Formation of ultra-low dielectric constant film by non-thermal laser deposition

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Semiconductor devices have been miniaturized to achieve improved performance in large-scale integration (LSI). However, the RC delay, caused by the wiring resistance and capacitance between the wires, was not improved by miniaturization. To improve the RC delay, the dielectric constant (k) of the interlayer dielectrics must be decreased. We focused on pulsed laser deposition (PLD) as a novel low-k film formation process. In PLD, nanoparticles can be deposited to form nanoporous films. Theoretical calculations suggest that the smaller the size of the nanoparticles, the lower the dielectric constant, owing to the quantum confinement effect [1]. Therefore, we believe that ultra-low-k films can be formed by depositing smaller nanoparticles. We attempted PLD using a deep ultraviolet laser with high photon energy for the efficient ablation of dielectric materials with a high bandgap and investigated the size of the deposited nanoparticles.

We formed nanoporous films using three combinations of lasers and materials: (a) the F_2 laser and SiO_2, (b) the ArF excimer laser and SiO_2, and (c) the ArF excimer laser and Al_2O_3. The repetition frequency was 100 Hz, and the ambient gas and fluence were as follows: (a) Ar, 10 J/cm^2; (b) O_2, 6 J/cm^2; and (c) O_2, 6 J/cm^2.

The size distribution of the deposited nanoparticles was analyzed, and the particle sizes with the highest deposition rate were as follows: (a) 0.75–1.0 nm; (b) 1.0–1.25 nm; and (c) 2.5–2.75 nm. We calculated the Gibbs free energy of the nanoparticles and determined the critical particle size that separated particle growth and decay in the thermal equilibrium process. The calculated critical particle sizes were approximately 1.3 nm for SiO_2 and 1.5 nm for Al_2O_3. In Fig. 1(b), the orange area shows the presence of particles of size larger than the critical particle size, indicating that the particles grew during the thermal equilibrium process. In Fig. 1 (a), the green and red areas show the presence of nanoparticles of size below the critical particle size that normally cannot exist as particles and would decay. This result may be attributed to the fact that ablation is a non-thermal equilibrium process. Non-thermal ablation can generate particles of size smaller than the critical particle size. Therefore, by non-thermal ablation, PLD can deposit smaller nanoparticles and form ultra-low-k films owing to the quantum confinement effect.

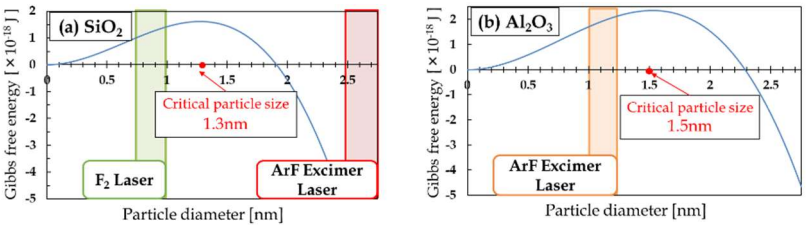

Fig.1 Size distribution of the deposited nanoparticles and calculation results for the Gibbs free energy and critical particle size of (a) SiO2 and (b) Al2O3.

Reference: [1] Raphael Tsu, Davorin Babić and Liderio Ioriatti, J. Appl. Phys. 82 (3), 1327-1229 (1997)