A bilayer diffusion barrier of atomic layer deposited (ALD)-Ru/ALD-TaCN for direct plating of Cu

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Abstract : As semiconductor devices are scaled down for better performance and more functionality, the Cu-based interconnects suffer from the increase of the resistivity of the Cu wires. The resistivity increase, which is attributed to the electron scattering from grain boundaries and interfaces, needs to be addressed in order to further scale down semiconductor devices [1]. The increase in the resistivity of the interconnect can be alleviated by increasing the grain size of electroplating (EP)-Cu or by modifying the Cu surface [1]. Another possible solution is to maximize the portion of the EP-Cu volume in the vias or damascene structures with the conformal diffusion barrier and seed layer by optimizing their deposition processes during Cu interconnect fabrication, which are currently ionized physical vapor deposition (IPVD)-based Ta/TaN bilayer and IPVD-Cu, respectively. The use of *in-situ* etching, during IPVD of the barrier or the seed layer, has been effective in enlarging the trench volume where the Cu is filled, resulting in improved reliability and performance of the Cu-based interconnect. However, the application of IPVD technology is expected to be limited eventually because of poor sidewall step coverage and the narrow top part of the damascene structures.

Recently, Ru has been suggested as a diffusion barrier that is compatible with the direct plating of Cu [2-3]. A single-layer diffusion barrier for the direct plating of Cu is desirable to optimize the resistance of the Cu interconnects because it eliminates the Cu-seed layer. However, previous studies have shown that the Ru by itself is not a suitable diffusion barrier for Cu metallization [4-6]. Thus, the diffusion barrier performance of the Ru film should be improved in order for it to be successfully incorporated as a seed layer/barrier layer for the direct plating of Cu. The improvement of its barrier performance, by modifying the Ru microstructure from columnar to amorphous (by incorporating the N into Ru during PVD), has been previously reported [7]. Another approach for improving the barrier performance of the Ru film is to use Ru as a just seed layer and combine it with superior materials to function as a diffusion barrier against the Cu. A Ru/TaN bilayer prepared by PVD has recently been suggested as a seed layer/diffusion barrier for Cu. This bilayer was stable between the Cu and Si after annealing at 700 °C for 1 min [8]. Although these reports dealt with the possible applications of Ru for Cu metallization, cases where the Ru film was prepared by atomic layer deposition (ALD) have not been identified. These are important because of ALD's excellent conformality.

In this study, a bilayer diffusion barrier of Ru/TaCN prepared by ALD was investigated. As the addition of the third element into the transition metal nitride disrupts the crystal lattice and leads to the formation of a stable ternary amorphous material, as indicated by Nicolet [9], ALD-TaCN is expected to improve the diffusion barrier performance of the ALD-Ru against Cu. Ru was deposited by a sequential supply of *bis*(ethylcyclopentadienyl)ruthenium [$Ru(EtCp)_2$] and NH_3plasma and TaCN by a sequential supply of $(NEt_2)_3Ta{=}Nbu^t$ (*tert*-butylimido-trisdiethylamido-tantalum, TBTDET) and H_2 plasma. Sheet resistance measurements, X-ray diffractometry (XRD), and Auger electron spectroscopy (AES) analysis showed that the bilayer diffusion barriers of ALD-Ru (12 nm)/ALD-TaCN (2 nm) and ALD-Ru (4nm)/ALD-TaCN (2 nm) prevented the Cu diffusion up to annealing temperatures of 600 and 550 °C for 30 min, respectively. This is found to be due to the excellent diffusion barrier performance of the ALD-TaCN film against the Cu, due to it having an amorphous structure. A 5-nm-thick ALD-TaCN film was even stable up to annealing at 650 °C between Cu and Si. Transmission electron microscopy (TEM) investigation combined with energy dispersive spectroscopy (EDS) analysis revealed that the ALD-Ru/ALD-TaCN diffusion barrier failed by the Cu diffusion through the bilayer into the Si substrate. This is due to the ALD-TaCN interlayer preventing the interfacial reaction between the Ru and Si.

Key Words : Cu Metallization, Diffusion Barrier, Atomic Layer Deposition, Ru, TaCN

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