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Magnetic phase diagrams of YCo_4B -based components

Z. G. Zhao, R. de Boer, and K. H. J. Buschow

Van der Waals-Zeeman Laboratory, University of Amsterdam, Valckenierstraat 65, 1018 XE Amsterdam, The Netherlands

Y. P. Ge and J. Y. Wang

Shenyang College of Architectural Engineering, Shenyang 110015, China

The magnetic properties of $(\text{Y,Nd})\text{Co}_4\text{B}$, $\text{Y}(\text{Co,Fe})_4\text{B}$, and $\text{YCo}_4(\text{B,C})$ compounds have been investigated. The spin-reorientation temperature of YCo_4B increases with substitution of Nd for Y and Fe for Co, but decreases with the replacement of B for C. The Curie temperature of YCo_4B decreases upon substitution of Nd for Y and C for B, whereas it increases upon the introduction of Fe. The magnetic phase diagrams are given for $(\text{Y,Nd})\text{Co}_4\text{B}$, $\text{Y}(\text{Co,Fe})_4\text{B}$, and $\text{YCo}_4(\text{B,C})$. The results show that the temperature range of the easy-axis anisotropy in YCo_4B is increased by C substitution, and decreased by Nd and Fe substitution. The saturation magnetization of YCo_4B increases by the introduction of Nd and Fe. Substitution of C for B changes the magnetic moment of Co only slightly. The magnetic anisotropy is increased by substitution of C for B.

I. INTRODUCTION

YCo_4B and the corresponding pseudoternary compounds crystallize in the CeCo_4B -type structure, which is derived from the CaCu_5 structure by partial substitution of B for Co in every two Co layers.¹ The structure and the magnetic properties of both Fe- and Co-based compounds of the CeCo_4B type have been studied extensively in the past few years because of their potential of being used in permanent magnets.²⁻⁸ Previous results have shown that in YCo_4B the Co-sublattice anisotropy is complex at low temperature.^{5,8} In this compound, a spin-orientation occurs at about 150 K which has been attributed to a change of the easy-magnetization direction of the Co sublattice from *c* axis at high temperature to basal plane at low temperature. Another anomaly is observed at about 60 K, the origin of which is still unknown. In order to understand the magnetic behavior of the Co sublattice in this type of compound, we have performed a detailed study of the magnetic phase diagrams of $(\text{Y,Nd})\text{Co}_4\text{B}$, $\text{Y}(\text{Co,Fe})_4\text{B}$, and $\text{YCo}_4(\text{B,C})$.

II. EXPERIMENTAL PROCEDURE

The compounds $\text{Y}_{1-x}\text{Nd}_x\text{Co}_4\text{B}$ ($x=0.0, 0.1, 0.2, 0.3$), $\text{YCo}_{4-x}\text{Fe}_x\text{B}$ ($x=0.0, 0.1, 0.2, 0.3, 0.4$), and $\text{YCo}_4\text{B}_{1-x}\text{C}_x$ ($x=0.0, 0.1, 0.2, 0.3$), were prepared by melting in an arc furnace in an argon atmosphere, followed by annealing in an atmosphere of highly purified argon at 900 °C for 2 weeks. Subsequently, the materials were quenched into ice water. X-ray-diffraction results showed that only negligible amounts of impurity phases were present.

The temperature dependence of the a.c. susceptibility was measured on bulk samples in the temperature range from 4.2 to 600 K. The high-field magnetization was measured at 4.2 K in the high-field facility at the University of Amsterdam on magnetically aligned samples. These samples were prepared by mixing fine powder of the compound with epoxy resin and letting the mixture subsequently solidify in a field of about 1 T.

FIG. 1. Temperature dependence of the a.c. susceptibility of $\text{Y}_{1-x}\text{Nd}_x\text{Co}_4\text{B}$ compounds between (a) 4.2 and 300 K, and (b) 270 and 400 K.

FIG. 2. Magnetic phase diagram of $Y_{1-x}Nd_xCo_4B$ compounds.

FIG. 4. Magnetic phase diagram of $YCo_{4-x}Fe_xB$ compounds.

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. $Y_{1-x}Nd_xCo_4B$

Substitution of Nd for Y markedly affects the anisotropy of YCo_4B . Figure 1 shows the temperature dependence of the a.c. susceptibility of the $Y_{1-x}Nd_xCo_4B$ compounds. The spin reorientation at 150 K in YCo_4B and the anomaly around 60 K are both strongly influenced by the introduction of Nd. The spin-reorientation temperature is found to increase with increasing Nd content. In the sample with $x=0.3$, the transition even occurs above room temperature, at 310 K. The anomaly at 60 K shifts to lower temperatures in a rather random way. The high-temperature parts of the a.c. susceptibility show that the Curie temperature of YCo_4B slightly decreases from 375 K for YCo_4B to 350 K for $Nd_{0.3}Y_{0.7}Co_4B$.⁵ Since $NdCo_4B$ has easy-plane magnetization at room temperature,⁶ the magnetization in the Nd-containing compounds can also be expected to change from easy axis at high temperature to easy plane at low temperature. Therefore we tentatively conclude from the composition dependence of the spin-reorientation temperature in the $Y_{1-x}Nd_xCo_4B$ system that the transition at 150 K in YCo_4B is also an axis-to-plane transition. The magnetic phase dia-

gram of the $(Y,Nd)Co_4B$ system constructed on the basis of these experimental results is shown in Fig. 2. The easy-axis region is only found in the Y-rich part and its width decreases strongly with increasing Nd content.

B. $YCo_{4-x}Fe_xB$

Substitution of Fe for Co in YCo_4B strongly influences the magnetic anisotropy of the 3d sublattice. Figure 3 shows the temperature dependence of the a.c. susceptibility of $YCo_{4-x}Fe_xB$ compounds between 4.2 and 300 K. The spin-reorientation temperature increases with increasing Fe content and for $x=0.2$, no spin reorientation is observed up to the Curie temperature. As YFe_4B also has easy-plane magnetization at room temperature,⁷ this composition dependence of the transition temperature can be taken as evidence that the transition is from easy axis at high temperature to easy plane at low temperature. Substitution of Fe for Co strongly enhances the easy-plane anisotropy. With increasing Fe content, the Curie temperature increases strongly from 375 K for YCo_4B to 490 K for $YCo_{3.6}Fe_{0.4}B$.⁷ This means that the 3d-3d exchange interaction is strongly increased

FIG. 3. Temperature dependence of ac susceptibility of $YCo_{4-x}Fe_xB$ compounds between 4.2 and 300 K.

FIG. 5. Temperature dependence of the a.c. susceptibility of $YCo_4B_{1-x}C_x$ compounds between 4.2 and 300 K.

FIG. 6. Magnetic phase diagram of $\text{YCo}_4\text{B}_{1-x}\text{C}_x$ compounds.

FIG. 7. Magnetization of $\text{YCo}_4\text{B}_{1-x}\text{C}_x$ compounds at 4.2 K for the field parallel (○) and perpendicular (●) to the alignment direction.

upon the introduction of Fe. The magnetic phase diagram in Fig. 4 shows that the easy-axis region is small and restricted to the Co-rich part.

C. $\text{YCo}_4\text{B}_{1-x}\text{C}_x$

The magnetic properties of the Co sublattice for YCo_4B are also affected by substitution of C for B. Figure 5 shows the temperature dependence of the a.c. susceptibility of $\text{YCo}_4\text{B}_{1-x}\text{C}_x$ compounds with $x=0.0, 0.1$, and 0.2 . Both transitions in the compound with $x=0.0$ at 60 and 150 K move to lower temperatures for $x=0.1$ and then disappear for $x=0.2$. In contrast to the types of substitution discussed before, substitution of C and B enlarges the temperature range of easy-axis magnetization, which is favorable for applications. Substitution of C for B in YCo_4B causes the Curie temperature to first slightly increase for $x=0.1$ and then to decrease for $x>0.1$. The phase diagram of the $\text{YCo}_4(\text{B,C})$ system is shown in Fig. 6.

The magnetization curves are shown in Fig. 7. From the planar diagram shown in Fig. 6 one would have expected that the magnetic moment of the compound with $x=0.1$ when measured in low fields applied parallel to the alignment direction would have been lower than the moment mea-

sured perpendicular to the alignment field (as for $x=0$). It is possible that this latter situation is realized in applied fields lower than those considered here with an intersection point between the isotherm below 1.3 T. It can be seen from Fig. 7 that the saturation magnetization of the compound changes only slightly with x . This is similar to what has been observed in the $\text{Nd}_2\text{Co}_{14}(\text{B,C})$ system.

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