AMTC Letters
Vol. 1 (2008)

Microstructures of diluted Cu(Ti) Alloy Interconnects with Self-Formation of Thin Barrier Metal Layers

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Fabrication of Cu interconnects with thin uniform barrier metal layers is essential for integrated devices.[1] With reducing the device sizes, a contribution of the barrier layers to the effective interconnect resistivity becomes large. The low-resistance Cu alloy interconnects with self-formed the ultra-thin barrier layers is desirable. Among various Cu alloys, the diluted Cu(Ti) alloy is one of the most attractive materials and thin $TiSi_xO_y$ barrier layers were self-formed uniformly on the low-k oxide interfaces by annealing.[2] The purpose was to investigate the macrostructures of the Cu(Ti) interconnects with self-formed thin barrier layers, which was fabricated in SiO_2-based interlayers by high temperatures and pressure anneal processes.[3] The microstructures were observed by a cross-sectional scanning transmission electron microscopy (STEM) equipped with an energy dispersive X-ray spectroscopy (EDS).

Figure 1 shows cross-sectional STEM-EDS images of the interconnect fabricated by embedding the Cu(Ti)/Cu films into the trenches. The Cu(Ti)/Cu interfaces formed before annealing are not clearly observed with residual diffraction contrasts due to formation of misfit dislocations and lattice distortion as shown by arrows in Fig. 1(a). This obscure interfaces are formed by intermixing of the Cu(Ti) alloy and pure Cu films, i.e. outward diffusion of the Ti atoms in Cu(Ti) into both the film surfaces and oxide interfaces. Although a seam-void is observed to form just above the trench, the voids could be polished off by a chemical mechanical polishing. Figures 1(b) and 1(c) show EDS mapping images corresponded to the distribution of Cu and Ti, respectively. Copper fills the trench uniformly, and significant diffusion of Cu into the oxide layers is not observed although the diffusivity of Cu in SiO_2 is very high. On the other hand, titanium is observed to segregate at the trench bottom and sidewalls, and self-formation of the uniformly thin $TiSi_xO_y$ barrier layers by reacting of the diffused Ti atoms and the oxide interlayers is achieved as shown in Fig. 1(c). From these results, the self-formed layer was demonstrated to have excellent thermal stability. Figure 2 shows EDS spectrum profiles of the Cu(Ti) interconnects. The positions obtained the spectrum are marked by circles (a) and (b) in the inserted STEM image. The X-ray peaks corresponding to titanium were not observed in the spectrum at a triple point grain boundary in the trench interior as shown by arrows in Fig. 2(a). This result indicates that the concentration of Ti both in the Cu grains and at the grain boundaries is very small. Thus, the influence of electron scattering by the Ti atoms on the resistivity is expected to be small and the low-resistance interconnect is expected. The Ti, Si and O peaks are detected in the EDS spectrum of the trench sidewall region as shown in Fig. 2(b), indicating the $TiSi_xO_y$ barrier layers are self-formed. The adhesion of the barrier layers to the sidewalls in the present Cu(Ti) interconnects is expected to be stronger than that of the conventional Ta-based barrier layers.

In summary, Cu(Ti)/Cu films sequentially deposited on the wafers were successfully embedded in 0.1 μm-wide trenches, and the Cu(Ti) alloy interconnects with self-formed thin $TiSi_xO_y$ barrier metal layers were fabricated. This barrier layers were observed to have excellent thermal stability against Cu diffusion into the SiO_2-based low-k interlayers. In terms of the present self-formation of the barrier layers, binary Cu-Ti alloys could be applied as the seed layer materials in conventional processes.

References

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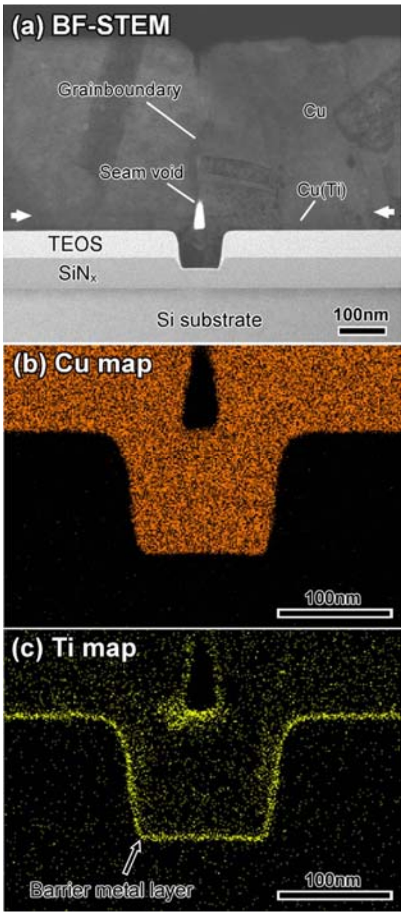

FIG. 1. Cross-sectional STEM-EDS images of the interconnect fabricated by embedding the Cu(Ti)/Cu films into the trench; (a) bright-field STEM image, and EDS elemental mapping image of (b) copper and (c) titanium.

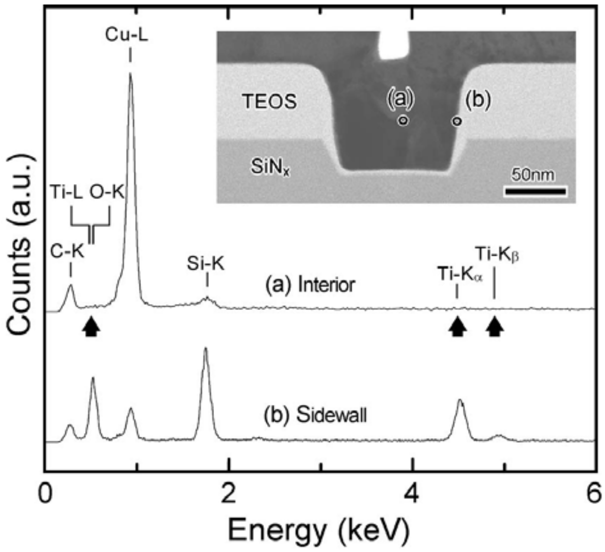

FIG. 2. EDS spectrum profiles obtained from the regions of (a) the trench interior and (b) the oxide interface, which are marked by circles in the STEM image inserted in the figure.