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Magnetic and transport properties of $PrTGe_3$ (T = Ni, Rh)

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Abstract

Two new ternary intermetallic compounds $PrNiGe_3$ and $PrRhGe_3$ were synthesized and investigated. $PrNiGe_3$ exhibits two magnetic transitions below 21 K and a field induced metamagnetic transition at 1.6 T (5 K). On the other hand $PrRhGe_3$ remains paramagnetic down to 2 K. We attribute the absence of magnetic order in $PrRhGe_3$ to be due to a large crystal field splitting between the nonmagnetic singlet ground state and first excited state confirmed by the temperature dependent magnetic susceptibility, resistivity and specific heat data.

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Keywords: D. Magnetic phase transitions; D. Metamagnetic transition; D. Magnetoresistance; D. Crystal fields

1. Introduction

RTX_3 (R = rare earths, T = transition elements and X = Si, or Ge) compounds are well known to exhibit quite interesting physical properties like Kondo effect, heavy-fermion behavior and superconductivity etc. [1–11]. For example, the Ce-based compound $CeFeGe_3$ is characterized as nonmagnetic heavy fermion compound [4]; $CeNiGe_3$ is a Kondo lattice system [5] which shows pressure induced heavy-fermion superconductivity around the critical pressure $\sim$ 5.5 GPa and a Fermi liquid behavior at higher pressure [6]. Another compound $CeCoGe_3$ is a heavy fermion system with unusual magnetic properties [7]. Si-doping in this compound lead to non-Fermi-liquid spin dynamics [8] and anisotropic quantum critical behavior [9]. $CeRhGe_3$ is a weak Kondo lattice system which exhibits a complex magnetic behavior [10,11]. Pr-based compounds also have the possibilities to exhibit interesting physical properties resulting from the crystal field effect. Low lying crystal field excitations are believed to be responsible for the heavy fermion behavior in superconducting $PrOs_4Sb_{12}$ [12–14]. Despite the fact that the Cerium-based intermetallic compounds $CeTX_3$ (T = transition metals, X = Si, Ge) have been paid attention to a reasonable extent, so far only one Pr-based 113 compound, namely, $PrFeGe_3$ is reported [15]. We attempted to prepare several $PrTGe_3$ (T = 3d, 4d, 5d elements) compounds. We were successful in synthesizing two new compounds $PrNiGe_3$ and $PrRhGe_3$ in single phase. We present here our results on these two compounds.

2. Experimental

We prepared polycrystalline samples of $PrNiGe_3$, $PrRhGe_3$ and their nonmagnetic analog $LaNiGe_3$ and $LaRhGe_3$ by standard arc melting technique under argon atmosphere with a subsequent annealing at 800°C for a week inside a vacuum sealed quartz ampoule. During the arc melting process the samples were flipped and remelted five times to improve the homogeneity. The loss in weight in this process was negligible ($\sim$ 0.2%). Samples were characterized by powder x-ray diffraction and scanning electron microscopy (SEM). Composition homogeneity was checked by energy dispersive x-ray analysis (EDAX). Magnetization was measured using a commercial SQUID magnetometer. The heat capacity was measured using relaxation method in a physical property measurement system (PPMS-Quantum design). Electrical resistivity was measured using ac-transport option of Physical Property Measurement System (PPMS-Quantum design).

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Table 1
Lattice parameters and unit cell volumes of $RTGe_3$ (R = Pr, La; and T = Ni, Rh) compounds

Compounds	a (Å)	b (Å)	c (Å)	V (Å^3)
$PrNiGe_3$	4.124	21.778	4.147	372.45
$LaNiGe_3$	4.403		9.681	187.69
$PrRhGe_3$	4.380		10.013	192.17
$LaRhGe_3$	4.415		10.043	195.82

Table 2
Refined atomic coordinates for $PrNiGe_3$ and $PrRhGe_3$

Atom	x	y	z
$PrNiGe_3$			
Pr	0	0.33140	1/2
Ni	0	0.11236	0
Ge1	0	0.05480	1/2
Ge2	0	0.21019	0
Ge3	0	0.44348	0
$PrRhGe_3$			
Pr	0	0	0.00000
Rh	0	0	0.65792
Ge1	0	0	0.42268
Ge2	1/2	0	0.25801

3. Results and discussion

The powder x-ray diffraction patterns of polycrystalline samples of $PrNiGe_3$ and $PrRhGe_3$ are shown in Fig. 1 and Fig. 2 together with the results of Rietveld refinements. While $PrRhGe_3$ forms in $BaNiSn_3$-type tetragonal structure (space group *I4 mm*) $PrNiGe_3$ crystallizes in $SmNiGe_3$-type orthorhombic structure (space group *Cmmm*). The crystal structures of these two novel Pr-compounds are similar to their corresponding Ce-analogs [5,10]. The lattice parameters, unit cell volumes and refined atomic coordinates are shown in Tables 1 and 2. For the best fits the least squares refinement had χ^2 values of 1.53 and 3.09 for $PrNiGe_3$ and $PrRhGe_3$ respectively. $LaNiGe_3$ and $LaRhGe_3$ crystallize in $BaNiSn_3$-type tetragonal structure (space group *I4 mm*). There were few weak unindexed peaks in XRD pattern of $LaNiGe_3$ due to the presence of impurity phase(s) which we estimate to be less than 5% of the main phase, which is further confirmed by the SEM image. The impurity phase(s) in $PrNiGe_3$ is estimated to be less than 3% and that in $PrRhGe_3$ and $LaRhGe_3$ less than 5%. The EDAX composition analysis shows the compounds to have the desired stoichiometric composition of 1:1:3.

A. $PrNiGe_3$

Fig. 3 shows the temperature dependence of magnetic susceptibility at two different fields of 0.01 T and 2.0 T below 30 K. We observe a pronounced peak at 21 K followed by another anomaly at 19 K at 0.01 T. While the peak at 21 K is due to antiferromagnetic order, the transition at 19 K is an order-order transition due to change of magnetic structure. With the increase in magnetic field strength the two peaks merge together and shift to lower temperature. The rapid decrease of magnetic susceptibility at 0.01 T below T_N indicates the presence of strong uniaxial anisotropy in this compound. At higher temperatures (above 50 K) the magnetic susceptibility data follow a modified Curie–Weiss behavior. On fitting the susceptibility data at 2 T to the equation $\chi = \chi_o + C/(T - \theta_P)$

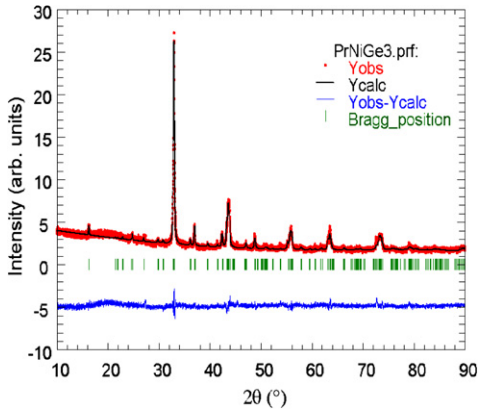

Fig. 1. (colour online): Powder x-ray diffraction pattern of $PrNiGe_3$ recorded at room temperature. The solid line through the experimental points is the Rietveld refinement profile calculated for $SmNiGe_3$-type orthorhombic structure (space group *Cmmm*). The lower curve represents the difference between the experimental and calculated results.

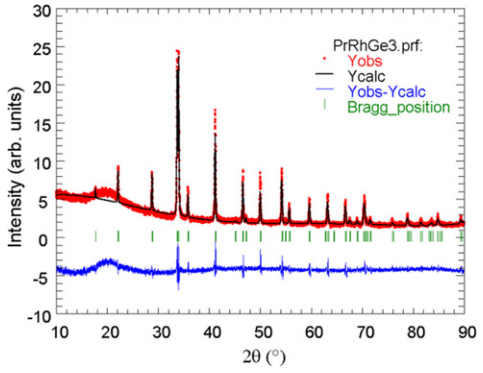

Fig. 2. (colour online): Powder x-ray diffraction pattern of $PrRhGe_3$ recorded at room temperature. The solid line through the experimental points is the Rietveld refinement profile calculated for $BaNiSn_3$-type tetragonal *I4 mm* structural model. The lower curve represents the difference between the experimental and calculated results.

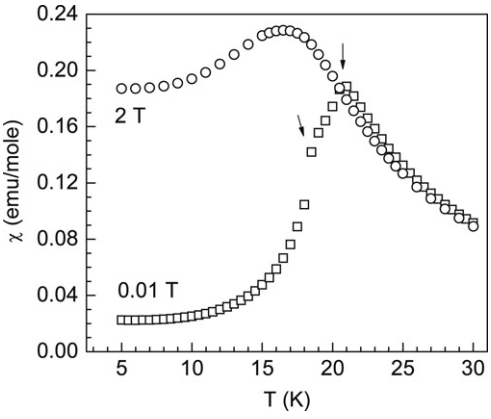

Fig. 3. Low temperature magnetic susceptibility plot of $PrNiGe_3$ as a function of temperature at two different fields.