Critical current in YNi_2B_2C and $HoNi_2B_2C$ thin films

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Abstract

Measurements of the critical current densities of epitaxial thin films of the non-magnetic borocarbide compound YNi_2B_2C and the magnetic $HoNi_2B_2C$ have been performed under varying conditions of temperature and applied magnetic field. The critical current is seen to vary in a highly anisotropic manner depending on whether the field is applied within the plane of the borocarbide unit cell or perpendicular to it. At the lowest measured temperature (2 K), the critical current density in zero field exceeds 2.5 $MAcm^{-2}$ in YNi_2B_2C and 1.4 $MAcm^{-2}$ in $HoNi_2B_2C$, but these values are rapidly suppressed under application of a magnetic field.

Key words: borocarbides; thin films; critical current; anisotropy

1. Introduction

The intermetallic series of rare-earth nickel borocarbides, RNi_2B_2C, is of interest due to the existence amongst its members of materials exhibiting both superconductivity and magnetic ordering, in several cases combined within the same compound. YNi_2B_2C (T_c = 15.5 K) is one example that is purely superconducting, while $HoNi_2B_2C$ exhibits a complex interplay between magnetism and superconductivity with T_N = 8.5 K, $T_c \approx 8$ K, and further metamagnetic transitions at 6.3 K and 5 K [1]. High-quality single-crystal samples of these materials have been available now for some time, although to date no complete analysis of the full angular dependence of the anisotropic characteristics has been presented. In contrast, although attempts have been made to prepare thin films of similar quality by techniques including sputtering [2,3] and pulsed laser deposition [4,5], until now it has only proved possible to obtain *c*-axis oriented fibre-textured samples. Recently, we reported [6] on the successful preparation of epitaxial films of YNi_2B_2C in a technique that has now been extended to cover other members of the series.

2. Experimental

The films investigated here were prepared by pulsed laser deposition onto MgO (100) single-crystal substrates as described in [6]. The deposition took place in an ultra-high vacuum environment (base pressure $< 10^{-9}$ mbar) from polycrystalline stoichiometric targets prepared by arc melting of the constituent elements. The deposition temperature of the YNi_2B_2C films was 750°C; for $HoNi_2B_2C$, a slightly higher deposition temperature of 800°C was found to be optimal. Under these conditions, a predominantly biaxial texture of the grown films was obtained with a full width at half maximum around 2.5° both in and out-of-plane.

Representative samples were lithographically patterned and chemically etched to produce a defined bridge structure of nominal dimensions 20 × 800 μm. The actual bridge size was measured using a contact profilometer. Film thickness of the YNi_2B_2C film was 600 nm; of the $HoNi_2B_2C$, 300 nm. Transport measurements were made along this bridge to determine the critical current of the samples, defined in terms of an electric field criterion of 1 μVcm^{-1}.

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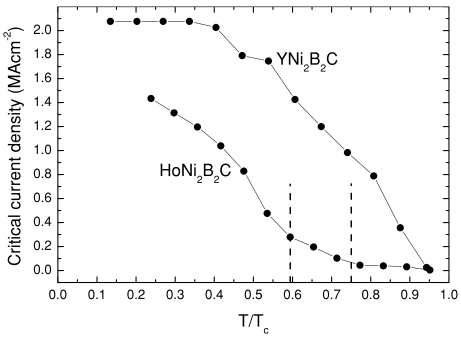

Fig. 1. Variation in the critical current density of an YNi_2B_2C (T_c = 14.9 K) and a $HoNi_2B_2C$ (T_c = 8.4 K) thin film with temperature, in zero field. Metamagnetic transition temperatures of $HoNi_2B_2C$ are indicated by the broken lines.

3. Results and discussion

Figure 1 shows the variation in critical current density, J_c, of YNi_2B_2C and $HoNi_2B_2C$ with temperature, in zero field. Contrary to the data reported in [3], a strictly linear increase in J_c with decreasing temperature is not observed for YNi_2B_2C, but rather a flattening off of the curve towards low temperatures. In spite of this, J_c reaches a value around an order of magnitude higher than those previously reported.

The results for $HoNi_2B_2C$ present a more complex behaviour. Across a temperature range extending from about 0.5 T_c up to T_c, J_c is clearly suppressed. This can be attributed to the existence throughout this temperature range of incommensurate magnetically ordered states, the first of which extends from above T_c to around 0.75 T_c, where a change in the behaviour of the $J_c(T)$ curve is evident. At around 0.6 T_c, the second metamagnetic transition occurs, and the material settles into a commensurate antiferromagnetic state.

Figures 2 and 3 show the variation in J_c under an applied magnetic field at a temperature of 2 K. Measurements were made with the field applied both parallel and perpendicular to the *c*-direction of the borocarbide unit cell. The results reveal a strong anisotropy in the two directions, with J_c being far more rapidly (almost instantaneously) suppressed for a field applied in the *c*-direction. This is indicative of an orientation-dependent pinning, with only weak pinning centres for flux penetrating perpendicular to the plane of the film, and significantly stronger pinning within the plane. The behaviour of the two materials is qualitatively similar, with one noteworthy difference: the suppression of J_c in the $HoNi_2B_2C$ sample with the field applied perpendicular to the *c*-direction is much less abrupt than in all other cases, although the field required for suppression of J_c in the case of $HoNi_2B_2C$ is an order of magnitude lower than that for YNi_2B_2C.

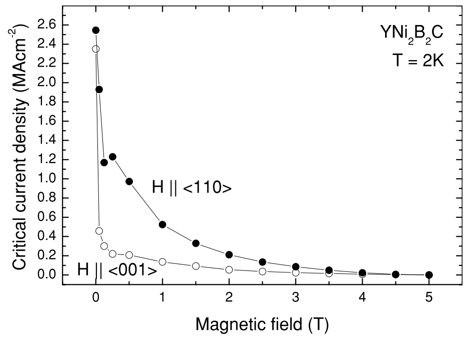

Fig. 2. Anisotropic field dependence of the critical current density at 2K of an YNi_2B_2C thin film measured with the field parallel (open symbols) and perpendicular (closed symbols) to the *c*-axis.

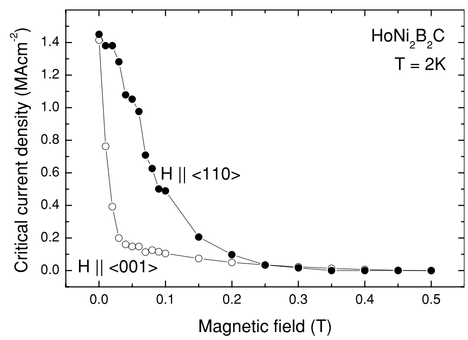

Fig. 3. Anisotropic field dependence of the critical current density at 2K of a $HoNi_2B_2C$ thin film measured with the field parallel (open symbols) and perpendicular (closed symbols) to the *c*-axis.

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