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COMMENT

Comment on the effects of overlayer thicknesses on the electrical resistivity of polycrystalline Cu/Cr double-layered thin films

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Abstract. The oscillatory behaviour of the electrical resistivity of Cu/Cr double layers where the Cr layer thickness is >7.5 nm has been attributed to the incommensurate–commensurate phase transition in Cr [1]. The present work shows that the resistivity variation is not due to the incommensurate–commensurate phase transition in Cr.

Recently Artunc [1] has reported on the observation of resistivity oscillations in Cu/Cr double layers in the temperature range 100 K to 300 K (where the layer thickness is >7.5 nm). For double layers with Cr layer thickness in the range 1.5–2.0 nm no oscillations were observed and the resistivity was found to decrease linearly with temperature. The observation of oscillations in the double layers with relatively thick Cr overlayers has been attributed to an incommensurate–commensurate (I–C) phase transition of the spin density wave (SDW) of Cr. However, our studies on Cu/Cr multilayers do not show any oscillatory behaviour of resistivity down to 30 K. Before discussing this specific point certain other aspects of Artunc's observations which are mentioned below need to be clarified and are equally important in understanding the electrical transport behaviour of Cu/Cr double layers.

(i) The transmitted electron diffraction patterns from the thin- and thick-Cr overlayer (2.0 nm and 9.5 nm respectively) double layers are shown in figures 1(a) and (b) of [1]. They clearly show the polycrystalline fine-grain nature of the microstructure in both the cases, as is correctly mentioned by Artunc. However, the diffraction behaviour appears rather contradictory. Generally, in plan-view transmission electron microscopy of thin films on substrates or base layers, the diffraction pattern will be a superposition of the diffraction behaviour of the top and bottom layers. As the overlayer thickness increases the contribution towards diffraction from the base layer decreases. In figure 1(a) this is clearly seen; the BCC rings pattern from the 2.0 nm thick Cr overlayer is superposed on the FCC rings pattern from the base Cu layer. However in figure 1(b) the Cr BCC rings pattern is either very weak or not clearly observed inspite of it being 9.5 nm thick.

(ii) From the results of Cu/Cr ($\leqslant 2.0$ nm) double layers Artunc concludes that the predominant scattering mechanisms contributing to the resistivity are surface scattering and grain boundary scattering with no contributions to scattering from the Cr/Cu interface. They find that the surface roughness parameter r_1 increases to ≈ 0.11 from 0 for the uncovered Cu surface while the interface roughness parameter r_2 is negligible in all the samples. This indicates that the absolute growth behaviour of Cr on Cu is not influenced by the Cu surface

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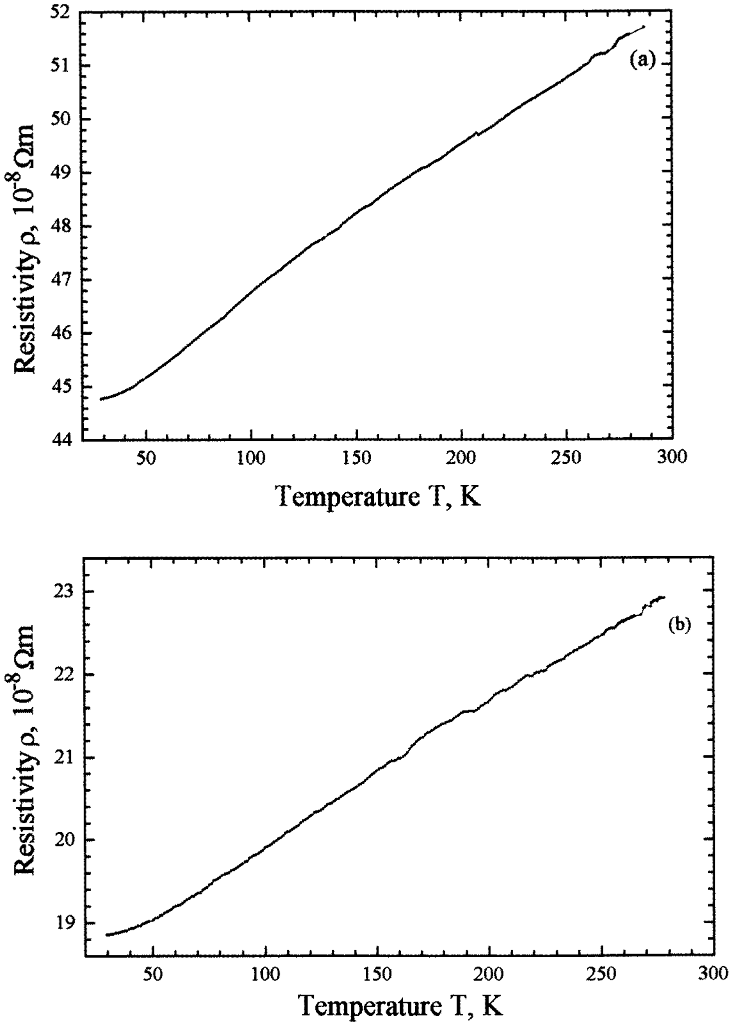

Figure 1. The variation of resistivity as a function of temperature for the periodic (a) and quasiperiodic (b) multilayers is shown. The thickness of the Cr layer in both the cases is 10 nm and the resistivity variation is linear with no oscillatory behaviour down to 40 K.

morphology (i.e. no interface roughness but only surface roughness), which is not true as the interface roughness in thin films is very much influenced by the surfaces. If it is indeed the case, then the apparent increase in resistivity can be explained simply as a result of the decrease in thickness of the Cu layer (figure 2 of [1]). The total resistivity ρ_f of the double layers in both cases, Cu/Cr-I and Cu/Cr-II, is significantly lower than the bulk resistivity of pure Cr, 12.9×10^{-8} Ωm. This in fact is again hard to understand because the resistivity of thin films is generally observed to be higher than the corresponding bulk value due to the presence of defects.

(iii) The observation of oscillations (figure 3 of [1]) in the Cu/Cr-II double layer films has been attributed to the I–C phase transition of the SDW in Cr. Cr is a typical antiferromagnet (AF) displaying SDW behaviour which has been extensively studied [2]. In the case of a single crystal, the paramagnetic phase undergoes a transition at 311 K (Néel temperature) to form a SDW AF-phase (AF_1). The wavelength of the SDW in the AF_1 phase is found to be typically 6.0 nm, incommensurate with the Cr crystal lattice. However, strain and grain size ($<$0.1 mm) in polycrystalline Cr powders were found to introduce a new *non-SDW* antiferromagnetic phase AF_0 in between the paramagnetic and AF_1 phases, which exists in the temperature range $\approx$200 K to 420 K [3]. Fitzsimmons *et al* [4] have recently found that AF is absent in grains $<$16 nm in size while in grains 73 nm in size it is only observed at 20 K. In the Cu/Cr-II double layers of Artunc the thickness of the Cr layer varies between 8.5 nm and 10.0 nm corresponding to grain sizes in the range 9.3 nm and 11.2 nm respectively (estimated using the simple relation $D = 1.12d$, mentioned in [1]). Since these values are $<$16 nm, there should be *no antiferromagnetism* in these double layers, let alone observation of an I–C transition of the SDW. Even if the estimated grain sizes are an order of magnitude less than the actual values, the Cr grains will still be in the AF_0 phase field region which does not have a SDW.

The electrical resistivity of Cu/Cr multilayers has been studied by us in the temperature range 30 K to 300 K and the results are shown in figure 1. The resistivity measurements were done under vacuum in a He closed-cycle refrigerator using the standard four-probe technique. A dc current of 0.1 mA delivered from a constant current source and a nanovoltmeter were used. The minimum voltage detected during the measurements is 30 nV. The level of accuracy is better than 0.1% in both the constant current source and the nanovoltmeter. The thickness of the individual layers, Cu and Cr in both the periodic (a) and quasiperiodic (b) multilayers is 10 nm each. The details of sample preparation are given in reference [5] and are similar to those used by Artunc [1]. The main objective of the work was to investigate the influence of size reduction and quasiperiodicity on the magnetic behaviour. However the electrical transport behaviour was also investigated and it was found that the resistivity decreases linearly with temperature down to 40 K in both the cases. The two dominant sources of scattering are the free surface scattering and the grain boundary scattering, with the temperature dependence coming from surface scattering. The difference in resistivity between the two cases is due to the fact that the top Cr layer is 10 nm thick in the periodic multilayer while that in the quasiperiodic multilayer is 20 nm thick (due to the specific construction procedure followed).

To summarize, it is clear both from our results and from the literature on the AF and SDW behaviour in pure Cr that the origin of resistivity oscillatory behaviour observed by Artunc [1] is *not due to* the I–C transition of the SDW in Cr.

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