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Transport properties of $Y_{1-x}R_xCo_2$ (R = Er, Ho) in magnetic field

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Abstract

Thermopower S and resistivity ρ of $Y_{1-x}R_xCo_2$ (R = Er, Ho) compounds have been measured in the temperature range from 1.5 to 300 K under magnetic fields up to 15 T. Strong enhancement of resistivity and fundamental changes in temperature variation of thermopower are observed at low temperatures in the compounds within the composition range where uniform Co 3d magnetization collapses. The magnetic state of Co 3d electrons has a dominant effect on the characteristic behavior of S and ρ in these compounds.

Keywords: Thermopower; Resistivity; Itinerant electron metamagnetism; Laves phase compounds

1. Introduction

The cubic Laves phase compounds of RCo_2 (R stands for rare earth elements and Y) have received much attention because of the large variety of magnetic properties due to the instability of Co moments. YCo_2 and $LuCo_2$ with no 4f moments involved, are exchange-enhanced Pauli paramagnets and show a first order metamagnetic transition under magnetic field $\mu_0 H_c \approx 70$ T. The magnetic compounds, $ErCo_2$, $HoCo_2$ and $DyCo_2$ undergo first order magnetic phase transition at corresponding Curie temperatures. This behavior is explained as the metamagnetic transition of Co 3d electrons, which are magnetized by the internal exchange field of the ordering 4f magnetic moments. The exchange molecular field of ordered 4f moments in these compounds exceeds the critical field $\mu_0 H_c$ for the metamagnetic transition of Co 3d electrons.

The main contribution to the electronic transport in RCo_2 compounds can be attributed to the scattering of conduction electrons on local fluctuations of magnetization of Co 3d itinerant electrons. The magnitude and the spectrum of these fluctuations are dependent on the effective magnetic field B_{eff} acting on Co 3d electrons: $B_{\text{eff}} = n_{\text{fd}}M - \mu_0 H_{\text{ext}}$, where n_{fd}, M and $\mu_0 H_{\text{ext}}$ are the intersublattice exchange coefficient, the uniform magnetization of 4f moments and the external magnetic field, respectively. This implies a strong dependence of the transport properties of the magnetic RCo_2 compounds on the substitution of the nonmagnetic element of Y for the magnetic element of R and on the external magnetic field $\mu_0 H_{\text{ext}}$.

In pure $ErCo_2$ the separation of Er and Co magnetic ordering temperatures was observed in external magnetic field [1]. It was reported that the separation of Er and Co magnetic ordering temperatures takes place in $Y_{1-x}Er_xCo_2$ compound with Er concentration of $x = 0.6$. In this compound, the magnetic ordering temperature T_C^{Co} of Co subsystem is lower than T_C^{Er} of Er subsystem [2,3]. On the other hand, no separation of magnetic ordering temperatures of R and Co subsystem has been found for $HoCo_2$ and for ferrimagnet $Y_{1-x}Ho_xCo_2$ compounds [4]. A possible reason for this different behavior is that Curie temperature of $HoCo_2$, $T_C \approx 77$ K, is close to the upper temperature limit for the metamagnetic transition of Co 3d subsystem of RCo_2 series.

In this paper, we present the results of the studies of thermopower S and electrical resistivity ρ of $Y_{1-x}Er_xCo_2$ and $Y_{1-x}Ho_xCo_2$ measured in the temperature range between 1.5 and 300 K under magnetic fields up to 15 T.

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2. Measurements

The polycrystalline samples of $Y_{1-x}R_xCo_2$ were prepared by arc-melting mixtures of rare earth metals (3 N) and cobalt (3 N) with a ratio of R:Co = 1:1.93 in order to avoid formation of magnetic RCo_3 phase. The ingots were annealed in vacuum at 700 °C for 1 week. The cubic Laves phase structure has been verified by X-ray diffraction measurements. The obtained lattice parameters of $ErCo_2$ and $HoCo_2$ compounds are in good agreement with the literature data. The samples used for measurements of S and ρ were cut by spark erosion to a size of 1 mm × 1 mm × 8 mm.

The measurements of S and ρ were carried out by using a differential dc-method with seesaw heating procedure [5] and a standard four-probe method, respectively. The direction of external magnetic field was parallel to the current and the temperature gradient in order to reduce the influences of additional thermomagnetic and galvanomagnetic effects. S and ρ were measured simultaneously in the temperature range between 1.5 and 300 K under magnetic field up to 15 T.

3. Results and discussion

Fig. 1(a) and (b) show magnetic phase diagrams of $Y_{1-x}Er_xCo_2$ and $Y_{1-x}Ho_xCo_2$ alloy systems, determined from the temperature dependencies of S and ρ in zero magnetic field. $ErCo_2$ and $HoCo_2$ are ferrimagnets. The magnetic transition temperatures T_C for both alloy systems decrease with decreasing content x of magnetic R element (Er or Ho). Peculiarities observed in the temperature dependent transport properties of $Y_{1-x}Er_xCo_2$ alloys with the composition in the range $0.5 < x < 0.7$ suggest that the Er and Co magnetic subsystems order at different temperatures T_C^{Er} and T_C^{Co}. In the alloys with $0.2 < x < 0.5$ Er 4f moments are ordered ferromagnetically, however no long range magnetic order in the Co 3d system was observed. In $Y_{1-x}Ho_xCo_2$ alloys with $x \gtrsim 0.5$ spin re-orientation transition from [1 1 0] to [1 0 0] direction takes place at T_r. No long range magnetic order can be detected for the alloy compositions with $x < 0.4$. Freezing phenomena in magnetization measurements reported in earlier investigations [6] suggest existence in these alloys of spin-glass phase with characteristic freezing temperature T_f.

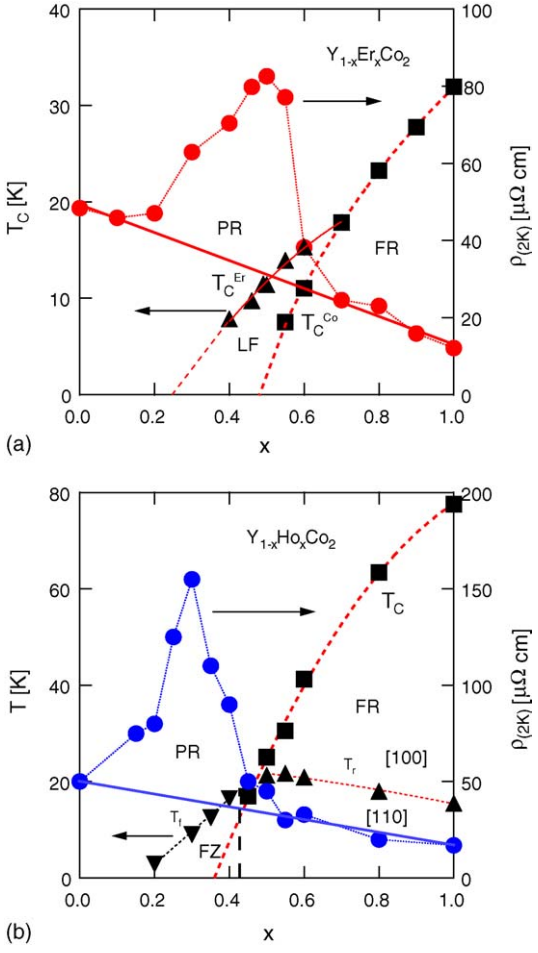

Fig. 1. Magnetic phase diagrams for $Y_{1-x}Er_xCo_2$ (a) and $Y_{1-x}Ho_xCo_2$ (b). The x dependence of resistivity (●) of $Y_{1-x}Er_xCo_2$ and $Y_{1-x}Ho_xCo_2$ at 2 K. PR: paramagnet, FR: ferromagnet, LF: localized ferromagnet, FZ: freezing phase.

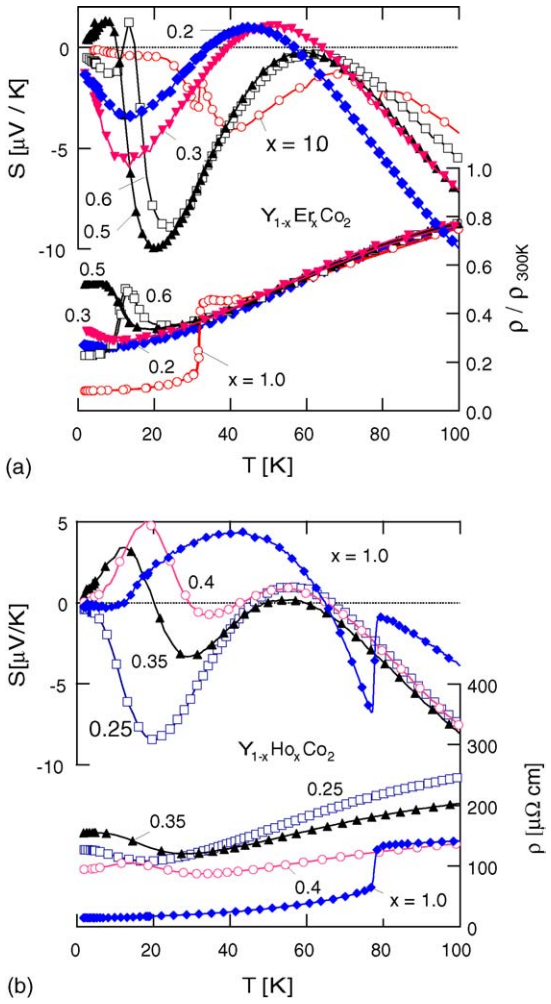

Fig. 2. The temperature dependence of S and ρ of $Y_{1-x}Er_xCo_2$ (a) and $Y_{1-x}Ho_xCo_2$ (b) systems.

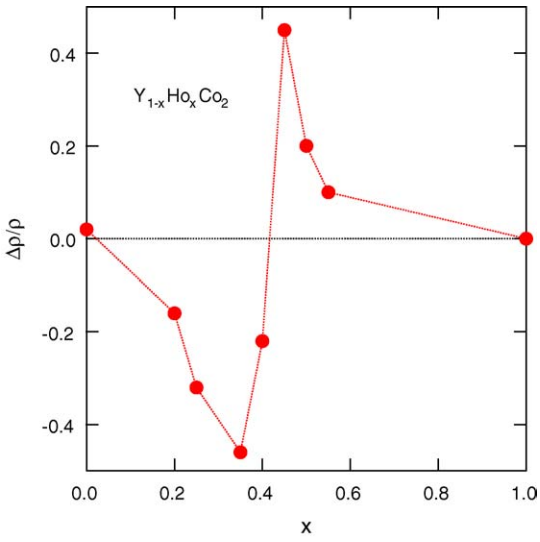

Fig. 3. The x dependence of magnetoresistivity of $Y_{1-x}Ho_xCo_2$ measured at 2 K in the magnetic field of 15 T.

No magnetic order was detected by electronic transport measurement results for both alloy systems for $x < 0.2$.

The x dependencies of resistivity at 2 K for $Y_{1-x}Er_xCo_2$ and $Y_{1-x}Ho_xCo_2$ are presented in Figs.1(a) and (b), respectively. The characteristic feature of the resistivity dependence on the composition for both alloy systems is the pronounced maximum, observed in the critical composition region where magnetic long range order disappears. Note, the composition dependence of resistivity of a nonmagnetic binary alloy is expected to follow Nordheim–Kurnakov rule: $\rho = A \cdot x \cdot (1 - x)$. The observed anomalous dependencies of resistivity on composition correlates with the peculiarities in the temperature dependencies of S and ρ for both alloy systems, shown in Fig. 2(a) and (b). There is an essential qualitative correlation between the alloy composition and the thermopower and resistivity temperature dependencies at low temperatures. In the resistivity temperature dependencies the well expressed minima are observed, whereas the low temperature thermopower changes its sign as alloy composition passes through the critical region. These results indicate that the magnetic state of Co 3d electrons have a dominant effect on the transport properties of the compounds at low temperatures. In general the transport property variations with alloy composition and with temperature found in $Y_{1-x}Er_xCo_2$ and $Y_{1-x}Ho_xCo_2$ are qualitatively similar to the behavior of these properties in $Y_{1-x}Gd_xCo_2$ [7,8]. A very unusual feature observed in $Y_{1-x}Gd_xCo_2$ system is the large positive magnetoresistivity (MR) of ferromagnetic alloys at low temperatures. This unusual for a ferromagnetic material sign of the MR as well as the variation of low-temperature resistivity with the alloy composition was explained in Ref. [8] as originating from an interplay of metamagnetic instability of Co 3d itinerant electrons and structural disorder within the R sublattice. Positive magnetoresistivity of even larger magnitude is found also in $Y_{1-x}Er_xCo_2$ alloys [2]. Fig. 3 depicts the magnetoresistivity ($MR = \Delta\rho/\rho$, $\Delta\rho = \rho(15\,T) - \rho(0\,T)$) of $Y_{1-x}Ho_xCo_2$ measured at 2 K. The MR shows a strong dependency on the alloy composition. Similar to $Y_{1-x}Gd_xCo_2$ and $Y_{1-x}Er_xCo_2$, the MR of $Y_{1-x}Ho_xCo_2$ is positive and very large for ferromagnetic alloys ($x > 0.4$). We believe that the same mechanism as that proposed for $Y_{1-x}Gd_xCo_2$ alloys is responsible for the transport properties behavior in $Y_{1-x}Er_xCo_2$ and $Y_{1-x}Ho_xCo_2$ systems.

In summary, thermopower and resistivity of $Y_{1-x}Er_xCo_2$ and $Y_{1-x}Ho_xCo_2$ alloys were measured at temperatures from 1.5 to 300 K in magnetic fields up to 15 T. Transport and magnetotransport properties of the alloys with the composition in the region where the uniform long range magnetic order of Co 3d electrons vanishes, show anomalous variation with temperature, composition and magnetic field. This behavior originates from an interplay of Co 3d electron itinerant metamagnetism and of the structural disorder within the R sublattice.

Acknowledgement

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