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XMCD study of local magnetic and structural properties of microcrystalline NdFeB-based alloys[1)]

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The discovery in 1984 of $Nd_2Fe_{14}B$ intermetallide with the maximum energy product $(BH)_{max}$ as high as 56 MGOe (445.7 kJ/m^3) [1, 2] made a breakthrough in magnetic materials research. This compound is superior [3] to its predecessors $SmCo_5$ and Sm_2Co_{17} not only due to its record energy product $(BH)_{max}$ but also due to the lower cost of constituting rare-earth element Nd which is more abundant resource than Sm. Nowadays, NdFeB-based alloys play very important role as functional components in contemporary devices leading to the enormous economic impact and ever-increasing market of permanent magnets. Among the most important applications of the NdFeB permanent magnets are: electric transformers, generators, synchronized motors, actuators, sensors, etc. [4].

Contemporary research of magnetic materials on the basis of NdFeB alloys is being conducted into two basic directions: addition of different elements to improve the microstructure of the magnets and understanding of the atomic origins of magnetic anisotropy responsible for coercivity. It has been found that addition of Zr leads to a much finer and uniform microstructure of NdFeB magnets and also improves its magnetic properties at room temperature [5].

Here we implement the advantages of element-specific technique x-ray magnetic circular dichroism (XMCD) to high-coercivity Zr-doped $Nd_2Fe_{14}B$ magnets [6] in order to locally probe Nd and Fe spin-dependent electronic states. XMCD study was performed at beamline ID 12 [7] of the European Synchrotron Radiation Facility (ESRF), Grenoble, France. Acquisition of XMCD spectra of $Nd_{10.4}Zr_{4.0}Fe_{79.2}B_{6.4}$ samples previously oriented along easy and hard axis of magnetization was carried out at room temperature at K absorption edge of Fe (7112 eV) and $L_{3,2}$ absorption edges of Nd (6208 and 6722 eV) in external magnetic field of ± 10 T.

XMCD spectra are presented on the left panel of Fig. 1. Here we should point out that in contrast to results of [8], obtained for $Nd_3Fe_{27.5}Ti_{1.5}$, we observe a significant difference of XMCD signal amplitudes at $L_{3,2}$-Nd absorption edges for orientation along easy and hard magnetization axes, while the shape of XMCD spectra measured at Fe K edge does not depend on magnetic orientation of the samples, so the magnetic moment on iron ions can be considered as the average for all crystallographic positions.

XMCD spectra were accompanied by XMCD magnetic curves, measured at room temperature in the fields up/down to ± 17 T (see right panel of Fig. 1). Exploration of local XMCD magnetic curves was carried out as follows. The energy of x-ray quantum was tuned precisely to the position of one of the major maxima of XMCD signal, and then the amplitude of the signal was measured during scanning of the magnetic field from -17 to $+17$ T with the increment of 1 T.

Thus the presented analysis of XMCD spectra at $L_{3,2}$-Nd and K-Fe edges for the first time revealed different magnetic ordering of Nd and Fe ions in Zr-doped $Nd_2Fe_{14}B$ magnets depending on magnetization orientation of samples.

This new approach to study local electronic structure and microscopic origin of magnetic properties in oriented polycrystalline permanent magnets based on NdFeB-based alloys will be very useful to understand its magnetic properties and to tailor them for specific applications.

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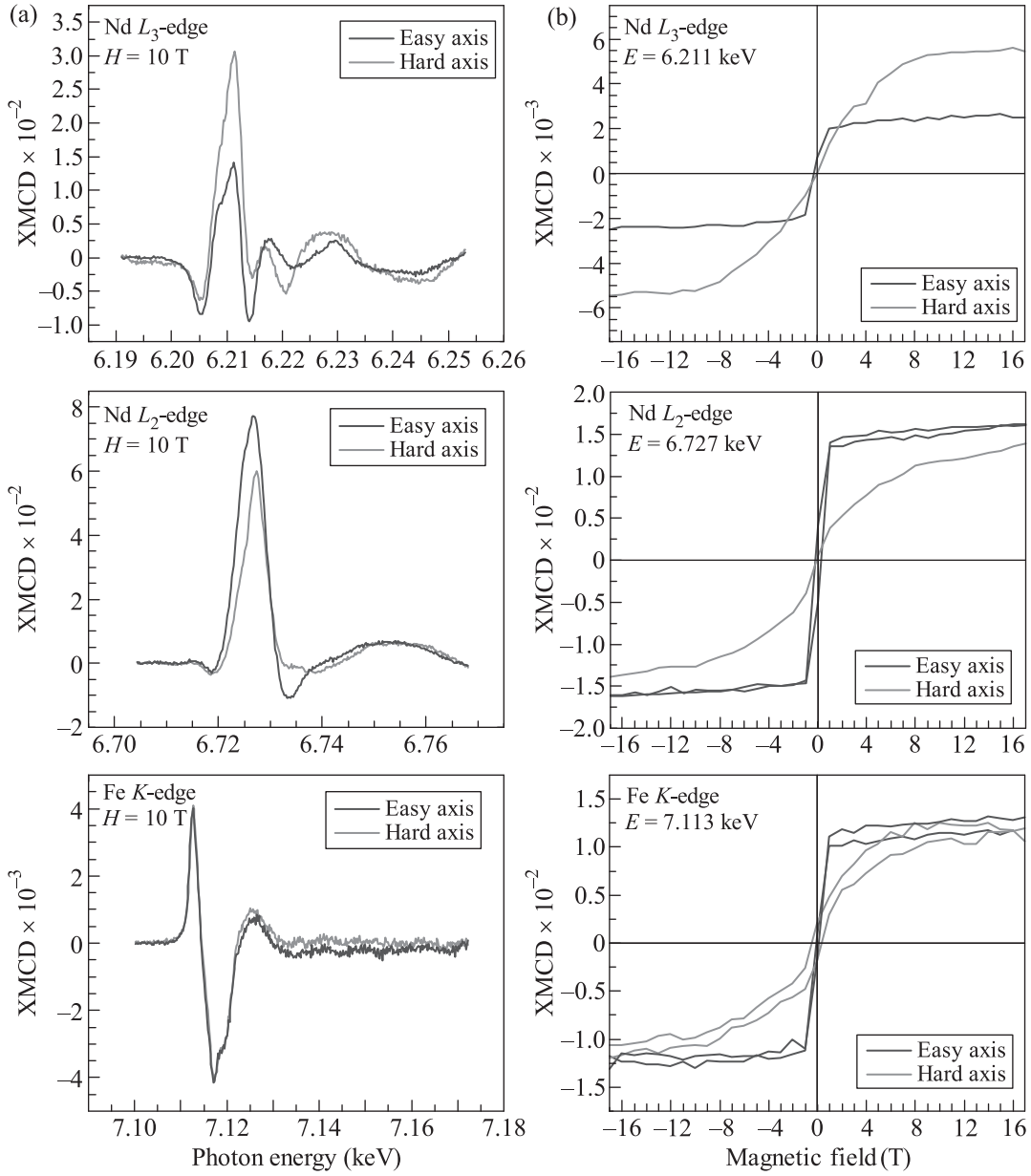

Fig. 1. (Color online) XMCD spectra of oriented polycrystalline samples $Nd_{10.4}Zr_{4.0}Fe_{79.2}B_{6.4}$ taken along easy and hard magnetization axes at Nd $L_{3,2}$ and Fe K absorption edges in magnetic field of 10 T (a) and corresponding magnetic field dependence of XMCD signal measured in magnetic field up/down to ±17 T (b)

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