DETERMINATION OF THE MAGNETIC ANISOTROPY CONSTANT IN MICROPARTICLES OF POWDER-BASED PERMANENT MAGNETS BY MOSSBAUER SPECTROSCOPY

Sh.M. ALIEV, Zh.G. IBAEV
Institute of Physics Dagestan Scientific Center, Russian Academy of Sciences, Makhachkala. Dagestan. Russia
e-mail: ibaev77@mail.ru, Tel.:+79285494601

A new Mossbauer technique for determining the uniaxial magnetic anisotropy constant in micro-particles of powder-based permanent magnets has been developed and experimentally verified.

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The technology of anisotropic powder-based permanent magnets includes alignment of the monodomain uniaxial panicles of a magnetically hard material in a magnetic field, followed by pressing the material in this oriented state [I]. As a result, the material acquires an axial magnetic texture whose degree of perfection is characterized by the texture scattering angle 8, or the relative remanent magnetization $\frac{M_r}{M_s}$ (M_r, and M_s, being the remanent and saturation magnetization, respectively).

Previously [2], we developed a method based on the Mossbauer spectroscopy for determining θ_t. and $\frac{M_r}{M_s}$. Using the results of that study, we propose a new technique for measuring the uniaxial magnetic anisotropy constant *K* of the microparticles of powder-based permanent magnets. The *K* value determines the coercive force and the specific energy of a permanent magnet [1].

The internal energy per unit volume of a permanent magnet in the external magnetic field *H* is [1]

$$E_U = \frac{1}{2}HM - \frac{1}{2}NM^2, \quad (1)$$

where *M* and *N* are the magnetization and demagnetization factors of the given magnet, respectively. Rotation of the magnetization vectors of panicles relative to their easy axes under the action of the field *H* is hindered by the magnetic anisotropy energy [1]

$$E_A = K sin^2\varphi, \quad (2)$$

where φ is a cenain average angle of deviation of the magnetization vectors from easy axes in the field *H*. The balance of E_u and E_A values yields

$$K = \frac{HM - NM^2}{2sin^2\varphi}\ , \quad (3)$$

Based on the conclusions derived in [2] and the relation obtained in that study.

$$cos^3\theta_t + \frac{9k-12}{3k+4}cos\theta_t + \frac{8-12k}{3k+4} = 0, \quad (4)$$

we can determine the magnetic texture scattering angle θ_t, using the parameter k determined as the ratio of areas under the second and first (or fifth and sixth) lines of the ^{57}Fe Mössbauer spectrum ($k = S_{2(5)}/S_{1(6)}$). The sample for Mössbauer measurements represents a thin plate cut from a magnet in the plane perpendicular to the axis of texture.

Once the texture scattering angle θ_t, is known, it is possible to determine the relative remanent magnetization as [2]

$$\frac{M_r}{M_s} = \frac{1+cos\theta_t}{2}\ , \quad (5)$$

The sample of a textured magnetic material can be formally represented by a single crystal plate with the magnetization vector M_s, making an angle φ_0 = arccos(M_r/M_s) with the normal to the sample surface (Fig. la). Using this approximation, it is possible to reduce the angles θ_t, between the axis of texture and easy axes to an

average angle φ_0, which simplifies solution of the problem. By the same token, the relative magnetization of a magnet in the field *H* applied along the texture axis (Fig. lb) can be expressed as

$$\frac{M_r}{M_s} = \frac{1+cos\theta_t}{2} = cos\varphi_1, \quad (6)$$

Using relations (3). (5) and (6) and taking into account $\varphi=\varphi_0-\varphi_1$ (Fig. 1), we finally oblain

$$K = \frac{M_s cos\varphi_1 (H - M_s cos\varphi_1)}{2sin^2(\varphi_0-\varphi_1)}\ , \quad (7)$$

The proposed method was verified on a 16BA-190 grade magnet based on barium ferrite $BaFe_{12}O_{19}$ [3]. The sample had the shape of a 70-μm-thick plate with a diameter of 15 mm, cut from the magnet along the plane perpendicular 10 the axis of texture. The measurements in a magnetic field were performed using a water-cooled solenoid. The source of γ-quanta was ^{57}Co in a chromium matrix, with a beam divergence angle not exceeding 5°.

131, H.Javid ave, AZ-1073, Baku
Institute of Physics
E-mail: jophphysics@gmail.com

Figure 2 shows the Mossbauer spectra of the sample measured with and without applied magnetic field. The spectra exhibit a superposition of five Zee man sextets related to iron ions in five magnetic sublatlices of barium ferrite [41, From these spectra, we have obtained $\theta_t = 40°$, $M_r/M_s = 0.88$, and φ_0=28°. In a magnetic field with H = 2,1 kOe, the corresponding values are $\theta = 19°$, $M_r/M_s = 0.97$, and φ_1= 12°. For the given magnetic material, $4\pi M_r$ = 3000 G [3] and, taking into account the relative remanent magnetization. M_s = 270 G. Substituting these data into (7) yields $K = 3.3\times10^6$ erg/cm^3. This value coincides with the values of the anisotropy constant obtained by the torsional pendulum and the ferromagnetic resonance techniques for single crystal ferrite $BaFe_{12}O_{19}$[5].

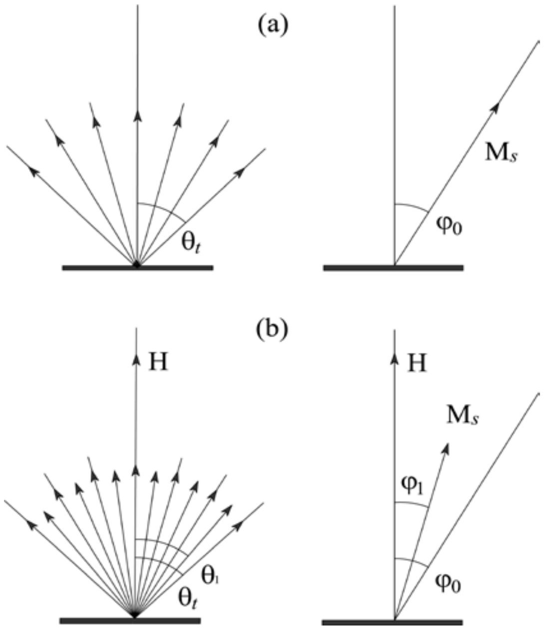

Fig. 1. Distribution of the panicle magnetization vector directions relative to the texture axis in a powder-based permanent magnet (left diagrams) and in a single crystal magnet with the easy axis making an angle φ_0 with the normal to the sample plane: (a) in the Reman ent magnetization state (demagnetizing field assumed equal to zero); (b) in a magnetizing field H applied along the texture axis.

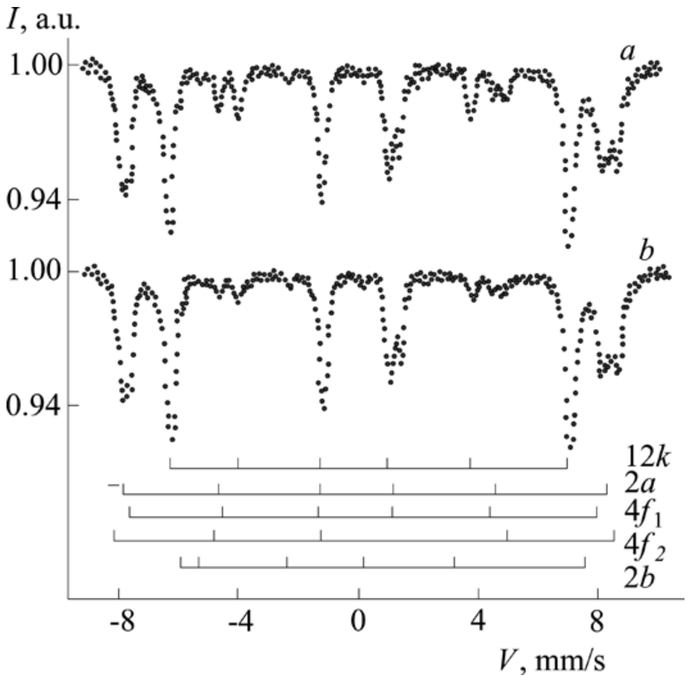

Fig. 2. ^{57}Fe Mössbauer spectra of a 16BA-190 permanent magnet measured (*a*) without applied magnetic field and (b) in a field of H= 2.1 kOe parallel to the texture axis. The direction of the beam of γ-quanta coincides with the axis of texture.

An advantage of the method described above is the possibility lo perform measurements on the commercial samples, which is very important for testing permanent magnets in order to control and optimize their technical characteristics. Note that the proposed technique has nothing preventing its use for determining the uniaxial anisotropy constants of magnetically hard materials of some other systems (Fe-Co-Ni-AI-Cu, Fe-Co-Cr, etc.) widely used in permanent magnet technology [I].

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