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Periodic Mesoporous Silicate Glass as Low-k Thin Film

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1. Introduction

Reducing interconnect capacitance is increasingly a more important issue in order to fabricate high-speed ULSI beyond sub-130 nm technology node. Under the constant operation speed of device, the reduction of interconnect capacitance leads to development of low power dissipation devices. In this way, lowering power dissipation as well as increasing speed of devices requires intermetal dielectric films with lower dielectric constant. Conventional technologies in fabricating low dielectric films are described as follows: (1) addition of fluorine to inorganic silica; (2) application of organic low dielectric materials; (3) intentional introduction of pores (air) into dielectric materials. There are, however, crucial problems among the above-noted technologies: (1) due to limit of amount of fluorine added, the resultant decrease in dielectric constant is at most 10~15%; (2) because of low thermal conductivity of organic insulator, wiring resistance can significantly increase due to the low heat dissipation property; (3) owing to the randomness of the structure and the size distribution of pores, mechanical strength of thus prepared porous dielectric is low. Technology in introduction of pores into dielectric film must be brushed up for development of low-k (k=1.5) in sub-100 nm technology node [1]. This paper describes periodic mesoporous silicate glass as low-k thin film.

2. Experimental

Periodic mesoporous silicate glass thin films were produced on silicon substrate by a sol-gel process from TEOS and water containing precursor [2,3]. The thus deposited films were annealed. The films were characterized by FT-IR (Fourier-transform infrared) spectroscopy, XRD (X-ray diffraction) analysis, TEM (transmittance electron microscopy) observation, ED (electron diffraction) analysis. Electrical characterization has been performed by leakage current, breakdown voltage and C-V measurement.

3. Results and Discussion

All the data shown in this section were obtained for the annealed mesoporous silicate film on silicon substrate. A typical FT-IR spectrum is shown in Figure 1. Absorption peaks ascribed to SiO-H (~3700, 3300~3500 cm^{-1}), Si-O (~1080cm^{-1}) were observed. Absorption band assigned to SiO-H is negligibly small, indicating this mesoporous silica has good resistance against water adsorption. When this mesoporous silica film is immersed into distilled water followed by air-dried for a day, FT-IR spectrum of the thus treated film remains almost unchanged (not shown). Figure 2 shows XRD pattern of the mesoporous silicate glass film. There is a sharp diffraction peak at $2\theta = 2.15^\circ$. This diffraction peak corresponds to (100) reflection. From this peak position, d-spacing (distance between diffractive planes) of this periodic structure is estimated to be 4.1 nm. To elucidate the origin of sharp XRD peak, TEM observation was carried out. Figure 3 shows a cross-sectional TEM image of mesoporous silica film on silicon. This photo reveals that pores introduced into silica are hexagonally arranged. Additional evidence for hexagonal structure of pores is an ED pattern inserted in Figure 3. Evaluated d-spacing and pore diameter in this TEM image are around 4.0 nm and 3.8 nm, respectively. This hexagonal porous structure is not transformed under the 30-min irradiation of electron beam (accelerating voltage = 200 kV), indicating the stability of this structure. Another TEM image gives intriguing information on structure of periodic mesoporous silica film (Figure 4). Figure 4 shows three domains of periodic mesoporous silica (domains are denoted by A, B and C). Together with XRD analysis, it is considered from TEM results that all the domains contain tube-like pores parallel to silicon substrate. Based on structural analysis from TEM observation, the percentage of pore volume introduced into silica film is evaluated to be ~70% and so the expected dielectric constant is between 1.9 and 1.3.

4. Conclusions

Mesoporous silica thin film with periodic porous structure has been successfully synthesized on silicon substrate. XRD, TEM and ED analyses proved that stable hexagonally assembled tube-like pores with a finite domain size are introduced into silica film. The porosity of this mesoporous silica film has been evaluated to be ~70%. This result implies ultra low-k dielectric with sufficient mechanical strength.

References

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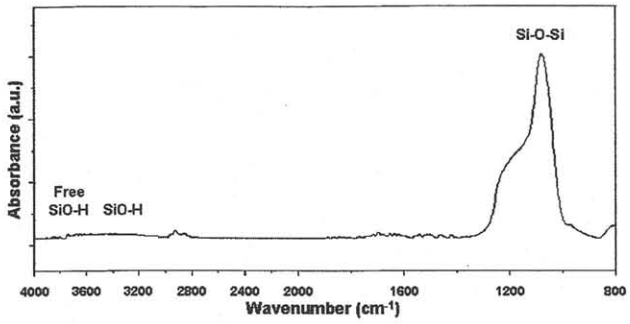

Fig. 1 FT-IR spectrum of mesoporous silicate glass film deposited on Si substrate.

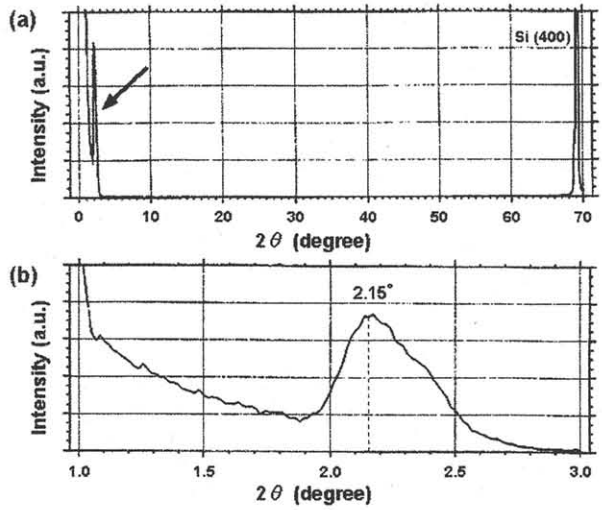

Fig. 2 X-ray diffraction patterns of mesoporous silicate glass film deposited on Si substrate. (a) A sharp peak of mesoporous silica is marked by solid arrow. The marked XRD peak is shown in detail in (B).

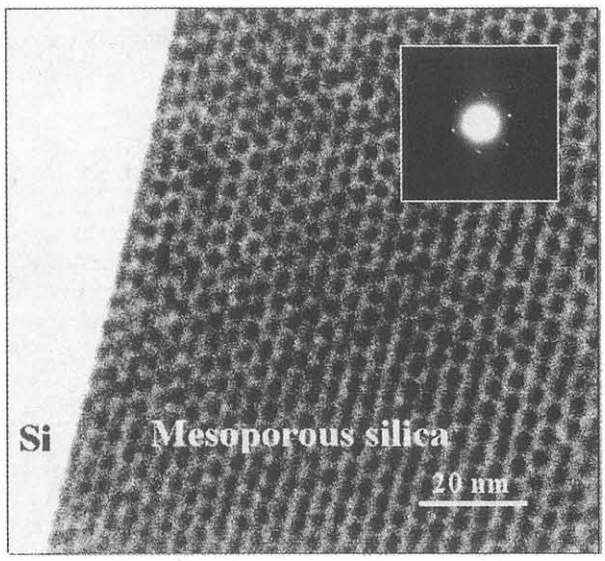

Fig. 3 Cross-sectional TEM photograph of mesoporous silicate glass film deposited on Si substrate. ED pattern is also inserted in this figure.

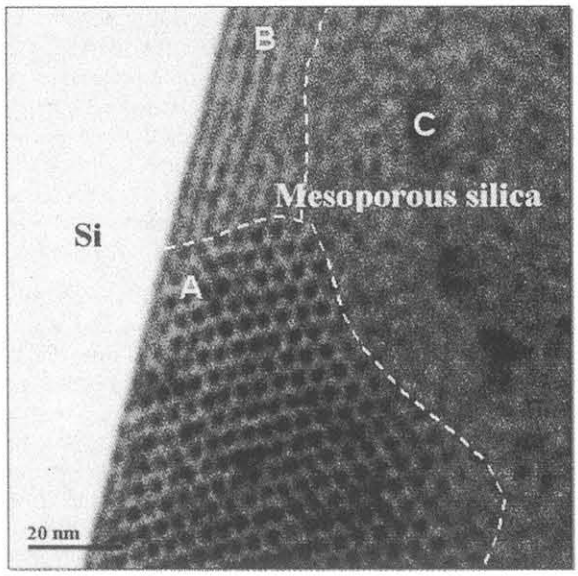

Fig. 4 Cross-sectional TEM photograph revealing domains (white broken lines are guided for eyes) of mesoporous silicate glass film deposited on Si substrate.