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POSITIVE MAGNETORESISTANCE IN NI/W SUPERLATTICES*

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Abstract: Transport properties of Ni/W superlattices have been studied at room temperature. Small positive magnetoresistance effect has been observed in samples with thin nickel layer thickness. Lorentz force magnetoresistance is taken into account to explain the resistance variation behavior of Ni/W superlattices in externally applied magnetic field.

Key words: positive magnetoresistance, superlattice, Lorentz
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INTRODUCTION

The magnetic and transport properties of thin magnetic multilayers have attracted considerable attention during the past years. Since discovery of negative giant magnetoresistance (GMR) by Baibich et al. in Fe/Cr multilayers (Baibich, 1998), extensive research has been done concerning both interlayer exchange coupling and magnetoresistance (MR) in various ferromagnetic (FM) /nonmagnetic metallic multilayers (Prtroff et al., 1991; Mosca et al., 1991; Binasch et al., 1989; Parkin et al., 1990; Parkin et al., 1991a; Krebs et al., 1989). The multilayer structured system usually consists of 3d transition magnetic layers separated by a monmagnetic spacer layer of commonly 5d, 4d or 3d elements (Parkin, 1991b). The nature of MR is intimately linked to the antiferromagnetic (AFM) exchange coupling of magnetic layers through the spacer layer. The parallel alignment of the magnetization of the successive magnetic layers forced by an externally applied magnetic field changes the scattering possibilities of spin-up and spin-down electrons and induces a decrease of the resistivity.

It is becoming clear that the material combination of the ferromagnetic and nonmagnetic layers is of fundamental importance for their magnetic and transport properties. Besides the negative GMR in a wide variety of magnetic multilayers, positive MR (PMR) effect had also been observed (Parkin, 1993) both in AF coupled magnetic multilayers with a small positive MR and in other superlattices with giant PMR (Verbanck et al, 1997; Tsui et al, 1994). For the AF coupled magnetic system in Parkin's paper (1987), the PMR effect is interpreted by a Lorentz mechanism, and is expected to be common in a wide range of magnetic systems but is usually obscured by large negative magnetoresistance effects. It is proposed that the position of the spacer layer material in the periodic table systematically affects the indirect magnetic exchange coupling, and that for magnetic multilayers containing transition metallic spacer layers from the left hand positions of the 4d and 5d periods, the MR relevant to spin structures becomes very small (Parkin, 1991b). When this MR is so low it cannot obscure the MR derived from other mechanisms, a PMR effect may be expected.

In this paper we present the results of our investigation on transport properties of Ni/W superlattices, where a weak indirect exchange coupling through the tungsten spacer layer was observed. This finding is consistent with previous reports (Parkin, 1991; Parkin, 1993). Lorentz force MR is considered to be responsible for the PMR effect occurring in Ni/W multilayers.

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SAMPLE PREPARATION AND MEASUREMENTS

The Ni/W superlattices were prepared in a dc magnetron sputtering system for a wide range of Ni and W layer thicknesses (Ni[40Å]/W[xÅ] with x = 10, 15, 20, 25, 35, 40, 45 and Ni[yÅ]/W[40Å] with y = 10, 20, 25, 30, 35, 40, 60 and 100 respectively). The Ni/W superlattices were fabricated on glass substrates by dual-target magnetron sputtering technique. The vaccum system was initially pumped down to below 1.33×10^{-4} Pa. The sputtering pressure was 1 Pa of argon gas. In this system two targets (99.9 W and 99.99 Ni) were clamped to the water-cooled chamber wall (cathode) and powered by two current regulators respectively.

The structural quality of the samples and the modulation wavelength could be determined using conventional θ-2θ x-ray diffraction (XRD). The measurements were performed both in a small-angle region (1 – 8° in 2θ) as well as in a large-angle region (30 – 50° in 2θ). Fig. 1 shows the XRD spectrum for sample Ni(40Å)/W(10Å). At least four diffraction peaks are shown in small angle region which demonstrates the good superstructure of the sample. In large angle region, two main peaks corresponding to Ni(111) and W(110) textures respectively can be distinguished which indicates that the combination layers are crystalline. Besides the relatively weak and wide peaks in Fig. 1 (b), no apparent satellite is observed. This may indicate a degradation of superlattice structure due to discrete growth of the layer, resulting in significant roughness. The transport properties were measured by using a standard four-terminal technique with gold-plated contacts.

MAGNETORESISTANCE IN NI/W SUPERLATTICES

Very small magnetoresistance effect was found in the sputtered Ni/W magnetic superlattices, the absolute ratio change $\Delta R/R_0$ less was than 2%. Here ΔR is defined traditionally by the deviation of the resistance in applied magnetic field from that the non-field resistance. Different from an earlier report (Parkin, 1993) on magnetic multilayers, both positive negative MR effect were observed. The PMR effect was observed in samples with nickel layer thinner of less than 30Å. In other samples, regardless of the spacer layer thickness, the resistance decreased monotonously with increasing applied magnetic field. Fig. 2 shows the variation of magnetoresistance versus Ni layer thickness for samples Ni(xÅ)/W(40Å) at room temperature. Typical negative MR effect was found in samples with Ni layer thickness equal to or more than 30 Å. This feature is common in magnetic multilayers. PMR effect is shown in Fig. 2 for samples with thin Ni layer. The anomalous MR behavior will be interpreted in light of the Lorentz force magnetoresistance of the conduction electrons in the spacer layer.

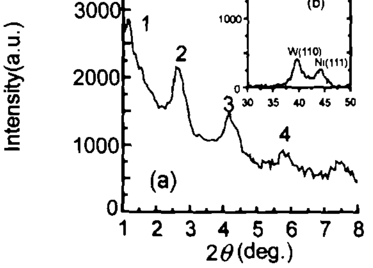

Fig. 1 The θ-2θ scan of x-ray diffraction for Ni(40Å)/W(10Å) multilayers, measured in (a) low angle region, and (b) high angle region.

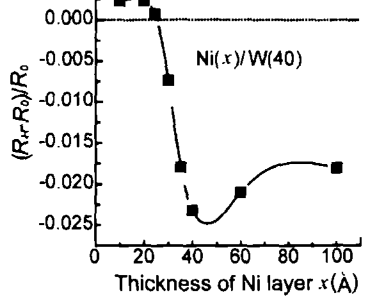

Fig. 2 Variation of the magnetoresistance versus Ni layer thickness for samples Ni(x?)/W(40?).

MR reflects the magnetic state of a multilayer, generally in a very complicated manner. It is believed, however, that the magnetoresistance is mainly a function of the angle between the magnetization of neighboring magnetic layers only, i.e., of the absolute value of the relative (with respect to the saturation value) magnetization of the superlattice. Natural resistance reduction was observed in Ni/W samples with applied magnetic field. The decuase of resistance, was due to the re-orientation of magnetization from antiparallel to parallel alignment in neighboring nickel layers. In fact, the resistance of magnetic multilayers is not only attributed to the interlayer exchange coupling which gives rise to a negative MR effect, but also ascribed to other scattering mechanisms including the Lorentz force magnetoresistance which results in a positive MR effect. Generally, Lorentz force effect that exists in all normal nonferromagnetic metals reduces the effective mean free path of the conduction carriers between scattering events and as a result enhances the resistance of the sample. In multilaryer maguctic layers, this effect is usually much smaller than negative GMR effect obscured by it.

In samples with thin nickel layer thickness, When the Lorentz effect prodominated over that of negative MR, PMR was observed. For thicker nickel layer thickness the AF coupling contribution to MR exceeded the Lorentz force MR and normal negative MR was shown. The resistance was easily saturated at $B \approx 0.5$ T for samples with negative MR. While for superlattices with PMR, no saturation tendency noted for the resistance within the limit of external magnetic field we could apply. It was reported (Pipard, 1989) that for a weak magnetic field, $MS \backsim H^2$ is the relationship between the Lorentz MR and applied magnetic field H; and that this causes the resistance increase monotonously with the applied magnetic field.

SUMMARY AND DISCUSSION

Transport properties of Ni/W magnetic multilayers were investigated at room temperature.

Positive MR effect was found for some Ni/W magnetic multilayers. This phenomenon is consistent with previous reports by Parkin (Parking, 1993). The mechanism of Lorentz force MR was considered to explain the PMR in Ni/W superlattices. Large PMR effect was reportedly observed in metallic Cr/Ag/Cr trilayers (Verbanck et al., 1997) and in rare-earth Dy/Sc multilayers. Modification of electron scattering and increasing magnetization at interfaces were used to explain the PMR effect, respectively, in these two kinds of multilayers. For the small PMR effect in Ni/W samples and different MR behavior with respect to sublayer thicknesses, it is not proper to attribute the small PMR to the above mentioned mechanisms. The present study showed that MR behavior in Ni/W superlattices can be well accounted for by Lorentz force mechanism.

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