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Novel approach for the interpretation of etching characteristics based on internal parameters employing combinatorial plasma process

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Plasma etching technology has been in charge of semiconductor device industry. As it is scaled down to several tens of nanometers, nano-leveled precise control has been indispensable to achieve the process requirements. However, up to now, a lot of trial-and-error processes have been carried out in development of plasma etching processes characterized by external parameters (input power, working pressure), since there has never been any scientific approach based on plasma science. We suggest the development of process map, designated as Plasma Nano Science, in which the process performances are characterized by internal parameters (fluxes and energy distributions of ions, radicals).

For the establishment of Plasma Nano Science, we have developed the combinatorial plasma etching process apparatus, in which a variety of results could be acquired by one trial under spatially inhomogeneous plasma. To develop and optimize a combinatorial plasma process (CPP) system with a spatially varying plasma density, Ar plasma profiles were investigated using a fluid simulation code. The plasma model is based on the continuity equation for heavy particles and the energy conservation equation for charged particles under the drift diffusion approximation [1]. Based on it, inductively coupled H_2/N_2 plasma driven by two internal low inductance antennas (LIAs) was realized for etching of organic low dielectric constant films. The spatial distributions of H and N radical and electron densities and etch rate were measured by vacuum ultra violet absorption spectroscopy (VUVAS) and RF-compensated Langmuir Probe, spectroscopic ellipsometry, respectively. Moreover, the synergetic effect of radical and UV/VUV radiation on etching characteristics were investigated employing pallet for plasma evaluation (PAPE) method [2]. Finally, high performance of CPP was demonstrated by the comparison to conventional unit process (CUP).

It has been reported that the etch characteristics on organic low-k films were mainly influenced by the synergetic effect of physical etching of ions such as NH_x^+ with chemical reactions by H and N radicals [3]. To clarify the internal parameters that affect the etching characteristics such as the etch rate, we investigated the radical and electron densities in a CUP as a function of the input power to the main antenna at same position and those spatial distribution in a CPP under a specific process condition. In a CUP, it was confirmed that the increase of electron and H, N radical densities with input power from 200 to 800 W resulted in the enhancement of etch rate. In a CPP, electron and H, N radical densities were highest near main antenna, which was supplied with RF power of 800 W, and those decreased with distance from main antenna. Electron and H, N radical densities were spatially well distributed over a broad range from 10^8 to 10^{10} cm^{-3} and 10^{12} to 10^{13} cm^{-3}, respectively. The behavior of spatial distribution of etch rate was similar to those of internal parameters. Based on these results, we have tried to interpret the etch rate by scientific terms, because it is meaningless to analyze by external parameters such as the input power, which are vary with mechanical variations and are not reproducible. Figure 1(a) demonstrates the superior performance of CPP over CUP. The behaviors in both processes were proportionally fitted with ion fluxes and H/(H+N) radical flux ratio. However, results by many trials in a CUP could be acquired by a single trial in a CPP.

Additionally, other internal parameters should be considered since it is determined by a synergetic effect between neutrals and ions bombarding the surface, or between neutrals and other species such as UV/VUV photons. To clarify the independent effects of radicals and the synergetic effect of VUV radiation and radicals on etching, etch rates were investigated in both of CUP and CPP employing PAPE technique [2]. Etch rates by a synergetic effect of radicals and VUV were higher than those by only radicals, since VUV radiation is sufficiently energetic to break and activate the bonding on the surface. As shown in Fig. 1(b), it was confirmed that the etch rate was proportional to internal parameters such as VUV intensity and H, N radical density ratio.

As summarized in this study, we have developed a compact combinatorial plasma etching process system driven by LIAs. To evaluate the high performance of CPP, internal parameters such as electron density and H and N radical densities and etch rates of organic low-k films were investigated using CUP and CPP. The etch rates in both processes were proportional to the ion flux and the H/(H+N) radical flux ratio incident on the substrate as well as VUV intensity and H, N radical density ratio. From those results, the possibility of the interpretation for the etching characteristics in terms of internal parameters was demonstrated. In addition, the high performance of CPP was shown by acquiring results in a single trial that would require many experiments using a CUP.

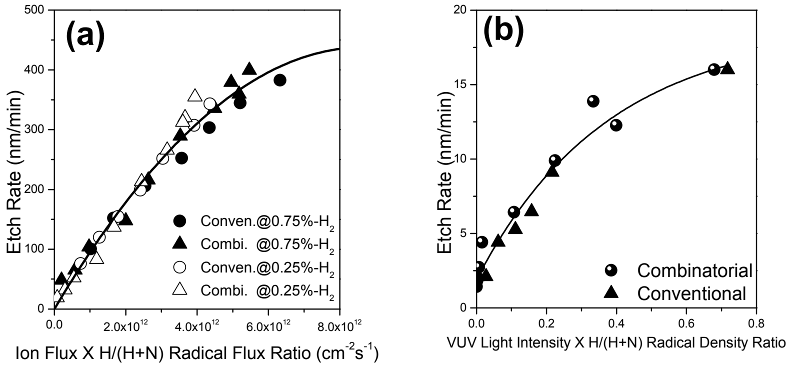

Fig. 1: High performance of CPP interpreted by internal parameters such as (a) ion and radical fluxes and (b) VUV radiation and radical.

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