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HIGH-FIELD MAGNETIZATION PROCESS AND CRYSTALLINE FIELD IN $\text{R}_2\text{Co}_{14}\text{B}$

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Abstract. — Magnetizations of $\text{R}_2\text{Co}_{14}\text{B}$ single crystals with $\text{R} = \text{Nd}$ and $\text{Pr}$ have been measured under steady magnetic fields up to 300 kOe. We have shown that the observed data can be well reproduced by nearly the same set of crystalline field and R-3d exchange parameters as that in $\text{R}_2\text{Fe}_{14}\text{B}$ system.

Since the discovery of $\text{Nd}_2\text{Fe}_{14}\text{B}$, a wide variety of magnetization curves in high fields has been observed for different $\text{R}_2\text{Fe}_{14}\text{B}$ ($\text{R}$ denotes a rare-earth element) compounds [1]. We have shown recently [2] that all these observations can be explained systematically by a simplified Hamiltonian which takes account of, at each R site, the crystalline electric field (CEF) and the molecular field due to the Fe-R exchange interaction. This success comes from the fact that, in this system, the Fe-Fe exchange interaction is so strong as compared with the Fe-R exchange that we can assume the Fe sublattice is "rigid" and therefore not affected by the R ion. The same situation occurs in the $\text{R}_2\text{Co}_{14}\text{B}$ system. According to the magnetic measurement of $\text{La}_2\text{Co}_{14}\text{B}$ single crystal [3], the Co sublattice is expected to favor the easy $c$-plane for the spontaneous magnetization, in contrast to the Fe sublattice in $\text{R}_2\text{Fe}_{14}\text{B}$. When an R sublattice in $\text{R}_2\text{Co}_{14}\text{B}$ favors the $c$-axis, a spin reorientation from the $c$-axis to $c$-plane takes place at high temperature owing to the Co contribution.

We report here the experimental results of high-field magnetization process in $\text{R}_2\text{Co}_{14}\text{B}$ with $\text{R} = \text{Nd}$, $\text{Pr}$ at 4.2 K and 290 K, where the Co contribution to the magnetic anisotropy is insignificant, and compare them with the calculations using a similar method to that described above.

Single crystals of $\text{Nd}_2\text{Co}_{14}\text{B}$ and $\text{Pr}_2\text{Co}_{14}\text{B}$ were embedded respectively into a cube of epoxy resin with the edges parallel to the principal crystallographic directions. Magnetizations have been measured by the vibrating-sample method or the sample extraction method in steady magnetic fields up to 300 kOe generated by a hybrid magnet system. Conventional pulsed-field method was used for higher field measurements.

Observed magnetization curves of $\text{Nd}_2\text{Co}_{14}\text{B}$ at 4.2 K and 290 K are shown in figure 1a. At 4.2 K the magnetization along the [100] direction shows a sudden jump [4] at about 210 kOe, which manifests the first order magnetization process (FOMP) observed also in $\text{Nd}_2\text{Fe}_{14}\text{B}$. At 290 K magnetizations along both [100] and [110] directions saturate above about 80 kOe, although the saturation values are slightly smaller than the easy direction value. This anisotropy of saturation values has also been observed in $\text{Nd}_2\text{Fe}_{14}\text{B}$.

In the case of $\text{Pr}_2\text{Co}_{14}\text{B}$, observed magnetization shown in figure 1b exhibits a very large anisotropy; at 4.2 K the magnetizations along the [100] and [110] directions are only less than half of expected saturation value even in the field of 300 kOe, without showing the FOMP which was observed in $\text{Pr}_2\text{Fe}_{14}\text{B}$ at 130 kOe and 160 kOe, respectively. Moreover, pulsed-field measurements at 4.2 K have shown that no anomaly occurs in the [100] and [110] curves at least up to 400 kOe. The saturation field of the hard axis magnetization at 290 K reaches 130 kOe, which is considerably higher than that of $\text{Pr}_2\text{Fe}_{14}\text{B}$, $\text{Nd}_2\text{Fe}_{14}\text{B}$ or $\text{Nd}_2\text{Co}_{14}\text{B}$. We also notice a marked difference in the saturation magnetization at 290 K.

In order to explain these magnetization curves we...
Table I. Reduced CEF parameters $b_n^m$ ($=A_n^m/A_n^{0m}$) and the molecular field parameter $H_m$ (in units of K) used in the calculation, where $A_n^m$ is the calculated CEF coefficient arising from the point charges of the five nearest $R^{3+}$ ions. The value in parentheses is the $A_n^m$ in units of $Ka_0^{-n}$, where $a_0$ is the Bohr radius. Other parameters fixed for both compounds are $b_4^0 = b_6^0 = 0$, $m_0 (0) = 1.4 \mu_B$ and $K_0 (0) = -1.3$ K.

<table>
<thead>
<tr>
<th>R</th>
<th>$b_2^0$</th>
<th>$b_2^{-2}$</th>
<th>$b_4^0$</th>
<th>$b_2^{-2}$</th>
<th>$b_4^0$</th>
<th>$b_2^{-6}$</th>
<th>$b_6^0$</th>
<th>$b_6^{-6}$</th>
<th>$H_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nd</td>
<td>0.22</td>
<td>0.19</td>
<td>1.2</td>
<td>-30</td>
<td>20</td>
<td>-200</td>
<td>25</td>
<td>185</td>
<td></td>
</tr>
<tr>
<td>Pr</td>
<td>0.22</td>
<td>0.20</td>
<td>1.1</td>
<td>-160</td>
<td>23</td>
<td>-220</td>
<td>22</td>
<td>220</td>
<td></td>
</tr>
</tbody>
</table>

The values of $b_n^m$ are comparable to those in $R_2Fe_{14}B$ compounds [2]. The fact that $b_4^0$ and $b_6^0$ are slightly larger and smaller than the corresponding values (0.15 and 2.0), however, implies quantitatively an enhancement of the uniaxial anisotropy in the $R_2CO_{14}B$ system, since the sign of $A_4^0$ is negative in contrast to $A_2^0$ in both series of compounds. On the other hand, the values of $H_m$ are rather smaller than those of $Pr_2Fe_{14}B$ (300 K) or $Nd_2Fe_{14}B$ (350 K). This may be ascribed to the smaller value of averaged Co magnetic moment (1.4 $\mu_B$) as compared with the Fe value of 2.2 $\mu_B$. Similar conclusions have been drawn independently in the recent work of Li et al. [5] from the comparison between the Nd compounds.

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