Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Physica C 388–389 (2003) 713–714
PHYSICA C
www.elsevier.com/locate/physc

Effect of variation of facets size on fractional flux vortices at asymmetric grain boundaries in YBCO films

R.G. Mints *, Ilya Papiashvili

School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv 69978, Israel

Abstract

We consider numerically unquantized Josephson vortices at asymmetric grain boundaries in YBCO films. The study is focused on the effect of random variations of facets size on the values of fractional flux carried by these vortices. The grain boundaries are treated as Josephson junctions with a critical current density alternating along the junctions with a typical length-scale of order of the facets size. Numerical simulations demonstrate that the value of the flux of the unquantized vortices varies along the junction depending on the local Josephson properties of the grain boundaries.

Keywords: High-temperature superconductivity; d-wave symmetry; Josephson vortices

1. Introduction

The asymmetric 45° [0 0 1]-tilt grain boundaries in YBCO films exhibit remarkable electromagnetic properties. The dependence of the critical current across grain boundaries on an applied magnetic field has a manifestly non-Fraunhofer behavior, a spontaneous flux is generated at grain boundaries in zero field cooled films [1–3]. These fundamental anomalies arise due to the existence of a dominant $d_{x^2-y^2}$-wave symmetry component of the superconducting order parameter and a facetted structure of grain boundaries in YBCO films, as a result the critical current density $j_c(x)$ alternates along the asymmetric grain boundaries [3–9].

The alternating j_c model was successfully used to consider the anomalous properties of the asymmetric grain boundaries [10–12]. In the case of a periodic $j_c(x)$ the analytical and numerical calculations exhibit two interesting and important features: (a) a spontaneous flux alternating along grain boundaries with an amplitude less than ϕ_0, (b) unquantized vortices with fractional fluxes $\phi_1 \geqslant \phi_0/2$ and $\phi_2 \leqslant \phi_0/2$ related by a complementarity condition $\phi_1 + \phi_2 = \phi_0$. The existence of these vortices and the values of ϕ_1 and ϕ_2 may be affected by an irregularity of the facets sizes.

In this paper we treat numerically the effect of random variations of the facets size l on the unquantized fractional vortices at asymmetric grain boundaries in YBCO films.

2. Numerical simulations

We write now $j_c(x) = \langle j_c \rangle [1 + g(x)]$, where $\langle j_c \rangle$ is the average value of $j_c(x)$ over distances $L \gg l$, the function $g(x)$ characterizes the Josephson properties of grain boundaries. In this study we use a model dependence $g(x) = g_0 \sin[2\pi x / l(x)]$, with this notation the phase difference across grain boundaries satisfies

$$\Lambda^2 \varphi'' - \{1 + g_0 \sin[2\pi x / l(x)]\} \sin \varphi = 0, \qquad (1)$$

where $\Lambda = \sqrt{c\phi_0 / 16\pi^2 \lambda \langle j_c \rangle}$ and λ are the Josephson and London penetration depths, $\Lambda \gg l \gg \lambda$.

First, we use Eq. (1) to treat grain boundaries with smoothly varying size of the facets. In Fig. 1 (curve *a*) is shown the phase $\varphi(x)$ obtained for $l(x)$ linearly increasing from 0.04Λ to 0.14Λ. This graph demonstrates the main effect of smooth variation of $l(x)$ on the

* Corresponding author.
E-mail address: mints@ccsg.tau.ac.il (R.G. Mints).

0921-4534/03/$ - see front matter © 2003 Elsevier Science B.V. All rights reserved.
doi:10.1016/S0921-4534(02)02491-7

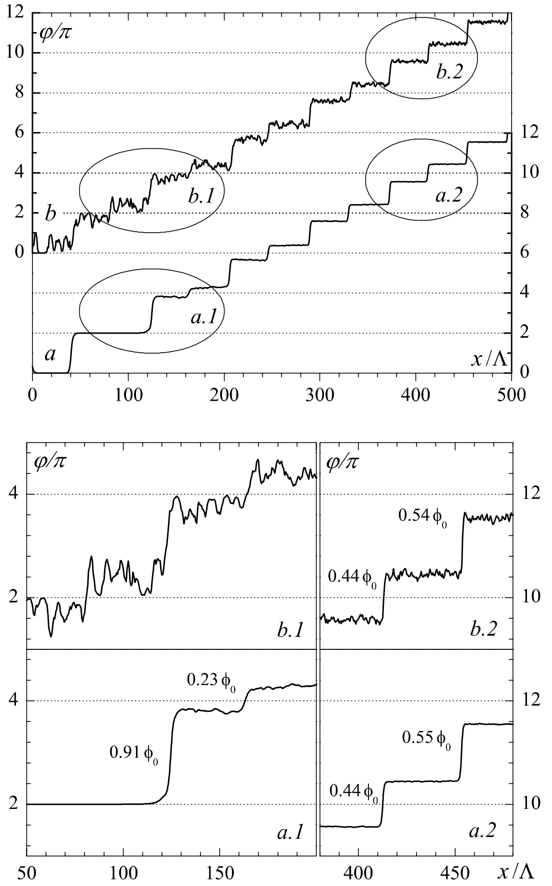

Fig. 1. The upper graph shows the effect of a smooth facets size variation (curves $a, a1, a2$) and an additional random variation of the size of each of the facets (curves $b, b1, b2$).

vortices at asymmetric grain boundaries: (a) the vortices with fractional fluxes may exist only in certain areas of grain boundaries, (b) the fluxes ϕ_1 and ϕ_2 may significantly depend on the vortices positions, (c) the complementarity condition relating ϕ_1 and ϕ_2 may be broken. Indeed, curve a exhibits vortices with fractional fluxes if $x > 100\Lambda$; ϕ_1 decreases from ϕ_0 at $x \approx 100\Lambda$ to $0.5\phi_0$ at $x \approx 500\Lambda$, and ϕ_2 increases from zero at $x \approx 100\Lambda$ to $0.5\phi_0$ at $x \approx 500\Lambda$; the complementarity condition is broken.

Next, we treat the combined effect of smooth and rough variations of the facets sizes on the unquantized fractional flux vortices. The phase $\varphi(x)$ shown in Fig. 1 (curve b) obtained for a random sequence of facets sizes with $\delta l = \sqrt{\langle l^2\rangle - \langle l\rangle^2} = 0.005\Lambda$ superimposed by a linear increase of $l(x)$ from 0.04Λ to 0.14Λ. This graph demonstrates that the random short order variations of $l(x)$ result in a wiggling phase difference $\varphi(x)$ with a wide range of length scales shorter than Λ. This wiggling can effectively mask the unquantized vortices with small fractional flux.

3. Summary

To summarize, we demonstrate numerically the existence of unquantized vortices with a fractional flux depending on the local Josephson properties of a non-uniform asymmetric grain boundary in YBCO films.

Acknowledgements

This research was supported by grant no. 2000011 from the United States—Israel Binational Science Foundation (BSF), Jerusalem, Israel. One of us (RGM) is grateful to H. Hilgenkamp, J.R. Clem, V.G. Kogan, J. Mannhart, and J.R. Kirtley for useful and stimulating discussions.

References

[1] C.A. Copetti et al., Physica C 253 (1995) 63.
[2] H. Hilgenkamp, J. Mannhart, B. Mayer, Phys. Rev. B 53 (1996) 14586.
[3] J. Mannhart et al., Phys. Rev. Lett. 77 (1996) 2782.
[4] M. Sigrist, T.M. Rice, Rev. Mod. Phys. 67 (1995) 503.
[5] D.J. Van Harlingen, Rev. Mod. Phys. 67 (1995) 515.
[6] C.C. Tsuei, J.R. Kirtley, Rev. Mod. Phys. 72 (2000) 969.
[7] C.L. Jia et al., Physica C 196 (1992) 211.
[8] S.J. Rosner, K. Char, G. Zaharchuk, Appl. Phys. Lett. 60 (1992) 1010.
[9] C. Træholt et al., Physica C 230 (1994) 425.
[10] R.G. Mints, V.G. Kogan, Phys. Rev. B 55 (1997) 8682.
[11] R.G. Mints, Phys. Rev. B 57 (1998) 3221.
[12] R.G. Mints, I. Papiashvili, Phys. Rev. B 64 (2001) 134501.