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The Magnetic Properties of Rapidly Quenched Yttrium-Palladium-Borocarbides Ribbon

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We have studied the superconductivity of rapidly quenched YPd_2B_2C ribbons. The superconductivity in bulk YPd_2B_2C is completely suppressed by annealing as-cast ingots at higher temperatures, suggesting that the superconducting phase is metastable. The rapidly quenched sample, in the as-quenched state, shows the superconducting transition temperature of about 21 K. From our magnetic data, the value for the upper critical field H_{c2} (0) is estimated to be 10 T. The critical current density and the expected specific heat discontinuity ($\Delta C/\gamma T_c$) were obtained to be about 10^8 A/m^2 at 10 Oe and 1.55, respectively.

1. Introduction

The discovery of a new family of intermetallic superconductors [1, 2, 3] in early 1994 has created a new path for novel superconductors. This new class of superconductors are borocarbides with characteristic consitutent elements yttrium (or rare earth), nickel, palladium, boron and carbon. Though many studies have been reported on borocarbides [4, 5] almost none of these studies consider the palladium-based system, despite the highest T_c value reported for this system. The superconductivity in the palladium-based borocarbides is associated with a metastable phase which is not efficiently fabricated by conventional synthesizing methods like arc-melting. By rapid-quenching from the melt it is possible to override the kinetics of phase separation and hence obtain at least a homogeneous, if not single phase material. One of the authors already reported superconductivity of rapidly quenched melt-spun YNi_2B_2C ribbon sample [6]. We recognize two main reasons for studying this new class of superconductors made by rapid-quenching method. One is the obvious advantage with a direct processing into ribbons which are more useful for applications. The other is the possibility to optimize the making environments and identify the appropriate microstructure for obtaning the best superconducting properties. We have undertaken an extensive superconductivity search study in Y-Pd-B-C and Y-Ni-B-C systems of various compositions using the rapid quenching technique. In this study, we present our experimental results dealing with YPd_2B_2C systems using the rapid quenching technique.

2. Experimental Procedure

Samples of nominal composition YPd_2B_2C were prepared by arc-melting with pure Y, Pd and coarse powerders of B and C. Samples of 3 g weight were arc-melted under flowing Ar gas on a water cooled copper hearth. The individual ingot samples have been remelted five times, flipping them each time for homogenization. To obtained the rapidly quenched materials, both splat cooling and melt spinning techniques have been used. The ribbons were melt-spun on a Cu wheel rotating at a linear velocity of 40 m/sec in Ar atmosphere with 6×10^{-5} vacuum. The splat-quenched samples were obtained in an arc-melter with a copper rod impinging at a hammer blow on a small droplet of the molten sample on the copper hearth. The resistance was determined by the standard four-lead method, the temperature and field dependencies of the DC magnetization were measured in a SQUID magnetometer. The annealing was performed in a thermogravimetry instrument (TGS) in an argon atmosphere. The structure of samples were measured by XRD with Cu Kα target at room temperature.

3. Results and Discussion

DC magnetic susceptibility measurements were carried out as a function of temperature. Fig. 1 shows the magnetic susceptibility of the YPd_2B_2C as-cast ingot measured at 10 G as a function of temperature. The as-cast ingot is found to be paramagnetic. Fig. 2 show the magnetic susceptibility measured at 10 G, both in zero field cooled (ZFC) and field cooled (FC) conditions for the melt-spun YPd_2B_2C ribbon sample. The rapidly quenched YPd_2B_2C sample shows the superconducting transition temperature of around 21 K. This is probably because superconductivity in the Pd-based borocarbides is associated with a metastable phase for which conventional synthesizing methods

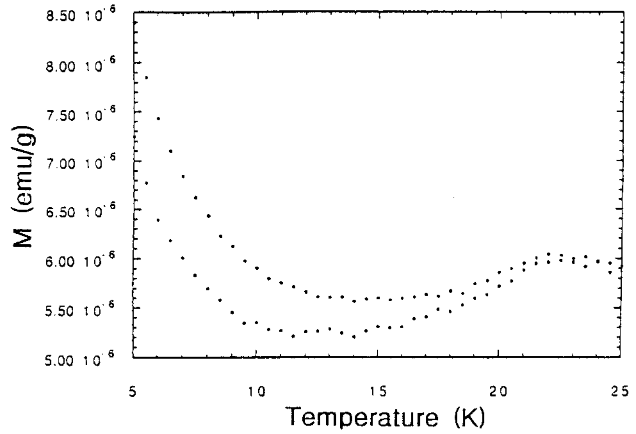

Fig. 1. Magnetic suscetibility of the YPd_2B_2C as-cast ingot measured at 10 G as a function of temperature.

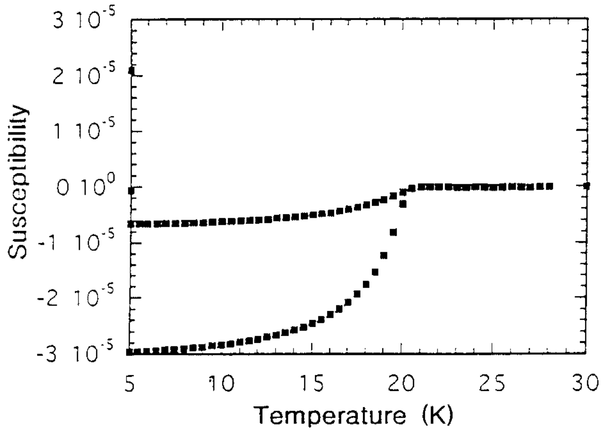

Fig. 2. Magnetic susceptibility of the melt-spun YPd_2B_2C ribbon measured at 10 G as a function of temperature both in zero field cooled (ZFC) and field cooled (FC) conditions.

like arc-melting will not be efficient and yield multiphase compounds with only a minor superconducting fraction, if at all. The existence of hysteresis for zero field cooling and field cooling indicates that these rapidly quenched materials are the type Ⅱ superconductor. The zero field cooled diamagnetic susceptibility value at 5 K of melt-spun ribbon sample equal to about 9 % of that expected for perfect diamagnetism. Field cooled diamagnetic susceptibility of melt-spun ribbon sample display Meissner effect of about 2 % of that of perfect superconductor. All the magnetizations are deduced based on the theoretical densities without the demagnetization corrections. The ratio of Meissner signal to the diamagnetic shielding signal of the ribbon sample at 5 K is about 0.2. In Fig. 3 the temperature dependence of the electrical resistivity is shown for the melt -spun YPd_2B_2C sample. As seen in the figure, the superconducting transition width of about 2 K for an 80 % drop in the resistivity is observed for the rapidly quenched state with the T_c onset temperature of 21.5 K. Fig. 4 shows the magnetization loop of melt-spun YPd_2B_2C ribbon sample at 5 K. The low critical field $H_{c1}(T)$ and upper critical field $H_{c2}(T)$ of YPd_2B_2C

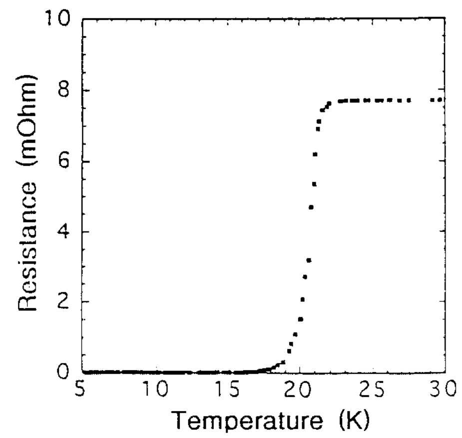

Fig. 3. Temperature dependence of the electrical resistivity for the melt-spun YPd_2B_2C ribbon.

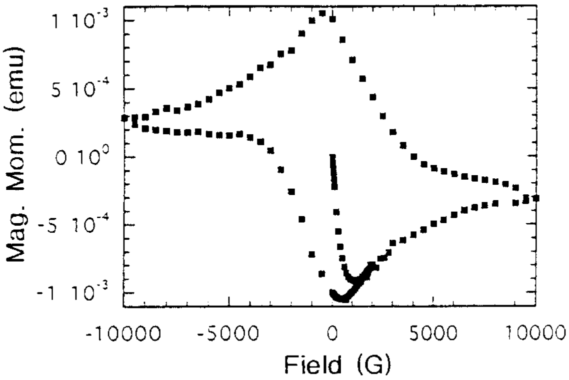

Fig. 4. Magnetization loop of melt-spun YPd_2B_2C ribbon at 5 K.

ribbon sample were measured using the values of magnetic susceptibility, x. $H_{c1}(T)$ is the field at which $M(H, T)$ deviates from linearity and we estimate it to be 90 G at 5 K. We have determined the $H_{c2}(0)$ from the magnetization versus temperature measurements made at different fields by using the Werthamer-Helfand-Hohenberg relation :

$$H_{c2}(0) = -0.69\ [\partial H_{c2}/\partial T]_{T_c}\ T_c \qquad (1)$$

Fig. 5 shows the field dependence of the temperature for the onset of diamagnetism, T_{on} for the melt-spun YPd_2B_2C ribbon sample. We obtained $H_{c2}(0) = 10$ T from the fit to the temperature dependence of T_{onset}. In addition, we estimate the coherence length, $\xi\ (0)$ of melt-spun YPd_2B_2C ribbon using well known relationship,

$$H_{c2}(0) = \phi_0/2\pi\ \xi^2(0). \qquad (2)$$

We obtained the coherence length of $\xi(0) = 57$ Å. The Ginzberg-Landau constant (K) and penetration depth (λ) estimate to be $K = 45$ and $\lambda = 834$ Å, respectively. Furthermore, we have calculated the value of critical current density of melt-

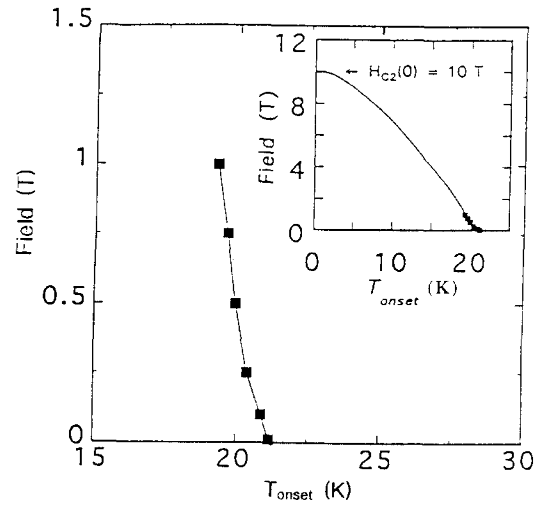

Fig. 5. The field dependence of the temperature for the onset of diamagnetism for the melt-spun YPd_2B_2C. The solid line through the data points and extended to lower temperatures in the insert shows the $H_{c2}(T)$ curve obtained from the WHH model.

spun YPd_2B_2C alloy via the critical state model with the average sample thickness of 40 m. The value was about 10^8 A/m^2. Using the slope of the upper critical field,

$$\Delta C/T_c = [1/8\pi K^2(\partial H_{c2}/\partial T)^2]T_c \quad (3)$$

the specific heat jump ($\Delta C/T_c$) was estimated from the phenomenological Ginzberg-Landau theory. The Sommerfield constant γ was also calculated. The values of $\Delta C/T_c$ and γ are found to be 9.6 mJ/mole K^2 and 6.2 mJ/mole K^2, respectively. From these values, we estimate the normalized specific discontinuity, $\Delta C/\gamma T_c$ and it is 1.55. This value is higher than that of 1.43, the BCS value for the weak-coupling limit. It may be pointed out that more strong-coupling effects are operative in this melt-spun YPd_2B_2C ribbon borocarbides. All the relevant superconductor parameters are listed in Table I for rapidly quenched melt-spun YPd_2B_2C ribbon.

Table I. The values of the lower critical field $H_{c1}(0)$, upper critical field $H_{c2}(0)$, peneatration depth λ, coherence length ξ, Ginzburg-Landau parameter K, the critical current density and normalized specific discontinuity ($\Delta C/\gamma T_c$) for the melt-spun YPd_2B_2C ribbon.

$H_{c1}(0)$	90 (Oe)
$H_{c2}(0)$	10 (T)
peneatration depth λ	834 Å
coherence length ξ	57 Å
Ginzburg-Landau parameter K	45
critical current density	~ 10^8 A/m^2
normalized specific discontinuity ($\Delta C/T_c$)	1.55

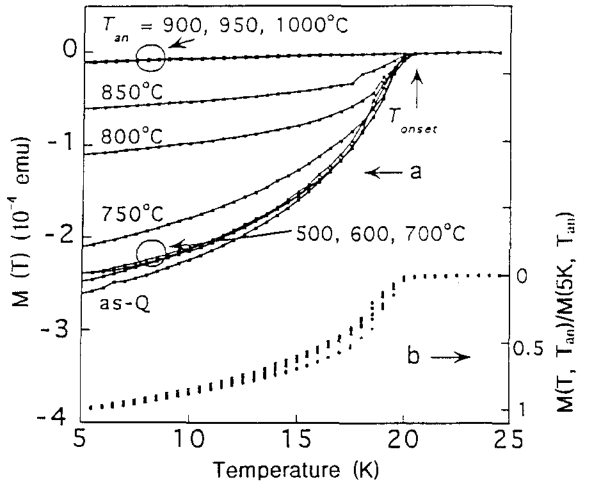

Fig. 6. (a) Temperature dependence of the diamagnetic state of splat-quenched YPd_2B_2C measured in 10 G field from the zero field cooled state of the melt-spun sample, and after each annealing. (b) The diamagnetic response, $M(T, T_{an})/M(5\ K, T_{an})$, now normalized to its value at 5 K for the various annealed states.

We deduce the loss of superconducting fraction on annealing the melt-spun YPd_2B_2C sample from the measured magnetization at 5 K in the zero-field cooled state. The full set of zero-field cooled curves is presented in Fig. 6. Annealing up to 700 ℃ did not significantly influence the temperature dependence of the magnetization. Above 750 ℃, the superconducting fraction begins to decrease and totally disappears on annealing at 900 ℃. When the magnetization data for samples annealed up to 850 ℃ are normalized with respect to the value at 5 K, they essentially collapse into a universal curve. Fig. 6 indicating that the superconducting phase has the same transition temperature during the various annealing states. It is also suggested that the nature of diamagnetism is not affected, and it is only the volume fraction of the superconductivity that is reduced by the annealing.

4. Conclusion

Melt-spun YPd_2B_2C alloy exhibits superconductivity with T_c as high as 21 K, although superconductivity was not observed in bulk state. We show that superconductivity in rapidly quenched melt-spun YPd_2B_2C is related to a metastable phase. The intrinsic superconducting parameters, the upper critical field H_{c2} and critical current density are estimated to be 10 T and about 10^8 A/m^2, respectively, for the melt-spun YPd_2B_2C ribbon. Our results show that this new class of superconductors made by rapid quenching method is obvious advantage with a direct processing into ribbon which are more useful for applications.

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References

[1] R. J. Cava, H. Takiki, B. Batlogg, H. W. Zandbergen, W. F. Peck, Jr., J. J. Krajewski, R. J. Felder, T. Siegrist, J. O. Lee, H. Eisaki, S. A. Karter and S. Uchida, Nature **367**, 146 (1994)

[2] R. J. Cava H. Takiki, H. W. Zandbergen, J. J. Krajewski, W. F. Peck, Jr., R. B. van Dover, R. J. Felder, T. Siegrist, K. Mizuhashi, J. O. Lee, H. Eisaki, S. A. Karter and S. Uchida, Nature **367**, 252 (1994)

[3] R. Nagarajan, C. Mazumdar, Z. Hussain, S. K. Dhar, K. V. Gopalakrishinan, L. C. Gupta, C. Godart, B. D. Padalia, and R. Vijayaraghavan, Phys. Rev. Lett, **72(2)**, 274 (1994)

[4] T. Siegrist, H. W. Zandbergen, R. J. Cava, J. J. Krajewski and W. F. Peck, Jr., Nature **367**, 254 (1994)

[5] Y. Y. Sun, I. Rusakova, R. L. Meng, Y. Cao, P. Gautier-Picard and C. W. Chu, Physica C, **230**, 435, (1994)

[6] V. Strom, K. S. Kim, A. M. Grishin and K. V. Rao, Physica C, **235**, 2537 (1994)