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Magnetic and electrical resistivity of RT_2X_2, RTX_2 and RTX intermetallic compounds

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Abstract

Ac susceptibility and electrical resistivity studies were carried out on some RT_2X_2, RTX_2 and RTX intermetallic compounds. The Néel temperatures of these compounds are between 3 K for $TmCo_2Si_2$ up to 75 K for $TbRh_2Ge_2$. The temperature dependencies of the electrical resistivity at high temperatures are typical of metallic conductivity. Anomalies in the temperature dependence of the resistivity near the Néel temperature are observed. © 1997 Elsevier Science S.A.

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1. Introduction

Recently, R-T-X compounds, where R is a rare earth, T is a transition metal and X is a p-electron metal have been investigated extensively since they show interesting magnetic properties [1].

In this work, the magnetic and electric properties of the following R-T-X compounds with different compositions are reported: the RT_2X_2 composition: $LaFe_2Si_2$, $TmCo_2Si_2$, $(Dy,Er)Ru_2Si_2$, $TbRh_2Ge_2$, $TbCo_2Ge_2$; the RTX_2 composition: $GdRhSi_2$, $(Tb,Er)Mn_xGe_2$ and the RTX composition: (Ce,Dy)AgSn, GdRhSi. The influence of the composition and of the type of crystal structure on the electrical resistivity is investigated.

2. Experiments and results

The experiments were carried out on the samples prepared by melting the constituent elements (purities 3N for the rare earth and 4N for other elements) in an arc furnace under an argon atmosphere. A homogenization was carried out at 800°C for a week in evacuated and sealed quartz tubes.

The single-phase structure of the compounds was checked by X-ray analysis. The 1:2:2 compounds have the tetragonal $ThCr_2Si_2$-type of structure. The 1:1:2 compounds crystallize in the orthorhombic $CeNiSi_2$-type while the 1:1:1 compounds appear in the hexagonal LiGeGa-type (RAgSn) and the orthorhombic TiNiSi-type (GdRhSi) of crystal structure [1].

The ac magnetic susceptibility was measured using a mutual inductance bridge in the temperature range between 2 and 30 K.

The electrical resistivity R measurements without and in the magnetic field H up to 12.4 kOe were taken in the temperature interval 2–300 K using a conventional four-point-probe method.

The temperature dependence of the magnetic susceptibility shows a low temperature maximum typical of the transition between antiferro- and paramagnetic states. For some compounds an additional phase transition to an ordered state is observed. $LaFe_2Si_2$ is a

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Pauli paramagnet. The determined values of the Néel T_N and the phase transition temperatures T_t are listed in Table 1.

The electrical resistivity $R(T)$ of all investigated compounds increases with increasing temperature, which is characteristic of metallic conductors. The data for some compounds are shown in Fig. 1.

According to Mattheissen's rule [2], the total resistivity of a magnetic material can be written as $R(T) = R_0 + R_{ph}(T) + R_{mag}(T)$ where R_0 is the residual resistivity, $R_{ph}(T)$ is the contribution of an electron-phonon interaction and $R_{mag}(T)$ is the contribution of an electron-spin wave scattering.

The temperature dependence of the resistivity above T_N is described by the function $R(T) = R_0 + R_1 T + R_2 T^2$. The determined values of R_0, R_1 and R_2 parameters are given in Table 1. The $TbMn_xGe_2$ and $ErMn_xGe_2$ samples have large values of the residual resistivity R_0 which results from a non-stoichiometric composition of these compounds.

In all samples at low temperatures, anomalies around the Néel temperature are observed. The anomalies are clearly visible in the temperature dependence of the dR/dT. The de Gennes and Friedel theory [3] describes well the anomalies observed near critical temperatures.

The following observations were made:

- the electric resistivity curve of $LaFe_2Si_2$ has a small minimum at $T_k = 10$ K and above T_k it increases linearly with temperature (see Fig. 1a) which suggests the Kondo effect;
- the temperature dependence of the electrical resistivity of $TmCo_2Si_2$, $TbCo_2Ge_2$ and $TbRh_2Ge_2$ shows an anomaly at T_N and a linear dependence above T_N (see Fig. 1b);
- for $DyRu_2Si_2$ the anomaly in $R(T)$ at T_N and a minimum of the resistivity at 3.2 K is observed;
- for $ErRu_2Si_2$, an anomaly only at $T_N = 5.7$ K is observed;
- for $GdRhSi_2$, the anomalies in the temperature dependence of the electrical resistivity are observed in $T_N = 20.5$ K and $T_t = 5.3$ K;
- the temperature dependence of the electrical resistivity of $TbMn_xGe_2$ and $ErMn_xGe_2$ in the whole temperature region between 2 and 300 K was presented in [4]. In this paper, the data at low temperatures only are presented. The anomalous temperature dependence of the electrical resistivity at low temperature for $TbMn_xGe_2$ and $ErMn_xGe_2$ is presented in Fig. 2. The resistivity of $TbMn_xGe_2$ has a minimum at $T_t = 4.67$ K. The value of T_t decreases linearly with increasing magnetic field (see insert in Fig. 2a);
- in zero magnetic field the electrical resistivity of $ErMn_xGe_2$ has a minimum at $T_t = 17$ K which disappears with an increase of the magnetic field (see Fig. 2b);
- for GdRhSi, CeAgSn and DyAgSn only a bend near the Néel temperature is observed. For CeAgSn near 30 K a bend-point of the electrical resistivity appears which indicates the Kondo effect;

The results of the electric resistivity measured in a varying magnetic field for all the compounds are presented below:

- for $LaFe_2Si_2$, the electrical resistivity increases with an increase of the magnetic field. This dependence is described by the function $R(H) - R(0) = a(T)H^2$ with $a(T) = 1.4 \times 10^{-3}$ $\mu\Omega$ cm/(kOe)^2 at $T = 4.2$ K;
- for $TmCo_2Si_2$, the electrical resistivity decreases with an increase of the magnetic field. The $a(T)$ coefficient is equal to -2.0×10^{-2} $\mu\Omega$ cm/(kOe)^2 at $T = 4.2$ K (in the paramagnetic state) and to -3.5×10^{-2} $\mu\Omega$ cm/(kOe)^2 at 2.0 K (in the antiferromagnetic state);
- for $DyRu_2Si_2$, the external magnetic field $H = 12.1$

Table 1
Magnetic and electrical resistivity data for some RT_2X_2, RTX_2 and RTX compounds

Compound	T_N (K)	T_t (K)	R ($\mu\Omega$ cm)		R_0 ($\mu\Omega$ cm)	R_1 ($\mu\Omega$ cm/K)	R_2 ($\mu\Omega$ cm/K^2)
			$T = 2$ K	$T = 300$ K			
$LaFe_2Si_2$	Pauli	Paramagnet	39.4	220	10	0.9	1.13×10^{-2}
$TmCo_2Si_2$	3		20	540	30	2.2	0
$TbCo_2Ge_2$	32		54	121	50	0.21	0
$DyRu_2Si_2$	28.5	3.2	8	32	0	0.12	0
$ErRu_2Si_2$	5.7		4.5	34	0	0.10	0
$TbRh_2Ge_2$	75		10.6	62.5	14	0.23	-3.7×10^{-4}
$GdRhSi_2$	20.5	5.3	54	152	58	0.41	-5.7×10^{-2}
$TbMn_xGe_2$	27		179	416	179	0.99	-2.2×10^{-2}
$ErMn_xGe_2$	3.4		212.5	264	183	2.34	1.4×10^{-2}
GdRhSi	18.5		31.5	126	24	0.56	-1.2×10^{-3}
CeAgSn	8.5		27	150	41	0.46	1.5×10^{-3}
DyAgSn	9.7		25	165	40	0.51	5.2×10^{-4}

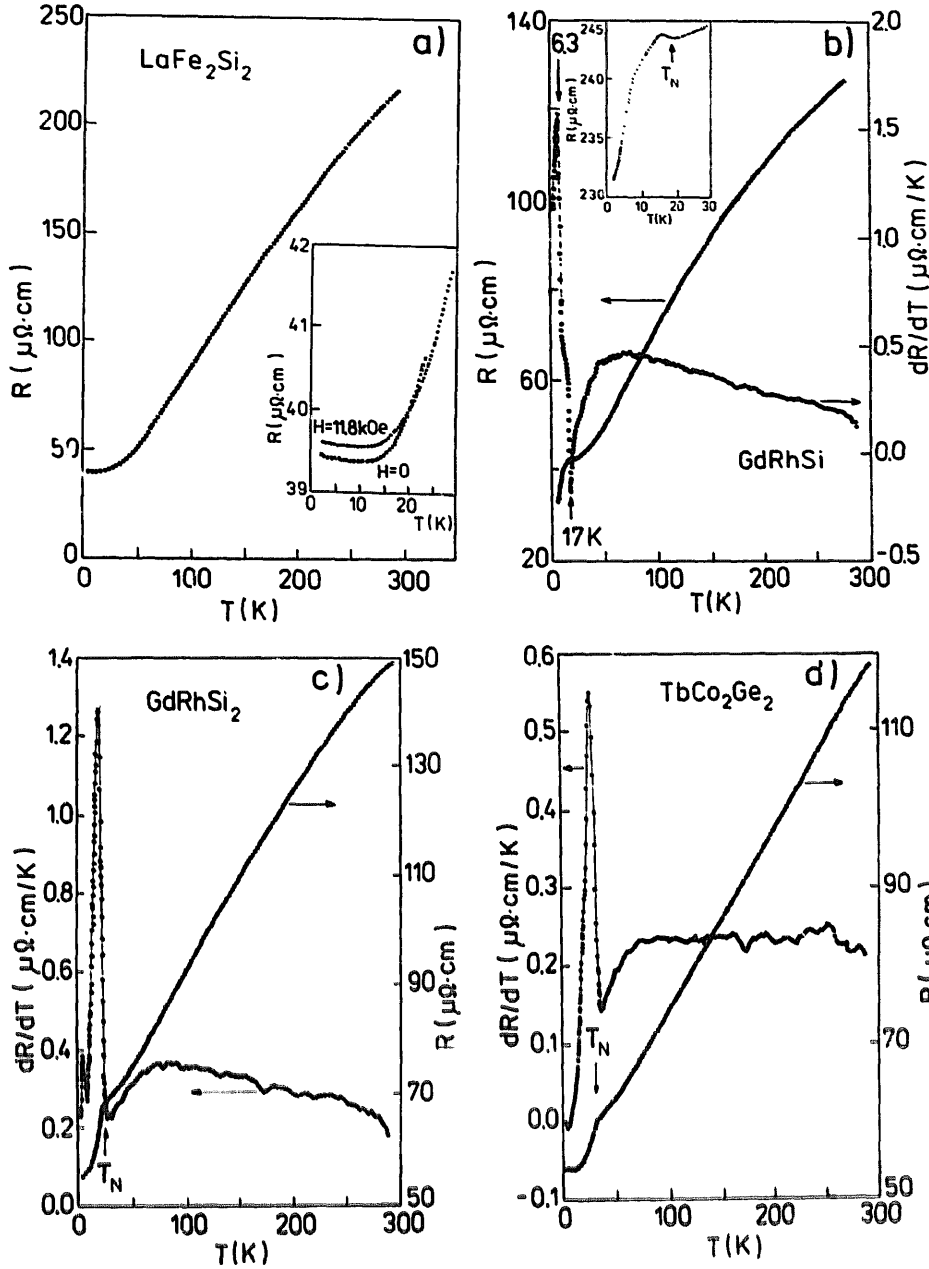

Fig. 1. Temperature variation of the electrical resistivity R and the differential resistivity dR/dT for: (a) $LaFe_2Si_2$, (b) GdRhSi, (c) $GdRhSi_2$ and (d) $TbCo_2Ge_2$.

kOe causes a disappearance of the minimum at 3.2 K and a decrease of the Néel temperature from 28.5 K to 26 K. The magnetic field dependence of the electrical resistivity of $DyRu_2Si_2$ differs at 4.2 K from that at 2.0 K and it has a complicated character. These results are in good agreement with the magnetic data presented in [5] which gave a complicated magnetic phase diagram (H,T) for $DyRu_2Si_2$ at low temperatures with different magnetic orderings at $T = 2$ K (square modulated) and at 4.2 K (sine modulated). The $R(H)$ dependences give the values of the critical fields which are in good agreement with those presented in [5]:

- the magnetic field dependences of the electrical resistivity of $ErRu_2Si_2$ have a similar character at 2.0 and 4.2 K. At both temperatures the effect is large and like that observed for $DyRu_2Si_2$ at 2 K which suggests a square modulated structure below T_N which agrees with the neutron diffraction data [6];
- the electrical resistivity of $GdRhSi_2$ is a linear function of the magnetic field at $T = 2.0$ and 4.2 K with $a(T) = 1.2 \times 10^{-2}$ $\mu\Omega$ cm/(kOe) at both temperatures;
- the electrical resistivities of GdRhSi, CeAgSn and DyAgSn are square functions of the external magnetic field with $a(T)$ coefficients equal to $2.2 \times$

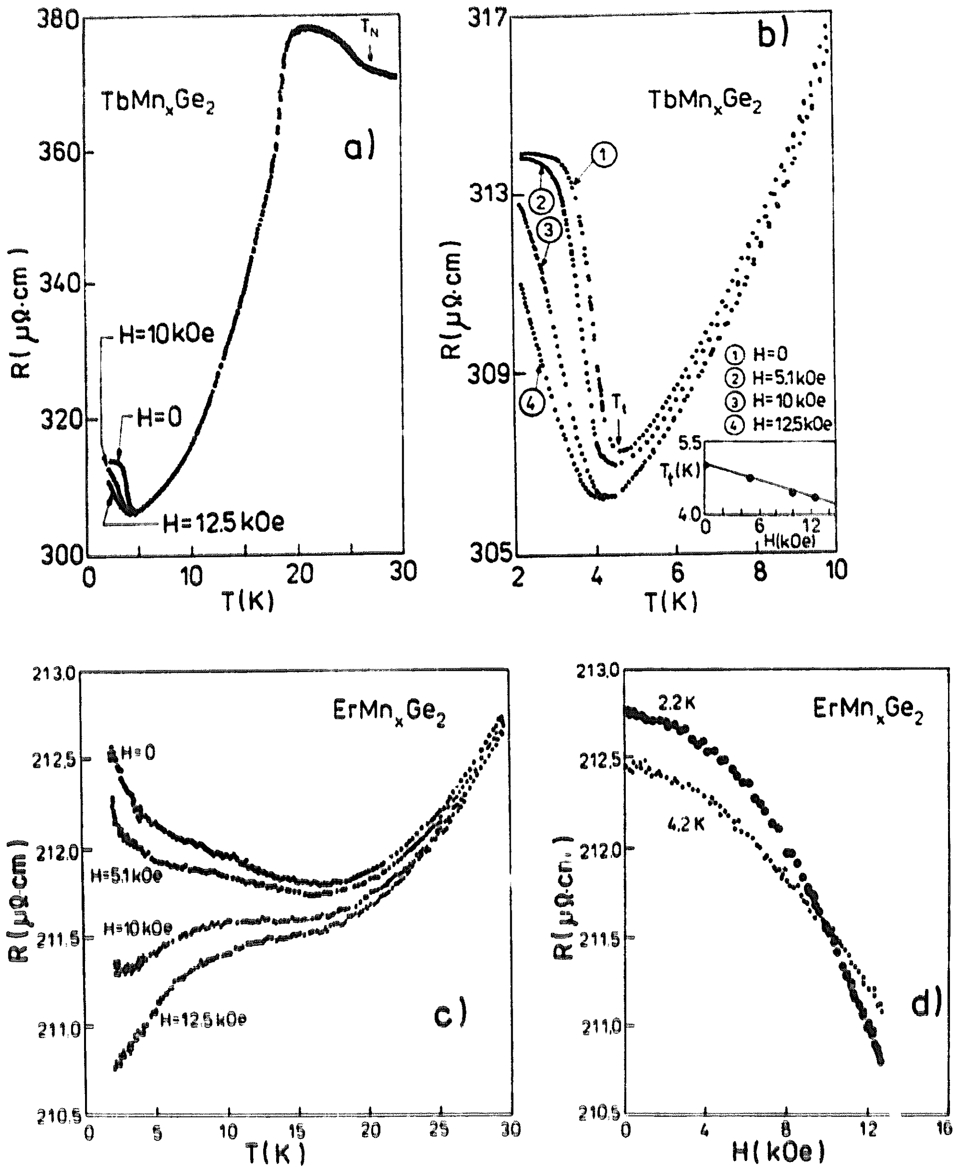

Fig. 2. (a) Temperature dependence of the electrical resistivity of $TbMn_xGe_2$ in the temperature range 2–30 K. Low temperature part of the electric resistivity of (b) $TbMn_xGe_2$ (inset shows the T_t vs. H) and (c) $ErMn_xGe_2$ and (d) field dependence of the electric resistivity of $ErMn_xGe_2$ at 2.2 and 4.2 K.

10^{-3} $\mu\Omega$ cm/(kOe)^2 at $T = 4.2$ K and to 2.7×10^{-3} $\mu\Omega$ cm/(kOe)^2 at $T = 2.0$ for GdRhSi and 2.9×10^{-3} $\mu\Omega$ cm/(kOe)^2 at $T = 4.2$ K for CeAgSn and 3.0×10^{-3} $\mu\Omega$ cm/(kOe)^2 at $T = 4.2$ K for DyAgSn.

3. Conclusions

Except for $LaFe_2Si_2$, all the compounds studied are antiferromagnets at low temperatures.

The results presented in this work indicate the metallic character of the electrical conductivity of all the compounds investigated. The parameters characterizing the electrical resistivity of these compounds are similar.

The anomalies in the temperature dependence of the electrical resistivity observed at low temperatures are connected with the change in the magnetic ordering. For example, a change in the magnetic order from the square modulated to the sine modulated was observed in $DyRu_2Si_2$.

For RT_2X_2 (excluding $LaFe_2Si_2$) and for RTX_2 compounds the electric resistivity decreases with increasing magnetic field whereas for RTX compounds it increases.

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