Effect of Pressure on the Superconducting Properties of $Ho_{0.5}Y_{0.5}Ni_2B_2C$

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Abstract

Electrical resistance and lattice constants of $Ho_{0.5}Y_{0.5}Ni_2B_2C$ have been measured at high pressure in order to clarify the competition between antiferromagnetism and superconductivity. It is found that the superconducting transition temperature and the upper critical fields decrease with increasing pressure.

Key words: high pressure; superconductivity; borocarbide

In the rare earth borocarbides RNi_2B_2C(R: rare earth element), the antiferromagnetism is well known to coexist with superconductivity for the materials with R=Ho,Tm and Er[1,2]. The structure of the borocarbides is a variant of the $ThCr_2Si_2$ type, which consists of alternating layers of RC planes and Ni_2B_2 slabs. Due to this fact, the physical properties are highly anisotropic. Among these compounds, the Ho-borocarbides have been studied extensively because the interplay of superconductivity and antiferromagnetism is the most significant, which is demonstrated by the large values of T_N/T_c of about 0.63. In the system of $Ho_xY_{1-x}Ni_2B_2C$, this ratio can be easily changed by controlling x. In the present work, we attempted to measure the electrical resistance at high pressure and high magnetic field to make clear the interplay of antiferromagnetism and superconductivity under high pressure. The lattice constans are also measured under high pressure.

In this work we selected the sample of $Ho_{0.5}Y_{0.5}Ni_2B_2C$ (x=0.5), in which T_c is 12 K and T_N is 1.7 K, i.e., this material is near the border of the disappearance of antiferromagnetism. The values of T_N/T_c is about 0.14, which is the same as that of $TmNi_2B_2C$. Single crystals are grown by a Ni_2B flux method. The details of the preparation and the characterization were reported elsewhere[3]. High pressure was generated by using piston-cylinder device. The details of the present apparatus were described previously[4]. Electrical resistance was measured using standard four-probe method. The lattice constants are measured by means of X-ray diffraction under high pressure[5].

Fig.1 shows the lattice constants, a/a_0 ,c/c_0 and V/V_0, as a function of pressure up to 15 GPa at room temperature, where a_0,c_0 and V_0 are the values at ambient pressure. The structure is stable up to 15 GPa. The compression curve is found to be approximated by straight lines within experimental errors. The linear compressibilities,$\kappa_i = -i^{-1}(\partial i/\partial P)$ (i= a or c), are 1.3 and 2.1×10^{-3} GPa^{-1} for a and c axis, respectively. The volume compressibility is 4.7×10^{-3} GPa^{-1}, i.e., the bulk modulus is 214 GPa, which is a little bit larger than that of x=1 ($HoNi_2B_2C$), 192 GPa[6]. Fig.2 shows the electrical resistivity $\rho(T)$ under high pressure. $\rho(T)$ decreases smoothly with decreasing temperature followed by a sudden decrease at T_c. It is found

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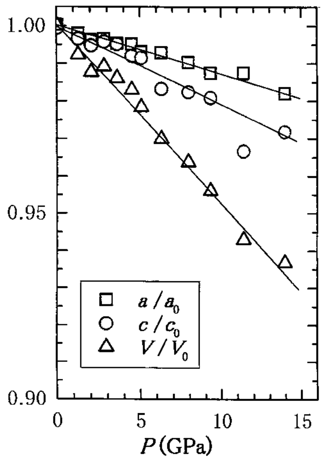

Fig. 1. a/a_0 ,c/c_0 and V/V_0 of $Ho_{0.5}Y_{0.5}Ni_2B_2C$ at 4.2 K as a function of pressure

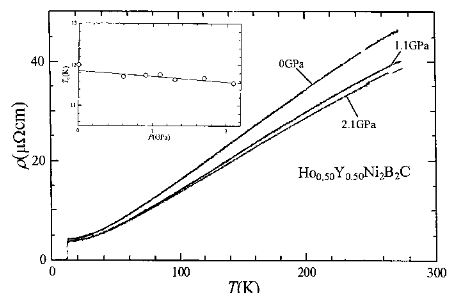

Fig. 2. Electrical resistivity $\rho(T)$ of $Ho_{0.5}Y_{0.5}Ni_2B_2C$ under high pressure. T_c is shown in the inset as a function of pressure.

that T_c decreases with increasing pressure:the pressure dependence is shown in the inset of Fig.2. The pressure coefficient is -0.14 K/GPa, which is smaller than those of x=1 and $TmNi_2B_2C$[7,8].

Fig.3 shows the upper critical fields H_{c2} of x=0.5 as a function of pressure. H_{c2} is found to decrease almost linearly with increasing pressure having a pressure coefficient of $(1/H_{c2})(\partial H_{c2}/\partial P)$= -0.14 GPa^{-1}, which is larger than that of YNi_2B_2C, -0.038 GPa^{-1}, but smaller than that of $HoNi_2B_2C$, -0.70 GPa^{-1}[9,10].

Here we compare the present results briefly with those of $TmNi_2B_2C$ using Grüneisen parameters Γ because T_N/T_c of x= 0.5 is nearly the same as that of $TmNi_2B_2C$, 0.14. Γ is defined as $\Gamma = -(\partial \ln E/\partial \ln V)$, where E is the characteristic energy. The values of Γ for T_c are estimated by using the bulk modulus obtained here to be, -3 and -19 for x=0.5 and $TmNi_2B_2C$, respectively. The detailed reason for this difference is not clear at present, but it should be noted that the coefficient of T^2 term in $\rho(T)$ of $TmNi_2B_2C$ above T_c is 3 times larger than that of x=0.5. This fact implies that the effect of spin fluctuation is more significant

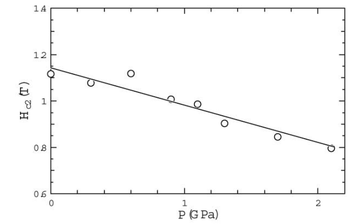

Fig. 3. The upper critical fields H_{c2} of $Ho_{0.5}Y_{0.5}Ni_2B_2C$ at 4.2 K as a function of pressure.

in $TmNi_2B_2C$ than in x=0.5 and this may give rise to a large value of Γ. Furthermore we also estimate Γ for H_{c2}. The values are 31 and 38 for x=0.5 and $TmNi_2B_2C$, respectively. These are comparable each other, which is largely different from the case of T_c. This is due to the fact that the antifrromagnetic ordering temperature of both sample is around 2 K, i.e., we observe H_{c2} near T_N. Near 4.2 K, the antiferromagnetism competes with the superconductivity becomes to give large value of Γ.

References

[1] R. Nagarajan, C. Mazumder, Z. Hossain, S.K. Dhar, K.V. Gopalakrishmann, L.C. Gupta, C. Godart, B.D. Paradalia, R. Vijayaghavan, Phys. Rev. Lett. **72** (1994) 274.

[2] R.J. Cava, H. Takagi, B. Battlogg, H.W. Zandbergen, J.J. Krajewski, W.F. Peck Jr., R.B. van Dover, R.J. Felder, T. Siwgrist, K. Mizuhashi, J.O. Lee, H. Eisaki, S.A. Carter, S. Uchida, Nature **367** (1994) 146.

[3] P.C. Canfield, B.K. Cho, D.C. Johnston, D.K. Finnemore, M.F. Hundley, Physica C **230** (1994) 397.

[4] G. Oomi, T.Kagayama, Physica B **239** (1997) 191.

[5] T. Kagayama, G.Oomi,J.Magn.Magn.Mater., **140-144** (1995) 1227.

[6] G. Oomi, I. Minamitake, M. Ohashi, T. Eto, B.K. Cho, P.C. Canfield, High Pressure Research, **22** (2002) 195.

[7] Y. Uwatoko, G. Oomi, P.C. Canfield, B.K. Cho, Physica B **216** (1996) 329.

[8] G. Oomi, N. Matsuda, F. Honda, T. Kagayama, K. Honda B.K. Cho, Physica B **259-261** (1999) 601.

[9] G. Oomi, H. Takeya, K. Kadowaki, Rev. High Pressure Sci. Technol. **7** (1998) 592.

[10] G. Oomi, T. Kagayama, H. Mitamura, T. Goto, K. Honda B.K. Cho, Physica B **294-295** (2001) 229.