Large magnetoresistance in metamagnetic $CoMnSi_{0.88}Ge_{0.12}$ alloy*

Zhang Cheng-Liang(张成亮), Wang Dun-Hui(王敦辉)†, Cao Qing-Qi(曹庆琪), Xuan Hai-Cheng(轩海成), Ma Sheng-Can(马胜灿), and Du You-Wei(都有为)

National Laboratory of Solid State Microstructures and Key Laboratory of Nanomaterials for Jiangsu Province, Nanjing University, Nanjing 210093, *China*

(Received 24 July 2009; revised manuscript received 14 August 2009)

The magneto-transport properties are investigated in metamagnetic $CoMnSi_{0.88}Ge_{0.12}$ alloy. By applying a magnetic field or increasing temperature, a metamagnetic phase transition from antiferromagnetic to ferromagnetic is observed in this alloy. Around the metamagnetic phase transition, $CoMnSi_{0.88}Ge_{0.12}$ alloy exhibits a large and negative magnetoresistance effect (∼32%) under a magnetic field of 20 kOe (1 Oe = 79.5775 A/m), which is ascribed to the spin-dependent scattering of conduction electrons.

Keywords: metamagnetic, magnetoresistance

PACC: 7530K, 7530V, 7215G

1. Introduction

The giant magnetoresistance (MR) effect has attracted attention increasingly for the interest of its physical mechanism and the practical applications in magnetic recording and memory devices, since it was discovered in antiferromagnetically coupled Fe/Cr multilayers[1] and many other artificial multilayer systems.[2−4] In addition to those artificial super-lattices, large MR has also been observed in many intermetallic compounds, such as $Ce(Fe_{0.93}Ru_{0.07})_2$,[5] FeRh,[6] $SmMn_2Ge_2$,[7] YMn_6Sn_6,[8] $Mn_2Sb_{0.88}Ge_{0.12}$,[9] and $NaZn_{13}$-type LaFeCoSi,[10] in which a metamagnetic phase transition can be induced by applying a magnetic field.

Recently, Zhang *et al.* studied the electric transport properties in CoMnSi alloy, and observed large magnetoresistance over a large temperature region.[11] It is known that CoMnSi alloy has a TiNiSi-type orthorhombic crystalline structure with the space group of *Pnma*. It shows double spiral antiferromagnetism below its Nèel temperature of 365 K.[12,13] Meanwhile, the isostructural compound CoMnGe exhibits collinear ferromagnetism with a Curie temperature of 337 K.[14] The substitution of Ge for Si could enhance the competition between antiferromagnetism and ferromagnetism, and consequently form the metamagnetic $CoMnSi_{1-x}Ge_x$ system.[14−17] In $CoMnSi_{1-x}Ge_x$ ($x > 0.08$) alloys, abrupt jumps of magnetization are observed in the thermal–magnetic (M–T) curves, which are identified as the first-order phase transition between the low-temperature antiferromagnetic (AFM) phase and the high-temperature ferromagnetic (FM) phase.[17] Recently, we reported on large and positive magnetic entropy changes as well as broad working temperature spans in $CoMnSi_{0.88}Ge_{0.12}$ alloy.[17] In the present paper, we investigate and discuss the MR effect in $CoMnSi_{0.88}Ge_{0.12}$ alloy by using the spin-dependent scattering theory.

2. Experiment

A polycrystalline sample of $CoMnSi_{0.88}Ge_{0.12}$ was prepared by arc melting the raw materials with nominal proportions in a high purity argon atmosphere. To ensure homogeneity, the ingot was re-melted several times. Then the ingot was pulverized into powder and pressed into some small tablets. Finally, the tablets were sealed in evacuated quartz tubes and annealed at a temperature of 740 °C for 5 days, and then quenched in cool water. The single phase of TiNiSi-type structure was confirmed in our sample by x-ray diffraction (XRD) analysis using Cu Kα radiation. The magnetic measurement was carried out by using

*Project supported by the State Key Program for Basic Research of China (Grant No. 2005CB623605), the National Natural Science Foundation of China (Grant Nos. 50701022 and 50831006) and the Program for New Century Excellent Talents of China (Grant No. NCET-08-0278).

†Corresponding author. E-mail: wangdh@nju.edu.cn

© 2010 Chinese Physical Society and IOP Publishing Ltd

a superconducting quantum interference device magnetometer (SQUID, Quantum Design). The electrical transport properties were investigated on the annealed tablets using a physical property measurement system (PPMS, Quantum Design) by the standard four-probe technique with a dc vertical magnetic field.

3. Results and discussion

The M–T curve for $CoMnSi_{0.88}Ge_{0.12}$ alloy measured at a magnetic field of 100 Oe (1 Oe = 79.5775 A/m) on heating is shown in Fig. 1. With increasing temperature, a metamagnetic phase transition from AFM to FM is observed. The phase transition temperature ($T_{\mathrm{AFM-FM}}$), defined as a temperature where $\mathrm{d}M/\mathrm{d}T$ is the maximum, is about 212 K. Figure 1 also shows the temperature dependence of the electrical resistivity (ρ–T) on heating between 100 and 300 K. The measurements are carried out at $H = 0$ and 20 kOe, respectively. In the case of zero field, the electrical resistivity first increases with the increase of temperature, showing a metallic behaviour. Then the electrical resistivity drops suddenly around the temperature of 210 K, which accords well with the $T_{\mathrm{AFM-FM}}$ obtained from the low-field (100 Oe) M–T curves. Obviously, the sudden decrease of electrical resistivity could be attributed to the temperature-induced metamagnetic phase transition between AFM and FM states. As temperature increases further, in the FM state, the electrical resistivity shows metallic behaviour again. Compared with the case in the zero field, the electrical resistivity of the AFM state in the 20 kOe field decreases largely near $T_{\mathrm{AFM-FM}}$, while that of the FM state is almost unchanged. In addition, $T_{\mathrm{AFM-FM}}$ shifts about 40 K towards lower temperatures as previously observed in M–T curves.[15] Therefore, a large negative MR effect, which is associated with the metamagnetic phase transition, could be expected in the vicinity of $T_{\mathrm{AFM-FM}}$.

The temperature dependence of MR ratio for $CoMnSi_{0.88}Ge_{0.12}$ alloy is plotted in Fig. 2. Here MR is defined as $\mathrm{MR} = [\rho(H) - \rho(0)]/\rho(0)$, with $\rho(0)$ and $\rho(H)$ referring to the electrical resistivities without and with applying a magnetic field, respectively. Large and negative MR is observed under a magnetic field of 20 kOe. For example, the peak value of MR reaches up to 32% at 191 K, which is comparable with those observed in some other metamagnetic materials, such as $Ce(Fe_{0.93}Ru_{0.07})_2$,[5] $SmMn_2Ge_2$,[7] $YMn_6Sn_{5.9}Ga_{0.1}$,[8] and $Mn_2Sb_{0.88}Ge_{0.12}$ alloys.[9] Compared with the case in CoMnSi alloy, though the temperature region of MR in $CoMnSi_{0.88}Ge_{0.12}$ alloy is smaller, the peak value of MR under a relatively low magnetic field is largely increased, owing to the abrupt metamagnetic phase transition induced by Ge-substitution.[11]

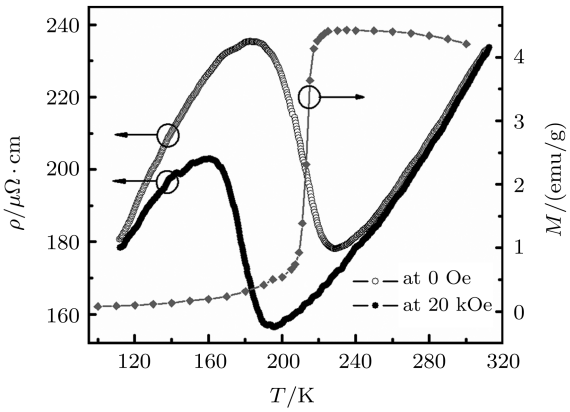


Fig. 1. Temperature dependences of electrical resistivity and magnetization for $CoMnSi_{0.88}Ge_{0.12}$ alloy.

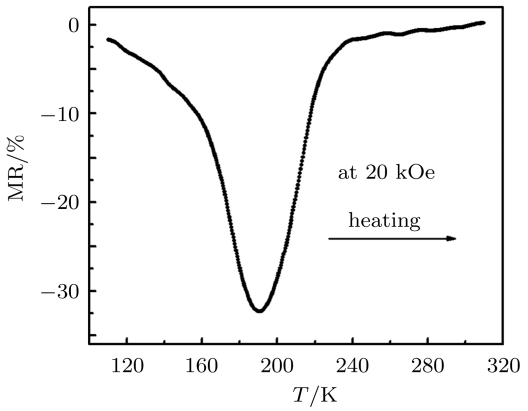


Fig. 2. Temperature dependence of magnetoresistance for $CoMnSi_{0.88}Ge_{0.12}$ alloy under a field of 20 kOe.

The isothermal magnetization (M–H) curves for $CoMnSi_{0.88}Ge_{0.12}$ alloy measured at 191 K and 200 K are shown in Fig. 3(a). During the measurement, the magnetic field first increases to 20 kOe and then returns to zero. Large jumps of magnetization (ΔM) (for example, about 90 emu/g at 191 K) are observed around the metamagnetic phase transition. The first-order nature of the phase transition is confirmed by the magnetic hysteresis between the process of increasing and decreasing fields. The metamagnetic critical field, which is defined as the inflexion point in the M–H curves, decreases significantly from 13.5 kOe at 191 K to 8.5 kOe at 200 K.

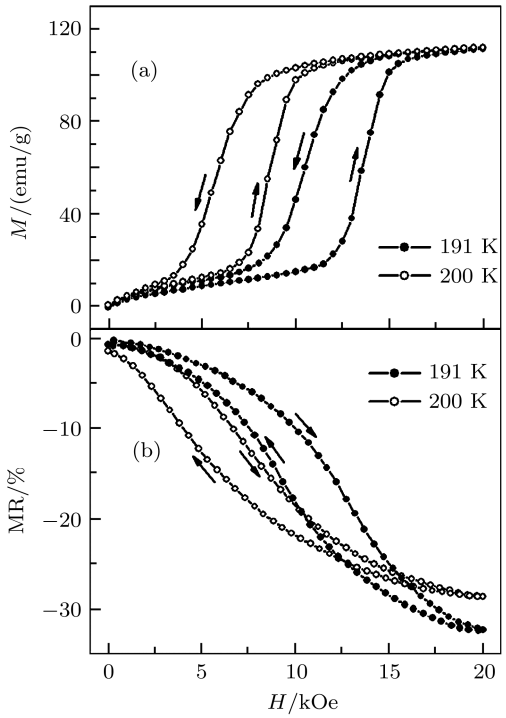


Fig. 3. (a) Isothermal magnetization curves for $CoMnSi_{0.88}Ge_{0.12}$ alloy measured at 191 K and 200 K, and (b) magnetic field dependences of magnetoresistance for $CoMnSi_{0.88}Ge_{0.12}$ alloy measured at 191 K and 200 K.

Figure 3(b) shows the magnetic field dependences of magnetoresistance (MR–H) for $CoMnSi_{0.88}Ge_{0.12}$ alloy measured at 191 and 200 K. At 191 K, the MR ratio grows slowly at low magnetic fields. With the increase of magnetic field, a sudden increase of MR ratio occurs around 13 kOe. Further increase of magnetic field leads to the MR value approaching the saturation value of 32%. From Figs. 3(a) and 3(b), it seems that the jump of MR ratio on MR–H curves should be ascribed to the metamagnetic behaviours. Although the saturation value of MR of 200 K is lower than 191 K, it has a larger MR ratio at low magnetic fields, for example at $H \leq 10$ kOe. This phenomenon can be understood by the fact that the metamagnetic critical field decreases as temperature increases.

As we know, spin-dependent scattering theory has been employed to explain the large MR in some natural multilayer alloys,[6,8,18] in which the metamagnetic phase transition was often observed. In CoMnSi alloy, neutron diffraction analysis reveals that the magnetic moments form a double spiral antiferromagnetic structure along the c-axes, and the spirals run through serials of Mn and Co basal planes and stack in the sequence of Mn–Mn–Co–Co–Mn–Mn–Co–Co, establishing a natural multilayer alloy.[19] The interactions within a Mn plane and a Co plane are ferromagnetic, but the interlayer couplings between Mn–Mn and Co–Co planes are antiferromagnetic with their respective angles rotating around the c-axes.[19] Therefore, a naturally and antiferromagnetically coupled multilayer-structure is formed along the c-axes and the conduction electrons experience relative strong scattering potentials and result in higher resistivity in the AFM state.[17] In the case of $CoMnSi_{0.88}Ge_{0.12}$ alloy, which probably possesses a similar magnetic structure to CoMnSi, the application of a magnetic field induces a metamagnetic transition from the AFM to FM state. It could be related to the large decrease in scattering potentials of conduction electrons and consequently low resistivity.[18] Therefore, a large and negative MR effect is exhibited around the metamagnetic phase transition in $CoMnSi_{0.88}Ge_{0.12}$ alloy.

4. Conclusion

The magnetotransport properties are studied in $CoMnSi_{0.88}Ge_{0.12}$ alloy from 100 K to 300 K. Owing to the large and abrupt change of magnetization associated with the metamagnetic phase transition from AFM to FM, a large MR effect is observed in the vicinity of metamagnetic phase transition temperature, suggesting their potential application as a magnetic field sensor. The large and negative MR effect is ascribed to the spin-dependent scattering of conduction electrons.

References

[1] Baibich M N, Broto J M, Fert A, Naguyen Van Dau F, Petroff F, Etienne P, Creuzet G, Friederich A and Chazelas J 1988 *Phys. Rev. Lett.* **61** 2472

[2] Parkin S S P, Bhadra R and Roche K P 1991 *Phys. Rev. Lett.* **66** 2152

[3] Petroff F, Barthélemy A, Mosca D H, Lottis D K, Fert A, Schroeder P A, Pratt Jr W P and Loloee R 1991 *Phys. Rev.* B **44** 5355

[4] Binasch G, Grünberg P, Saurenbach F and Zinn W 1989 *Phys. Rev.* B **39** 4828

[5] Kunkel H P, Zhou X Z, Stampe P A, Cowen J A and Williams G 1996 *Phys. Rev.* B **53** 15099

[6] Moruzzi V L and Marcus P M 1992 *Phys. Rev.* B **46** 14198

[7] van Dover R B, Gyorgy E M, Cava R J, Krajewski J J, Felder R J and Peck W F 1993 *Phys. Rev.* B **47** 6134

[8] Zhang S Y, Zhao P, Cheng Z H, Li R W, Sun J R, Zhang H W and Shen B G 2001 *Phys. Rev.* B **64** 212404
[9] Zhang Y Q and Zhang Z D 2004 *J. Phys.* D: *Appl. Phys.* **37** 819
[10] Hu F X, Qian X L, Wang G J, Sun J R, Shen B G, Chen Z H and Gao J 2005 *Chin. Phys.* **14** 2329
[11] Zhang Q, Li W F, Sun N K, Du J, Li Y B, Li D, Zhang Y Q and Zhang Z D 2008 *J. Phys.* D: *Appl. Phys.* **41** 125001
[12] Johnson V and Frederick C G 1973 *Phys. Stat. Sol.* (a) **20** 331
[13] Nizioł S, Bińczycka H, Szytuł A, Todorović J, Fruchart R, Senateur J P and Fruchart D 1978 *Phys. Stat. Sol.* (a) **45** 591
[14] Niziol S, Zach R, Senateur J P and Beille J 1989 *J. Magn. Magn. Mater.* **79** 333
[15] Niziol S, Fruchart R and Senateur J P 1979 *Phys. Stat. Sol.* (a) **51** K23
[16] Sandeman K G, Daou R, Özcan S, Durrell J H, Mathur N D and Fray D J 2006 *Phys. Rev.* B **74** 224436
[17] Zhang C L, Wang D H, Cao Q Q, Han Z D, Xuan H C and Du Y W 2009 *J. Phys.* D: *Appl. Phys.* **42** 015007
[18] Havela L, Sechovsky V, Prokes K, Nakotte H, Fujii H and Lacerda A 1996 *Physica* B **223–224** 245
[19] Szytula A, Bazela W and Radenkovic S 1983 *J. Magn. Magn. Mater.* **38** 99