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Search for complex order parameters in grain boundary junctions

W.K. Neils, D.J. Van Harlingen*

Department of Physics and the Frederick Seitz Materials Research Laboratory, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

Abstract

We are measuring the critical current of grain boundary Josephson junctions fabricated from pure and magnetically doped cuprate films to search for the onset of subdominant superconducting phases. Complex order parameters $d_{x^2-y^2} + is$ or $d_{x^2-y^2} + id_{xy}$ are predicted to arise near interfaces and magnetic impurities due to a suppression of the d-wave state by Andreev reflection from the strongly anisotropic order parameter. Simulations indicate that this should significantly alter the variation of the critical current with temperature and magnetic field. © 2000 Published by Elsevier Science B.V. All rights reserved.

Keywords: Grain boundaries; Josephson junctions; Order parameter; YBaCuO patterned

1. Motivation

The d-wave state dominant in the bulk of high-temperature superconductors is readily suppressed at surfaces, interfaces, vortex cores, and near impurities because of its strong magnitude and phase anisotropy [1]. This allows the emergence of localized regions with subdominant symmetries, likely including complex order parameter states that break time-reversal symmetry. These novel phases are of scientific interest, and important for understanding the microscopic pairing mechanism and for electronic device applications of HTSC.

We are searching for the existence of subdominant superconducting phases by measuring the critical current of grain boundary Josephson junctions. These are ideal for studying the modification of the symmetry because they allow directional probing of the surface order parameter. In this paper, we outline the signatures of a complex superconducting order parameter in the variation of the critical current of grain boundary junctions with

temperature and magnetic field, and present preliminary measurements in asymmetric 45°-grain boundary junctions of YBCO.

2. Simulations

The d-wave symmetry of the cuprates is clearly seen in the critical current of asymmetric 45°-grain boundary junctions in which the lobe of the bulk d-wave order parameter in one electrode faces the node in the other. A complex variation with magnetic field is observed due to interference of the Josephson supercurrent between facets of the interface that probe oppositely signed lobes [2]. This provides a sensitive geometry to test for the onset of secondary phases in the bulk of the superconductors or near the interface. To demonstrate this, we calculated the critical current of asymmetric 45° grain boundary junctions as a function of temperature and field. We assume directional tunneling with critical current proportional to the order parameters normal to the interface in the two electrodes, and take account of the phase coherence across the junction in the short junction limit. We consider a faceted boundary, randomly-varying from a straight line. In Fig. 1, we compare the critical

*Corresponding author. Fax: + 1-217-244-8544.

E-mail address: dvh@uiuc.edu (D.J. Van Harlingen)

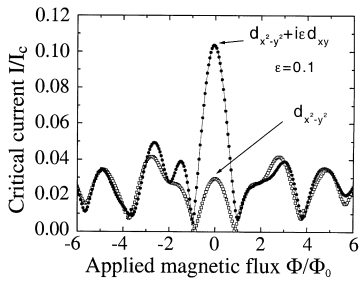


Fig. 1. Calculated critical current modulation of a grain boundary junction for d and $d + id'$ symmetries.

current versus field for $d_{x^2-y^2}$ symmetry and a complex mixture state $d_{x^2-y^2} + id_{xy}$ incorporating a 10% d_{xy} component. The onset of an order parameter component in the node causes a significant increase in the critical current at zero-field, and more subtle variations in the diffraction pattern for finite fields. Similar results are obtained for a $d_{x^2-y^2} + is$ state. The zero-field critical current exhibits a sharp increase at the onset temperature of the secondary phase as the node in the order parameter is removed, even for very small complex mixture fractions.

3. Results

The magnetic field diffraction pattern of a YBCO asymmetric 45° grain boundary junction, fabricated by pulsed laser ablation, is shown in Fig. 2. Fine structure in the modulation is characteristic of $d_{x^2-y^2}$ symmetry, but we find no significant modification in the shape of the pattern over the temperature range from $T_c = 85$ K down to 1.5 K, indicating that the symmetry remains unchanged. The zero-field supercurrent is observed to increase smoothly with decreasing temperature, showing no features that we would identify as the onset of a secondary superconducting phase. Since a spontaneous

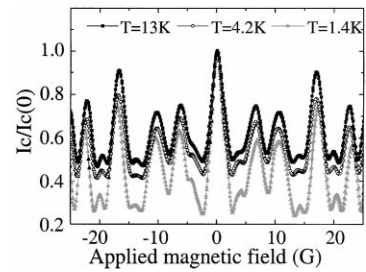


Fig. 2. Measured critical current modulation versus temperature for a YBCO asymmetric 45° -grain boundary junction.

splitting of the zero bias conductance, suggestive of a complex order parameter, is observed below 10 K in SIN junctions [3], but not in grain boundary junctions [4], we are now considering the effect of the high transmission of the grain boundary junction [5]. We are also extending the measurements to lower temperatures (20 mK) and testing magnetically doped cuprates in which a bulk complex order parameter has been suggested by thermal conductivity measurements [6].

Acknowledgements

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