Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.290-291

C-5-1 (Invited)

Nano-meter order Structures of Porous Low-k Films and their Impacts on Cu/Low-k Processes

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Abstract

nm-order structures of porous low-k films have been successfully characterized by a transmission electron microscopy (TEM). Two proposed applications will be presented in this paper. Using a TEM tomographic technique, 3-dimensional structures of pores in porous low-k films have been quantitatively evaluated and it was shown how the pore structures influenced on materials penetration phenomena into the porous structures. A valence electron energy loss spectroscopy (V-EELS) combined with a scanning TEM (STEM) clearly showed distributions or change of dielectric constants in the porous low-k trench structures with nm-order spatial resolution induced by plasma processes such as dry etch and ash without any change in composition.

Introduction

Porous low-k films have been investigated[(1)] as one of key materials for logic devices. However porous low-k films have several problems such as poor mechanical properties and plasma damages because of their mechanical and electronic structures, so developments of characterization methods for those have been expected.

In this paper, 3-dimentional (3-D) mechanical structures of pores and their spatial distribution, which affect mechanical properties of the porous low-k films [(2)] [(3)], and electronic structures of trench patterned porous low-k films which reflect dielectric constants will be presented using the newly proposed 3-D TEM and STEM / V-EELS [(4)(5)], respectively, correlated with their impacts on Cu / low-k processes.

3-D structures of pores by the 3-D TEM technique

Two types of porous poly-methylsiloxane (MSX) low-k dielectrics (Type A and Type B, k=2.5, Porosity ~30%) were prepared on 300mm wafers with adequate cure treatments after spin coating. The porous MSX specimen were prepared for the TEM observation, and two or several tens images were taken by tilting the specimen at +/- several angles (a stereo-TEM) or from low to high angle (a TEM tomography) with adequate observation conditions and then 3-D reconstructions with quantitative analyses of the images were performed [(6)].

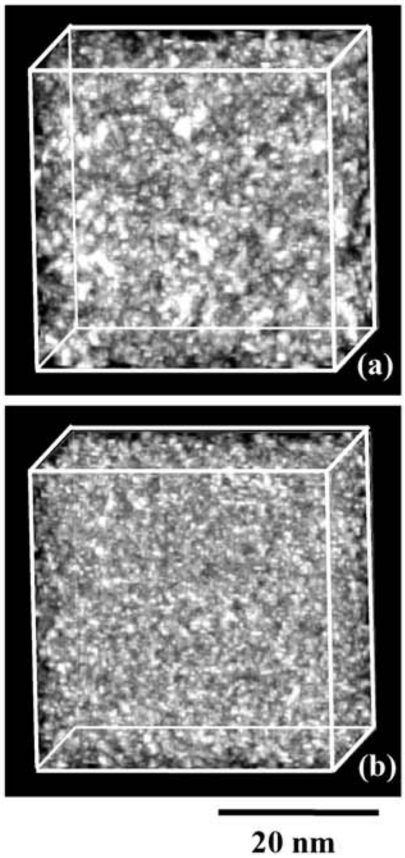

Fig. 1 3-D reconstruction images of vacant spaces, or pores, in Type A film (a) and Type B film (b).(From ref.(3))

Fig.1 shows 3-D reconstruction images of pores in porous low-k films using the TEM tomographic method with resolution less than 1 nm. In Fig.1, brighter contrast region shows vacant space or pores in the films. In Type A, the shape of pores was not spherical and all large pores are connected with relatively thick pipes, while in Type B, almost pores are isolated and only some of the small pores are connected. Maximum / population size of pores / maximum pore size (calculated as spherical here) and pipe size were as follows; 2.2 / 13nm and 1nm for Type A, 0.7 / 2.4nm and 0.3nm for Type B. Compared with Type A film, Type B film has significantly small pores and thin pipes with tight distribution in size.

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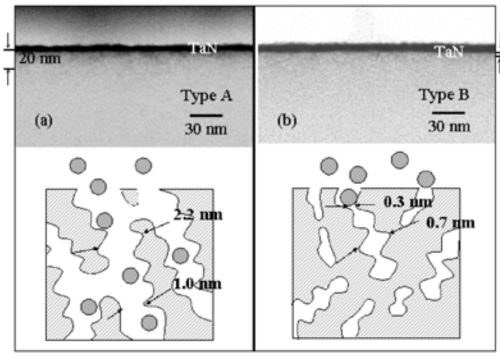

Fig. 2 Cross-section TEM images and penetration models of ALD-TaN materials penetration into (a) Type A and (b) Type B films. (From ref.(3))

Such pore structures behaved in quite different manners during the Cu/Low-k processing. For instance, as shown in Fig.2, different phenomena in ALD-TaN materials penetration were observed. Molecules of the ALD source gas of 0.9 nm diameter could pass into the pores easily and penetrated into a large region in Type A film because it had larger pores than the molecule size and all the pores were connected with thick pipes. On the other hand, Type B film which had smaller pores than the molecules with thinner pipe showed higher resistance for the penetration into the porous structure.

Dielectric constants by STEM / V-EELS technique

To characterize electronic structures of the porous low-k films, V-EELS was mainly studied at a 0 - 20 eV region as shown in Fig.3 in stead of higher energy than 50 eV (conventional EELS) to characterize compositions which has been applied widely [(7)]. V-EELS reflects optical constants (refractive index or dielectric constants) and electronic density of state (DOS). V-EELS spectra were obtained from the porous MSX trench patterned structures with nm-scale spatial resolution combined with STEM. Three kinds of gas ashing with O_2, NH_3 or H_2/He were carried out after the trench dry etch [(8)]. Kramers -Kronig analysis (KKA) [(9)] has been applied to estimate dielectric constants from the obtained V-EELS spectra.

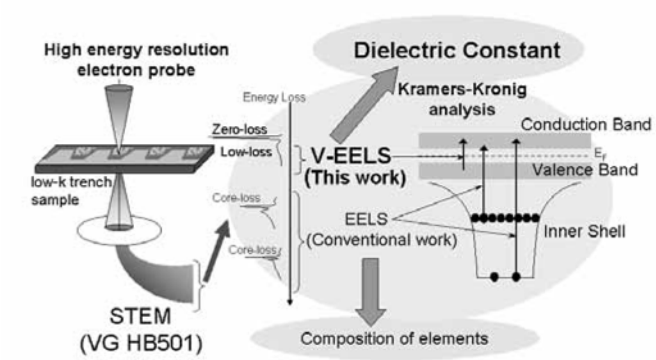

Fig. 3 Schematic diagram of STEM / V-EELS. (From ref.(5))

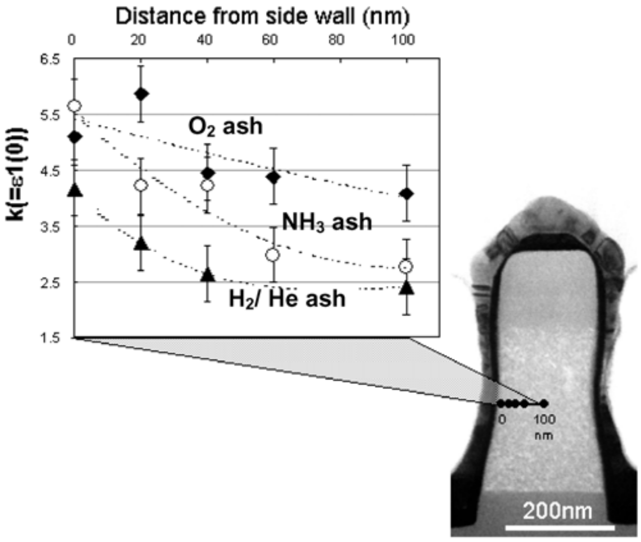

Fig.4 Distributions of dielectric constants in trench patterned porous MSX films. (From ref.(5))

Fig.4 shows distributions of calculated dielectric constants from the side wall to the center region of the trench patterned porous MSX structures with a STEM photograph of the sample, in which measured points were marked. V-EELS spectra were obtained at distances of 0, 20nm, 40nm, 60nm, 100nm (center of the MSX) from the side wall. It is clear that dielectric constants increased gradually from the center area toward to the edge area and that the dielectric constants close to the side wall showed higher value than that at the center region. The increase was presumably occurred by damage in electronic structures from the ashing processes and it is clear that the damage depended on the ashing gas species, while no change was observed in chemical compositions of the MSX films by means of the conventional EELS.

Conclusion

Using the TEM techniques, the 3-D mechanical structure analyses of pores and the characterization of 2-D distribution of dielectric constants in patterned low-k structures with nm-order spatial resolution have been demonstrated. It revealed that the nm-order structures of pores strongly correlate with the material penetration into the pores and that the plasma damages distributed in the dry-etched / ashed trench structures.

References

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