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Investigation of Barrier Property of Copper Manganese Alloy on Ruthenium

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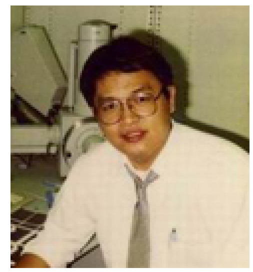

In this study, we investigated the properties of CuMn/Ru stack as barrier materials for next-generation Cu interconnects. CuMn has been proposed as a self-forming barrier, which generates a thin barrier layer between CuMn and SiO2 after annealing at 450 °C [1-4]. However, to achieve high thermal stability and low resistivity, the annealing time, temperature and the concentration of Mn atoms in CuMn alloy processes are strictly specified [5]. Therefore, a structure of CuMn with an underlayer, such as Ru or Ta, is proposed in this study to further increase the thermal stability and process tolerance of the CuMn alloy.

For the experiment, barrier materials were grown on SiO_2/p-Si (111) wafer with thermally oxidized SiO_2 (100 nm). Barrier materials including Ru, Ta and CuMn were deposited by single-target sputtering method, and the thicknesses of Ru, Ta, and CuMn were controlled at 20, 30, and 150 nm respectively. The Mn concentration in CuMn alloy is from 0%-10%. Rapid thermal annealing (RTA) was applied to anneal the stack-layer structures for 30 min and the samples were then taken to thermal stability test.

Fig. 1 shows atomic distribution of CuMn/SiO_2, CuMn/Ta/SiO_2 and CuMn/Ru/SiO_2 after 500 °C and 600 °C annealing, where the Mn concentration is 1% in CuMn alloy. The extension of Cu signal into the dielectric layer tells the barrier ability. We can observe when the annealing temperature was set at 500 °C, Cu atoms diffused into the dielectric layer in the CuMn/SiO_2 and CuMn/Ta/SiO_2 structures. In Fig. 1(d), the CuMn/Ru/SiO_2 structure prevents the diffusion of Cu atoms even after annealing at 600 °C for 30 min, which agrees with TEM observations in Fig. 2. The Mn atoms blocked the diffusion paths in the Ru layer, and enhanced the barrier properties. With increasing Mn content, the thermal stability improved. Fig. 2 show the TEM pictures of CuMn/Ru/SiO2 with different Mn concentration. From Fig. 2(a), we knows that pure Ru is not able to prevent the diffusion of Cu and some Cu atoms was observed at the interface between Ru and SiO2. The barrier properties improved with increasing Mn content, as shown in Fig. 2(b), where the diffusion of Mn can be observed instead of Cu. The CuMn/Ru structure prevented the diffusion of Cu, but the CuMn/Ta structure did not when the Mn concentration is 1%. Therefore, with a Ru layer, the amount of Mn in CuMn can be lower than that with a Ta layer. The number of diffusion paths in the Ru layer is lower than that in the Ta layer, thus only a few amount of Mn content can still fully block the path in Ru.

These results indicate that with an underlayer of Ru, the tolerance in Mn concentration become higher. The decrease in Mn content leads to a decrease in the resistance of the metal line, which is beneficial for the interconnect requirement and sequential electroplating processes. In conclusion, the decrease in the Mn content not only increases the conductance of the metal line but also reduces the number of excess Mn atoms in Cu after heat treatment. Thus, the CuMn/Ru/SiO_2 structure enhances not only the electrical properties but also adhesion and the barrier properties.

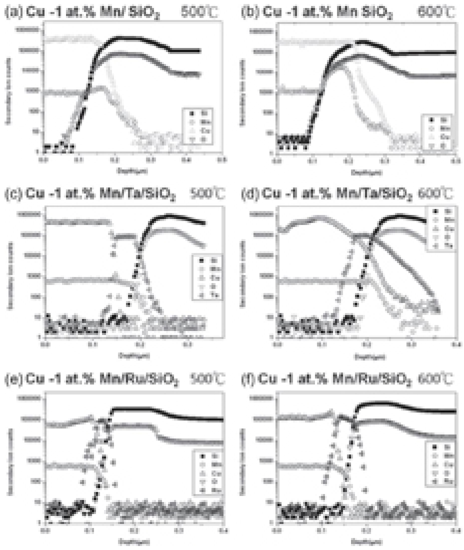

Figure 1. SIMS compositional depth profiles of (a) and (b) CuMn/SiO2, (c) and (d) CuMn/Ta/SiO2, and (e) and (f) CuMn/Ru/SiO2 with 1% Mn conctration after RTA process.

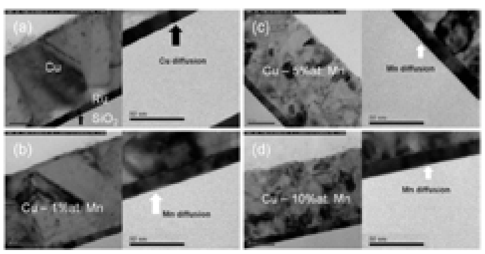

Figure 2. Cross-sectional TEM images of (a) Cu, (b) Cu–1 at.% Mn/Ru, (c) Cu–5 at.% Mn/Ru, and (d) Cu–10 at.% Mn/Ru samples after 500 ◦C RTA process

Reference:

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