Characterization of Patterned SiOC film by STEM-VEELS at Lower (80kV) Acceleration Energy

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Abstract

Electron Energy Loss Spectroscopy (EELS) equipped with Transmission Electron Microscope (TEM) at lower-kV has been carried out for precise characterization of nm-order structures of low-k interconnect dielectrics. Structural changes after plasma processes such as dry etch and ashing were characterized by using valence EELS (V-EELS) at lower accelerating voltage such as 80keV. Because the electron irradiation damage and the unexpected effects of Cerenkov radiation can be significantly ignored at low-kV VEELS, so that we could derive more precise dielectric constant profile than characterization at conventional 200 kV.

Introduction

For a rapid development of low-k materials in copper metallization for ULSI devices, nm-order characterization methods of low-k materials after several processes such as dry etching, metal sputter deposition are required to optimize materials and processes quickly. We have already proposed a dielectric constant measurement technique by VEELS [1]. Recently some difficulties were pointed out to measure the dielectric constant from VEELS [2] so that it is not an easy way to characterize damages in the low-k materials.

In this study, low accelerating voltage VEELS has been applied to eliminate electron beam damages and Cerenkov radiation loss in characterization of process damage in low-k materials with higher spatial resolution.

Experimental

A porous SiOC (p-SiOC) of k=2.4 patterned structure on a SiO2 layer with Cu interconnect (Ta/TaN barrier) was used for characterization. A TEM cross sectional specimen was prepared by a FIB method. The STEM-VEELS analysis was performed with JEOL ARM200 at 80keV, equipped with GATAN Imaging Filter (Quantum). Typical energy resolution was 0.4eV FWHM. EELS were recorded with the illumination semi-angle $\alpha$ of about 10.0 m-rad and the collection semi-angle $\beta$ of about 40 m-rad at probe diameter of 0.2nm. Specimen thickness $t$ was determined from the VEELS of SiO2 region by the log-ratio method [3], in this study absolute specimen thickness was 115nm. We assumed that the thickness of TEM specimen was constant by FIB thinning and normalized by thickness for Kramers-Kronig analysis (KKA) [4]. Regards to Cerenkov radiation loss, we ignored it because the low kV EELS such as at 80keV obtain information only from low refractive index materials [2].

Results and Discussion

Figure 1 shows a STEM image of the patterned SiOC structure with a Cu wiring and figure 2 shows spatially resolved VEELS loss functions from the sidewall of the Cu wiring to 25nm inner region of SiOC. In Fig.2, 2-3eV peaks gradually increased near the sidewall in the area of 10nm. In our previous study, Carbon composition gradually decreased in the area of 40nm [5]. So these peaks presumably appeared not because of the compositional change such as carbon depletion directly. In Figure 2, there was another broad intensity distribution around 5-6eV, which was not seen in loss function of SiO2. An origin of this peak is attributed to the existence of methyl group in the SiOC structure. The intensity of 5-6eV was gradually decreased and slightly shifted to higher energy close to the sidewall.

Fig. 1. Bright field STEM image of the patterned p-SiOC film.
Fig. 3 shows complex dielectric function, real part ($\varepsilon_1$) and imaginary part ($\varepsilon_2$). In $\varepsilon_1$, there were critical changes of 0-2eV profiles at the positions of 3-10nm from the sidewall. The value of $\varepsilon_1$ at energy = 0 means “so-called” dielectric constant $k$, so $k$ values are increased close to the sidewall in the area of 10nm. Figure 4 shows the $k$ value profile from the VEELS-KKA result. It clearly shows the increase of $k$ values by the process damage, which is not equal to the region of the carbon depletion.

**Conclusion**

Using the low-kV (80keV) STEM-VEELS technique, process damages of patterned p-SiOC film have been successfully characterized for the first time. The characterization is not affected by Cerenkov radiation loss, and precise dielectric constant profile was derived by KKA. Of course dielectric constant by high energy electron measurement such as TEM only gives electron polarization intensity inherently, however it is useful to characterize the electrical damage structures at high spatial resolution. At the adjacent of the side wall, the peak at 2eV is significantly increased in $\varepsilon_2$, it assumed that defects such as silicon dangling bonds were generated during the Cu/Low-k processing. It has been demonstrated that the combination of conventional composition analysis and VEELS at low-kV (80keV) is very useful for characterization of the damages in the patterned Cu / low-k interconnect structure for advanced ULSI processing because the electron irradiation damage and the unexpected effects of Cerenkov radiation can be significantly ignored.

**References**