

Magnetic properties of rare-earth-iron-boron permanent magnet materials

M. Sagawa, S. Fujimura, H. Yamamoto, Y. Matsuura, and S. Hirotsawa
Sumitomo Special Metals Co., Ltd., Egawa, Shimamotocho, Mishima-gun, Osaka 618, Japan

Static magnetic measurements have been carried out on single crystals of $\text{Nd}_2\text{Fe}_{14}\text{B}$, $\text{Sm}_2\text{Fe}_{14}\text{B}$, and $\text{Y}_2\text{Fe}_{14}\text{B}$ from 4.2 to 590 K. Values of K_1 estimated from high field measurements at room temperature are 4.5, -12, and 1.1 MJ/m³ for $\text{Nd}_2\text{Fe}_{14}\text{B}$, $\text{Sm}_2\text{Fe}_{14}\text{B}$, and $\text{Y}_2\text{Fe}_{14}\text{B}$, respectively. Anisotropic behavior of the magnetization versus magnetic field curves in the basal plane has been observed for $\text{Sm}_2\text{Fe}_{14}\text{B}$, indicating large amplitude of the high order coefficients, K_2 and K_3 . In $\text{Nd}_2\text{Fe}_{14}\text{B}$, the magnetization has been found to tilt from the *c* axis and simultaneously increase in magnitude. Average Fe moment is estimated to be 2.23 μ_B/Fe at 4.2 K from the saturation magnetization of $\text{Y}_2\text{Fe}_{14}\text{B}$.

I. INTRODUCTION

Much attention has been focused on the $\text{R}_2\text{Fe}_{14}\text{B}$ intermetallics since high energy permanent magnets having maximum energy products larger than 280 kJ/m³ were developed on the basis of $\text{Nd}_2\text{Fe}_{14}\text{B}$.¹ Recent improvements involving addition of Co and Dy, which offer increased energy products and thermal stability, have broadened the fields of potential applications for this new class of permanent magnets.² Because of this technological impact, there have been increasing quests for fundamental investigations of the basic magnetic properties of the $\text{R}_2\text{Fe}_{14}\text{B}$ intermetallics which form in the tetragonal structure except for $\text{R} = \text{La}$. Especially an accurate measurement of the temperature dependence of the magnetocrystalline anisotropy constants has been most desired in connection with a relatively rapid fall of coercive force of the $\text{Nd}_2\text{Fe}_{14}\text{B}$ -based magnets at elevated temperatures. For this reason, we have carried out magnetic measurements on single crystals of $\text{Nd}_2\text{Fe}_{14}\text{B}$, $\text{Sm}_2\text{Fe}_{14}\text{B}$, and $\text{Y}_2\text{Fe}_{14}\text{B}$. The yttrium compound was chosen because its magnetic properties arise only from the Fe sublattice and hence provide the Fe background of magnetic properties of the $\text{R}_2\text{Fe}_{14}\text{B}$ series. $\text{Sm}_2\text{Fe}_{14}\text{B}$ was examined as a typical example of $\text{R}_2\text{Fe}_{14}\text{B}$ with planar anisotropy.

II. EXPERIMENTAL PROCEDURE

Single crystals of $\text{Nd}_2\text{Fe}_{14}\text{B}$ and $\text{Y}_2\text{Fe}_{14}\text{B}$ were grown in an infrared imaging furnace by the floating-zone melting

technique. Single crystals of $\text{Sm}_2\text{Fe}_{14}\text{B}$ were prepared in a BN crucible in an Ar atmosphere by very slow cooling of the alloy from a temperature just above the melting point of $\text{Sm}_2\text{Fe}_{14}\text{B}$. The purity of starting materials was 99.5% for rare earths, 99.9% for Fe, and 99.5% for B. The single crystals thus obtained were qualified by means of x-ray diffraction analysis and optical microscope observation. Magnetic measurements were performed on cleaved single crystals of the size of about 0.5 mm embedded in epoxy resin. Alignment of the crystals was achieved by the use of external magnetic fields at approximately 370 K before the epoxy resin hardened. The temperature dependence of magnetization was measured in our laboratory using a vibrating sample magnetometer (VSM), in an external magnetic field of 800 kA/m. High field magnetic measurements up to 11.5 MA/m were carried out with a VSM and a water cooled Bitter type magnet at the High Field Laboratory for Super Conducting Materials, Research Institute of Iron, Steel and other Metals of Tohoku University.

III. RESULTS AND DISCUSSION

Results of the high field measurements of $\text{R}_2\text{Fe}_{14}\text{B}$ ($\text{R} = \text{Nd}$, Sm and Y) at room temperature are shown in Figs. 1-3. No appreciable coercivity is observed. The high field susceptibility at room temperature is negligibly small. In the case of $\text{Nd}_2\text{Fe}_{14}\text{B}$ (Fig. 1) the magnetization versus magnetic field

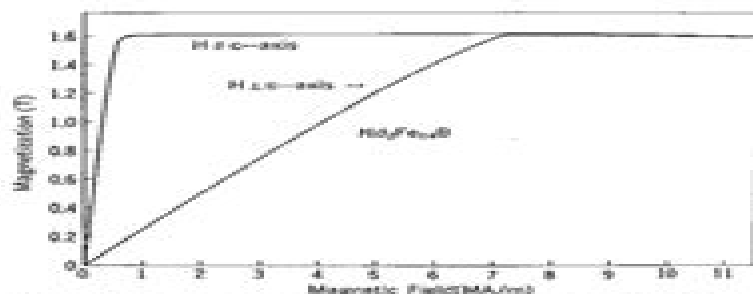


FIG. 1. Magnetization vs magnetic field curves of a single crystal of $\text{Nd}_2\text{Fe}_{14}\text{B}$ at room temperature.

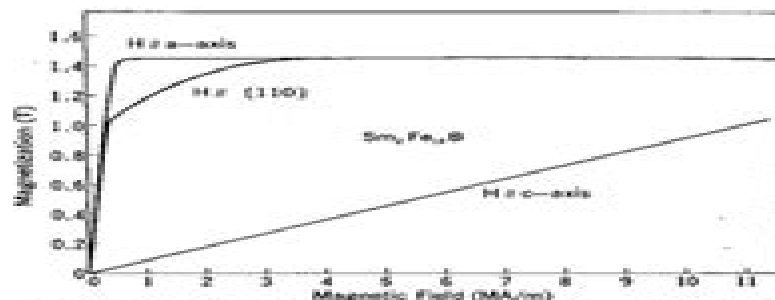


FIG. 2. Magnetization vs magnetic field curves of a single crystal of $\text{Sm}_2\text{Fe}_{14}\text{B}$ at room temperature.

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