The Effects of Plasma Treatments on the Properties of Ultra Low-k Dielectrics and Ta Diffusion Barrier

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Interconnect RC delay can be reduced by the use of a low resistivity copper metallization and a low dielectric constant material. Methyl-silsesquioxane (MSQ) based porous spin-on dielectric material is one of the leading candidates for the formation of the dual damascene copper and ultra low-k (ULK) interconnects. However, ULK dielectrics are prone to process interactions that give rise to yield and reliability issues [1]. Thus, before a ULK material can be used, it is necessary to evaluate its suitability and stability for the various process steps in the formation of dual damascene structures in a ULK process integration scheme. Plasma etching and photoresist stripping are two critical processes influencing the physical, chemical and electrical properties of the ULK materials.

In this study, a detailed investigation has been carried out to study the impact of etching and stripping plasma chemistries on the properties of a MSQ ULK material. The porous MSQ film was subjected to O_2, H_2/N_2, H_2/He, CH_2F_2, C_4F_8 and a combination of C_4F_8 and H_2/He plasma treatments. After plasma exposure, the changes in film properties were characterized by AFM, TEM, FTIR, XPS and XRD techniques. It was found that the film surface roughness, wettability, dielectric constant, chemical bonding and elemental composition varied with the type of plasma treatment. The depletion of carbon and the corresponding change in the dielectric constant of the film was found to be dependent on the plasma treatment conditions. In particular, the surface roughness and the dielectric constant of the films were found to be higher for films treated with fluorine based plasma chemistries.

Dry etching of ULK materials is also known to affect the properties of copper and tantalum (Ta) based barrier films [2]. In the second part of this study, a 150 Å Ta barrier film was deposited onto the plasma treated ULK MSQ films by physical vapor deposition to study their effects on the microstructure of the Ta barrier layer. It was found that fluorine based plasma treatments have a detrimental impact on the surface roughness of the ULK film and this influences the microstructure of the Ta barrier layer deposited on the surface of plasma treated ULK films. As deposited Ta films showed the β-Ta phase as evident from sheet resistance and XRD analysis. The microstructure of Ta films deposited on surfaces treated with etch plasma chemistries containing fluorine was different from Ta films deposited on untreated MSQ film surface and surfaces treated with non-fluorine based O_2, H_2/N_2 and H_2/He plasmas. The sheet resistance of Ta film deposited on surface treated with CH_2F_2 based chemistry was extremely high in comparison with Ta deposited on other surfaces. This indicated thinning of the Ta film due to diffusion of Ta into the pores and micro-channels formed after the etching of porous dielectric film (Fig. 1). The surface roughness of the porous ULK was reduced by depositing a very thin dielectric barrier layer of SiC underneath the Ta barrier film and its effect on the Ta microstructure was studied. This thin dielectric barrier film reduced the surface roughness by acting as a sealing layer for the porous ULK films. However, the microstructure of Ta film was found to have changed with a peak corresponding to β-Ta (002) phase absent in Ta films deposited on these surfaces (Fig. 2). A possible mechanism for the development of microstructure in Ta films on MSQ surfaces treated with fluorocarbon plasmas will be described.

References:
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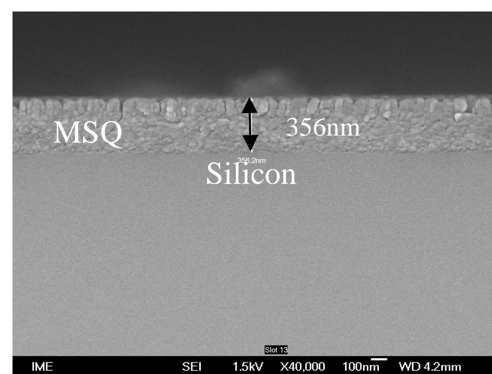

Fig. 1 Micro-channel formation on porous MSQ film after C_4F_8 containing etching plasma treatment causing increase in surface roughness

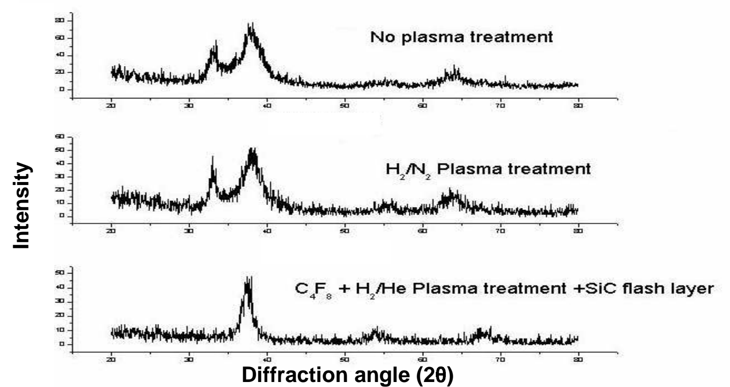

Fig. 2 Change in the micro-structure of Ta film deposited on surface treated with fluorine containing plasma chemistry as compared to untreated surface or non-fluorine based plasma chemistry treatments