Giant Hall effect in Co-SiO$_2$ nanocomposites

2000 J. Phys.: Condens. Matter 12 3397

(http://iopscience.iop.org/0953-8984/12/14/315)

J. Phys.: Condens. Matter **12** (2000) 3397–3399. Printed in the UK PII: S0953-8984(00)10984-1

Giant Hall effect in Co–SiO$_2$ nanocomposites

J C Denardin†, A B Pakhomov†§, M Knobel†, H Liu‡ and X X Zhang‡

† Instituto de Física 'Gleb Wataghin', Universidade Estadual de Campinas (UNICAMP),
CP 6165, Campinas 13083-970, SP, Brazil.
‡ Physics Department, Hong Kong University of Science and Technology, Clear Water Bay,
Kowloon, Hong Kong, China

Received 13 January 2000

Abstract. Measurements of both the ordinary and extraordinary components of the Hall effect in co-sputtered granular magnetic Co–SiO$_2$ nanocomposites are presented. The experiments were done in the temperature range 5–300 K, and fields up to 7 T. Both components show a large enhancement when the metal volume fraction is reduced to the metal–insulator transition. However the enhancement of the ordinary Hall effect is much weaker than that of the extraordinary one. We discuss the implications of this observation for understanding of the giant Hall effect.

The name giant Hall effect (GHE) was given to an enhancement of the extraordinary Hall coefficient R_s in co-sputtered granular magnetic metal–insulator nanocomposites when the metal volume fraction x decreases from 1 to the critical value where the metal–insulator transition occurs [1, 2]. The GHE was first observed in (NiFe)–SiO$_2$ composites where R_s for $x \approx 0.53$ was found to be almost four orders of magnitude greater than the value for pure metal film. A somewhat smaller (a factor of 700) enhancement of the ordinary Hall coefficient was observed in non-magnetic Cu–SiO$_2$ composites [3] with a structure close to that of (NiFe)–SiO$_2$ films. To develop a theory of GHE it is important to understand if this difference is just material related, or there is a basic difference in the behaviour of the magnetic and non-magnetic components of the Hall resistivity. Using the former assumption, there are already works where the authors tried to extend the concept of quantum interference in disordered metals [3] or in hopping insulators [4] to explain the GHE. By thoroughly measuring the variation of both extraordinary and ordinary Hall resistivities with metal concentration, simultaneously on the same material (co-sputtered granular Co–SiO$_2$), in this paper we show that, though the enhancement is present for both components, it is much stronger for the extraordinary part.

The 1 μm thick granular Co$_x$–(SiO$_2$)$_{1-x}$ films with metal volume fraction $0.4 < x < 0.9$ were prepared by co-sputtering on glass and Kapton substrates. The HRTEM study on these samples show microstructure typical of previously studied composites [2, 3], with nanometre-sized crystalline metal particles embedded in the amorphous matrix. However, in contrast with [2], we do not observe metallic particles smaller than approximately 2 nm. Metal concentration was determined by EDX.

Magnetization, resistivity and Hall resistivity were measured in the Quantum Design MPMS XL7 system in the temperature range 5–300 K and fields up to 7 T. At low temperatures magnetization was well saturated in high fields. The results of magnetic measurements, for magnetic field perpendicular to the sample plane, at $T = 5$ K, are shown in figure 1 for $x = 0.77$ and $x = 0.51$.

---

§ Present address: Materials Characterization and Preparation Facility, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China.

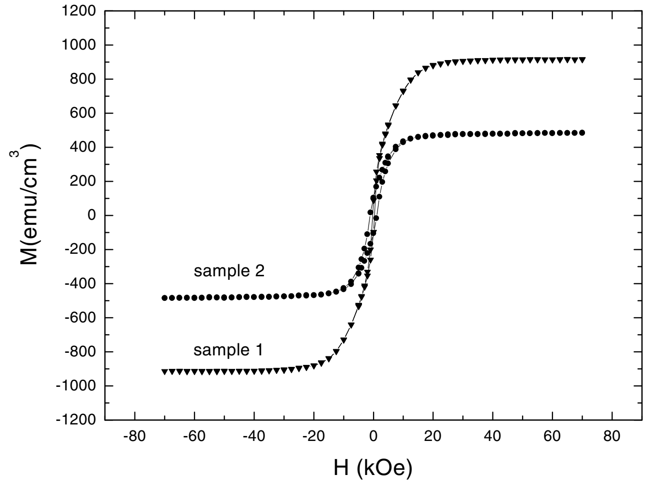

Figure 1. DC magnetization as a function of magnetic field at $T = 5$ K, for sample 1 ($x = 0.77$) and sample 2 ($x = 0.51$).

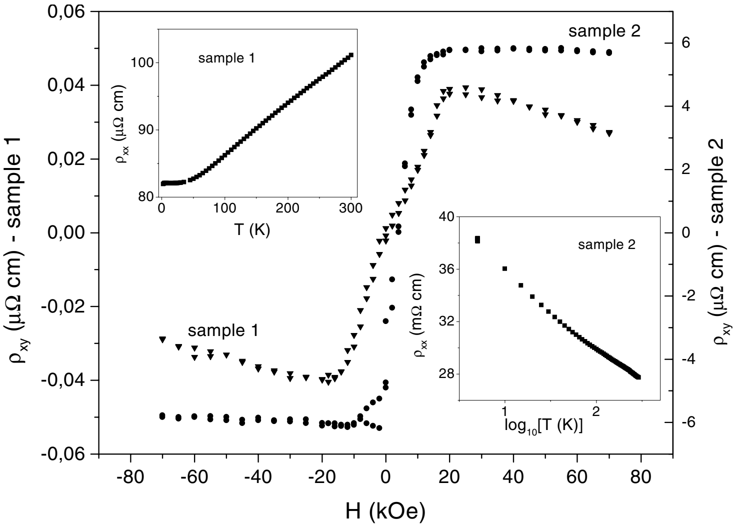

Figure 2. Hall resistivity for sample 1 ($x = 0.77$) and sample 2 ($x = 0.51$) as a function of magnetic field at $T = 5$ K. The temperature dependences of resistivity are shown in the insets.

Figure 2 shows the Hall resistivity for an almost metallic sample (sample 1, $x = 0.77$), and another sample which has a Co concentration very close or just below the metal–insulator transition (sample 2, $x = 0.51$), as a function of magnetic field at $T = 5$ K. The temperature dependences of resistivity for these two samples are shown in the insets. From the resistivity ρ_{xx}–T curves, sample 1 behaves as a typical 'dirty' metal. In sample 2, the dependence is approximately logarithmic, $\rho \propto -\log T$, with negative temperature coefficient of resistivity. Recent combined conducting atomic force microscopy and computer simulation studies of co-sputtered metal–insulator films showed that this dependence is a signature of the dominating tunnelling conduction in the system of fine metal grains [5]. The saturation extraordinary Hall resistivity ρ_{xys} was determined by extrapolation of parts of the ρ_{xy}–H curves from above 3.5 T to zero field, while the ordinary Hall coefficient R_0 was obtained from the slopes at fields larger than 3.5 T. The value of R_0 increased from -2.3×10^{-7} $\mu\Omega$ cm Oe^{-1} in sample 1 to -3.4×10^{-6} $\mu\Omega$ cm Oe^{-1} in sample 2 (a factor of 15). On the other hand, ρ_{xys} increases by a factor of 133 (from 0.045 $\mu\Omega$ cm to 6.0 $\mu\Omega$ cm). Thus, the enhancement of the extraordinary effect is much greater. This means that the GHE cannot be explained by merely taking into account the interference effects. Spin–orbit interactions which lead to the extraordinary Hall effect in magnetic metals must be incorporated in the theory of GHE for the case of tunnelling between grains. Notice that the signs of both components of the Hall effect in nanocomposite Co–SiO$_2$ films are the same as in pure cobalt: positive for extraordinary and negative for ordinary Hall effect. We also note that the enhancement of the extraordinary Hall effect in Co–SiO$_2$ composites is considerably smaller than that in either (NiFe)–SiO$_2$ [1, 2] or Fe–SiO$_2$ [4, 6]. This feature of cobalt-containing composites has been also noticed in [7]. As has been mentioned before, in Co–SiO$_2$ films no metal particles of sizes less than about 2 nm are detected. While in (NiFe)–SiO$_2$, the majority of particles are smaller than 1 nm [2]. This means that the fine structure of the composite plays a primary role for the giant Hall effect.

Acknowledgments

Brazilian agencies FAPESP and CNPq and Hong Kong RGC with number HKUST6159/99P are acknowledged for their financial support. The electron microscopy work has been performed with the JEM-3010, 300 kV microscope of the Laboratório de Microscopia Eletrônica/LNLS, Campinas, Brazil.

References

[1] Pakhomov A B, Yan X and Zhao B 1995 *Appl. Phys. Lett.* **67** 3497
[2] Jing X N, Wang N, Pakhomov A B, Fung K K and Yan X 1996 *Phys. Rev.* B **53** 14 032
[3] Zhang X X, Liu H and Pakhomov A B *ETOPIM-5 (Hong Kong, 1999) Physica* B **279** 81
[4] Aronzon B A, Kovalev D Yu, Lagar'kov A N, Meilikhov E Z, Ryl'kov V V, Sedova M A, Negre N, Goiran M and Leotin J 1999 *JETP Lett.* **70** 90
[5] Luo E Z, Pakhomov A B, Zhang Z Q, Chan M C, Wilson I H, Xu J B and Yan X 2000 *Physica* B **279** 98
Chan M C, Pakhomov A B and Zhang Z Q 2000 *J. Appl. Phys.* **87** at press
[6] Zhao B and Yan X 1997 *J. Appl. Phys.* **81** 4290
[7] Sato H, Kobayashi Y, Hashimoto K, Aoki Y, Sugawara H, Mitani S, Fujimori H and Ohnuma S 1998 *J. Phys. Soc. Japan* **67** 2193