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Composition dependence of morphology, electrical and mechanical properties of sputtered Cu-Mn alloy films

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For large scale integrated electronic devices Cu-Mn alloy is perspective contact and interconnect material [1]. As a result of the continuous decrease of device sizes in semiconductor industry the idea of self organized processes emerged. Cu-Mn alloy has been found a promising multicomponent system for this process. For interconnect materials various requirements exist including low resistivity, excellent diffusion barrier property and acceptable adhesion strength. Therefore the investigation of structure and morphology of Cu-Mn alloy films and their effect on electrical and mechanical properties is fundamental for the development of a reproducible technology. Consequently, analysing electrical and mechanical properties vs. composition curves is a plausible way of phase analysis and film characterisation.

Cu-Mn alloy films were prepared by co-deposition in an ultra-high-vacuum DC magnetron sputtering system onto SiO_2 and SiO_x substrates at room temperature. The base pressure was $<1x10^{-5}$ Pa, while the sputtering gas was Ar at $2x10^{-1}$ Pa pressure. The thickness of the films was about 1µm. Deposition rate corresponded to 0.4 nm/s. Composition of the films was controlled by calibrating deposition rates as a function of sputtering power. Nanoindentation was carried out in a UMIS 2000 nanoindenter using a Berkovich tip. In plane sheet resistance was measured by a conventional four-point probe in the temperature range of ~80-323 K. Cross-sectional specimens were prepared using low-energy Ar ion milling preceded by mechanical grinding. Structural and chemical characterisation was carried out in Philiphs CM20 and JEOL 3010 electron microscopes.

Phase transformations appear on specific resistivity curves as changes in the derivative. Figure 1. shows the specific resistivity of Cu-Mn films as a function of composition. A single maximum exists at 80 at% Mn corresponding to 205 µΩcm. Beside pure fcc Cu and pure αMn phases three one phase regions can be distinguished by a linear behaviour. In the low Mn content zone up to ~20 at% Mn a Cu based solid solution is formed. Between ~40-70 at% Mn an amorphous disordered structure can be observed as shown on Figure 2. While form ~80 at% Mn content αMn type solid solution forms. Deviations from the linear characteristic mark the two phase zones of the system. In both zones larger crystallites of the majority phase are surrounded by an amorphous Cu-Mn phase. In the region of ~30-40 at% Mn, crystallites have Cu based fcc structure while at ~70-80 at% Mn, αMn based grains can be found.

The temperature dependence of temperature coefficient of resistivity (TCR) is shown on Figure 3 for all samples with the exception of pure Cu. Since lattice distortions significantly decrease the conductivity of Cu based solid solutions TCR curves exhibit the characteristics of weakly conducting metals. In the 40-80 at% Mn region the TCR turns negative indicating the non-metallic nature of the alloy films in this composition range. In this region a local minimum of TCR can be observed in the temperature range of 273-310 K presumably due to a magnetic transformation [2]. As Mn content increases the location of this minimum shifts to lower temperatures. Meanwhile the TCR values decrease with the composition in the amorphous range, they increase when crystallites appear at 80 at% Mn.

Nanoindentation measurement shows a good correlation with the revealed phase regions. In the nanohardness vs. composition curve (indicated on Figure 4.) a single minimum exists at 40 at% Mn, the border of the disordered region. The curve shows a monotonous increase of hardness in the Cu based fcc region and from 40 at% up to 100 at% Mn as well.

1. J. Koike et al., Journal of Applied Physics 102 (2007), p. 043527.
2. P. A. Beck, Progress in Materials Science 23 (1980), p. 1.
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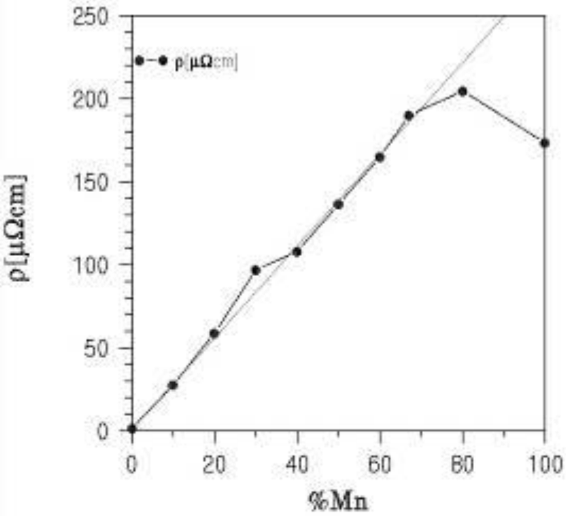

Figure 1. Specific resistivity of Cu-Mn alloy films as the function of composition at room temperature.

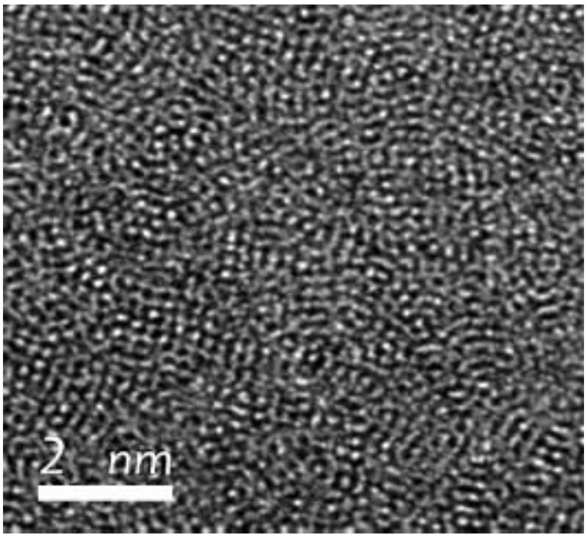

Figure. 2. High resolution image of 65 at% Mn alloy film.

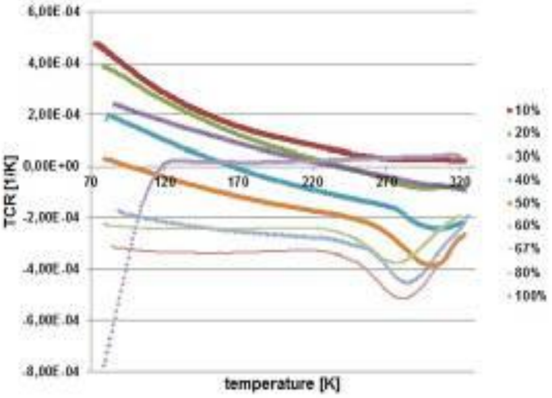

Figure 3. The temperature dependence of TCR of Cu-Mn alloy films in the temperature range of ~80-323 K.

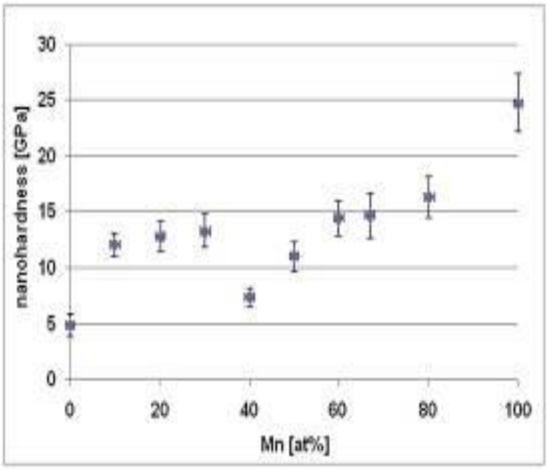

Figure 4. Nanohardness of Cu-Mn alloy films as a function of composition.