Magnetostriction and transformation of crystal structure of intermetallic compound NdCo$_2$

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Abstract. Ferromagnetic compound NdCo$_2$ has complex magnetic transformation, which are accompanied by changes of the crystal lattice. The purpose of this paper was the investigation of influence of these transformations on the field and temperature dependence of magnetostriction. It was found that near the Curie temperature $T_C = 98$K, where the transition from cubic to tetragonal phase is observed, there is a maximum in the temperature dependence of the transverse magnetostriction $\lambda_\perp(T)$ in the field $B=4$T. In this field $\lambda_\perp$ reaches high values of $\lambda_\perp \approx 200 \times 10^{-6}$ at temperatures higher than $T_C$. This shows that in this field, the tetragonal distortion and band magnetism of 3d-subsystem remain even at $T>T_C$. At $T<42$K $\lambda_\perp$ decreases in field $B=0.5$ T due to phase transition from tetragonal phase to orthorhombic. The curve $\lambda_\perp(H)$ at $T = 10$ K anomalies are observed. They are associated with the fact that under the action of the external field there are consistent transitions from orthorhombic phase to tetragonal and then to cubic. Thus, it was found that the compound NdCo$_2$ crystal structure is reconstructed with magnetic field.

1. Introduction

These in the past 15 years the attention of many researchers [1-4] was attracted by magnetically ordered materials in which there is coexistence of magnetic and structural phase transitions. They usually have gigantic values of the magnetocaloric effect, magnetostriction and magnetoresistance [2-3]. Among these materials there are RCo$_2$ compounds, in which there is a sharp dependence the magnetic phase transitions from the lattice parameters [5-9]. Transformation of the crystal and magnetic structure as a result of magnetic phase transitions in NdCo$_2$ on polycrystalline samples was studied in [1], with methods of X-ray and neutron diffraction. Temperature dependence of the magnetostriction constants $\lambda_{100}$ for RCo$_2$ was calculated by measuring the lattice constant in [1,8,10] and it was shown that $\lambda_{100}$ for NdCo$_2$ reaches very high values of $\lambda_{100} \approx 3.2 \times 10^3$. However there is no data about the temperature dependence of linear and volume magnetostriction induced by magnetic field in NdCo$_2$. That hinders the development of physical models, taking into account the relationship between structural transitions and the strong
magnetoelastic interactions. In ferrimagnetic NdCo₂ compound complex magnetic transformations occur, which is accompanied by the transformation of crystal structure [1, 10].

The purpose of this investigation was to study the influence of transformations of the crystal lattice on the field and temperature dependence of magnetostriction and to determine magnetoelastic contributions of magnetostrictive deformation in NdCo₂.

In this work, longitudinal \( \lambda_\parallel \) and transverse \( \lambda_\perp \) magnetostriction induced by the magnetic field up to 10T in the temperature range 4.2 - 135K in NdCo₂ were measured. Measurements were carried out with resistance strain gauges.

2. Experimental details

As cast NdCo₂ 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 research of microstructure of as cast samples was performed by a method of an optical microscopy (magnification in 1000). The measurements of both longitudinal \( \lambda_\parallel \) and transverse \( \lambda_\perp \) magnetostriction induced by the magnetic field up to 10T in the temperature range 4.2 - 130K in NdCo₂ were carried out with resistance strain gauges. The Vishay Micromeasurements SR-4 strain gauges were pasted on a surface of the sample.

3. Results and discussion

Figures 1, 2 and 3 shows the temperature dependence of \( \lambda_\parallel, \lambda_\perp \) and \( \omega \) of NdCo₂ in magnetic fields up to \( B = 4-10T \). As shown in figures the value of \( \omega \) reaches high values of \( \sim 600\cdot10^{-6} \) near the Curie temperature \( T_c = 98K \), where the transition from the paramagnetic to the ferromagnetic state is observed. It is accompanied by a transition from cubic to tetragonal phase according to [1].

![Figure 1](image.png)

**Figure 1.** Field (a) and temperature (b) dependence of the transverse magnetostriction of polycrystalline samples NdCo₂

It should be noted the presence of high values of magnetostriction \( \lambda_\parallel, \lambda_\perp \) and \( \omega \) in the paramagnetic region at \( T>T_c \). Thus at temperatures 20K above \( T_c \) (Fig. 1) magnetostriction \( \omega \) reaches \( 200\cdot10^{-6} \), that can be explained with the influence of magnetic field on the Co magnetic sublattice.

While further decreasing of temperature below \( T_c \) and the achievement of a phase transition from tetragonal to orthorhombic phase there is an even higher positive maximum \( \omega=750\cdot10^{-6} \) at \( T_{SR}=42K \) (Fig. 3).

Isotherms of the magnetostriction \( \lambda_\parallel(H) \) and \( \lambda_\perp(H) \) (Figures 1a and 2a) measured in the temperature range \( T_{SR}-T_c \) show a change of magnetostriction with increasing field from zero up to \( B = 1T \). This contribution to the \( \lambda_\parallel, \lambda_\perp \) due to the orientation of the magnetostrictive deformations in magnetic
field. As a result the tetragonal crystal structure transforms into a cubic, it was established with X-ray and neutron diffraction studies [1].

![Figure 2](image2.png)

**Figure 2.** Field (a) and temperature (b) dependence of the longitudinal magnetostriction of polycrystalline samples NdCo₂.

The temperature range below $T_{SR} = 42$K attract attention. At $T<T_{SR}$ transverse magnetostriction decreases sharply in a field $B=0.5$T (Fig. 1b), due to phase transitions from tetragonal phase to orthorhombic. With increasing of the field jump $\lambda_{\perp}$ at $T_{SR}$ smooth, and in the field of 4T curve $\lambda_{\perp}(T)$ reveals only a small anomaly at $T=T_{SR}$. This can be explained by the fact that the orthorhombic structure is suppressed by the field and converted to cubic.

![Figure 3](image3.png)

**Figure 3.** Temperature dependence of the volume magnetostriction in polycrystalline samples NdCo₂.

The details of this transformation are observed on the curve of the field dependence of $\lambda_{\parallel}$ measured at 10K(fig.4). Based on the data obtained with the field dependence of neutron reflections [1], it can be argued that the maximum in the curve of the field dependence $\lambda_{\parallel}(H)$ at $B=0.8$T corresponds to the transition from orthorhombic phase to tetragonal, and the minimum at curve $\lambda_{\parallel}(H)$ at $B=2.8$T corresponds to the transition from tetragonal to cubic phase. Hence, our experimental data of temperature and field dependence of magnetostriction NdCo₂ and neutron diffraction data [1] indicate the unusual for RCo₂ compounds phenomenon - the restructuring of the crystal structure under the influence of a magnetic field.

In figure 5 measurements of thermal expansion of polycrystalline sample NdCo₂ are presented. At $T<98$K anomalies of the thermal expansion are observed, caused by imposing of spontaneous volume magnetostriction on phonon part of thermal expansion. In magnetic field the curve of temperature expansion transforme because of the appearance of additional magnetostriction deformations. It is necessary to note, anomaly of thermal expansion reaches high values $\Delta l/l=1000 \cdot 10^{-6}$. 

![Figure 4](image4.png)

**Figure 4.** The field dependence of $\lambda_{\parallel}$ measured at $T=10$K in polycrystalline samples NdCo₂.
On the curve of temperature dependence coefficient of thermal expansion $\alpha(T)$ (fig. 6) at $B=0$ the extrema are observed, connected with magneto-structural phase transitions at $T=42$K and $T=98$K. In the field $B=2T$ these extrema are smoothed because of arisen additional magnetostriction deformations.

4. Conclusion
NdCo$_2$ is a ferromagnet, which combines the band magnetism of the Co sublattice and localized magnetism of the Nd sublattice. Below the Curie temperature $T_c=98$K there are giant values of linear and volume magnetostriction, which sharply increases with decreasing temperature.

The temperature and field dependence of linear and volume magnetostriction at $T<T_c$ can be attributed to the transformation of the crystal lattice from cubic to tetragonal phase during the magnetic ordering. At $T<T_c$ the tetragonal phase is transformed into a cubic under the influence of an external magnetic field. It is manifested with the huge values of linear and volume magnetostriction.

While the increasing of the external field at $T<T_{Sr}=42$K temperature and field dependence of magnetostriction show transitions between orthorhombic - tetragonal - cubic phases. Obtained data confirmed that in the NdCo$_2$ compound magnetic and structural phase transitions co-exist.

References
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