Physica C 470 (2010) S651–S652

Contents lists available at ScienceDirect

Physica C

journal homepage: www.elsevier.com/locate/physc

Consequences of the peculiar intrinsic properties of MgB_2 on its macroscopic current flow

M. Eisterer *, H.W. Weber

Atominstitut, Vienna University of Technology, 1020 Vienna, Austria

A R T I C L E I N F O

Article history:
Accepted 21 October 2009
Available online 27 October 2009

Keywords:
MgB_2
Critical currents
Percolation
Kramer plot
Volume pinning force
Heterogeneous media

A B S T R A C T

The influence of two important features of magnesium diboride on the macroscopic transport properties of polycrystalline MgB_2 is discussed in the framework of a percolation model. While two band superconductivity does not have significant consequences in the field and temperature range of possible power applications, the opposite is true for the anisotropy of the upper critical field. The field dependence of the critical current densities strongly increases and the macroscopic supercurrents disappear well below the apparent upper critical field. The common scaling laws for the field dependence of the volume pinning force are altered and Kramer's plot is no longer linear, although grain boundary pinning dominates in nearly all polycrystalline MgB_2 conductors. In contrast to the conventional superconductors NbTi and Nb_3Sn, a significant critical current anisotropy can be induced by the preparation technique of MgB_2 tapes.

This contribution focuses on the peculiar properties of magnesium diboride, MgB_2, and their influence on the macroscopic current transport: two band superconductivity, the anisotropy of the upper critical field, γ, and the strong effect of impurity scattering. The two types of charge carriers in the σ- and π-bands of the boron orbitals [1] have different energy gaps [2] and their contributions to the superfluid density changes differently when a magnetic field is applied [3]. While both bands contribute approximately equally at zero field, the superconducting charge carriers of the π-band are rapidly suppressed by small magnetic fields. This leads to a field and temperature dependence of the magnetic penetration depth [4–6] and significant alterations of the reversible magnetization [7,6]. However, even at zero field, the contribution of the π-band to the condensation energy [6] and to the critical current is small ($\sim$20%) [8,3], which is a consequence of the small energy gap in the π-band. This contribution is further suppressed by the application of rather small magnetic fields. This means that the theoretically interesting two band nature of superconductivity in MgB_2 has a negligible influence on the current transport under application relevant operation conditions and the material can be modeled as a single (σ-)band superconductor.

The influence of the intrinsic anisotropy on the macroscopic transport properties is much more significant. Polycrystalline materials with randomly oriented grains can be considered as inhomogeneous in magnetic fields [9]. Different grains attain different properties, defined by their orientation with respect to the applied field. This results in a strong field dependence of the critical current density, J_c, even in the case of strong pinning [10]. At the zero resistivity (or irreversibility) field, $B_{\rho=0}$, above which currents are no longer loss free, the remaining superconducting volume of the sample decomposes into disconnected clusters of superconducting grains. $B_{\rho=0}$ is significantly below the apparent upper critical field, B_{c2}, which is defined by grains oriented with their boron planes parallel to the applied field and corresponds to B_{c2}^{ab}. It is approximately 14 T in the clean limit [3]. However, large currents, as required for most applications, can be expected [9] only up to about $B_{c2}^{c} = B_{c2}^{ab}/\gamma$, which is $\sim$ 3 T in clean MgB_2. Fortunately, B_{c2} can be significantly enhanced by the introduction of disorder [11–13], which also reduces the upper critical field anisotropy [14]. Both effects enlarge the maximum operation field. This improvement occurs at the expense of a T_c reduction [15], which competes with the beneficial effects of disorder and even leads to a degradation of the properties at high temperatures. Hence, material optimization for operation at $\sim$20 K is much more difficult than for operation in liquid helium.

The changed field dependence of the critical currents also alters the Kramer plot and shifts the peak of the volume pinning force, $F_p(B)$, to significantly lower fields [16]. The Kramer plot is no longer linear near the irreversibility field and extrapolation of its (pseudo-)linear part near the inflection point (Fig. 1) results in a Kramer field B_k, which is in between B_{c2}^{c} and $B_{\rho=0}$. It is somewhat surprising that the peak in $F_p(b)$ remains nearly at the position for isotropic superconductors, if B is normalized by B_k instead of $B_{\rho=0}$ [17]. (They

* Corresponding author.
E-mail address: eisterer@ati.ac.at (M. Eisterer).

0921-4534/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.physc.2009.10.051

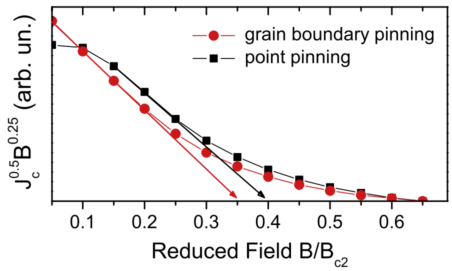

Fig. 1. Determination of the Kramer field B_k.

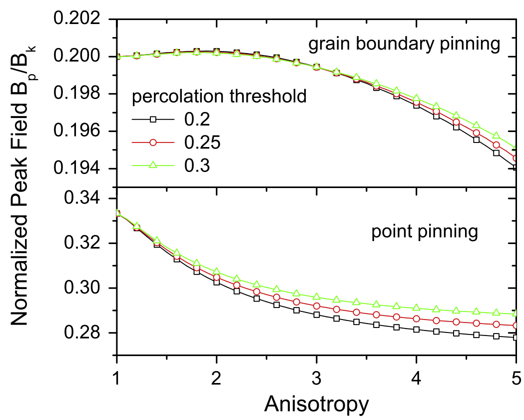

Fig. 2. The peak position B_p does not significantly change with anisotropy, if the field is normalized by the Kramer field.

are equivalent only in isotropic superconductors and the Kramer plot was originally proposed for the determination of $B_{\rho=0}$.) The small influence of γ is demonstrated for grain boundary (upper panel) and point pinning (lower panel) in Fig. 2. Even $F_p(b)$ follows the theoretical isotropic behavior [18] up to $b = B/B_k = 1/2$ (not shown in Fig. 2).

The macroscopic critical current anisotropy observed in some MgB_2 tapes [19,20] is another manifestation of the intrinsic anisotropy. The rolling process induces partial texture, which renders the distribution function of the local J_c dependent on the orientation of the tape with respect to the field [21]. This effect is absent in conventional isotropic superconductors as Nb_3Sn and NbTi. The cuprates on the other hand, need a much higher degree of texture, since large angle grain boundaries strongly reduce the macroscopic current. Hence, all grains must be oriented nearly identically and J_c should be, therefore, equal in all of them.

References

[1] J.M. An, W.E. Pickett, Phys. Rev. Lett. 86 (2001) 4366.
[2] I.I. Mazin, V.P. Antropov, Physica C 385 (2003) 49.
[3] M. Eisterer, Supercond. Sci. Technol. 20 (2007) R47.
[4] A.A. Golubov, A. Brinkman, O.V. Dolgov, J. Kortus, O. Jepsen, Phys. Rev. B 66 (2002) 054524.
[5] M. Angst et al., Phys. Rev. B 70 (2004) 224513.
[6] M. Eisterer, M. Zehetmayer, H.W. Weber, J. Karpinski, Phys. Rev. B 72 (2005) 134525.
[7] T. Klein, L. Lyard, J. Marcus, Z. Holanova, C. Marcenat, Phys. Rev. B 73 (2006) 184513.
[8] E.J. Nicol, J.P. Carbotte, Phys. Rev. B 72 (2005) 014520.
[9] M. Eisterer, C. Krutzler, H.W. Weber, J. Appl. Phys. 98 (2005) 033906.
[10] M. Eisterer, M. Zehetmayer, H.W. Weber, Phys. Rev. Lett. 90 (2003) 247002.
[11] M. Putti et al., Appl. Phys. Lett. 86 (2005) 112503.
[12] M. Eisterer, R. Müller, R. Schöppl, H.W. Weber, S. Soltanian, S.X. Dou, Supercond. Sci. Technol. 20 (2007) 117.
[13] A. Gurevich et al., Supercond. Sci. Technol. 17 (2004) 278.
[14] C. Krutzler, M. Zehetmayer, M. Eisterer, H.W. Weber, N.D. Zhigadlo, J. Karpinski, Phys. Rev. B 75 (2007) 224510.
[15] M. Putti, P. Brotto, M. Monni, E. Galleani, A. Sanna, S. Massidda, Europhys. Lett. 77 (2007) 57005.
[16] M. Eisterer, Phys. Rev. B 77 (2008) 144524.
[17] E. Martínez, P. Mikheenko, M. Martínez-López, A. Millán, A. Bevan, J.S. Abell, Phys. Rev. B 75 (2007) 134515.
[18] D. Dew-Hughes, Philos. Mag. 30 (1974) 293.
[19] P. Lezza, R. Gladyshevskii, V. Abächerli, R. Flükiger, Supercond. Sci. Technol. 19 (2006) 286.
[20] P. Kováč, I. Hušek, E. Dobročka, T. Melišek, W. Haessler, M. Herrmann, Supercond. Sci. Technol. 21 (2008) 015004.
[21] M. Eisterer, W. Häßler, P. Kováč, Phys. Rev. B 80 (2009) 174516.