Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Physica C 388–389 (2003) 159–160
PHYSICA C
www.elsevier.com/locate/physc

Reversible and irreversible properties of superconducting MgB_2

M. Zehetmayer [a], M. Eisterer [a], H.W. Weber [a,*], J. Jun [b], S.M. Kazakov [b], J. Karpinski [b]

[a] Atominstitut der Österreichischen Universitäten, Stadionallee 2, A-1020 Vienna, Austria
[b] Solid State Physics Laboratory, ETH, CH-8093 Zürich, Switzerland

Abstract

We report on measurements of the magnetic moment in superconducting MgB_2 single crystals by SQUID magnetometry. Neutron irradiation is employed to modify the defect structure. We show that both the reversible as well as the irreversible properties are significantly affected by irradiation. The upper critical field and the irreversibility line are strongly enhanced for $H_a \| c$ and the critical current density shows a very pronounced fishtail.

Keywords: MgB_2; Single crystal; Neutron irradiation; Fishtail

1. Introduction

Measurements of the magnetic properties in superconducting MgB_2 single crystals and the assessment of the temperature dependence of most fundamental mixed state parameters by different evaluation methods were reported recently [1]. For $H_a \| c$ (applied field parallel to uniaxial crystal axis) $\mu_0 H_{c2}^c(0) \cong 3.2$ T, $\mu_0 H_{c1}^c(0) \cong 63$ mT, $\mu_0 H_c(0) \cong 0.28$ T, $\lambda_{ab}(0) \cong 82$ nm, $\xi_{ab} \cong 10$ nm and $\kappa^c \cong 4.7$ at T_c were found. The anisotropy $\gamma = H_{c2}^{ab}/H_{c2}^c = \lambda_{ab}/\lambda_c$ shows a significant temperature dependence and varies from about 1 near T_c to almost 4.6 at 0 K. It was concluded that MgB_2 was a rather low—κ type II superconductors in the clean limit with an intermediate electron phonon coupling strength, but very large anisotropy. In this paper we report on new results including effects of neutron irradiation.

2. Neutron irradiation

Neutron irradiation took place in the TRIGA reactor in Vienna [2] to a fast neutron ($E > 0.1$ MeV) fluence of 1×10^{22} m^{-2}. The neutron induced defects in MgB_2 are not very well known so far, but some aspects were discussed recently [3]. In brief, the most prominent reaction is the neutron capture by ^{10}B atoms leading to ^{7}Li and ^{4}He reaction products. The cross section is very large for thermal neutrons and would destroy most of the crystal structure at the surface. Therefore, these neutrons were removed by a cadmium shield. Still, the mean free path of the remaining neutrons is not very long, but the small thickness of the crystal ($a \times b \times c \cong 660 \times 570 \times 21$ μm^3) ensures the presence of neutron induced defects in the whole sample volume.

3. Results and discussion

After neutron irradiation, the crystal was measured again by SQUID magnetometry as described in Ref. [1] and references therein. The transition temperature decreased from about 38 to 34.1 K (by ~10%), and the transition width (~0.7 K) remained small, indicating a rather uniform defect structure.

Fig. 1 shows the upper critical field (H_{c2}^c)—obtained from the $m(T)$ curves—for $H_a \| c$ before and after irradiation. We find a strong enhancement of $\mu_0 H_{c2}$ upon irradiation from 3.2 to 6.8 T at 0 K. Differently from the

* Corresponding author. Tel.: +43-1-58801-14140; fax: +43-1-58801-14199.
E-mail address: weber@ati.ac.at (H.W. Weber).

0921-4534/03/$ - see front matter
doi:10.1016/S0921-4534(02)02705-3

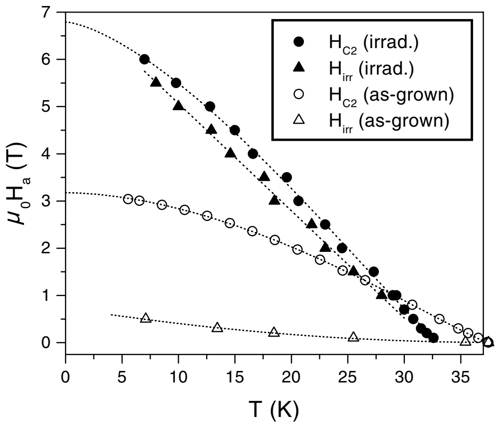

Fig. 1. Upper critical field and irreversibility line of MgB_2 for $H_a\|c$ before (as-grown) and after neutron irradiation (irrad.).

as-grown crystal, we find a positive curvature of $H_{c2}(T)$ near T_c, which could be caused by an inhomogeneous defect distribution. Apart from this, both curves exhibit a typical BCS behavior. Corresponding to H_{c2}, the Ginzburg–Landau coherence length ξ ($\mu_0 H_{c2} = \phi_0/[2\pi\xi^2]$) decreases from 10 to about 7 nm at 0 K.

Fig. 1 also shows the enormous shift of the irreversibility line (obtained from field cooled and zero field cooled $m(T)$ curves) due to the irradiation. While such a behavior is highly desirable for future applications, it makes an evaluation of the magnetic penetration depth from the magnetisation curves—as done in [1]—impossible.

Fig. 2 compares the critical current density (J_c) in the *ab*-planes ($H_a\|c$) before and after neutron irradiation at several temperatures. J_c is calculated from the hysteresis

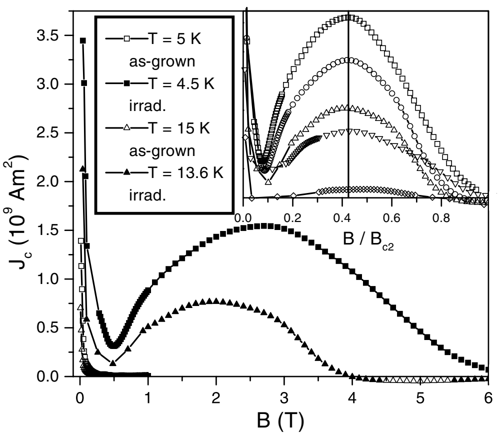

Fig. 2. Critical current density before (as-grown) and after irradiation (irrad.) at the same reduced temperatures (T/T_c). Inset: J_c vs. reduced field (B/B_{c2}) after irradiation at 4.5, 10, 13.6, 20 and 27.2 K.

of $m(H_a)$ in increasing (m_+) and decreasing (m_-) fields ($m_i = [m_+ - m_-]/2$) employing the Bean model [4] for rectangular samples, i.e. $J_c(B) = \{m_i(B)/\Omega\} \times \{4/[b(1 - b/3a)]\}$, B is numerically calculated from $J_c(H_a)$. The maximum in $J_c(T)$ before irradiation is about 1.4×10^9 Am^2. After irradiation, J_c increases by a factor of about 2.5 in the remnant state, almost independently of the temperature.

The fishtail effect (second peak) is a well-known feature in high T_c superconductors, but rather uncommon in low T_c materials [5], and reported here for the first time for MgB_2. It is very pronounced and extends over almost the whole mixed state (see Fig. 2). The responsible mechanism is still under discussion, but it is evident that the defect distribution plays an important role. The fishtail is usually present in the as-grown state of the high T_c's, which is usually highly disordered, and often disappears after neutron irradiation [5], whereas the effect emerges in the MgB_2 single crystal, when defects are introduced. Therefore, investigating the interplay of the neutron dose and the fishtail effect will possibly provide us with new information about this phenomenon. A first interesting result is shown in the inset of Fig. 2, which demonstrates that the temperature dependence of the peak position follows that of the upper critical field. We find that this peak position corresponds approximately to B_{c2} of the as-grown state.

In conclusion, we have shown that neutron irradiation increases both the upper critical field and the irreversibility line in single crystalline MgB_2 for $H_a\|c$ and we have found a very pronounced and wide fishtail after irradiation.

Acknowledgements

We wish to thank F.M. Sauerzopf for useful discussions and H. Hartmann for technical assistance. This work was supported in part by the Austrian Science Foundation (FWF project 14422) and the Swiss National Science Foundation.

References

[1] M. Zehetmayer, M. Eisterer, H.W. Weber, J. Jun, S.M. Kazakov, J. Karpinski, A. Wisniewski, Phys. Rev. B 66 (2002) 052505.
[2] H.W. Weber, H. Böck, E. Unfried, L.R. Greenwood, J. Nucl. Mater. 137 (1986) 236.
[3] M. Eisterer, M. Zehetmayer, S. Tönies, H.W. Weber, M. Kambara, N. Hari Babu, D.A. Cardwell, L.R. Greenwood, Supercond. Sci. Technol. 15 (2002) L9.
[4] C.P. Bean, Phys. Rev. Lett. 8 (1962) 250.
[5] M. Werner, F.M. Sauerzopf, H.W. Weber, A. Wisniewski, Phys. Rev. B 61 (2000) 14795.