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The magnetostriction of the intermetallic compound $ErCo_2$ near the magnetic phase transition paramagnetism-ferrimagnetism

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Abstract. The purpose of this work was the investigation of magnetostriction near magnetic phase transition paramagnetism-ferrimagnetism in ferrimagnetic intermetallic compound $ErCo_2$. It is known that 3d-electrons are delocalized and form a 3d-zone in it, whereas 4f-electrons localized and create an effective exchange field which acts on the Co sublattice. It leads to magnetic ordering of the last. We have found there is a sharp jump in the curve of thermal expansion near T = 37K, which indicates the presence of first order phase transition. Volume magnetostriction ω reach huge values (3.10^{-3} in the field μ_0H = 4T near T_C). At temperatures $T > T_C$ $\lambda_{\|}$ and $\lambda_{\perp}$ have small values in the absence of an external magnetic field. However, in fields $H>H_{crit}$ $\lambda_{\|}$ and $\lambda_{\perp}$ rapidly increase and get the values that have the same order of magnitude as at $T \approx T_C$. This indicates that the external magnetic field can restore the magnetism of 3d-subsystem at $T>T_C$.

1. Introduction

Magnetism of intermetallic RCo_2 compounds is the object of intense research due to the unique combination of itinerant magnetism of the cobalt 3d-sublattice and localized 4f-sublattice magnetism of rare-earth ions [1-5]. RCo_2 compounds with nonmagnetic rare-earth elements (Y, Lu) are exchange-enhanced paramagnetics, which do not have the spontaneous moment in the cobalt sublattice. However, the rare-earth sublattice of the ions having magnetic moments induces a moment of the cobalt sublattice due to the R-Co exchange interaction. The effective exchange field $H_{R\text{-}Co}$ is defined by the spin and total angular momentum of the RE ion and electron density of states at the Fermi level. The magnitude of the magnetic moment of the itinerant Co sublattice strongly depends on the magnitude of $H_{R\text{-}Co}$. If $H_{R\text{-}Co}$ is large, the Co sublattice has a stable zone magnetic moment ($GdCo_2$, $TbCo_2$). Reduction of the $H_{R\text{-}Co}$ leads to situation when the magnetic moment M_{Co} disappears above the Curie temperature ($ErCo_2$, $HoCo_2$). But it can occur near Tc due to the external magnetic field, which is added to the $H_{R\text{-}Co}$. In this case phase transitions of the first order and restoration of itinerant magnetism of the Co sublattice above Tc are observed due to the influence of an external magnetic

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field. To find out the physical nature of this transition it is important to determine the energy contributions to the thermodynamic potential near Tc and to determine the influence of lattice parameters on order of magnetic phase transitions [6].

The purpose of this investigation was to study the magnetoelastic characteristics (longitudinal, transverse and volume magnetostriction, thermal expansion) near the magnetic phase transition (paramagnetism-ferrimagnetism) of ferrimagnetic intermetallic compound $ErCo_2$.

$ErCo_2$ compound has a cubic crystal lattice Laves' phase type, and it is the two-sublattice magnet. It is known that there 3d-electrons are delocalized and form a 3d-zone, whereas 4f-electrons, on the contrary, are localized and create an effective exchange field which acts on the Co sublattice, that leads to the magnetic ordering of the last[1].

Taking into account the abovementioned, in the cubic intermetallic compounds RCo_2 (unlike RFe_2, where the single-ion magnetostriction (MS) dominates) two mechanisms of MS are observed. In addition to the single-ion (anisotropic) MS there is a volume (isotropic) magnetostriction [7, 8]. This phenomenon was studied in detail by us during measurements of longitudinal and transverse magnetostriction $ErCo_2$ compound in fields up to 100 kOe in the temperature range 4.2-120K.

2. Experimental details

As cast $ErCo_2$ samples were prepared with method of high-frequency induction melting in an atmosphere of argon. The samples have plate shape and the linear sizes 4x5x2 mm. The crystalline structure and phase composition of the samples were checked by X-ray diffraction. The measurements of both longitudinal $\lambda_{||}$ and transverse $\lambda_{\perp}$ magnetostriction induced by the magnetic field up to 10T in the temperature range 4.2 - 120K in $ErCo_2$ were carried out with resistance strain gauges. The Vishay Micromeasurements SR-4 strain gauges were pasted on a surface of the sample.

3. Result and discussion

Fig. 1 shows the field (a) and temperature (b) dependence of the longitudinal magnetostriction of $ErCo_2$ in fields up to B = 10T. It is evident that $\lambda_{||}<0$ and increases in absolute value below Tc = 38K, where the transition from the paramagnetic state to a ferromagnetic occur [3]. The presence of the critical magnetic field Hc at T> Tc attracts attention, at which $\lambda_{||}$ increases dramatically. Hc appears on the isotherms of the transverse magnetostriction $\lambda_{\perp}$ (Fig. 2a) at T>Tc more clearly. There are huge positive values of $\lambda_{\perp}$, reaching values of $\sim 1800 \cdot 10^{-6}$ near Tc = 38K. The increase of temperature at T>Tc decreases the jump on the isotherms $\lambda_{\perp}(H)$ little, since the value of Hc increases with increasing of temperature. The temperature dependence of Hc is shown in Fig. 2(b). $\lambda_{\perp}$ (T) has a huge maximum of $\sim 1900 \cdot 10^{-6}$ near Tc.

a) b)

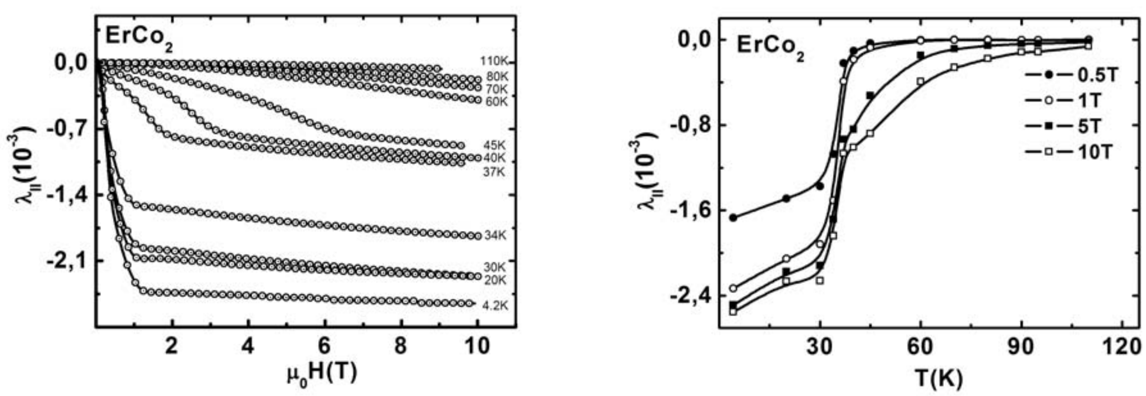

Figure 1. Field (a) and temperature (b) dependence of the longitudinal magnetostriction of polycrystalline samples $ErCo_2$

Using the obtained data of $\lambda_{\|}$ and $\lambda_{\perp}$ we received temperature dependence of $H_{crit}(T)$ of metamagnetic transition (fig.3). It is seen that H_{crit} linearly increases in area of temperatures above the Tc and reaches values from small, at a point of transition at Tc=33K, to H_{crit}=5T at T=44K. The results of investigations show, the energy barrier, that separate paramagnetic and ferrimagnetic phases, increases with temperature increasing.

a) b)

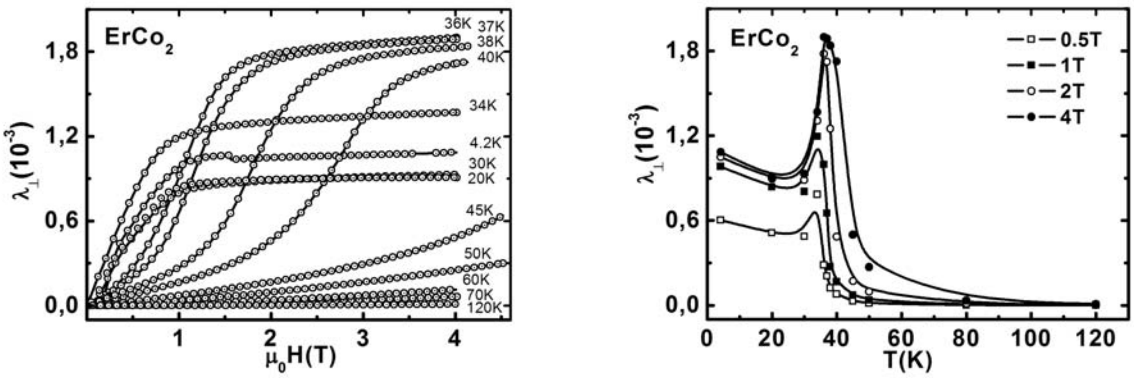

Figure 2. Field (a) and temperature (b) dependence of the transverse magnetostriction of polycrystalline samples $ErCo_2$

Hence, $\lambda_{\|}$ and the $\lambda_{\perp}$ reveal two magnetostrictive contributions. The first - when T <Tc is characterized by strong anisotropy $\lambda_{\|}<0$ and $\lambda_{\perp}> 0$. This contribution is caused by the single-ion anisotropic magnetostriction, which is due to the magnetocrystalline interaction, especially its magnetoelastic part. The second contribution is caused by the band magnetostriction, which is induced by the magnetic field near and above Tc at H>Hc. Significantly, in $ErCo_2$ volume magnetostriction is extremely high near Tc have a maximum $\omega \sim 2700 \cdot 10^{-6}$(fig.4). The measured curve of thermal expansion shows that giant magnetostriction values exist in the sample even in the absence of a magnetic field (fig.5). The influence of magnetic field on band structure of the compound leads to additional volume effect.

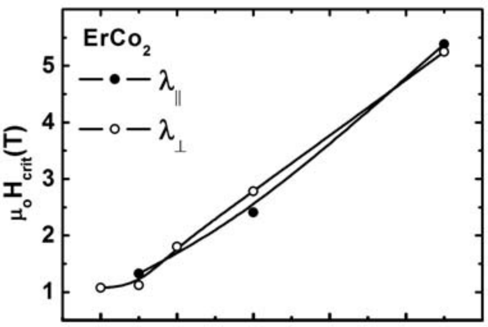

Figure 3. Temperature dependence of critical field of polycrystalline samples $ErCo_2$

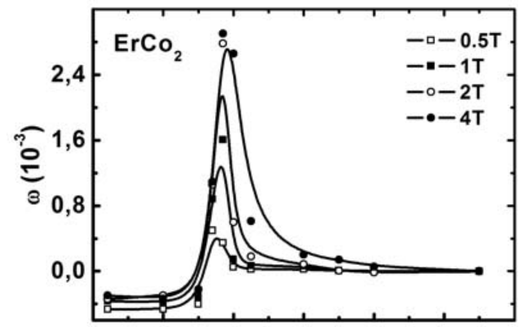

Figure 4. Temperature dependence of the volume magnetostriction of polycrystalline samples $ErCo_2$

It is seen that in $ErCo_2$ at T<Tc there is a huge spontaneous magnetostriction and invar anomaly of the coefficient of thermal expansion (fig.6). Because of the additional to usual thermal expansion volume expansion, caused by spontaneous band magnetostriction, the coefficient of thermal expansion reveals anomaly - sharp negative peak on a curve $\alpha(T)$ (fig.6). Since the magnetic field displaces

temperature of metamagnetic transition to the higher temperature region, the negative maximum on curve B=2T is displaced to the right.

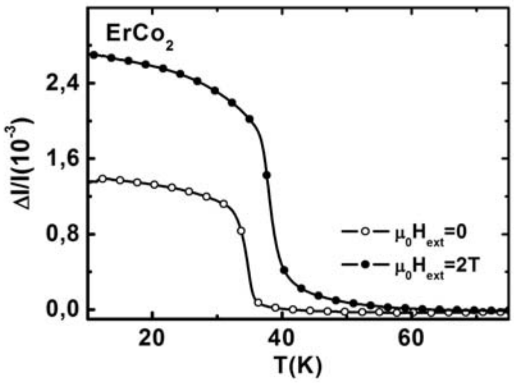

Figure 5. Thermal expansion of polycrystalline samples $ErCo_2$

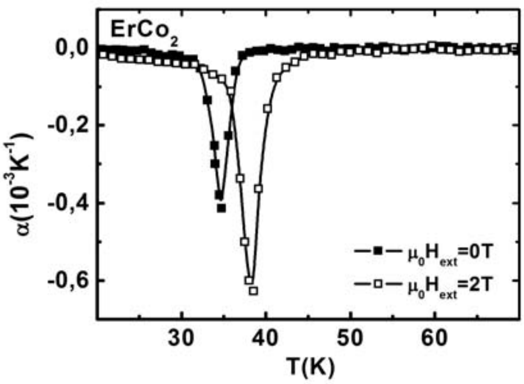

Figure 4. Temperature dependence of the coefficient of thermal expansion of polycrystalline samples $ErCo_2$

4. Conclusion

In intermetallic $ErCo_2$ compounds magnetostriction has two contributions: 1) the anisotropic single-ion magnetostriction is caused by the magnetoelastic energy due to magnetocrystalline interaction, 2) the band magnetostriction, which is due to the influence of the magnetostriction deformations on band structure of 3d-electrons.

The band magnetostriction has a giant value of more than 10^{-3}. It is restored at T>Tc in the fields above critical as a result of the metamagnetic transition, at which external magnetic and exchange fields induced the band magnetism of 3d-sublattice. Band magnetostriction caused by the dependence of energy 3d-band from the interatomic distances.

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