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Cu-Resistivity and Intrinsic EM-Reliability Study in Ta/Cu, Co/Cu and Ru/Cu Systems for Advanced BEOL Cu-Interconnections

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Abstract

The Cu resistivity and the intrinsic electromigration performance of Ta/Cu, Co/Cu and Ru/Cu systems were experimentally studied for Cu thickness in the range between 10 and 20 nm. The Cu resistivity was comparable on Ta and Co liners but higher on Ru liners. The lower Cu resistivity can be attributed to significantly larger Cu grain sizes found on Ta and Co liners than on Ru liners, resulting in reduced electron scattering at Cu grain boundaries. Furthermore, it was found that both Co and Ru liners are electromigration boosters with respect to Ta liners with a larger impact for the Ru liner. Thus, both Co and Ru liners can be considered as candidates to extend Cu interconnections.

1. Introduction

Continuous technology scaling has led to the constant reduction of film thicknesses in Cu interconnects, making the continuity/integrity of the individual layers used in Cu interconnect metallization marginal. In the case of PVD Cu seed layers, this marginality leads to poor Cu ECP fill performance, which results in void formation within the interconnects and eventually to reliability issues and failures at the circuit level. To overcome this issue, the replacement of the conventional Ta liner by Co or Ru liners was suggested [1], [2]. In these reports, the benefit of Co and Ru liners over Ta liners was attributed to improved Cu adhesion and wetting, leading to better PVD Cu seed continuity and coverage. Such an enhancement layer also allow for PVD Cu seed reflow, either to fill narrow features or to widen the Cu ECP fill process window. The aim of this work is to assess the Cu resistivity and the intrinsic electromigration (EM) performance in Ta/Cu, Co/Cu, and Ru/Cu systems from a systematic experimental approach, both using damascene and blanket vehicles.

2. Experimental

The Cu resistivity was investigated as a function of the liner material using both single damascene (SD) and blanket layer approaches. The SD vehicle consisted of 44-nm-pitch Cu metal lines formed within a low-k dielectric material (k = 2.4). TaN/Co, TaN/Ru, and Mn/Ru systems were used as barrier/liner stacks. In such structures, the Cu resistivity was determined as a function of the Cu area using a methodology based on the temperature coefficient of the resistance (TCR) [3]. In blanket-level experiments, stacks mimicking the damascene structures were used. The stacks consisted of a PVD Cu layer with nominal thicknesses of 10 nm, 15 nm, or 20 nm, encapsulated at each side by barrier/liner stack of TaN/Ta, TaN/Co, or TaN/Ru. In all cases, the liner was in contact with the Cu surface at both sides. The thickness of the TaN barrier was 3 nm for all the samples. The liner thicknesses were varied between 1 and 5 nm. Finally, the stack was capped with a SiCN layer. Subsequently, the Cu thickness, resistivity and microstructure were characterized by Rutherford backscattering spectrometry (RBS), sheet resistance (Rs), and both symmetric and grazing-incidence x-ray diffraction (XRD, GIXRD) measurements. The intrinsic EM as a function of the liner was investigated at package level using 22 nm wide and 100 μm long single damascene structures at a temperature of 330 ^{0}C and a current density of 4.5 MA/cm^2. A resistance increase of 20 % resistance increase was defined as the failure criterion.

3. Results and Discussion

Figure 1 illustrates the Cu resistivity ρ_{Cu} as a function of the Cu area as determined by TCR method [3] for the SD structures. Co liners systematically led to lower Cu resistivity than Ru liners in a very wide range of Cu areas. To understand the root cause of this behavior, Cu resistivity and microstructure were assessed at blanket level, as described above. Figure 2 shows the Cu resistivity trend at blanket level as a function of the Cu thickness for the different liners (Ta, Co, Ru) on TaN barriers. The Cu resistivity was extracted from sheet resistance measurements of the stacks and corrected for liner contributions by extrapolating the liner thickness to zero. RBS measurements of the Cu thicknesses in the different stacks indicated a maximum thickness difference among all samples as low as 0.4 nm. Hence, the differences in sheet resistance cannot be attributed to variations in Cu thickness but must rather stem from variation in the Cu resistivity. Identical to the behavior of damascene structures, Co liners and Ta liners led to nearly identical Cu resistivity that were lower than for Ru liners. Figures 3a and 3b depict the XRD and GIXRD spectra of samples with 10 nm Cu films and different liners, respectively. Major differences in the Cu microstructure were observed as a function of the liner material. On Ta liners, Cu was highly (111) textured whereas Cu on Co and Ru liners was closer to a random polycrystal. Using the Scherrer equation, Cu grain sizes can be determined from the XRD patterns.

The average Cu grain size was about 8.9 nm on Ta, 8.5 nm on Co, and only 2.5 nm on Ru liners. At small dimensions, the main contributors to resistivity are electron scattering at grain boundaries and surfaces [4]. Our data thus suggest that the lower Cu resistivity on Ta and Co liners compared to Ru-liner can be attributed to the much larger Cu grain sizes, resulting in a lower probability for electron scattering at grain boundaries. Furthermore, the results indicate that Cu adatom mobility is larger on Ta and Co liners than on Ru-liner leading to larger Cu grain size during deposition [6]. Figure 4 illustrates the intrinsic EM performance, $t_{50\%}$ in SD structures for different barrier/liner/Cu systems investigated as a function of the thickness occupied by barrier/liner, T_{MB}, within the total trench width, W_{TRENCH}. The data indicate that both Co and Ru liners are EM boosters with respect to the Ta reference with a larger effect of Ru liners. Such an improved intrinsic EM reliability might be explained by an enhancement of Cu wetting on Co and Ru liners with respect to Ta liners, as discussed in [2]. Thus, despite the higher resulting Cu resistivity, the Ru liner should not be discarded for advanced interconnect technology nodes since a higher Cu resistivity can possibly be compensated by the use of a thinner liner, leading to lower line resistance in Cu damascene architectures [5] with benefit in intrinsic EM reliability.

4. Conclusions

The Cu resistivity and the intrinsic EM performance were experimentally investigated for Ta/Cu, Co/Cu and Ru/Cu liner/conductor systems for BEOL Cu interconnect applications. For Cu thicknesses in the range between 10 and 20 nm, Co and Ta liner led to comparable resistivity that was systematically lower than for Ru liners. The differences in Cu resistivity could be linked to significantly larger Cu grain sizes formed on Ta and Co liners compared to Ru liners, leading to reduced electron scattering at Cu grain boundaries. Moreover, it was found that both Co and Ru liners are EM boosters with respect to Ta liners with a larger impact for Ru liners. The results indicate that Co liners are very attractive to extend Cu interconnect technology. However, Ru liners should also not be ruled out due to their better intrinsic EM behavior and possibility to compensate for the higher Cu resistivity by the possible use of a thinner liner/barrier resulting in lower line resistance in advanced Cu damascene interconnects.

References

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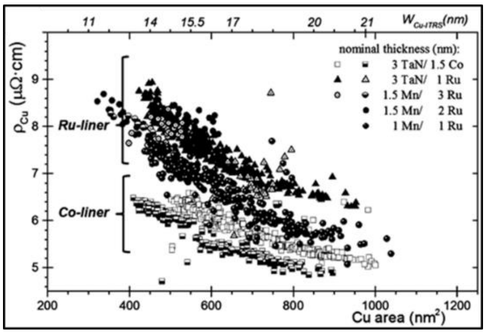

Figure 1. Cu resistivity, ρ_{Cu}, as a function of cross-sectional Cu area for barrier/liner stacks of TaN/Co, TaN/Ru, and Mn/Ru systems in single damascene Cu lines with CDs in the range of range between 22 and 32 nm.

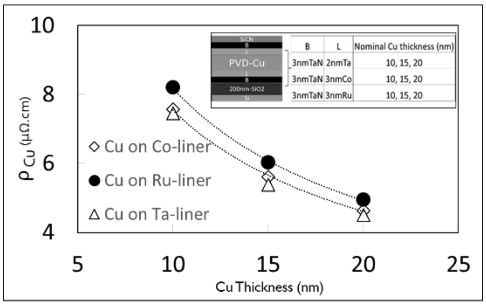

Figure 2. Cu resistivity variation as a function of the Cu thickness at blanket level, as described in the inserted table.

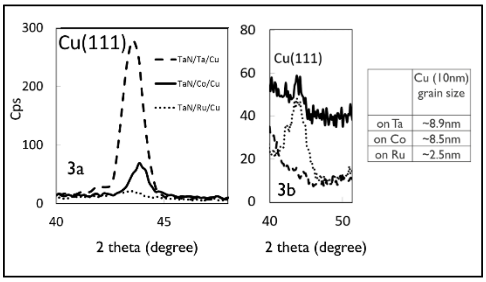

Figure 3. (a) XRD and (b) GIXRD spectra as measured for blanket stacks including 10-nm-thick Cu films.

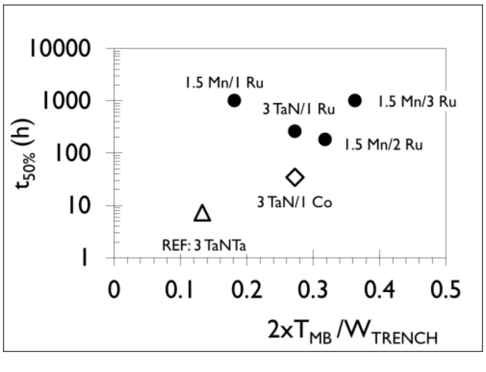

Figure 4. EM lifetime of SD interconnects for various barrier/liner/Cu systems, as indicated. Numbers indicate layer thicknesses in nm.