

2. Material and experimental details

In this work the anisotropic $\text{Nd}_2(\text{Fe}, \text{Co})_{14}$ B-type magnet with the composition of $\text{Nd}_{13,6}\text{Fe}_{73,7}\text{Co}_{6,6}\text{Ga}_{0,6}\text{B}_{5,5}$ has been investigated. The magnet was produced using the hot pressed Magnequench powder obtained from melt spun ribbons. Material prepared by this route was then hot deformed at 750°C in a steel capsule by means of the apparatus INSTRON 8035 with maximum pressure force of 500 kN. The hot deformation process was performed at a strain rate ($\dot{\varepsilon}$) of 0.002 s^{-1} . A deformation degree defined as $\varepsilon = (\Delta h/h_0) \cdot 100\%$ was equal to 65% (Δh is the change in the sample high after deformation, h_0 is the starting high). The strain rate $\dot{\varepsilon} = \Delta\varepsilon/\Delta t$ [s^{-1}].

Using the LakeShore vibrating sample magnetometer (VSM) the sets of recoil curves have been measured in an external magnetic field up to 2 T. These curves were obtained after applying the certain magnetizing field of $\mu_0 H_i$ ($i = 1, 2, \dots, 40$), reducing it to zero (magnetization remanence state of $\mu_0 M^r(\mu_0 H_i)$) and increasing back to $\mu_0 H_i$. In the next step the value of magnetizing field was increased by 0.05 T and the procedure was repeated. The same procedures have been performed in a negative field direction $-\mu_0 H_i$ starting from a remanence $\mu_0 M_R$ state after saturating by a positive field of 14 T. After reducing a negative field to zero value the sample was in the demagnetization remanence state of $\mu_0 M^d(\mu_0 H_i)$. From the sets of recoil curves the relationship between the reduced demagnetization remanence M^d/M_R and reduced magnetization remanence M^r/M_R have been derived.

Magnetic domain structure has been observed by means of the magnetic force microscopy (MFM) MESP Nanoscope V, Multimode-type with the Co/Cr tip. The magnetic contrast imaging was performed in tapping (Atomic Force Microscopy)/lift (Magnetic Force Microscopy) mode at the tip high of 100 nm. The signal was obtained by measuring the phase shift of an oscillating cantilever. The oscillation phase changes which occur under the influence of magnetic force gradient acting on the tip were processed into the contrast changes.

The surface of the studied magnet were polished using abrasive paper, diamond pastes and diamond powder of the different gradations. Domain structure was observed for an ac-demagnetized sample.

3. Results and discussion

Fig. 1 shows the dependence of the reduced demagnetization remanence M^d/M_R versus the reduced magnetization remanence M^r/M_R along with the Wohlfarth

relation (1), which is obeyed for any system of noninteracting single domain particles [5]:

$$\frac{M^d}{M_R}(H_i) = 1 - 2 \frac{M^r}{M_R}(H_i), \quad (1)$$

Any deviations from the straight line are interpreted as being due to the magnetic interactions between the neighboring grains. All experimental points lie below the line (1) certifying that in the magnet investigated there exist the long range dipolar magnetic interaction.

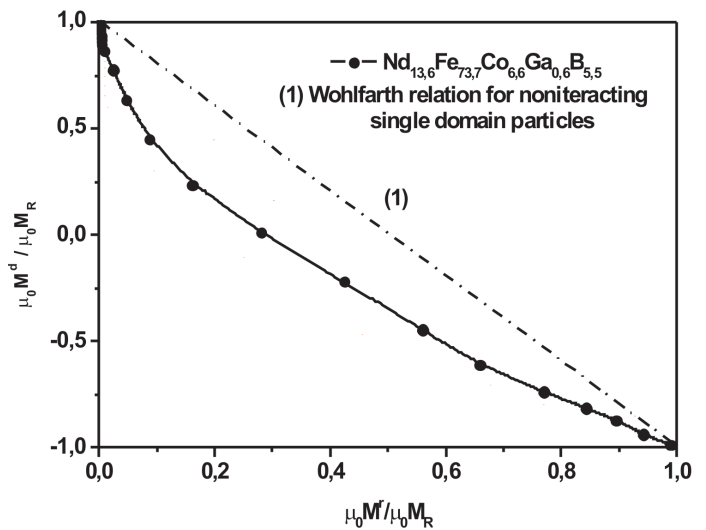


Fig. 1. Wohlfarth remanence curve for $\text{Nd}_{13,6}\text{Fe}_{73,7}\text{Co}_{6,6}\text{Ga}_{0,6}\text{B}_{5,5}$ magnet

The interactions between the grains and particles are the reason for forming the so-called interaction domains. For hot deformed $\text{Nd}_{13,6}\text{Fe}_{73,7}\text{Co}_{6,6}\text{Ga}_{0,6}\text{B}_{5,5}$ magnet at the deformation degree of 65% the majority of grains on the surface perpendicular to the deformation direction have diameter from 360 nm to 500 nm [1]. Fig. 2 illustrates the MFM image with a scan size $5\mu\text{m} \times 5\mu\text{m}$ on such surface. Fig. 3 shows the change of magnetic contrast along the scanning line marked in Fig. 2. The width of bright domain amounts to $1.778 \mu\text{m}$. However the dark domains on the left-hand side and the right-hand side of the bright one have the width of $0.994 \mu\text{m}$ and $0.783 \mu\text{m}$, respectively. The domain sizes are larger than the grain size of the sample. One can suppose that observed domains are the interaction domains. The characteristic feature of MFM image is the oscillating change of magnetic contrast with significant amplitude of $6\text{--}7^\circ$ occurring in both the bright and dark areas.

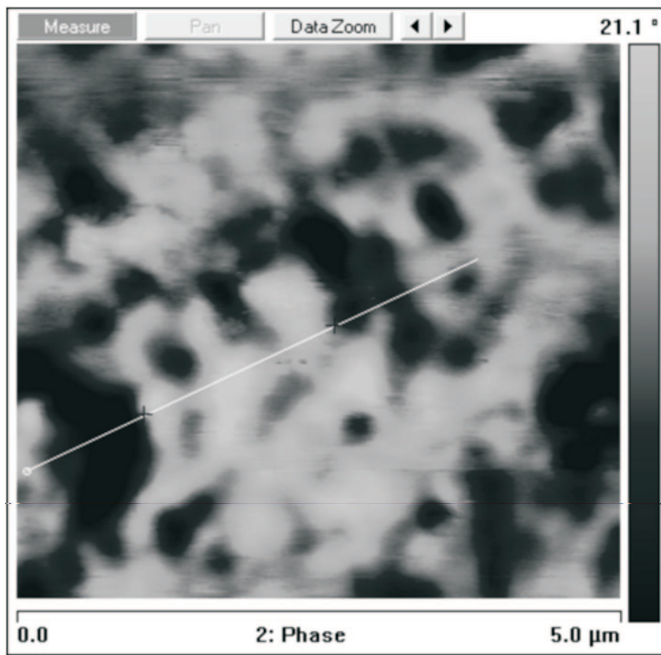


Fig. 2. MFM image of the sample $\text{Nd}_{13.6}\text{Fe}_{73.7}\text{Co}_{6.6}\text{Ga}_{0.6}\text{B}_{5.5}$ on the surface perpendicular to the deformation direction. Scan size is $5\text{ }\mu\text{m}\times 5\text{ }\mu\text{m}$

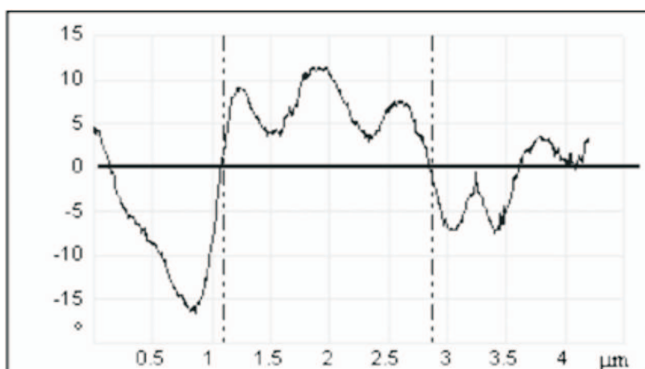


Fig. 3. Magnetic contrast changes along the line marked in Fig. 2

These changes occur in the area comparable with the grain size. Similar changes of contrast have been observed in magnets produced on the base of Nd-Fe-B alloys but an amplitude of changes was smaller [4, 6]. Such behaviour of magnetic contrast can be attributed to the existence of certain order of the grains as a result of dipolar magnetic interaction. For the magnet composed of grains with size of a few hundreds nanometers exchange coupling interaction is very weak and can not make the grains align.

4. Conclusions

From Wohlfarth's remanence curve results that between the neighboring grains there exist the magneto-static (dipolar) interactions. The interaction domains observed in the investigated magnet confirm this fact. In both the bright and dark domain area the magnetic contrast changes oscillatory as a result of dipolar (magneto-static) interaction between the adjacent grains.

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