Journal of Magnetism and Magnetic Materials 177–181 (1998) 587–588

ELSEVIER

Journal of magnetism and magnetic materials

Magnetic properties of $Mn_3(Ga, Al)C$ under high magnetic field and high pressure

K. Kamishima[a,*], T. Goto[a], T. Kanomata[b], M.I. Bartashevich[c]

[a] *ISSP, University of Tokyo, Roppongi 7-22-1, Minato-ku, Tokyo 106, Japan*
[b] *Department of Applied Physics, Tohoku Gakuin University, Tagajo 985, Japan*
[c] *IPAM, Ural State University, 620083 Ekaterinburg, Russia*

Abstract

Mn_3GaC is antiferromagnetic (AFM) at low temperatures and ferromagnetic (FM) above T_t ($\sim$ 160 K). The magnetization of $Mn_3Ga_{1-x}Al_xC$ with $x \leqslant 0.08$ has been measured under pressure (p) with a special interest in the p dependence of magnetic properties in this system. It is found that the pressure enhances the magnetic moment of Mn μ_{FM} in the FM phase and changes the AFM to a new magnetic phase with spontaneous magnetization. The forced magnetostriction of $Mn_3Ga_{1-x}Al_xC$ with $x = 0.015$ and 0.07 indicates $\mu_{FM} < \mu_{NEW\ PHASE} < \mu_{AFM}$.

Keywords: Itinerant magnetism; Magnetization – pressure dependent; Magnetostriction – forced volume; Phase transitions – order–order; Phase transitions – pressure effect

The intermetallic compound Mn_3GaC has a cubic crystal structure of perovskite type, is antiferromagnetic (AFM) below T_t ($\sim$160 K) and exhibits a first-order transition to a ferromagnetic (FM) phase with abrupt decrease in volume at T_t [1]. Experiments of the AC susceptibility under high pressure indicate that an intermediate (IM) phase appears between the AFM and FM phases and that the Curie temperature T_C of about 250 K at 0 kbar increases with pressure [1]. The substitution of Al for Ga in Mn_3GaC is considered to produce a chemical pressure in this system [2]. According to neutron diffraction experiments [3], the AFM structure at 4.2 K is of the ($\pi\pi\pi$) type with an Mn moment of $\mu_{AFM} = 1.8\ \mu_B$ and μ_{FM} in the FM phase equals 1.2 μ_B at 170 K. In order to investigate the behavior of the complicated magnetic transitions, we have measured the magnetization of $Mn_3Ga_{1-x}Al_xC$ with $x \leqslant 0.08$ under pressure and the forced magnetostriction of $Mn_3Ga_{1-x}Al_xC$ with $x = 0.015$ and 0.07.

Fig. 1 shows the temperature (T) dependence of the magnetization (M) of Mn_3GaC under pressure (p). The

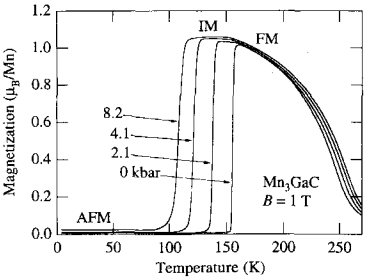

Fig. 1. The M–T curves of Mn_3GaC at various pressures.

IM phase seems to exist in a narrow region even at 0 kbar and expands with p. It should be noted that μ_{FM} is enhanced with increasing p. The value of $d\ln M/dp$ at $T = 165$ K and $B \geqslant 1$ T in the FM phase is estimated to be about $+2.5 \times 10^{-3}\ kbar^{-1}$. Mn_3GaC in the AFM phase exhibits a metamagnetic transition from the AFM to a forced FM state with hysteresis. The IM phase is not distinguished in the magnetization curves, which can be caused by the higher sweeping rate of pulsed magnetic fields. Fig. 2 shows the average critical field of the transition $B_C^{AV}(T)$ as a function of T, from which we can estimate the coefficient of the electronic specific heat in the forced FM state γ_{FM} using the known value of

* Corresponding author. Tel.: + 81 3 3478 6811; fax: + 81 3 3478 5472; e-mail: kamisima@mgl.issp.u-tokyo.ac.jp.

0304-8853/98/$19.00
PII S0304-8853(97)00920-7

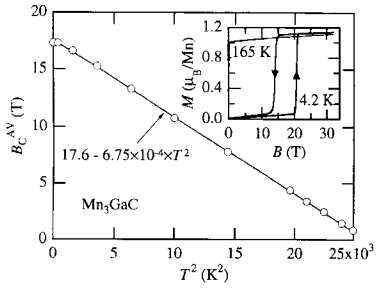

Fig. 2. Average critical field of Mn_3GaC as a function of T. The magnetization curves at 4.2 and 165 K are shown in the inset.

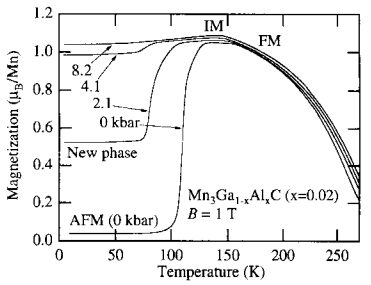

Fig. 3. The M–T curves of $Mn_3Ga_{0.98}Al_{0.02}C$.

$\gamma_{AFM} = 19\ mJ/K^2\ mol$ in the AFM state [4] and the Clausius–Clapeyron relation

$$dB_C/dT = -\Delta S_{AFM\text{-}FM}(T)/\Delta M_{AFM\ FM}(T). \quad (1)$$

Here, $\Delta S_{AFM\text{-}FM}$ $(=(\gamma_{FM}-\gamma_{AFM})\cdot T)$ and $\Delta M_{AFM\ FM}$ $(=1.052\ \mu_B/Mn = 17.62\ A\ m^2/mol)$ are the changes of the entropy and the magnetization due to the metamagnetic transition. The estimated value of $\gamma_{FM} = 43\ mJ/K^2\ mol$ is extremely large compared with other itinerant ferromagnets and suggests the possibility of huge spin fluctuations in the FM state. Fig. 3 shows the M–T curves of $Mn_3Ga_{1-x}Al_xC$ with $x = 0.02$ at various p. The AFM phase is changed to a new magnetic phase with spontaneous magnetization around 2 kbar. The new phase disappears and is replaced by the IM phase at 8.2 kbar. These experimental results suggest that the compound Mn_3GaC also exhibits the same transitions at higher p. Fig. 4a and Fig. 4c show the field dependence of M and volume magnetostriction (ω) of $Mn_3Ga_{1-x}Al_xC$ with $x = 0.015$ at 4.2 K. The changes of M and ω between the AFM and forced FM states are almost the same as those of Mn_3GaC [5]. In contrast, $Mn_3Ga_{1-x}Al_xC$ with $x = 0.07$ exhibits transitions from the new state to the IM and then to the forced FM state with increasing magnetic field and the change of ω equals

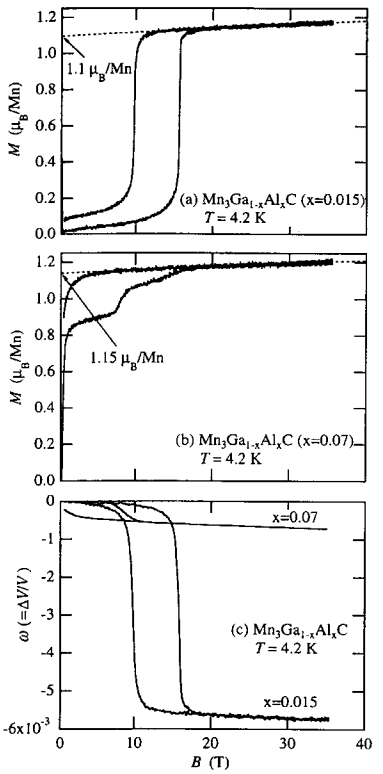

Fig. 4. Magnetization curves of $Mn_3Ga_{1-x}Al_xC$ at $x = 0.015$ (a) and 0.07 (b), and magnetostriction (c) at 4.2 K.

8.95% of that of the compound with $x = 0.015$, as shown in Fig. 4b and Fig. 4c. $\mu_{NEW\ PHASE}[x = 0.07]$ is estimated to be 1.23 μ_B, assuming $\mu_{AFM}[x = 0.015] = 1.8\ \mu_B$ and applying the expression $\omega = a\cdot\mu^2$ for the specimens with $x = 0.015$ and 0.07. These results indicate that $\mu_{FM} < \mu_{NEW\ PHASE} < \mu_{AFM}$.

References

[1] T. Kaneko, T. Kanomata, T. Shirakawa, J. Phys. Soc. Japan 56 (1987) 4047.
[2] T. Kanomata, H. Yasui, H. Yoshida, T. Kaneko, J. Magn. Magn. Mater. 70 (1987) 263.
[3] D. Fruchart, E.F. Bertaut, F. Sayetat, M. Nasr Eddine, R. Fruchart, J.P. Senateur, Solid State Commun. 8 (1970) 91.
[4] J. Garcia, J. Bartolome, D. Gonzales, J. Chem. Thermodyn. 15 (1983) 1059.
[5] T. Kanomata, M. Kikuchi, T. Kaneko, K. Kamishima, M.I. Bartashevich, H.A. Katori, T. Goto, Solid State Commun. 101 (1997) 811.