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XRD, SEM and Low temperature electrical transport in a metallic multilayer

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ABSTRACT

A multilayer, $[Ni(100nm)/Fe(100nm)]_3$ has been investigated for the structure and low temperature resistivity. The resistivity increased with increase in temperature. The residual resistivity ratio (RRR) and the temperature coefficient of resistivity (TCR) were determined. The power law variations of resistivity with temperature were established. The contributions to resistivity for T above 80K are attributed to be predominant by electron-phonon and electron-magnon scatterings and for below 30K they are ascribed to be predominant by electron-electron and electron-defect scattering.

KEYWORDS

Multilayer;
Grain size;
Resistivity;
Residual resistivity ratio (RRR).

INTRODUCTION

In the past few decades, the research on the structural and electrical properties of magnetic multilayers has gained[1]. For example, $[Ni(86Å)/Fe(29Å)]_{11}$ multilayer was probed for magnetic properties as a function of deposition temperature[2]. An irradiated multilayer, $[Ni(13Å/Fe(33Å)]_{10}$ with swift heavy ions was studied for magneto-optic Kerr effect and electrical resistivity as a function of temperature[3]. The interface mixing leading to alloy phase formation was observed when the films were irradiated. Similar studies were reported for Si^+ ion irradiated Fe(28Å)/Ni(85Å) multilayers. Power laws for the resistivity variation with temperature were established. Experimental results on resistivity and magnetization in Ni-Fe alloy films are reported[4]. The Ni/Fe bilayers are technologically very important because of their low resistivity. In view of the literature we embarked on detailed studies of structure and low temperature electrical properties of a Nickel/Iron multilayer.

EXPERIMENTAL

The multilayer, $[Ni(100nm)/Fe(100nm)]_3$ (where subscript 3 represents number of repeats) has been deposited on to a glass substrate at 473K and a pressure of 5 x 10^{-6} mbar. The Ni and Fe layers were deposited by evaporating the nickel and iron sources from two separate molybdenum crucibles using two independent electron beam guns. The thickness of the layers was measured with the help of quartz crystal thickness monitor. The films were annealed to room temperature slowly in the vacuum chamber[5].

Structural investigations were carried out by grazing incidence X- ray diffraction (GIXRD) studies using Brucker-D8 advance diffractometer with Cu-Kα radiation of 1.5406 Å wavelength. The microstructure of the films was probed using Cambridge Instruments Stereoscan (Model 150) Scanning Electron Microscope. The low temperature (4.2K to 300K) resistivity, ρ has been measured by adopting four probe method in an Oxford Instruments make resistivity setup.

RESULTS AND DISCUSSION

Grazing incidence X-ray diffraction (GIXRD) studies

The GIXRD spectra for 2θ between 42^0 and 48^0 for the present film is shown in Figure 1(a) and the Gaussian fit to the peak is depicted in Figure 1(b). The observed single sharp peak does not exactly represent any plane in Fe or Ni crystals and therefore considered to be representing a mixed phase (Ni(111)/Fe(110)) of Fe and Ni. The average grain size is estimated using Scherrer's formula[6]. The interplanar spacing, d was calculated using the Bragg's relation.

The structure around the peak has been analyzed. The grain size and inter-planar spacing were determined to be 22.74 nm and 2.0167 Å respectively.

Scanning electron microscopy (SEM) studies

The recorded SEM image of the film shown in Figure 2 have been used for examining the microstructure of the film. The SEM image appear smooth, compact and fine in structure which indicates a high content of nanocrystalline particles.

Resistivity variation with temperature

The ρ increased with increasing temperatures. The ρ varied between 0.480 μΩm and 0.823 μΩm for the temperature range from 5K to 300K. The room temperature (300K) ρ is greater by an order of magnitude than the bulk ρ values of the two components (Ni ~ 0.072 μΩm and Fe ~ 0.09 μΩm). The larger ρ measured for this film can be due to intermixing of layers at the interface[10] and this was also evident from GIXRD results.

The temperature coefficient of resistivity is determined to be 1.732 x 10^{-3} K^{-1}[5]. The positive TCR points

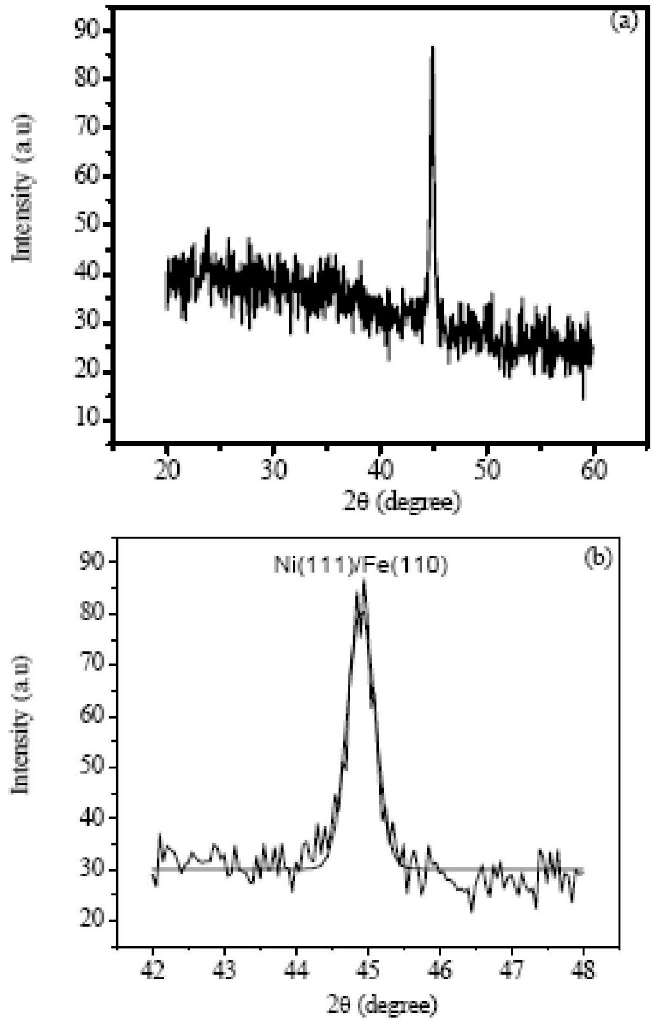

Figure 1 : (a) GIXRD spectra for the film and (b) spectra around the peak position. The solid line in Figure (b) is a Gaussian fit to the peak.

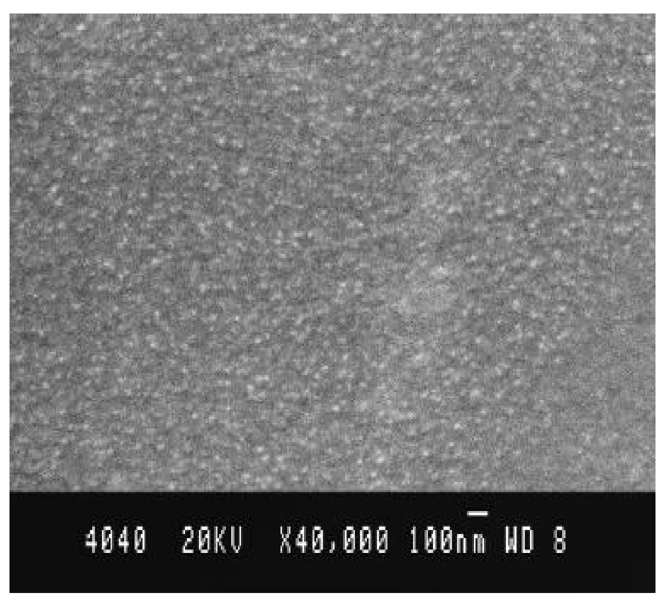

Figure 2 : SEM image of the film.

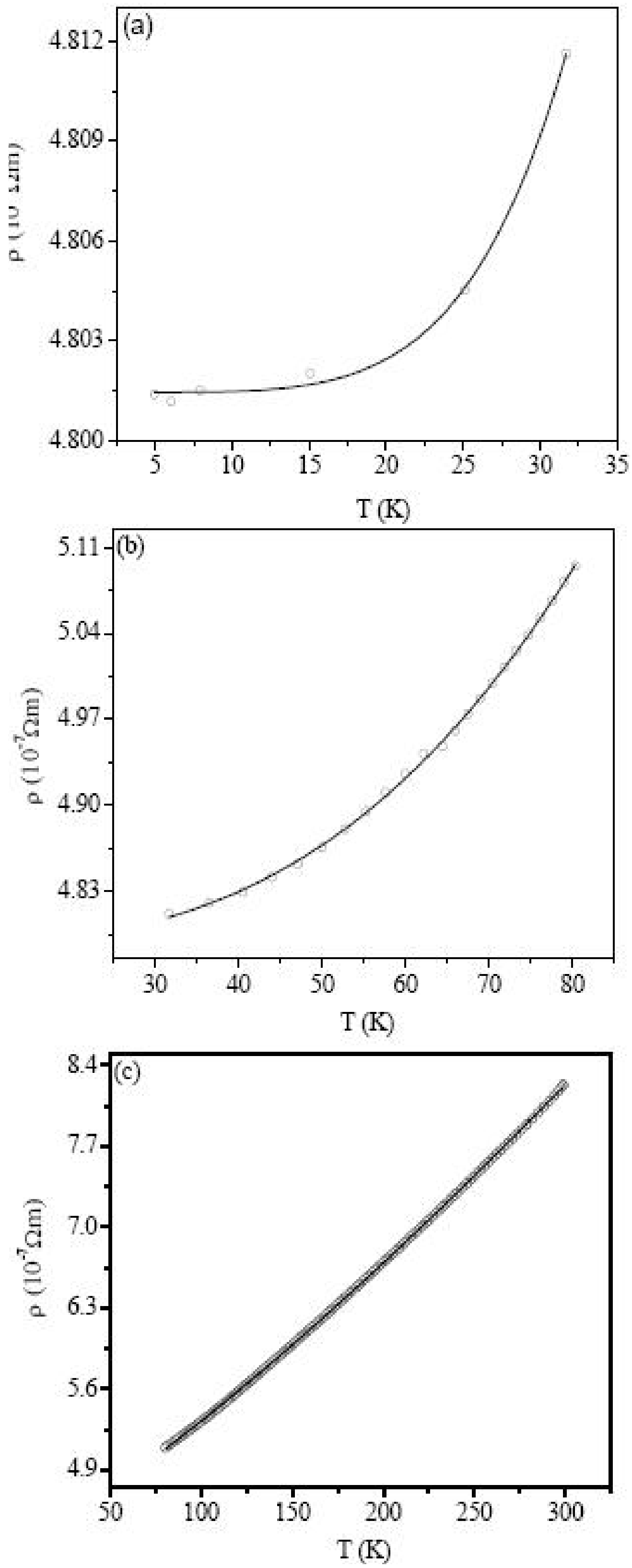

Figure 3 : Resistivity, ρ versus temperature, T plots of (a) 5K to 30K, (b) 30K to 80K and (c) 80K to 300K. The continuous curves passing through the data are the non-linear fits.

to the metallic nature of the film. The residual resistivity ratio, RRR is 1.71. The small RRR value observed in this films can be attributed to enhanced electron-electron, interfacial, grain boundary etc., scatterings[5, 11].

Variation of ρ with T revealed that there exist three different power laws for the measured temperature range. Hence, the expressions, $\rho(T) = \rho(0) + a_1 T^k$ for T = 30K, $\rho(T) = \rho(0) + a_2 T^m$ for 30K = T = 80K and $\rho(T) = \rho(0) + a_3 T^n$ for 80K = T = 300K, were fit to the data. Here, $\rho(0)$ is the residual resistivity which is taken to be equal to the measured value at 5K in all the films. By non linear curve fitting, the coefficients a_1, a_2 and a_3 and exponents k, m and n were determined. The fit parameters thus obtained are $a_1 = 0.284$ μΩ m K^{-k}, $a_2 = 1.282$ μΩ m K^{-m}, $a_3 = 3.556$ μΩ m K^{-n}, k = 5.03, m = 2.82 and n = 1.22. The fit curves are shown in Figure 3(a-c).

In the temperature range, 80K = T = 300K the coefficient, n is obtained to be slightly more than unity which reveals the predominance of electron-phonon scattering. In Fe/Ni multilayer[3], the resistivity was found to vary as $T^{1.44}$ for the temperature range from 80K to 300K and this was attributed to additional electron-magnon (s-d) scattering, where s electrons were expected to scatter by magnons in to d band holes. In the temperature range, 30K = T = 80K, the exponent, m is found to be 2.82 and that agrees with a magnetic layer[3] and deviates from White and Woods value of 3.3 for bulk Fe[13]. For the temperature, T = 30K, the exponent, k is found to be 5.03. This result points out that in this range of temperature major contributions are from electron-electron and electron-defects (which includes impurity) scatterings.

CONCLUSIONS

The structure and grain size of a multilayer $[Ni(100nm)/Fe(100nm)]_3$ have been investigated. Electrical resistivity in the temperature range from 4.2K to 300K has been measured. Resistivity increased with increasing temperature. The power laws for the resistivity variation with temperature were established. Based on the exponent values obtained, it is concluded that in this film, electron-electron and electron-defect scatterings are predominant below 30K and, electron-phonon and electron-magnon scatterings are predominant above 80K.

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