Peculiarities of Development of High-Coercivity State of Sm-Co-Fe-Cu-Zr Magnets upon Step Cooling

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The Sm-Co-Fe-Cu-Zr magnets have the highest known maximum energy product $(BH)_m$ together with high thermal stability of magnetic hysteresis properties. The coercivity H_c originates from the pinning of domain walls at interfaces of the $Sm_2(Co,Fe)_{17}$ ($R3m$ - 2:17) and $Sm(Co,Cu)_5$ ($P6/mmm$ - 1:5) phases of the nanocrystalline cellular structure, which is formed via the precipitation of the high-temperature-solid solution at 800-850°C [1]. The subsequent re-distribution of the alloy components between the 2:17 and 1:5 phases in the course of step cooling from 800 to 400°C increases coercivity H_c of the magnets. This work studies with XRD analysis of peculiarities of high-coercivity state development in the high temperature (HTPM - $Sm(Co_{0.76}Fe_{0.12}Cu_{0.09}Zr_{0.03})_{7.0}$) and high energy (HEPM - $Sm(Co_{0.64}Fe_{0.28}Cu_{0.06}Zr_{0.02})_{7.57}$) permanent magnets in the course of the step annealing. The main increase of H_c in the HEPM (which has about 15 vol. % of the 1:5 phase) occurs after annealing at T = 700°C (Fig. 1a). The quenching of the magnet from 830°C results in a large misfit of the c lattice parameters of the coherent 2:17 and 1:5 phases, as well as increased stresses at the interface. The Cu diffusion from the 2:17 into the 1:5 phase upon annealing at T = 700°C leads to the relaxation of the stresses (Fig.1 d). At T < 700°C, H_c grows negligibly (Fig. 1a). The volume fraction of the 1:5 phase in the HTPM quenched from 830°C reaches 50%; and the difference in the c lattice parameters of the 2:17 and 1:5 phases is negligible (Fig.1 e). Therefore, the Cu redistribution at T = 700 and 600°C is slow and insignificant. The annealing at 500°C considerably accelerates the Cu diffusion and increase of H_c, especially, this is true for the initial step of annealing (t < 0.2 h). As is shown in [1], interface stresses grow upon annealing at the temperature lower than the Curie temperature of the 1:5 phase (~ 550°C). The lattice extension of the 1:5 along the c axis originating from the magnetic elasticity increases the misfits (Fig.1 f) and stresses. The Cu-enrichment of the interface of the 2:17 and 1:5 phases relaxes the stresses and increases the boundary-energy gradient, as well as H_c.

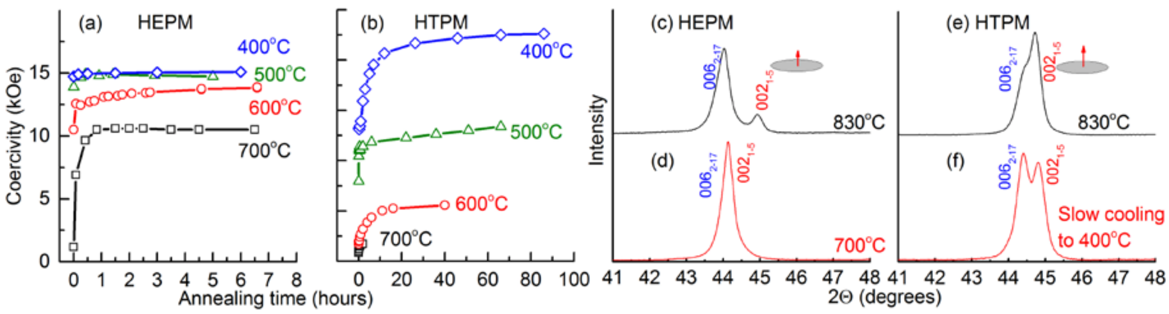

Figure 1: Coercivity kinetics (a,b) and fragments of x-ray diffraction patterns taken from the planes perpendicular to the texture direction of the HEPM (c, d) and the HTPM (e, f).

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References

[1] - A. G. Popov, O. A. Golovnia, A V. Protasov, et al. *IEEE Trans Magn* **54**, 6 (2018).