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Magnetic Properties of the Intermetallic Compound Mn_3InC

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A compound Mn_3InC possesses a cubic perovskite-type structure with lattice parameter 3.992 Å. Mn_3InC has a saturation moment at 4.2 K of 23.1 emu/g equivalent to 1.2 μ_B per molecule, the Curie temperature being ~272 K. The paramagnetic susceptibility χ, measured over the temperature range 300–810 K, is found to vary with temperature in a manner different from normal ferromagnetic materials, the $1/\chi$–T curve possessing pronounced curvature concave to the temperature axis. © 1992 Academic Press, Inc.

1. Introduction

Ternary manganese compounds Mn_3MX (M = Al, Zn, Ga and Sn; X = C and N) have the cubic perovskite crystal structure, in which the Mn atoms are located at the face centered positions, the M atoms on the cubic corners, and the X atoms at the body centered positions. It is known that the compounds Mn_3GaC, Mn_3ZnC, and Mn_3SnC show interesting magnetic behaviors (*1*, *2*). The magnetic properties of Mn_3GaC are characterized by an antiferromagnetic (AF)–ferromagnetic (F) transition at a temperature $T_t \simeq 170$ K. The compound Mn_3ZnC also shows the transition between magnetically ordered states at $T_t \simeq 230$ K. Neutron diffraction studies show that both AF and F states coexist below T_t and the F state appears above T_t (*3*). In the case of Mn_3SnC both AF and F states coexist up to the Curie temperature 292 K (*4*). The transition to the paramagnetic (P) state is of the 1st order, where the magnetization disappears discontinuously and an abrupt change of lattice parameter takes place (*5*).

In this paper, we report our studies on Mn_3InC and present experimental data on crystallographic and magnetic properties about which very little is known, except that Morgan (*6*) found $Mn_{65}In_{15}C_{20}$ to be ferromagnetic and to consist of two phases, one of which had the perovskite structure, a = 3.932 Å.

2. Experimental

A polycrystalline sample of Mn_3InC was prepared from Mn (99.9%), In (99.9%), and spectroscopic grade carbon which were

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TABLE I

OBSERVED INTERPLANAR d SPACING (Å) AND OBSERVED AND CALCULATED RELATIVE INTENSITIES OF X-RAY DIFFRACTION LINES FOR Mn_3InC

h	k	l	d (Å)	$I_{obs.}$	$I_{cal.}$
1	0	0	4.001	10.4	10.3
1	1	0	2.826	20.1	19.3
1	1	1	2.306	100.0	100.0
2	0	0	1.999	55.7	54.9
2	1	0	1.787	6.8	5.6
2	1	1	1.631	8.8	7.2
2	2	0	1.412	38.9	32.6
2	2	1	1.331	3.8	2.3
3	1	0	1.263	3.9	3.1
3	1	1	1.204	37.5	33.1
2	2	2	1.153	13.6	10.8
3	2	0	1.107	2.0	1.4
3	2	1	1.067	5.1	4.1
4	0	0	0.998	7.2	5.9
3	2	2	0.968	2.9	1.2
3	3	0	0.941	3.6	1.0
3	3	1	0.916	20.8	20.7
4	2	0	0.893	28.4	24.2

mixed in the desired proportion, sealed in an evacuated silica tube, and heated for 7 days at about 800°C. The reaction product was pulverized, mixed, heated again *in vacuo* at about 800°C for 7 days, and quenched in water.

The crystal structure of Mn_3InC was examined by the X-ray powder diffraction method. The measurements of magnetization were made in a vibrating sample magnetometer in static magnetic fields up to 145 kOe. The magnetic susceptibility was measured by a magnetic balance in the temperature range from 300 to 800 K, and the temperature was measured using a platinel thermocouple.

3. Results and Discussion

The X-ray diffraction study showed that all diffraction lines could be indexed with a cubic structure. As seen in Table I, the observed intensities of all the fundamental and the superlattice lines agreed well those calculated for the perovskite-type structure. The lattice parameter was determined to be 3.992 Å larger than that found by Morgan (*6*) for the two-phase alloy $Mn_{65}In_{15}C_{20}$.

Figure 1 shows the magnetization curves for Mn_3InC at 4.2 K. The magnetization curve follows the equation $\sigma = \sigma_0 + \chi H$; the saturation magnetization σ_0 and the high field susceptibility χ were obtained to be 23.1 emu/g (1.2 μ_B/f.u.) and 6.1 $\times$ 10^{-2} emu/g kOe, respectively. The magnetization process at other temperatures up to 100 K exhibits a behavior similar to that at 4.2 K. The inset shows the temperature dependence of σ_0 for Mn_3InC. The saturation magnetization of Mn_3InC is small compared with those of Mn_3MC(M = Al, Zn and Ga). The magnetizations at 7.3 kOe were measured in the temperature range from 77 to 278 K. The result is shown in Fig. 2. As seen in the figure, an abrupt decrease in the magnetization occurs at the Curie temperature $T_c \simeq$ 272 K.

The temperature dependence of the in-

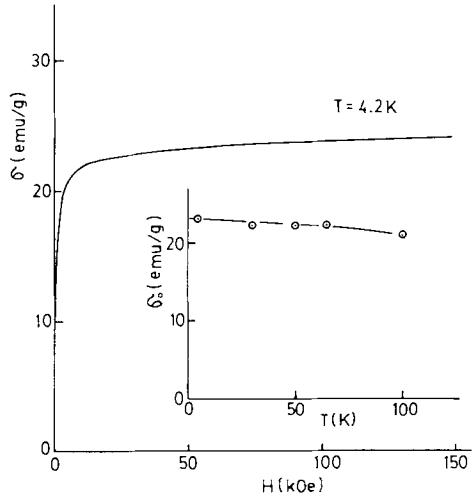

FIG. 1. Magnetization σ of Mn_3InC as a function of applied magnetic field H at 4.2 K. Inset in the figure is the result of the temperature dependence of the saturation magnetization for Mn_3InC.

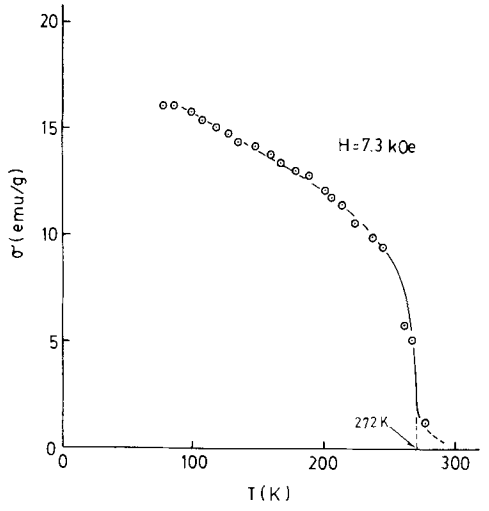

FIG. 2. The temperature dependence of the magnetization for Mn_3InC.

verse susceptibility $1/\chi_m$ above the Curie temperature, shown in Fig. 3, does not follow the Curie–Weiss law. The slope of the $1/\chi_m$ curve decreases with increasing temperature. Similar behavior of the temperature dependence of the inverse susceptibility was observed for the compounds Mn_3AlC (*7*), Mn_3SnC (*2*, *5*), and Cr*M*As (*M* = Ru,Rh) (*8*). We tried to reproduce the susceptibility vs. temperature relation by a formula $\chi_m = C'_m/(T - \theta')^\gamma$. When $\ln(\chi_m^{-1})$ is plotted against $\ln(T - \theta')$ with $\theta' = 201$ K for the temperature range investigated, a very good straight line is obtained. The values of γ and C'_m are found to be 0.45 and 0.094 from the linear relation of the $\ln(\chi_m^{-1})$ vs. $\ln(T - \theta')$ curve. If we use the value of C'_m for estimation of the magnetic moment, we get a very small value of 0.32 μ_B per molecule. This means that the parameter C'_m does not have any relation to the usual Curie constant. Similar magnetic behavior for the temperature dependence of the magnetization has been observed in Mn_3SnC. Furthermore, the magnetic transition temperature and the value of the saturation moment are also comparable to those of Mn_3SnC. So, we consider that the magnetic structure of Mn_3InC is presumably of the Mn_3SnC type.

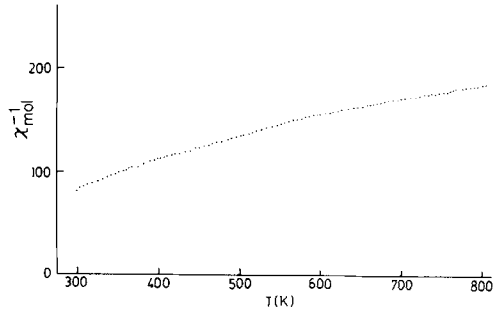

FIG. 3. The temperature dependence of the inverse susceptibility for Mn_3InC.

Recently, Motizuki and Nagai (*9*) and Motizuki *et al.* (*10*) calculated the band structures of Mn_3MC (*M* = Zn, Ga, In, and Sn) by a self-consistent augmented plane-wave method. According to their calculation, the density of states consists of three parts: the bonding and antibonding *d*–*p* bands and the nonbonding *d* band, with the Fermi level lying in the nonbonding. The nonbonding *d*-band width is about 5 eV, which is fairly wide. Therefore, they concluded that the *d* electrons of Mn atoms should be treated not as localized electrons, but as itinerent electrons. So, it is considered that the magnetic properties of Mn_3InC should be discussed in terms of the itinerent-electron magnetism.

Acknowledgment

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