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LOW-TEMPERATURE TRANSPORT IN EPITAXIAL $CoSi_2$ FILMS

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Low-temperature magnetotransport measurements have been performed in ultra-thin films of $CoSi_2/Si(111)$. The electron phase breaking scattering rates were determined from the low field magnetoresistance for films of thickness between 3.9 and 22.0nm. The temperature independent contribution to the phase breaking rate, which was attributed to spin-spin scattering of the conduction electrons, was found to increase as the film thickness is decreased. The origin of this scattering rate and its importance to the low-temperature transport are discussed.

1. INTRODUCTION

Epitaxial cobalt disilicide crystalline thin films have attracted considerable interest stemming from the high quality samples that can be grown on $Si(111)$. (1-4) The scattering of conduction electrons from the surfaces of these films has been shown by Hensel et al. to be essentially specular. (5) Furthermore a strong divergence of the residual resistivity as a function of inverse film thickness has been attributed to a quantum size effect. (4,6) Badoz et al. (7) found that the superconducting critical temperature (T_c) was abruptly depressed in films of thickness less then 10nm. This measurement was of particular interest since the mechanism for the T_c suppression could not be associated with a transition to a localized regime. Instead it was hypothesized that the cause of the T_c depression was the presence of magnetic Co atoms near the $CoSi_2/Si(111)$ interface.

2. EXPERIMENT

Magnetoresistance (MR) measurements have been carried out in order to study the important electron scattering mechanisms as a function of film thickness. The epitaxial crystalline $CoSi_2$ on $Si(111)$ thin films used in this experiment were prepared and analyzed in the same manner as reported by Hensel et al. (4,5) The low field MR was studied at various temperatures in five film thicknesses ranging from 3.9nm to 22.0nm. The magnetic field sweeps showed a positive MR for all fields up to 7T (including field sweeps around zero field using 0.1mT increments). The positive MR at low fields is due to the large spin orbit scattering rate in this material. (8) The contribution to the MR from interaction effects is small and will not be considered throughout the analysis of the data. (9) The MR data for the 6.4nm film is shown in figure 1 along with the fits to weak localization theory for fields up to .3T.

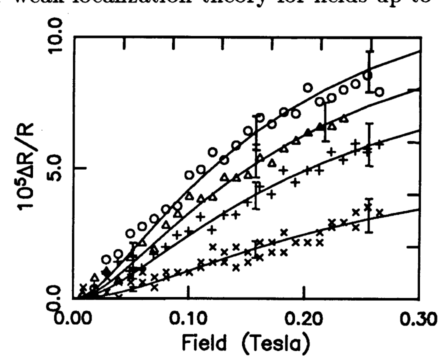

FIGURE 1

The magnetoresistance of the 6.4nm $CoSi_2$ film at temperatures of 1.3(○), 4.2(△), 10.0(+), and 20.0K(×). The lines are the fit to the data using weak localization theory. The error bars represent the range of the fits for a 10% variation in the phase breaking scattering rate.

3. ANALYSIS

The MR data was fit to weak localization theory following the review of Al'tshuler et al. (10) where we have also included the Maki-Thompson (MT) fluctuation terms for the samples showing a superconducting transition. The detailed analysis was similar to that of McGinnis et al. (11) with the inclusion of a MT scattering term. (12) The fits to the MR allowed a determination of the phase breaking scattering rate (τ_ϕ^{-1}) to within ±10%. The τ_ϕ^{-1} for the five films studied are shown in figure 2 over a temperature range between .2 and 20K. This analysis clearly shows a temperature independent scattering rate that increases by a factor of 150 from the bulk like 22.0nm film to the 3.9nm film.

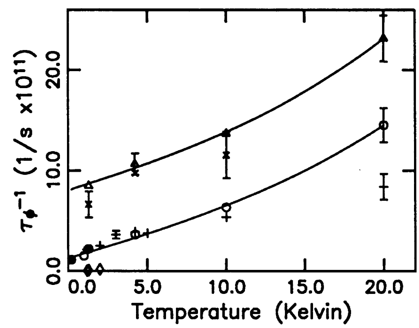

Figure 2

The phase breaking scattering rates for films of thickness 22.0 (◇), 12.0(+), 8.4(○), 6.4(△), and 3.9nm (×) from the fits to the magnetoresistance. The lines are the fits to the data for the 8.4 and 6.4 nm films for a $A + BT + CT^3$ dependence. The error bars shown represent the uncertainty in the fits due to the scatter in the data.

4. DISCUSSION

The temperature independent contribution to the phase breaking scattering rate is associated with a spin flip scattering by paramagnetic defects in the sample. We do not believe that the origin of this magnetic scattering rate can be associated with a random distribution of magnetic impurities. Such a contribution would not show the thickness dependence such as that seen here. Because the samples were all prepared in the same chamber and four of the films were deposited on the same Si wafer at the same time we expect that the concentration of these types of impurities would be nearly constant from film to film. Instead we believe the origin of this scattering rate is the presence of magnetic cobalt atoms at the $Si/CoSi_2$ interface. (7) The magnetic properties of the interface will thus have a more dominant effect on the electron transport properties of the thinner films.

We have used the Abrikosov and Gor'kov (13) model to calculate the suppression of the superconducting critical temperature in our films due to the measured magnetic scattering rate. The calculated T_c's are as follows with the measured T_c in parenthesis; 22nm 1.24K (1.06K), 12nm 1.013K (0.57K), 8.4nm 1.067K (<.20K), 6.4nm <.001K (<.20K), 3.9nm <.001K (<.20K). From this comparison we believe that the magnetic scattering rate measured from the low field MR is at least partially responsible for the T_c suppression in our films. It is difficult to make a reliable absolute comparison between the calculated and measured T_c depression since our values of the magnetic scattering rate are dependent on the diffusion constant. Our method for determining the diffusion constant from the residual resistivity may be inaccurate and will add a small systematic error to the calculated scattering times. Still it is suggestive that in the region of thickness with appreciable T_c depression, a corresponding increase in the magnetic scattering rate of the right magnitude is found.

5. SUMMARY

We have carried out careful measurements of the localization contribution to the magnetoresistance in the $CoSi_2/Si(111)$ thin film system for the first time. The electron phase breaking rates have been accurately determined from the MR. A magnetic scattering rate which increases with decreasing film thickness has been found. The magnetic scattering rate has been associated with the depression of the superconducting critical temperature and related to the film interface properties.

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