Available online at www.sciencedirect.com
SCIENCE DIRECT®
Physica C 408–410 (2004) 662–663
PHYSICA C
www.elsevier.com/locate/physc

Anisotropy in MgB_2 thin film studied by magnetic field dependent complex microwave conductivity

A. Dulčić [a], M. Požek [a,*], D. Paar [a], E.-M. Choi [b], H.-J. Kim [b], W.N. Kang [b], S.-I. Lee [b]

[a] *Department of Physics, Faculty of Science, University of Zagreb, P.O.Box 331, HR-10002 Zagreb, Croatia*
[b] *National Creative Research Initiative Center for Superconductivity and Department of Physics, Pohang University of Science and Technology, Pohang 790-784, South Korea*

Abstract

Field and temperature dependent microwave measurements on high quality MgB_2 thin film have been performed. From the complex microwave conductivity one can identify the mean-field (MF) coherence length deeply in the mixed state, and the Ginzburg–Landau (GL) coherence length at the transition to the normal state. The analysis reveals the temperature independent anisotropy ratio $\xi^{ab}_{\mathrm{MF}}/\xi^{c}_{\mathrm{MF}} \approx 2$, and $\xi^{ab}_{\mathrm{GL}}/\xi^{c}_{\mathrm{GL}} \approx 2.8$. The analysis of depinning frequencies shows collective pinning behavior.

PACS: 74.25.Op; 74.25.Nf; 74.40.+k; 74.78.Db; 74.25.Qt
Keywords: Microwave response; MgB_2 film; Mixed state; Depinning; Fluctuations

---

There is a general agreement that coherence length in the recently discovered binary compound MgB_2 is anisotropic, but a controversy arised on the question whether this anisotropy is temperature dependent or not. Here, we study several aspects of anisotropy in MgB_2 superconductor by the magnetic field and temperature dependent microwave response in high quality MgB_2 thin film.

The thin film of MgB_2 was grown on Al_2O_3 substrate as described earlier [1,2]. The film thickness was 400 nm.

Microwave measurements were carried out in an elliptical cavity resonating in ${}_e\mathrm{TE}_{111}$ mode at 9.3 GHz. The thin film was mounted on a sapphire sample holder and placed in the center of the cavity where the microwave electric field E_ω was maximum. The sample was oriented with *ab*-plane parallel to E_ω. The measured quantities were the *Q*-factor of the cavity loaded with the sample and the resonant frequency f.

From the complex frequency shift $\Delta\tilde{\omega}/\omega = \Delta f/f + \mathrm{i}\Delta(1/2Q)$ one can obtain by inversion the complex conductivity $\tilde{\sigma} = \sigma_1 - \mathrm{i}\sigma_2$ of the film using the cavity perturbation expression [3].

Two approaches for the determination of the upper critical field are illustrated in Fig. 1. The response of the superconductor in the mixed state to an oscillating electric field E_ω is given by an effective complex conductivity [4]:

$$\frac{1}{\tilde{\sigma}_{\mathrm{eff}}} = \frac{1 - \frac{B/B_{c2}}{1-\mathrm{i}(\omega_0/\omega)}}{\left(1 - \frac{B}{B_{c2}}\right)(\sigma_1 - \mathrm{i}\sigma_2) + \frac{B}{B_{c2}}\sigma_n} + \frac{1}{\sigma_n}\,\frac{B/B_{c2}}{1 - \mathrm{i}\frac{\omega_0}{\omega}}.$$

From experimentally determined $\tilde{\sigma}_{\mathrm{eff}}$ one can extract two quantities, B/B_{c2} and ω_0, for every measured point. B/B_{c2} is the volume fraction of the vortex cores in the sample volume, while ω_0 is the depinning frequency.

The linear part of the curves in Fig. 1(a) represents the MF behavior where vortices comprise many Landau levels [5]. The corresponding values of B^{MF}_{c2} are shown by symbols in Fig. 2. As the transition to the normal state is approached, the higher Landau levels are lifted and the

---

[*] Corresponding author.
E-mail address: mpozek@phy.hr (M. Požek).

0921-4534/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.physc.2004.03.101

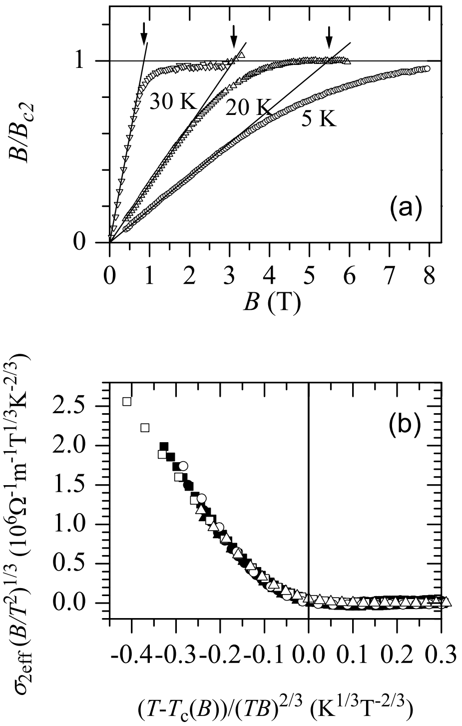

Fig. 1. (a) Variations of the volume fraction of the vortex cores. The lines mark the low field linear segments of the curves wherefrom B_{c2}^{MF} can be determined (indicated by the arrows). (b) The lowest Landau level scaling of the imaginary part of the fluctuation conductivity for six experimental curves: three obtained by field sweeps and three by temperature sweeps.

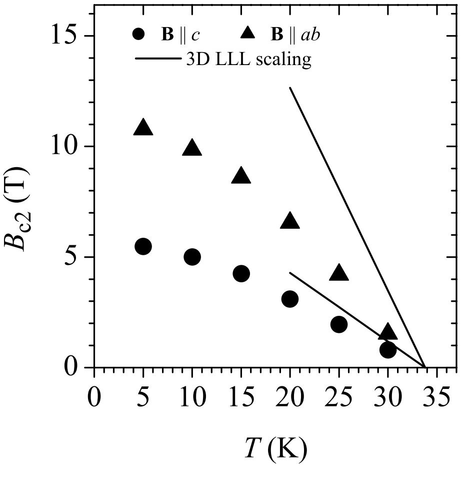

Fig. 2. The upper critical fields determined by various methods, B_{c2}^{MF} (symbols), B_{c2}^{GL} (full lines).

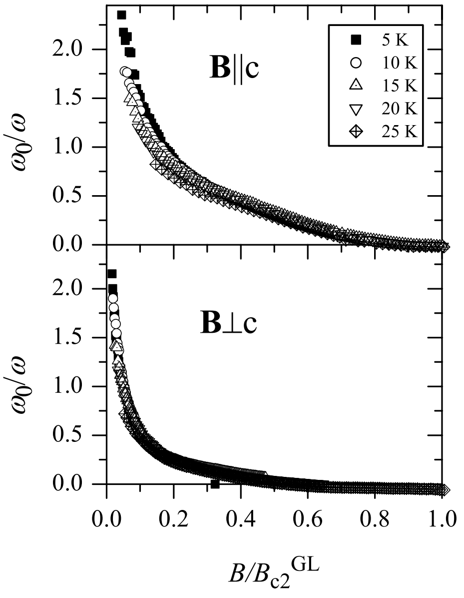

Fig. 3. Field dependences of the depinning frequencies.

curves in Fig. 1(a) become nonlinear. The transition itself is characterized by the fluctuations at the lowest Landau level. Fig. 1(b) shows the scaling law wherefrom the B_{c2}^{GL} lines are deduced (full lines in Fig. 2). In terms of the coherence lengths, we find the temperature independent anisotropy ratios $\xi_{\mathrm{MF}}^{ab}/\xi_{\mathrm{MF}}^{c} \approx 2$, and $\xi_{\mathrm{GL}}^{ab}/\xi_{\mathrm{GL}}^{c} \approx 2.8$.

The depinning frequencies are plotted in Fig. 3 versus B/B_{c2}^{GL}. One observes an almost universal behavior characteristic of collective pinning [6], but with different field dependences along the two directions. One can conclude that the pinning force is stronger for the vortices directed along *c*-axis.

In conclusion, we have identified two types of coherence lengths, the MF coherence length deeply in the superconducting state, and GL coherence length at the transition to the normal state. Both types of coherence lengths exhibit temperature independent anisotropy. The depinning frequency provides evidence of collective pinning.

References

[1] W.N. Kang, H.J. Kim, E.M. Choi, C.U. Jung, S.-I. Lee, Science 292 (2001) 1521, cond-mat/0104266.

[2] H.-J. Kim, W.N. Kang, E.-M. Choi, M.-S. Kim, K.H.P. Kim, S.-I. Lee, Phys. Rev. Lett. 87 (2001) 087002, cond-mat/0105363.

[3] D.-N. Peligrad, B. Nebendahl, M. Mehring, A. Dulčić, M. Požek, D. Paar, Phys. Rev. B 64 (2001) 224504.

[4] A. Dulčić, M. Požek, Physica C 218 (1993) 449.

[5] A. Dulčić, M. Požek, D. Paar, E.-M. Choi, H.-J. Kim, W.N. Kang, S.-I. Lee, Phys. Rev. B 67 (2003) 020507(R).

[6] M. Golosowsky, M. Tsindlekht, D. Davidov, Supercond. Sci. Technol. 9 (1996) 1.