Thermal Reactions of Cu/Fluorinated Silicon Oxide and Cu/Organosilicate Glasses on Silicon

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In order to obtain an interconnection system with small RC (resistance-capacitance) delay, replacement of the aluminum with copper and the application of low dielectric constant (low-k) materials are inevitable. Fluorinated silicon oxide (FSG) produced by PECVD has been a widely accepted low-k material. However, its dielectric constant is not low enough for 0.13 μm devices. Organosilicate glasses (OSG), also produced by PECVD, are current potential dielectric materials for 0.13 μm generation. Because copper is a fast diffusion species in silicon and silicon dioxide, it shall also diffuse rapidly into FSG and OSG. Thus it is important to characterize the interface diffusion and/or reaction between copper and FSG or OSG. In this work, we investigate the thermal reactions of Cu/FSG and Cu/OSG bilayered structures, bother deposited on bare Si.

The FSG and OSG films, 280 nm in thickness, were deposited on Si wafer at Applied Materials, Taiwan (in a single wafer, parallel-plate plasma CVD system based on Applied Materials Producer process chamber). All samples had been baked at 400 °C in N_2 atmosphere before Cu deposition (to ensure no moisture remaining at film surface during the transportation). The Cu films (180 nm) were prepared using sputtering at a negative substrate bias. After deposition, Cu/FSG/<Si> and Cu/OSG/<Si> samples were annealed in vacuum (with Ti foils to reduce residual oxygen) at temperatures ranging from 400 °C to 800 °C, with an interval of 100 °C, at 2×10^{-5} Torr for 1 hr to investigate their thermal reactions.

All samples before and after annealing were characterized with four-point probe for sheet resistance. Figure 1 shows the sheet resistances of Cu/FSG/<Si> and Cu/OSG/<Si> as a function of annealing temperature. In comparison with the values of as-deposited samples, the sheet resistances of both systems were lowered after annealing at 400 °C. This is mainly attributed to the grain growth and defect annihilation of the Cu films. However, the sheet resistance is generally higher for Cu/FSG/<Si> than for Cu/OSG/<Si>. It may be related with a minor interfacial reaction of fluorine atoms in FSG with Cu.

Increase in sheet resistance of both systems is observed after annealing at 800 °C. However, the degree of increase is more significant for Cu/FSG/<Si> than Cu/OSG/<Si>. In order to understand the difference in the resistance variation for these samples, both types of samples were further investigated by glancing incident angle x-ray diffraction (GIAXRD), scanning electron microscopy (SEM) and Auger electron spectrometry (AES) for phase formation, surface morphology and compositional distribution in depth.

AES depth profiles of Cu/FSG/<Si> after annealing at 800 °C are showed in Fig. 2. After 800 °C annealing, the Cu, Si and O AES signals are very slanting at the interface, indicating that a severe reaction had occurred in the sample. In addition, SEM micrograph shows that significant holes of irregular shape had appeared on the surface of Cu/FSG/<Si> after annealing at 800 °C.

On the other hand, by using SEM, only scattered and small holes are seen on the surface of the 800 °C annealed Cu/OSG/<Si> sample. Figure 3 presents the AES depth profiles of Cu/OSG/<Si> after annealing at 800 °C. The Cu, Si, O profiles indicate of no significant reaction at the interface. The carbon signal appears all over the depth. Increase of sheet resistance for the 800 °C annealed Cu/OSG/<Si> sample shall be due to the carbon diffusion into copper.

In conclusion, thermal stability of Cu/OSG interface is evidently superior to that of Cu/FSG, in the temperature range of 400-800 °C. OSG is therefore a highly promising material for interconnection application.

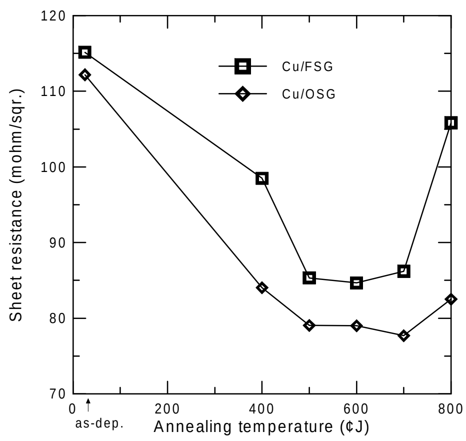

Fig.1 Sheet resistance of Cu/FSG/<Si> and Cu/OSG/<Si> as a function of annealing temperature.

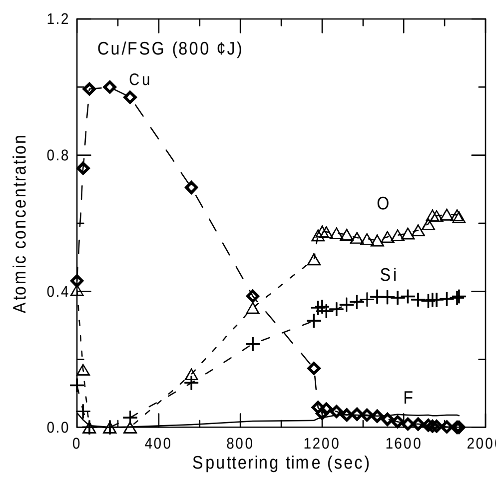

Fig.2 AES compositional depth profiles of Cu/FSG/<Si> after 800 °C annealing.

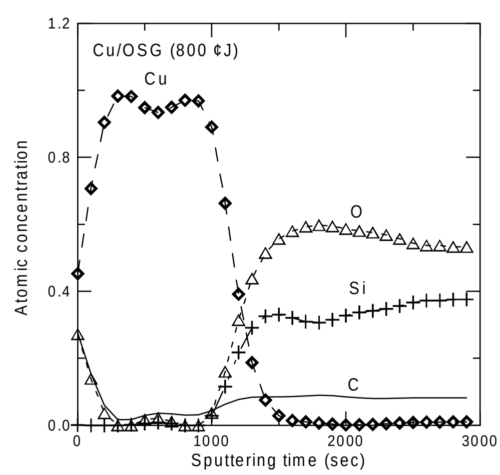

Fig.3 AES compositional depth profiles of Cu/OSG/<Si> after 800 °C annealing.