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Magnetic properties of the $FeMn_{1-x}Ni_xGe$ compounds

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ABSTRACT

The crystal structure and magnetic properties of the $FeMn_{1-x}Ni_xGe$ ($0 \le x \le 1$) compounds have been studied by room temperature X-ray powder diffraction and magnetometric measurements within the temperature interval of 5–400 K and for magnetic fields up to 5 T. All compounds crystallize in a hexagonal Ni_2In-type crystal structure with space group $P6_3/mmc$ and show ferromagnetic behavior. It has been found that the temperature of magnetic ordering (T_C) increases nearly linearly with increasing Ni concentration from 163 K ($x=0$) to 304 K ($x=0.4$). Samples with $x \ge 0.8$ are ferromagnetically ordered above 400 K. The concentration dependency of the saturation magnetization at 5 K (M_S) shows a maximum of $M_S=2.81\ \mu_B$ per formula unit for $x=0.4$.

1. Introduction

Intermetallic compounds formed by the 3d transition metals with main group elements have been of considerable interest due to their interesting structural and physical properties [1–10]. For example, Nizol et al. [5] investigated magnetic properties of the $Co_xNi_{1-x}MnGe$ compounds. It was found that all compounds crystallize in the orthorhombic TiNiSi-type crystal structure at low temperatures and in the hexagonal Ni_2In-type crystal structure at high temperatures. The compounds with $0 \le x \le 0.2$ have a helicoidal magnetic structure, while collinear ferromagnetic ordering is observed for $x \ge 0.5$. Samples with $0.3 \le x \le 0.5$ show helicoidal, non-collinear ferromagnetic and collinear ferromagnetic structure with increasing temperature. Lin et al. [10] studied structural and magnetic properties of $MnFe_{1-x}Co_xGe$ compounds by using X-ray diffraction (XRD) and magnetization measurements. It was shown that the hexagonal Ni_2In-type crystal structure is observed for $x \le 0.8$ and the orthorhombic TiNiSi-type crystal structure is stable for $x > 0.8$. The Curie temperatures range from 159 K ($x=0$) to 345 K ($x=1$) for $MnFe_{1-x}Co_xGe$ compounds. For $MnFe_{1-x}Co_xGe$ compounds, saturation magnetization measured at 5 K increases with increasing x from 1.94 μ_B/f.u. ($x=0$) to 4.13 μ_B/f.u. ($x=1$).

FeMnGe and FeNiGe compounds adopt the hexagonal Ni_2In-type crystal structure with space group $P6_3/mmc$ [2,10]. In this structure, 3d transition metals occupy 2a(0,0,0) and 2d(1/3,2/3,3/4) sites and Ge atoms reside on 2c(1/3,2/3,1/4) sites. Fig. 1 shows the Ni_2In-type crystal structure drawn by using the Xcrysden code [11].

Previous investigations on FeMnGe and FeNiGe compounds have shown FeMnGe and FeNiGe orders ferromagnetically. The Curie temperature T_C and the saturation magnetization M_S at low temperatures are 159 K and 1.94 μ_B/f.u. for FeMnGe, 770 K and 0.5 μ_B/f.u. for FeNiGe, respectively [2,10]. This study deals with the crystal structure and the magnetic properties of the $FeMn_{1-x}Ni_xGe$ ($0 \le x \le 1$) compounds.

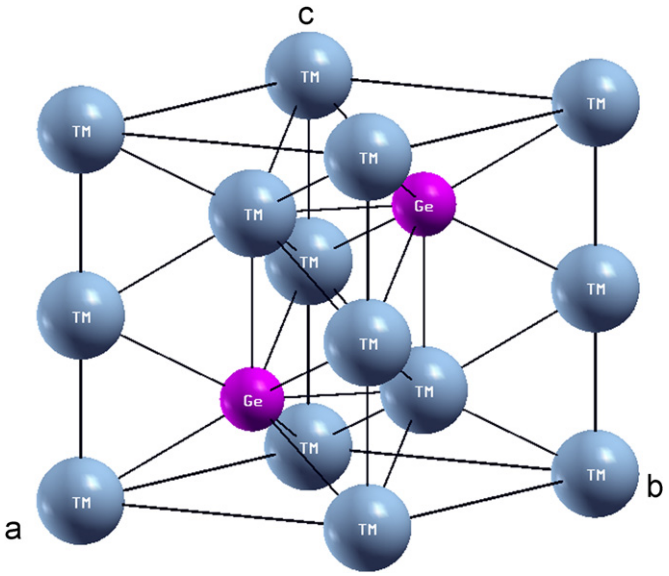

Fig. 1. Ni_2In-type crystal structure.

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2. Experimental

$FeMn_{1-x}Ni_xGe$ $(0 \le x \le 1)$ compounds were prepared by arc-melting the metals Fe (99.98%), Mn (99.99%), Ni (99.98%) and Ge (99.99%) in an argon atmosphere using a non-consumable tungsten electrode and a water-cooled copper hearth. The compound was re-melted several times to achieve a homogeneous composition. Samples, the mass of which had been determined carefully, were controlled after melting for mass loss. The mass loss was less than 3%. All measurements were performed on as-cast samples. X-ray diffraction (XRD) studies were carried out by using a Bruker D8 Advance diffractometer with CuKα radiation in two-theta range from 20° to 70°. The lattice parameters have been determined using the standard pattern matching method of the FULLPROF [12] program. The field-cooling (FC) and zero-field-cooling (ZFC) temperature dependence of magnetization were performed with a superconducting quantum interference device (SQUID, MPMS-5, Quantum Design, USA) in the temperature range from 5 to 400 K and, the magnetization curves were measured at 5 K in fields up to 50 kOe. The sample was initially cooled in zero magnetic field and the ZFC data were collected on warming by applying a magnetic field of 100 Oe. Subsequently, the FC data were collected upon cooling without removing the applied field. The values of the Curie temperatures (T_C) have been estimated from the temperature derivative of the FC magnetization versus temperature curve (dM/dT).

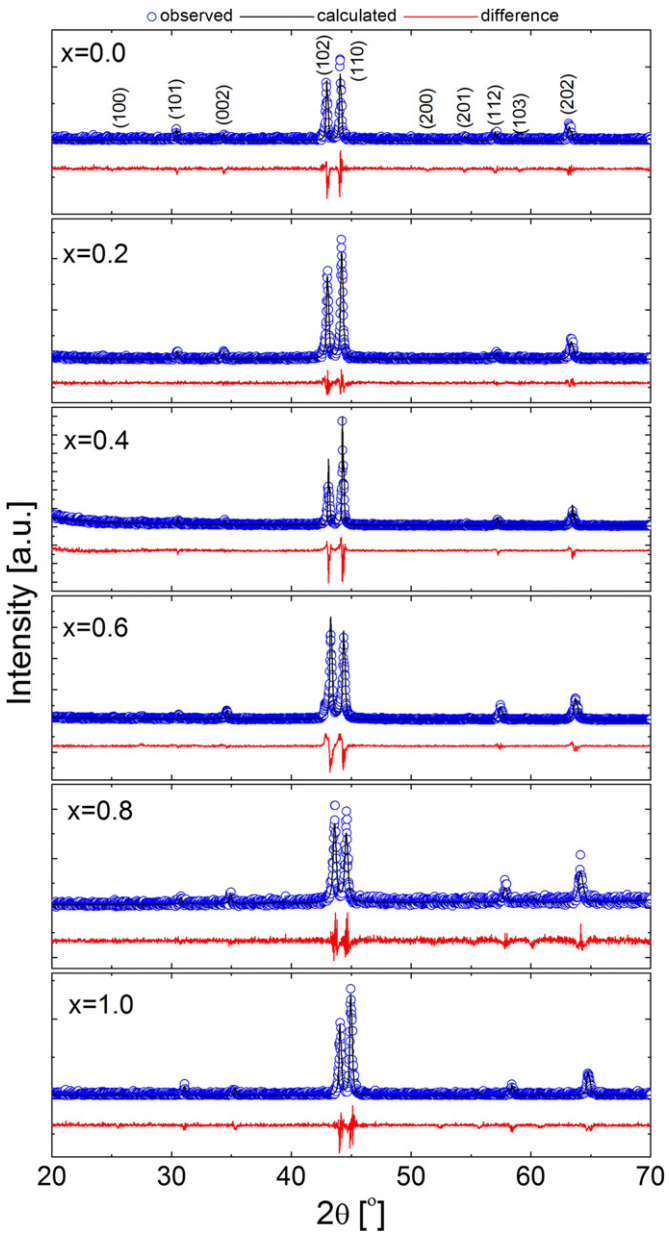

Fig. 2. The profile fittings for the $FeMn_{1-x}Ni_xGe$ compounds.

3. Results and discussion

The X-ray diffraction patterns confirm the existence of a hexagonal phase having the Ni_2In-type structure with the space group $P6_3/mmc$. Fig. 2 shows the X-ray diffractogram of the $FeMn_{0.6}Ni_{0.4}Ge$ compound as a representative example. The lattice parameters a and c, and the unit cell volume V for the $FeMn_{1-x}Ni_xGe$ samples at room temperature are shown in Fig. 3, while the refined unit-cell parameters a and c, and unit cell

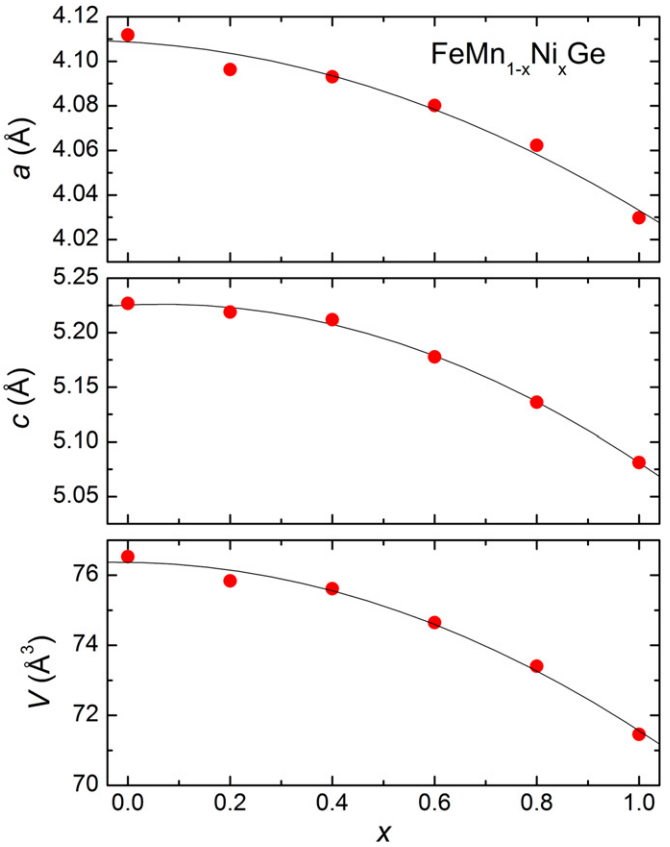

Fig. 3. Variation of the lattice constants a and c, the unit cell volume V with Ni concentration x at room temperature for the $FeMn_{1-x}Ni_xGe$ compounds. Solid lines are polynomial fits and serve as guide to the eye.

Table 1
The lattice constants a and c, volume V, the Curie temperature (T_C), the saturation magnetization M_S for the $FeMn_{1-x}Ni_xGe$ compounds.

x	a (Å)	c (Å)	V (Å^3)	T_C (K)	M_S (μ_B/f.u.)
0.0	4.1118(5)	5.2268(8)	76.53(3)	163(3)	1.638(5)
0.2	4.0964(6)	5.2189(8)	75.84(3)	268(2)	2.693(3)
0.4	4.0931(3)	5.2118(4)	75.62(2)	304(5)	2.806(2)
0.6	4.0802(4)	5.1777(6)	74.65(2)	243(3)	2.222(2)
0.8	4.0623(6)	5.1362(8)	73.40(3)	–	1.153(2)
1.0	4.0298(6)	5.0812(8)	71.46(3)	–	0.641(5)