RECYCLING ROUTE OF SINTERED ND-FE-B MAGNETS: FORMATION OF THE CORE-SHELL STRUCTURE

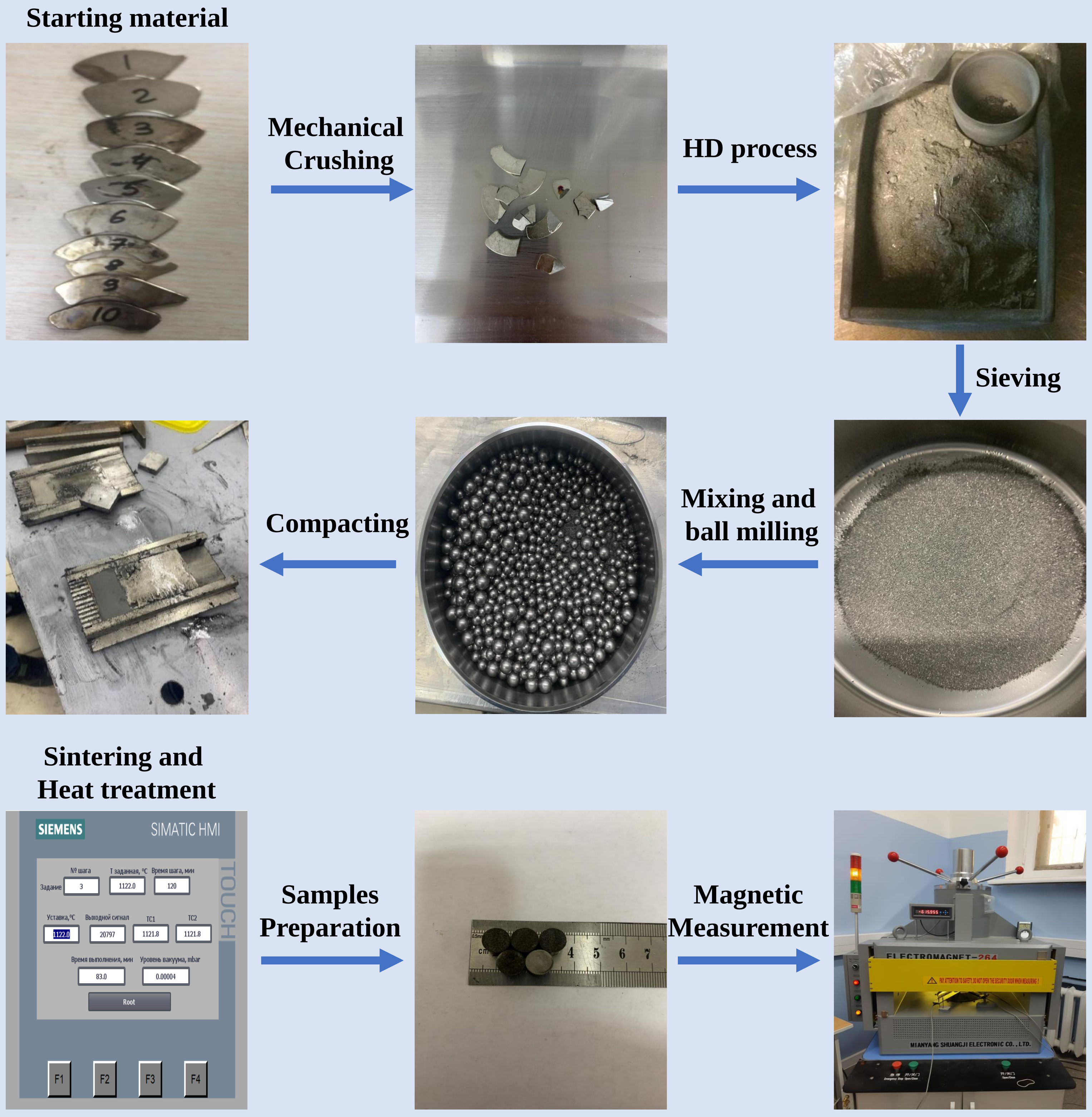
P.A. Prokofev, N.A. Dormidontov, N.B. Kolchugina,
A.S. Bakulina, D.A. Rusinov
Baikov Institute of Metallurgy and Materials Science, Russian Academy of Sciences

INTRODUCTION

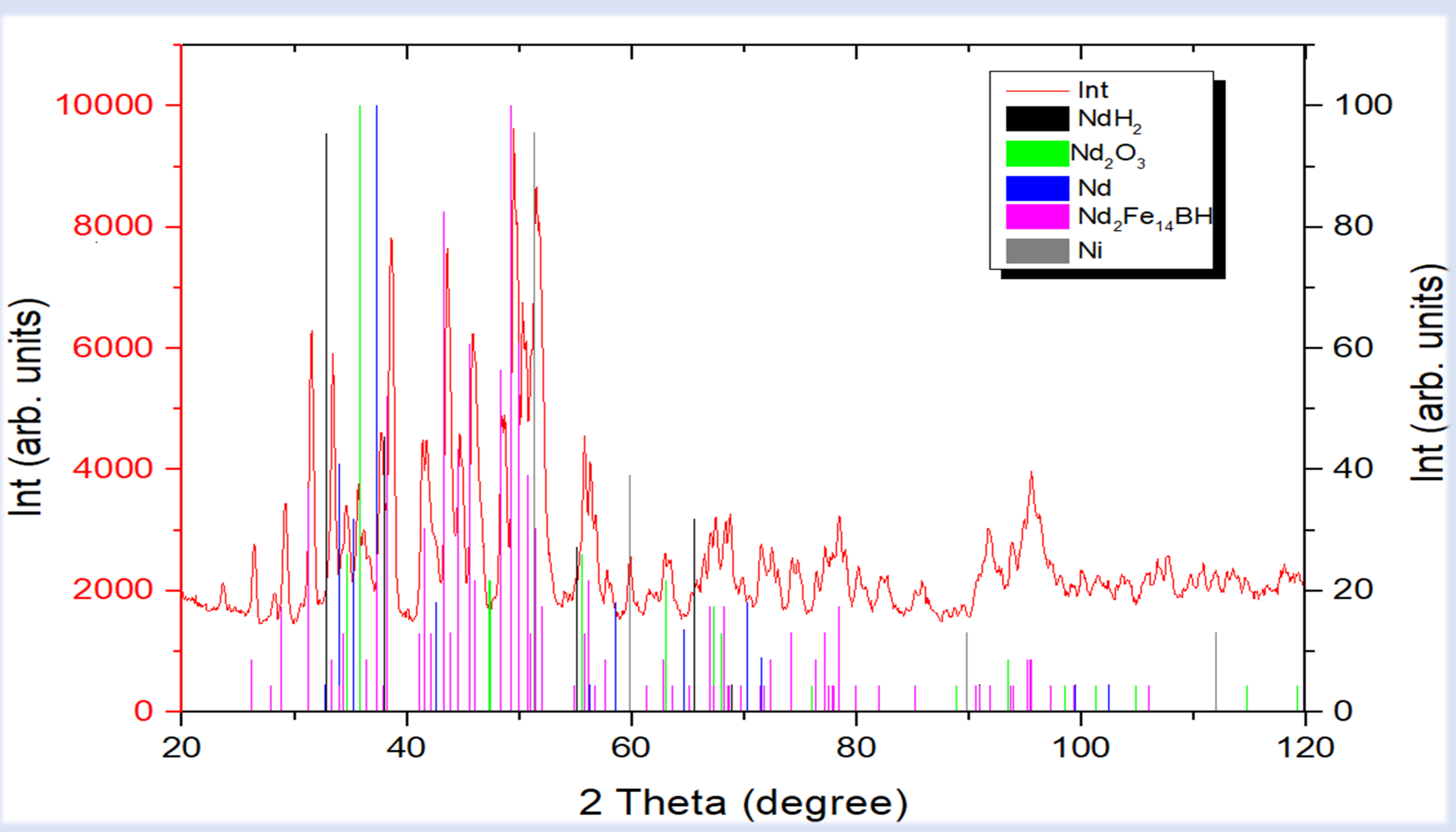
The demand for rare-earth permanent magnets continues its strong and steady growth, due to their application in existing and future energy systems. Therefore, the rare-earth metals (REMs) are among the most critical elements, in particular, from the viewpoint of their availability. This fact determines the problem of the development of efficient technologies for recycling sintered Nd-Fe-B permanent magnets, which is closely related to the development of new approaches to the formation of high-coercivity and high-performance states of the Nd-Fe-B permanent magnet materials. One approach to solving the problem consists of using the grain boundary modification (GBM) of sintered magnet materials, which includes grain-boundary diffusion (GBD) and grain-boundary structuring (GBS). These processes effectively increase the coercivity of Nd-Fe-B magnets with a small amount of rare earth additives; the remanence is usually only slightly reduced. At present, these processes are realized in the course of the recycling process of sintered Nd-Fe-B magnets, are unable to substantially change (melt or decompose) the $Nd_2Fe_{14}B$-based phase, and allow one to closely tailor the properties of magnets to meet a wide variety of end-user applications. The considered GBM approach is used for so-called magnet-to-magnet recycling, which assumes that the metals in sintered Nd-Fe-B magnets are recycled simultaneously. GBM can be realized via the careful addition of compounds or blended elements and the application of hydrogen.

The aim of the present study is to investigate the possibility of recycling Nd-Fe-B magnets using hydrogen decrepitation, a blending powder procedure and mixtures of magnets of different grades.

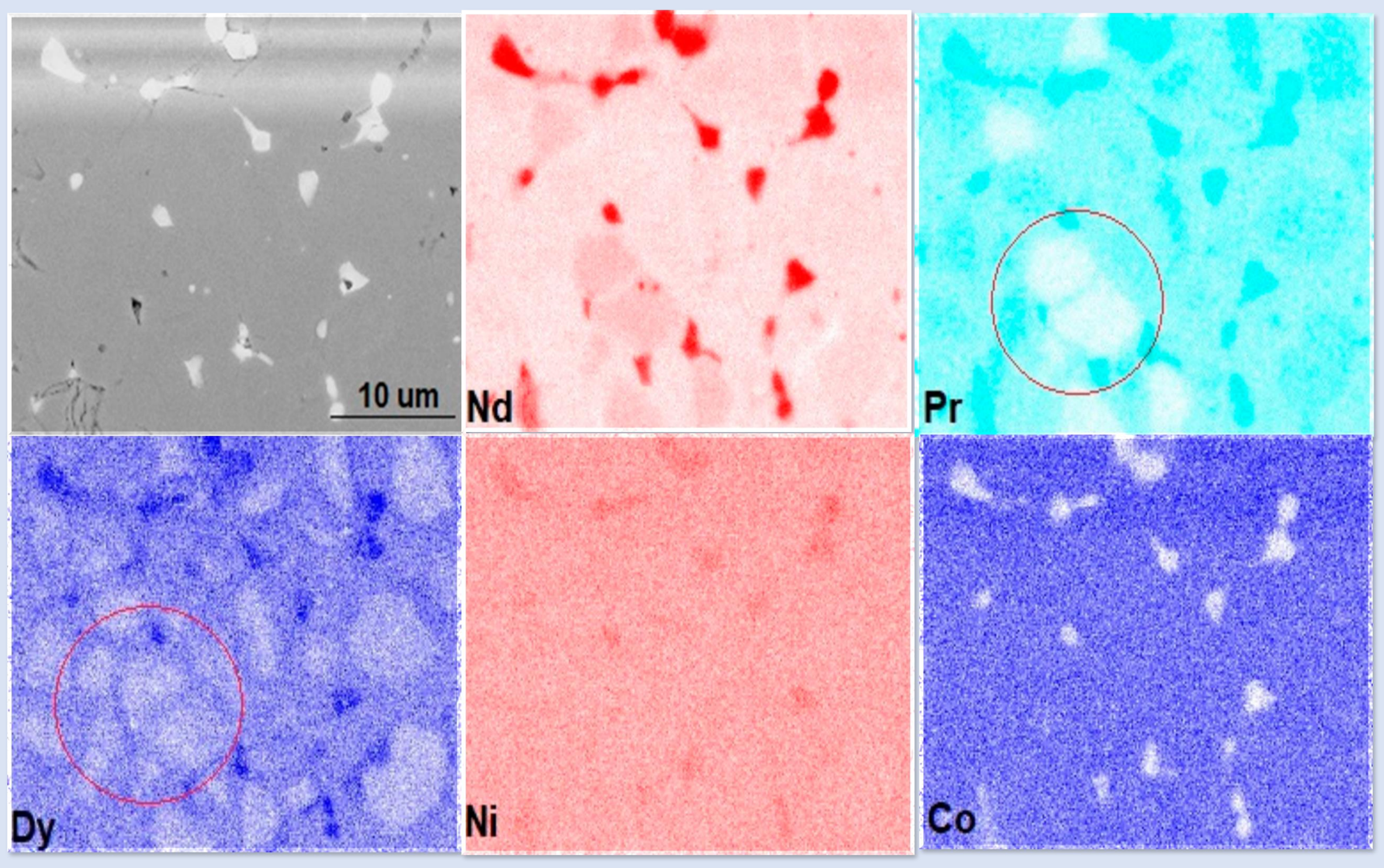
Scheme of preparation of sintered Nd-Fe-B magnets



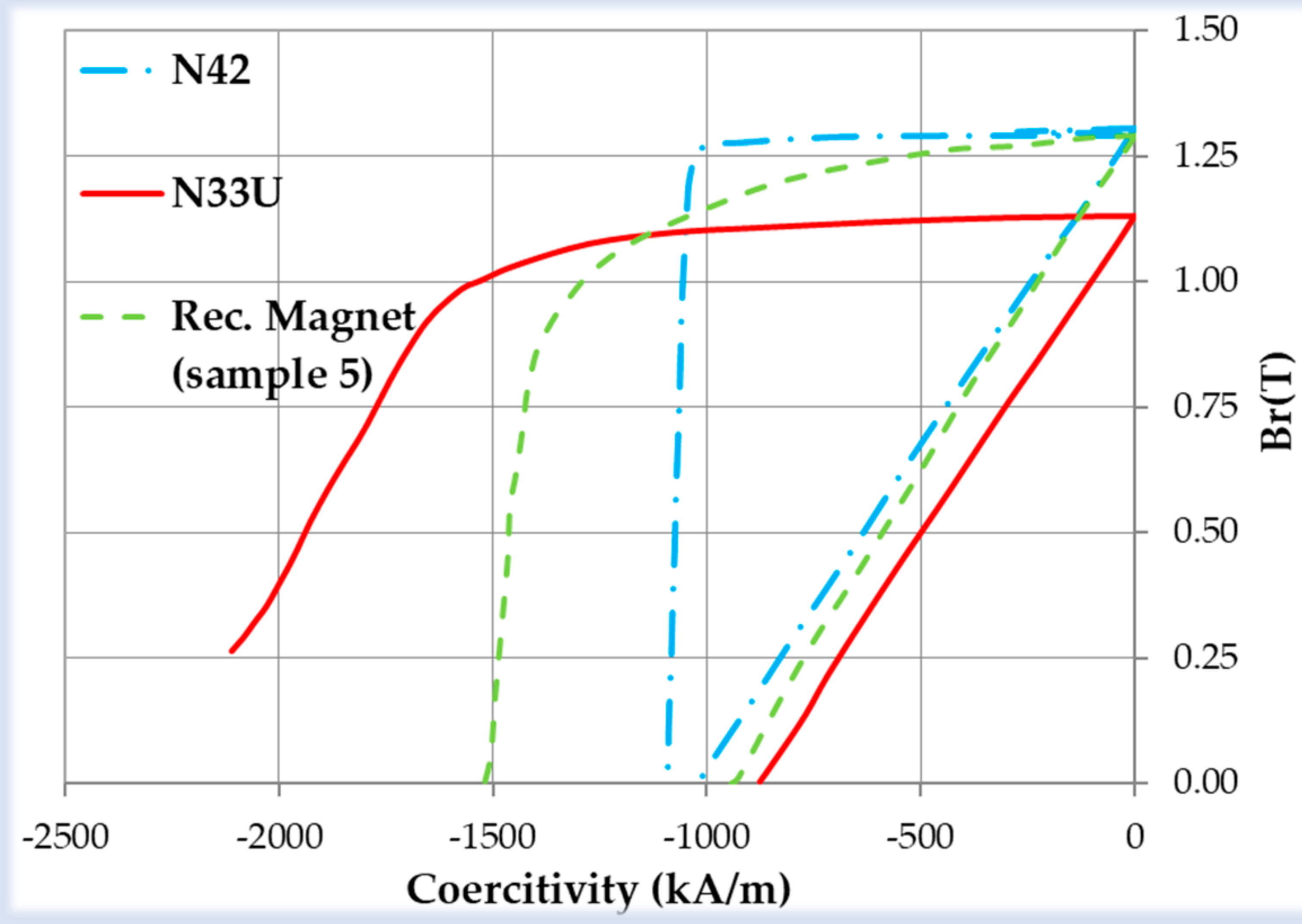
Phase composition of Nd-Fe-B powder after hydrogen treatment of secondary raw materials



Analysis of core-shell structure and mapping of RE and transitions elements (SEM)



Magnetic properties of magnets prepared by recycling route



Measurement temperature K (ºC) *	B_r (T)	H_{cM} (kA/m)	$(BH)_{max}$ (kJ/m³)	$\Delta B_r/(B_r \cdot \Delta T) \cdot 100$, %/ºK	$\Delta H_{cM}/(H_{cM} \cdot \Delta T) \cdot 100$, %/ºK
293 (20)	1.30	1220	293	-0.08	-0.47
333 (60)	1.25	840	273		
373 (80)	1.22	647	263		

* Measurement of magnetic properties at elevated temperatures to determine the temperature coefficients of coercivity and induction in accordance with GOST R 52956-2008 "Magnetically hard sintered materials based on neodymium-iron-boron alloy"

CONCLUSIONS

Grain boundary diffusion engineering is a revolutionary production technology of Nd-Fe-B magnets, which can be used in the recycling process, since it effectively ensures the utilization of rare earth elements from waste magnets and saves rare earth resources.

The recycling process of N42 and N33U (Dy-containing) magnets (magnet-to-magnet recycling) improves the coercivity of N42 magnets by using reduced contents of heavy rare-earth metal. It was demonstrated that the existence of the core-shell structure in the recycled magnet ensures the improvement of the coercivity. Usually, the coercivity enhancement by Dy substitution is achieved at the expense of a decrease in the remanence, and therefore, in the maximum energy product because of the antiferromagnetic coupling of Dy and Fe atoms in the (Nd, Dy)$_2$Fe$_{14}$B lattice.

The temperature coefficients of coercivity and induction were determined using AMT-4 hysteresisgraph with a heating unit.

FUNDING

This study was performed in terms of state task, no. 075-01176-23-00