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Etching of Organic Low *k* Dielectric, their Gas Phase and Subsurface Reactions in Ultra High Frequency Plasma

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1. Introduction

As the critical dimension of integrated circuits is scaled down, a larger portion of the total circuit transmission time becomes a bottleneck. To address these issues, the combination of copper films with its relatively low resistivity, and interlayer films with lower dielectric constant (low *k*) have been proposed. An organic low *k* film, FLARE™, has the low dielectric constant (k = 2.85), good thermal stability (450°C), and is considered to be one of the most prospective candidates for interlayer films with low *k* [1]. So far, FLARE™ etching has been studied in inductively coupled N_2/H_2 and N_2/NH_3 plasmas [2].

In this study, the organic low-*k* film etching has been carried out in ultrahigh frequency (UHF: 500MHz) plasma employing N_2/H_2 and N_2/NH_3 gases. The VUVAS technique was applied to measure the absolute densities of H and N radical in etching plasma and the etching characteristics of organic low k film was obtained at the different substrate temperatures. Moreover, the etching surface reactions were investigated using Fourier transform-infrared attenuated total reflection (FT-IR ATR).

2. Experimental

Figure 1 shows a schematic diagram of UHF plasma etcher of 8 inch-wafer production level with the VUVAS system employing microdischarge hollow-cathode lamp (MHCL) in this study. A 6 spokewise antenna with a diameter of 30 cm was set on quartz window at the top of chamber. Plasma power operating at 500 MHz was applied to the spokewise antenna. The etching conditions were maintained at a total pressure of 2 Pa and a total flow rate of 100 sccm. The self-bias voltage (V_{dc}) was fixed at -500 V by adjusting the RF bias power (1.6 MHz).

3. Results and Discussions

Figure 2 shows the etch rate of FLARE™ as a function of the H atom ratio in feed gases. In the N_2/H_2 plasma, as the ratio of H atom ratio in feed gases increased, the etch rate increased, reached the maximum of 400 nm/min at N_2/H_2 = 30/70 sccm, that is H atom ratio in feed gases = 70 %, and then decreased. On the other hands, in N_2/NH_3 plasma, as the rate of H atom in feed gases increased, the etch rate increased, reached the maximum of 450 nm/min at N_2/NH_3 = 0/100 sccm. Figure 3 shows SEM image of etched profile employing N_2/NH_3 plasma at H atom ratio in feed gases = 0.5 (N_2/NH_3 = 50/50 sccm) and substrate temperature of 0°C. By adjusting the etching conditions, the anisotropically etched profile was obtained. Figure 4 shows N and H radical densities as a function of H atom ratio in feed gases employing VUVAS technique. In N_2/H_2 plasma, as H atom ratio in feed gases increased, the absolute H radical densities increased, reached the maximum of 1.3×10^{13} cm^{-3}, then decreased. On the other hand, in N_2/NH_3 plasma, H radical densities are increased with increasing H atom ratio in feed gases. Figure 5 shows the amount of bowing at the sidewall of the line pattern as a function of the substrate temperature. As the substrate temperature increased, the taper profile was changed to the bowing profile due to less formation of protection layer at the sidewall. Figure 6 shows the micro-trench depth at the bottom of the line pattern as a function of the substrate temperature. The micro-trench depths were almost constant at the different substrate temperatures, which were different from results of bowing. The formation of micro-trench depth was due to the contribution of radicals and ions in gas phase than substrate temperature.

To clarify the mechanism of anisotropically etched profile, the subsurface reactions were investigated by FT-IR ATR. Figure 7 shows the time evolution of absorption intensity spectra when N_2 plasma was exposed to FLARE. As N_2 plasma irradiation time increased, sp^3-hybridized carbon [N-C(sp^3)] and sp^2-hybridized carbon [N=C(sp^2)] bonds decreased. Figure 8 shows the time evolution of absorption intensity spectra when H_2 plasma was exposed to the sample exposed by N_2 plasma. As H_2 plasma irradiation time increased, sp^1-hybridized carbon [N≡C(sp^1)] bond and N=C(sp^2) bonds decreased. Therefore, it was found that CN layer composed of N-C(sp^3) bond on etched surface were working as a passivation layer on the sidewall against H atom etching.

4. Conclusions

The organic low *k* film was etched in UHF plasma. H radicals were important species for organic low-*k* film etching. N radical formed CN layer, which is composed of N-C(sp^3) and N=C(sp^2) bonds on etched surface. Especially, N-C(sp^3) bond were working as a passivation layer on the sidewall against H atom etching for obtaining vertical profile of etched pattern.

References

[1] K. S. Lau et al.: *Proc. 14th Int. Conf. VLSI Multilevel Interconnection, Santa Clara, California*, pp. 577 (1997).
[2] H. Nagai et al.: J. Appl. Phys., **91**, 2615 (2002).

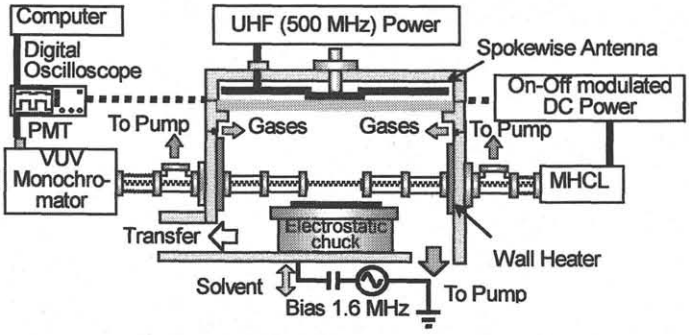

Fig. 1 Schematic diagram of UHF plasma etcher of 8 inch-wafer production level with the VUVAS system employing MHCL.

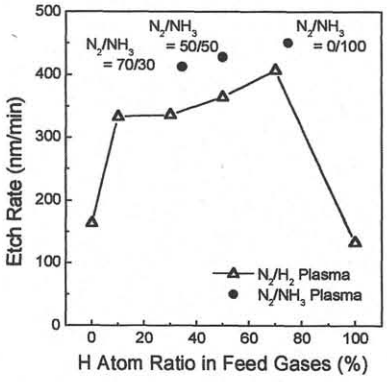

Fig. 2. The etching characteristics of FLARE™ using UHF-N_2/H_2 and N_2/NH_3 plasma as a function of H atom ratio in feed gases.

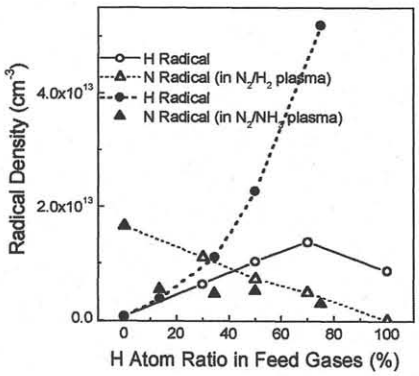

Fig. 3. N and H radical densities in UHF plasma measured using VUVAS technique as a function of H atom ratio in feed gases.

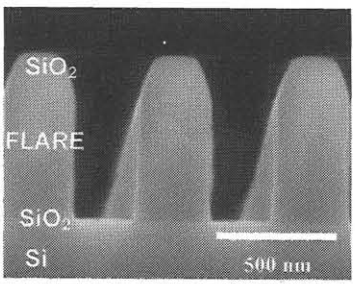

Fig. 4. SEM image of the etched profile of FLARE at UHF power of 1kW, N_2/NH_3=50/50 sccm and substrate temperature of 0°C.

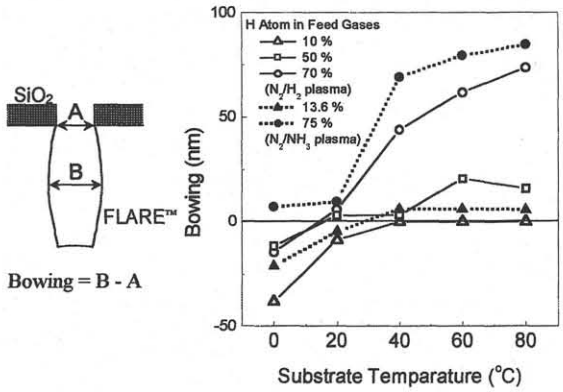

Fig. 5. The amount of bowing at sidewall of the line shape as a function of the substrate temperature.

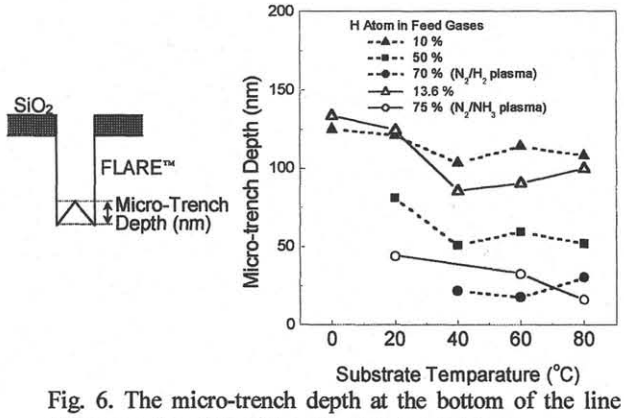

Fig. 6. The micro-trench depth at the bottom of the line shape as a function of the substrate temperature.

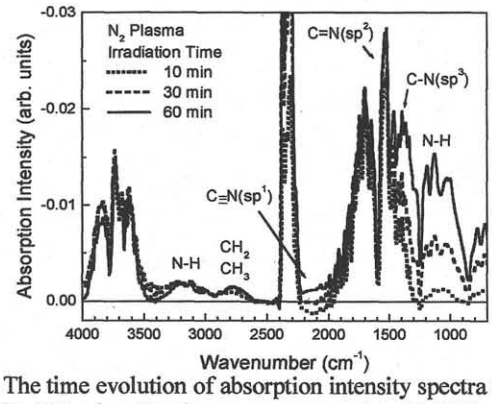

Fig. 7. The time evolution of absorption intensity spectra measured by FT-IR ATR when N_2 plasma was exposed to FLARE.

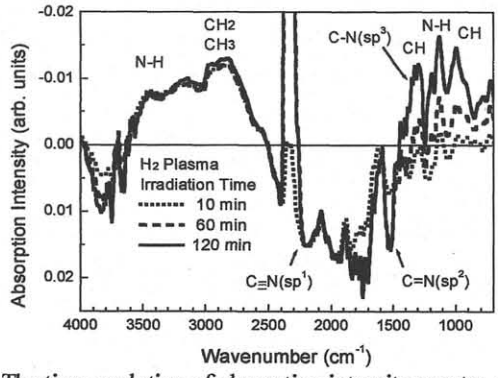

Fig. 8. The time evolution of absorption intensity spectra measured by FT-IR ATR when H_2 plasma was exposed to sample exposed by N_2 plasma.