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Effect of Pressure on the Giant Magnetoresistance of Magnetic Multilayers

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The magnetoresistance (MR) of magnetic multilayers, Fe/Cr and Co/Cu, was measured at high pressure. It was found that the effect of pressure on the MR depends on the specimen: the MR of Fe/Cr decreases much more than that of Co/Cu. The large effect of pressure on the MR in Fe/Cr is shown to be due to the suppression of spin-dependent scattering at high pressure. The relation between the effect of pressure on GMR and the interfacial roughness is discussed briefly.

Key words: high pressure, GMR, magnetic multilayer

1. Introduction

Extensive studies have been carried out on the giant magnetoresistance (GMR) of magnetic multilayers (MML) in which the magnitude of MR ratio is of the order of several tens percent[1),2)]. Another characteristics of MMLs is that the MR ratio oscillates as a function of the thickness t_p of paramagnetic layers[3),4)]. This fact indicates the importance of the interlayer exchange interaction between the ferromagnetic layers which is dominated by the magnitude of t_p. In order to get a better understanding about the origins of GMR effect in MML, it is worthwhile to investigate GMR under high pressure because we can controll t_p very precisely using high pressure.

We have measured until now the effect of pressure on GMR of Fe/Cr, Co/Cu and Fe/Cu and obtained a lot of many interesting results[5)–7)].

In the present work we compare the results of Fe/Cr with that of Co/Cu to make clear the difference in the effect of pressure on GMR. The results will be discussed in connection with the effect of pressure on the spin dependent scattering of conduction electrons due to interface roughness.

2. Experimental method

In the present work we used two types of MMLs having the formulas, $[\mathrm{Co}(10.8\text{Å})/\mathrm{Cu}(t_{\mathrm{Cu}}\text{Å})]_{15}$ (abbreviated as $\mathrm{Co}/\mathrm{Cu}(t_{\mathrm{Cu}})$) and $[\mathrm{Fe}(30\text{Å})/\mathrm{Cr}(t_{\mathrm{Cr}}\text{Å})]_{24}$ ($\mathrm{Fe}/\mathrm{Cr}(t_{\mathrm{Cr}})$). The details of sample preparation were reported previously[5),6)].

High pressure up to 2.2 GPa was generated by a piston-cylinder apparatus utilizing the conventional teflon-cell technique. The pressure inside the cell was kept constant by controlling the load of hydraulic press. The temperature in the cell was measured by a calibrated Cu(Fe)-Chromel thermocouple. The electrical resistance was measured by means of the standard four-probe method. The details of the present apparatus were reported previously[8)].

3. Experimental results

In the following, we report the effect of pressure on the two samples, Fe/Cr(9.5) and Co/Cu(9.8), which exist near the 1st peak of the oscillation of GMR.

Electrical resistivity ρ of these two MMLs decreases smoothly with pressure at room temperature. The pressure coefficients of ρ, $\partial \ln \rho/\partial P$, are summarized in Table 1. The resistivity of Fe/Cr(9.5) decreases with pressure more rapidly than that of Co/Cu(9.8).

Figure 1 shows the MR ratio $\Delta\rho/\rho_s$ of Fe/Cr(9.5) at 4.2 K as a function of magnetic fields H at 0, 1.0 and 2.0 GPa. Here $\Delta\rho/\rho_s$ is defined as $\Delta\rho/\rho_s(H) = (\rho(H) - \rho_s)/\rho_s$, where $\rho(H)$ and ρ_s are the resistivities below and above saturation field (saturation resistivity), respectively. $\Delta\rho/\rho_s(0)$ is found to be almost constant below 1 GPa but to decrease with pressure above 1 GPa. By applying 2 GPa, the value of $\Delta\rho/\rho_s(0)$ decreases by about a half of that at ambient pressure. Since ρ_s decreases with pressure, $\Delta\rho(H=0)$ decreases by applying pressure more rapidly than ρ_s. The half of full width of half maximum in the $\Delta\rho/\rho_s(H)$ curves increases with increasing pressure.

Table 1: Values of the pressure coefficient of electrical resisitivity at room temperature for Co/Cu(9.8) and Fe/Cr(9.5) magnetic multilayers.

Magnetic multilayer	t_i (Å)	$\partial \ln \rho/\partial P$ ($\times 10^{-2}\mathrm{GPa}^{-1}$)
Co(10.8 Å)Cu(t_i Å)	9.8	−1.7
Fe(30 Å)Cr(t_i Å)	9.5	−8.5

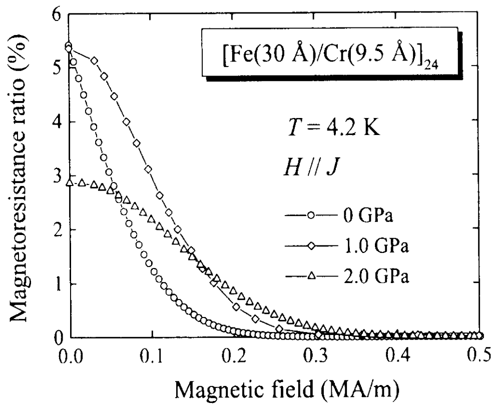

Fig. 1: MR ratio of Fe/Cr(9.5) at 4.2 K at high pressure as a function of the magnetic field.

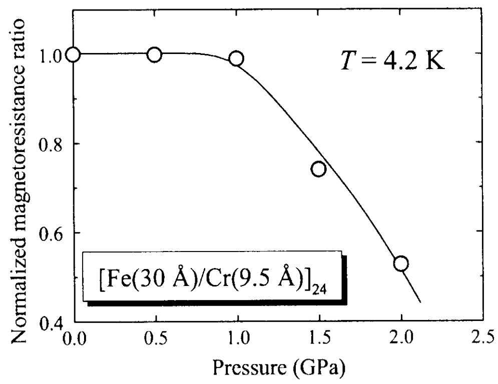

Fig. 2: Relative change in the MR ratio at $H = 0$ as a function of the pressure.

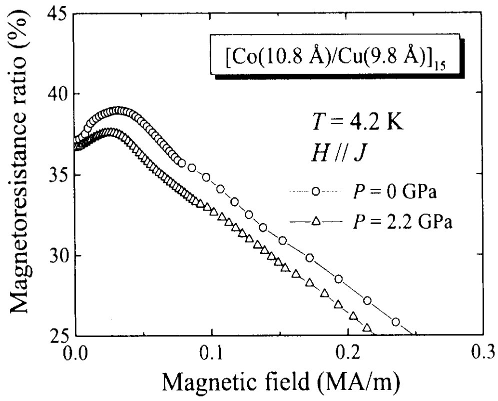

Fig. 3: MR ratio of Co/Cu(9.8) at 0 and 2.2 GPa.

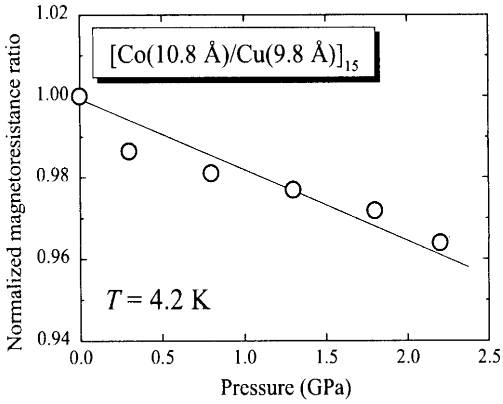

Fig. 4: Relative change in the MR ratio $(\Delta\rho/\rho)_{\max}$ as a function of the pressure.

Figure 2 shows the pressure dependence of $\Delta\rho/\rho_s(0)$ of the Fe/Cr MML of t_{Cr}=9.5 Å, in which the relative change of that is shown. The MR ratio is nearly constant below 1 GPa but begins to decrease rapidly above 1 GPa with increasing pressure.

The MR ratio of Co/Cu having t_{Cu}=9.8 Å is shown in Fig. 3 at 4.2 K as a function of H. The MR ratio has a peak near 0.02 MA/m. By applying pressure,the MR ratio decreases as a whole and the maximum values in the MR ratio, $(\Delta\rho/\rho)_{\max}$, decrease slightly. Figure 4 shows the relative change in the value of $(\Delta\rho/\rho)_{\max}$ as a function of pressure. It is found that the MR ratio of Co/Cu(9.8) decreases smoothly with increasing pressure without any anomaly like Fe/Cr case as shown in Fig. 2. By applying 2.2 GPa, it decreases by about 3.6% compared with that at ambient pressure, which is extremely smaller than that of Fe/Cr.

4. Discussion

The magnitude of GMR has been explained by taking into account the spin-dependent scattering of conduction electrons[1]. In order to examine this fact we analyze the present data in the following[9]. The effect of pressure on the MR ratio, $\Delta\rho/\rho_s$, is devided into two parts; the first is the effect of pressure on $\Delta\rho$ and the second is that on ρ_s. For the first part the pressure change of spin-dependent scattering may be dominant but for the second, that of bulk scattering may be dominant.

Figures 5(a) and (b) show the values of ρ_s and $\Delta\rho$ of Fe/Cr(9.5) at 4.2 K as a function of pressure. ρ_s decreases linearly with pressure having a rate $(1/\rho_s)(d\rho_s/dP) = -6.3 \times 10^{-2}$ GPa^{-1}. On the other hand, $\Delta\rho(H = 0)$ decreases gradually below ca. 1 GPa but begins to decrease rapidly above 1 GPa: it becomes about a half of the value at ambient pressure by applying 2 GPa. This behavior is largely different form

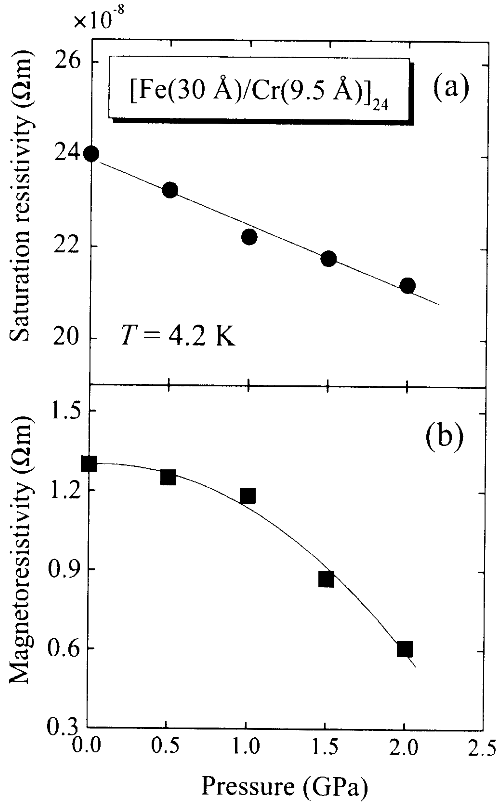

Fig. 5: (a) Saturation resistivity ρ_s and (b) magnetoresistivity $\Delta\rho$ ($H = 0$) of Fe/Cr(9.5) as a function of the pressure at 4.2 K.

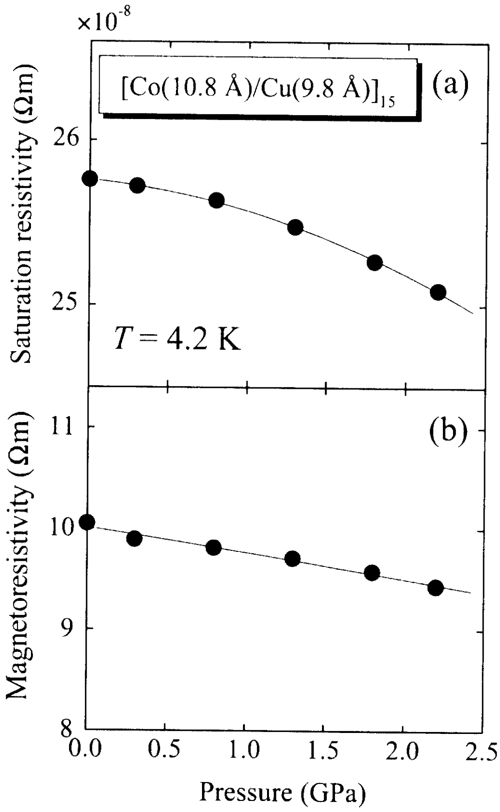

Fig. 6: (a) Saturation resistivity ρ_s and (b) magnetoresistivity $\Delta\rho(H = 0)$ of Co/Cu(9.8) as a function of the pressure at 4.2 K.

that of ρ_s as shown in Fig. 5(a), in which ρ_s decreases only by 13% at 2 GPa. This result implies that the pressure dependence of $\Delta\rho/\rho_s$ is mainly dominated by spin dependent scattering of conduction electrons more than spin-independent scattering: the former is more suppressed than the latter by pressure.

Figures 6(a) and (b) show ρ_s and $\Delta\rho$ of Co/Cu(9.8) at 4.2 K as a function of pressure. ρ_s decreases smoothly with pressure. $\Delta\rho$ decreases almost linearly. The initial pressure coefficients of ρ_s and $\Delta\rho$ are -0.63×10^{-2} GPa^{-1} and -2.7×10^{-2} GPa^{-1}, respectively. By applying 2 GPa, ρ_s decreases by about 2.4% but $\Delta\rho$ by 8.7%. This fact indicates that the spin dependent scattering of conduction electrons is suppressed by pressure more than the spin independent one, which is similar to that of Fe/Cr.

Here we compare the effect of pressure on the values of ρ_s and $\Delta\rho$ for both samples. Figure 7 shows the relative pressure change of the bulk resistivity, $\rho_s(P)/\rho_s(0)$, as a function of pressure for Fe/Cr(9.5) and Co/Cu(9.8). The change of ρ_s in Fe/Cr(9.5) at 2 GPa is about 6 times larger than that of Co/Cu(9.8). This suggests that the magnetic state of Fe/Cr(9.5) is unstable against pressure compared with Cu/Cu(9.8).

Figure 8 shows the pressure dependence of the values of $\rho_s(\mathrm{P})/\rho_s(0)$.It is seen that the change of $\Delta\rho(H = 0)$ in Fe/Cr(9.5) at 2 GPa is 10 times larger than that of Co/Cu(9.8), i.e., the effect of pressure on $\Delta\rho(H = 0)$ is more significant than that on ρ_s as is seen from Figs. 7 and 8.

Although there have been many theoretical and experimental works on the GMR of MMLs[10),11)], the origin of GMR is not well understood until now. However, it has been suggested that the interfacial roughness (IR) is a very important factor dominating the magnitude of GMR. The relationship between IR and the magnitude of GMR has recently investigated extensively by many authors[12)-15)]. The details of IR are not simple but may include several ingredients such as compositional mixing due to interdiffusion[16)], lattice uncertainty[13)] and so forth. It is found that the MR ratio in Fe/Cr MML is enhanced by IR as long as the Fe layer is coupled antiferromagnetically, reaches a maximum at an optimum and then decreases with a further increase of the roughness[14),15)]. The present results in Figs. 5, 6, 7 and 8 indicate that the effect of pressure is more significant for $\Delta\rho$ than for ρ_s and more significant in Fe/Cr(9.5) than in Co/Cu(9.8). Assuming that $\Delta\rho$

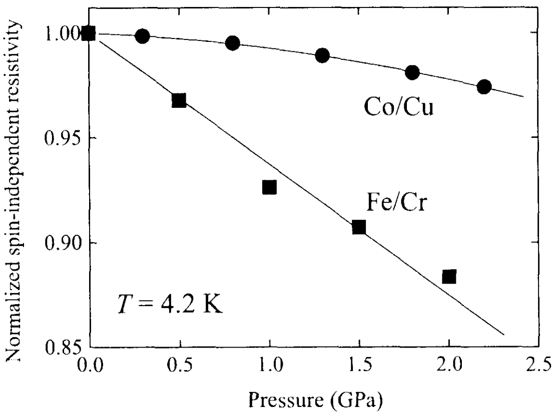

Fig. 7: Relative change of ρ_s of Co/Cu(9.8) and Fe/Cr(9.5) as a function of the pressure.

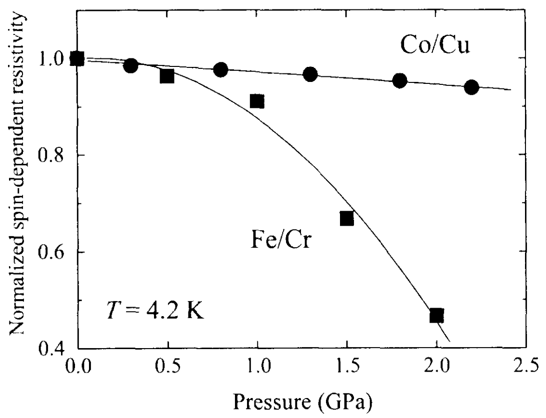

Fig. 8: Relative change in $\Delta\rho$ of Co/Cu(9.8) and Fe/Cr(9.5) as a function of the pressure.

is dominated mainly by IR[14], the effect of pressure on the magnitude of GMR is attributed to the change in the IR by applying pressure, i.e., the spin dependent scattering of conduction electrons at the interface plays an important role in explaining its pressure effect.

As was mentioned in section 1, we may consider the effect of interlayer exchange coupling (IEC) on the magnitude of GMR because it changes at high pressure through a change in t_p. However since the pressure change of t_p is extremely small, it is difficult to explain the large effect of pressure on GMR only by assuming the change of IEC[9]. Recently it has been suggested[17] that the oscillation period is changed by applying pressure, i.e., the 1st peak shifts to larger t_{Cu}. In order to confirm this fact we need more data about the Fermi surface of MML under pressure.

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