etch rates than BCl_3. The higher etch rates obtained with Cl_2 compared with HCl are due to the fact that plasma fragmentation of Cl_2 yields two reactive species compared to only one obtained in the cracking pattern of HCl. These results suggest that pattern transfer in AlN is due to chemical etching or at least chemically assisted etching. The chemical nature of the etch is confirmed by the related etch rate non-uniformities which were as low (<5%) as those known from chemical etching of standard CMOS materials; this was also evidenced from the steep drop of the optical emission intensity in the endpoint trace.

For patterning of Al_2O_3, the removal rates were increasing when changing from HCl (45nm/min) and Cl_2 (55nm/min) to BCl_3 (140nm/min). For all etch chemistries the obtained non-uniformities were unusually high (~30%) exceeding those obtained for AlN by almost an order of magnitude; such high etch rate non-uniformities are indicative of the pattern transfer being dominated by physical bombardment with heavy species rather than chemical reactions; indeed, the erosion rates for Al_2O_3 increase with the molecular mass of the species bombarding the wafer. The long decay of the endpoint signals obtained for Al_2O_3 patterning gives evidence of the observed high non-uniformities. In general, the low removal rates obtained for Al_2O_3 reflect the high molecular binding energy (1677kJ/mol, /2/).

Under high flow, low density conditions, radial symmetry of the etch rate distribution across the wafer was obtained for all plasma processes, with the wafer center etching faster than the edge. With these assumptions, the non-uniformity (NU) determined by 5-point-measurements can be expressed as a function of the ratio $\Delta t/t_1$, with t_1 and Δt being the time to the decay (till the film starts clearing in the wafer center) and the decay time (the duration of the signal decay), respectively:

$$NU = 0.5 \cdot \frac{\Delta t/t_1}{1 + 0.2 \cdot \Delta t/t_1} \quad [\%]$$

Thus determining t_1 and Δt from the optical endpoint trace allows a quick and reliable assessment of the non-uniformity. A comparison of non-uniformities obtained from partial AlN and Al_2O_3 etches with the values obtained from the endpoint traces are in excellent agreement.

Conclusion

A study of the etching characteristics of AlN and Al_2O_3 in chlorine based process gases, gives evidence that pattern transfer in AlN is due to chemical(ly assisted) etching whereas patterning of Al_2O_3 is dominated by physical bombardment.

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References

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