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Journal of Magnetism and Magnetic Materials 226–230 (2001) 1631–1632

Journal of magnetism and magnetic materials

www.elsevier.com/locate/jmmm

Transport and magnetotransport properties of Co thin films on Si

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Abstract

Resistance, magnetoresistance and Hall effect were studied in sputtered cobalt films of varying thickness, deposited on silicon substrates, in the temperature range of 5–350 K and magnetic field up to 7 T. Contributions from both metallic cobalt and silicide layers are revealed. The latter undergo a metal–insulator transition in the temperature range of 260–280 K. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Magnetoresistance—thin films; Resistance; Hall effect

The interaction of cobalt thin films with silicon substrates has been intensively studied in relation to the problem of metallization of semiconductors in microelectronics technology by growing metallic $CoSi_2$ phase [1–3]. Magnetic properties of Co thin films on Si have also been studied [4,5]. In this work we report a study of transport and magnetotransport properties of thin Co films on Si. Co films of thicknesses 30, 160 and 440 Å were prepared by magnetron sputtering from a Co target onto a Si (1 0 0) substrate held near room temperature. Thickness was measured by RBS. We measured the resistance, magnetoresistance and the Hall effect in the van der Pauw geometry in the temperature range 5–350 K.

Fig. 1 shows effective resistivity as a function of temperature for three samples of different thicknesses. At low temperatures, a behavior typical of metallic thin films is observed. However, resistance drops in the range 230–280 K. The most dramatic drop, by a factor of 4.5, is seen in the thinnest sample (30 Å). We interpret it as due to an insulator–to–metal transition in a cobalt silicide layer which is formed at the interface during deposition. We use the term 'effective resistivity' as it refers to a double-layered structure. Similar unusual behavior of resistance has been observed before in Ti/Si thin films [6].

Fig. 2 shows effective resistivity (a) and Hall resistivity (b) for the 440 Å thick sample. At low temperatures (5–260 K), the sample shows anisotropic magnetoresistance and extraordinary Hall effect [7] typical of ferromagnetic cobalt. Magnetoresistance is negative. The extraordinary part of the Hall resistivity, which is saturated at a field of about 1.5 T, is positive. The ordinary Hall effect is negative [8]. However, at temperatures higher than 280 K, both magnetoresistance and Hall effect change sign above saturation. Notably, the ordinary Hall coefficient becomes positive, which means a change of the effective carrier sign. Fig. 3 shows the results of effective resistivity (a) and Hall resistivity (b) measurements for the 160 Å thick sample. Qualitatively the behavior is similar to the previous case, but the contribution of the non-magnetic layer is more pronounced. The positive components of both the ordinary Hall effect and magnetoresistance are bigger, and the transition happens at a lower temperature. One can still observe both the extraordinary Hall effect (Fig. 3b) and

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PII: S0304-8853(00)01044-1

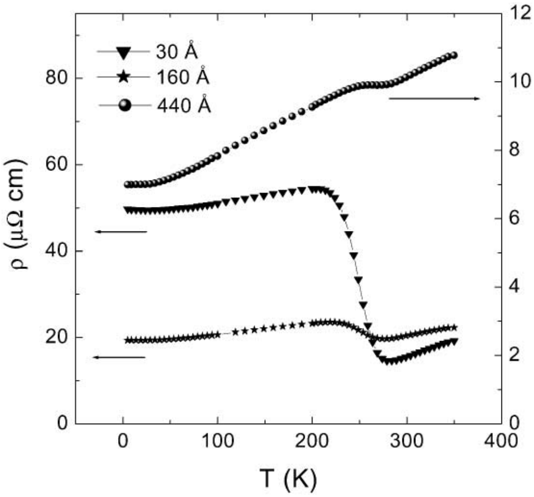

Fig. 1. Effective resistivity as function of temperature in films of different thicknesses.

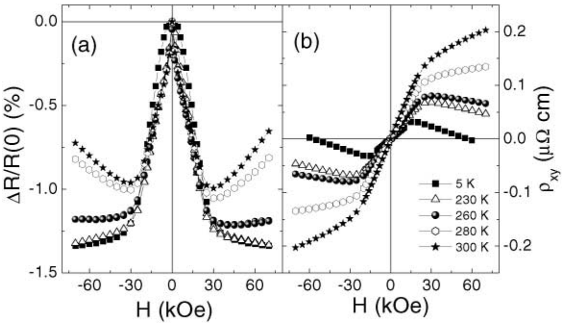

Fig. 2. (a) Magnetoresistance and (b) effective Hall resistivity in the 440 Å film for different temperatures.

negative magnetoresistance in small fields (Fig. 3a) at all temperatures. In the thinnest sample (30 Å) the negative component of magnetoresistance is not seen at high temperatures. Maximum positive magnetoresistance of 8% at $H = 70$ kOe is observed at the temperature 280 K (Fig. 4a). This is the temperature where resistivity as a function of temperature has a minimum. At temperatures higher than 280 K, the extraordinary part of the Hall effect is negligible. That is, the non-magnetic layer in the sample is dominant in magnetotransport.

These results may indicate that diffusion and chemical bonding during cobalt deposition leads to formation of a silicide layer at the Co/Si interface. To estimate the effective resistivity of the resulting double-layered structure, one needs to take into account conduction via this layer, which occurs in parallel with the Co film. In a recent paper [9], a behaviour of resistance and magnetoresistance of metal films on Si, similar to that described here, was discussed in terms of switching conduction channels between metal film and electron inversion layer on Si in a MOS structure involving negative Si oxide.

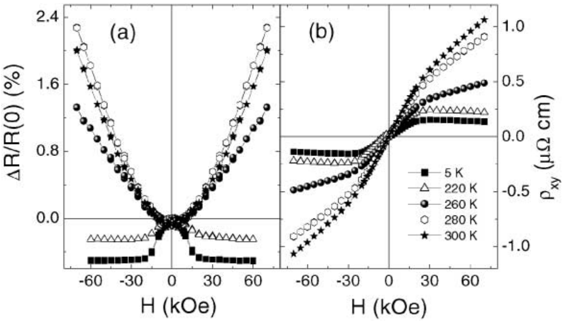

Fig. 3. (a) Magnetoresistance and (b) effective Hall resistivity in the 160 Å film for different temperatures.

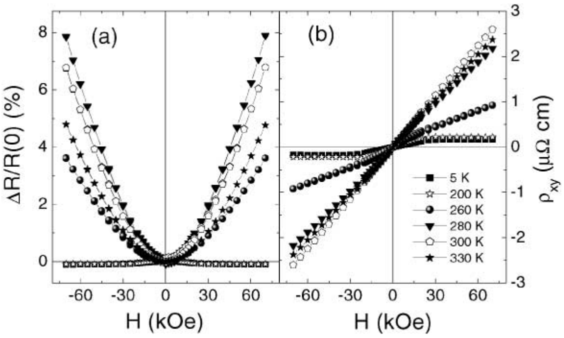

Fig. 4. (a) Magnetoresistance and (b) effective Hall resistivity in the 30 Å film for different temperatures.

Brazilian agencies FAPESP, CNPq and Hong Kong ISF number AF/155/99 are acknowledged for their financial support.

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