Evaluating the critical current magnitude and distribution width of tridimensional Josephson junction arrays

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Abstract

In this contribution we present a simple and effective procedure to determine the average critical current of a tridimensional disordered Josephson junction array (3D-DJJA). Using a contactless configuration we evaluate the average critical current and the typical width of the distribution through the analysis of the isothermal susceptibility response to the excitation field amplitude, $\chi_{AC}(h)$. A 3D-DJJA fabricated from granular Nb is used to illustrate the method.

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The low-frequency magnetic response of Nb-AlO$_x$-Nb Josephson junction arrays (JJA) has been investigated by Araujo-Moreira and coworkers\cite{1,2}, through the temperature ($T$) and excitation field ($h$) dependence of the AC magnetic susceptibility, $\chi_{AC}$. Based on simulations of a single-plaquette model, they have successfully explained the dynamic reentrance presented by $\chi_{AC}(T)$ for certain values of $h$, as well as the isothermal susceptibility $\chi_{AC}(h)$. Simulated magnetization versus applied field curves for the single-plaquette model, predict that a certain class of arrays would exhibit, upon excitation by a field, a remanent moment in a limited interval of temperatures, depending on the critical current, $I_c$, and other modeling parameters of the junctions. As a matter of fact, the McCumber parameter, $\beta_L$ is the
actual key feature controlling the appearance of a magnetic remanence, which is predicted to exist for $\beta_L << 1$. 

It has been demonstrated recently\textsuperscript{3} that tridimensional disorderd Josephson junction arrays (3D-DJJA) can be produced in a controlled manner. Arrays were fabricated from granular superconductors, using either conventional (LTS) or high-temperature (HTS) powder. These specimens have proved to exhibit\textsuperscript{3-5} all relevant signatures of a JJA, including the typical Fraunhofer dependence of the critical current with the applied magnetic field, the Wohlleben effect (WE), and the magnetic remanence anticipated by numerical simulations.

On the other hand, these 3D-DJJAs can also be envisaged as especially assembled specimens of granular superconductors and, conceivably, their intragranular transport and magnetic properties could be treated by the commonly employed approaches based on critical state models\textsuperscript{6-10}. Evidently this would not be the case for the intergrain response, since it is originated by weak links arranged in a 3D-DJJA, whose behavior does not obey critical state models. In this contribution we present results of a systematic study of the isothermal susceptibility response to the excitation field amplitude, $\chi_{AC}(h)$, of a 3D-DJJA fabricated from granular Nb.

Samples were fabricated following a standard procedure described elsewhere\textsuperscript{3}. In short, niobium powder is separated according to grain size, using a set of special sieves, with mesh gauges ranging from 38 to 44 $\mu$m. The powder is then uniaxially pressed in a mold to form a cylindrical pellet of 2.5 mm radius by 2 mm height. This pellet is a tridimensional disordered JJA (3D-DJJA) in which the junctions are weakly-coupled grains, i.e., weak-links formed by a sandwich between Nb grains and a Nb-oxide layer originally present on the grain surface.

Measurements of $\chi_{AC}(h)$ were carried out using the AC-module of a Quantum Design SQUID magnetometer, for an excitation frequency of 100 Hz, at temperatures ranging from $T = 2$ K up to $T_c = 8.9$ K. In this paper we focus on the upper part of the temperature window, closer to $T_c$. Fig.1 shows the real ($\chi'$) and imaginary ($\chi''$) parts of $\chi_{AC}(h)$ for some values of $T$. The field at which $\chi''$ peaks, $h_p$, is an indirect measure of the average critical current density of the intergranular matrix\textsuperscript{6-8}, i.e., $< J_c >$ of the array. For a
sample of cylindrical shape of radius $a$, $h_p = a < J_c >$. The exponential critical state model (ECSM) was used to simultaneously fit $\chi'$ and $\chi''$, from which the temperature dependence of $< J_c >$, its typical distribution width, $p(T)$, and the granular fraction of the sample, $f_g(T)$, are determined. It is worth mentioning that, as expected, the ECSM fits well the experimental data above $h_p$, but fails to fit the whole curve, as below $h_p$ the JJA behavior substitutes that of a critical state. Consistently, up to $h = h_p$ the array gives a positive (WE) contribution to the real part of $\chi_{AC}$, so that $\chi' > -1$ and the sample is not perfectly diamagnetic. On the other hand, the dispersive activity of the vortices differs from that of an ordinary granular sample, being either lower, when the flux lines are pinned, or higher, when they are temporarily free to relocate, depending on the value of $h$.

The main curve in Fig.2 shows the average $J_c(T)$, whereas the insets depict $p(T)$ (lower left) and $f_g(T)$ (upper right). The line connecting the experimental points for the average $J_c(T)$ is a fit of the form $J_c(T) = J_{c0}(1 - T/T_c)^{2.38}$, as introduced by Wright and coworkers for a matrix formed by grains linked by Josephson couplings. Here, $T_c$ is the critical temperature of the array, which was obtained from the fitting as been 8.05 K, in excellent agreement with the value of $T^*$ determined by independent means in Ref. for the same sample. Not surprisingly, the numbers obtained for the average critical current density of the 3D-DJJA are comparable to those reported previously for the intergranular critical current of a melt-textured YBa$_2$Cu$_3$O$_{7-\delta}$ sample, an ordered 2D-JJA of Nb-AlO$_x$-Nb and a 3D-DJJA of YBCO, among others. As could be anticipated, the critical current distribution of the array broadens as $T$ approaches $T_c$, as can be inferred by the continuous decrease of its typical dispersion, $p(T)$. A corresponding decrease on the granular fraction, measured by the volume fraction of superconducting grains to the normal matrix, $f_g$, occurs as the superconducting properties degrade with increasing $T$, weakening at the grain boundaries and, from there, towards the center of the grains.

To properly consider the significance of measuring $< J_c >$ of a 3D-DJJA using a contactless configuration, one should bear in mind that performing conventional current-voltage measurements in the disordered array studied here, would be infeasible.
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REFERENCES

1. F. M. Araujo-Moreira, P. Barbara, A. B. Cawthorne and C. J. Lobb, Phys. Rev. Lett. 78 (1997) 4625
2. P. Barbara F. M. Araujo-Moreira, A. B. Cawthorne and C. J. Lobb, Phys. Rev. B 60 (1999) 7489
3. W. A. C. Passos, P. N. Lisboa-Filho, E. C. Pereira, R. de Andrade Jr., F. M. Araujo-Moreira and W. A. Ortiz, "Experimental realization of tridimensional Josephson junction arrays", submitted to Phys. Rev. Lett.
4. W. A. C. Passos, F. M. Araujo-Moreira and W. A. Ortiz, J. Appl. Phys. 87 (2000) 5555
5. W. A. C. Passos, P. N. Lisboa-Filho and W. A. Ortiz, accepted, Physica C cond-mat [http://arXiv.org/abs/cond-mat/0002280]
6. F. M. Araujo-Moreira, J. S. de Carvalho Jr., W. A. Ortiz and O. F. de Lima, Physica C 235-240 (1994) 3205
7. F. M. Araujo-Moreira and W. A. Ortiz, J. Appl. Phys. 80 (1996) 3390
8. F. M. Araujo-Moreira, W. A. Ortiz and O. F. de Lima, Physica C 311 (1999) 98
9. W. A. Fiet, M. R. Beasley, J. Silcox and W. W. Webb, Phys. Rev. 136 (1964) A335
10. D. X. Chen, A. Sanchez and J. S. Munoz, J. Appl. Phys. 67 (1990) 3430
11. A. C. Wright, K. Zhang and A. Erbil, Phys. Rev. B 44 (1991) 863
12. A. C. Wright, T. K. Xia and A. Erbil, Phys. Rev. B 45 (1992) 5607
13. W. A. C. Passos, P. N. Lisboa-Filho and W. A. Ortiz, paper 2Q-20, this volume
FIGURES

Fig. 1. Real ($\chi'$) and imaginary ($\chi''$) parts of $\chi_{AC}(h)$ for three values of $T$. The field at which $\chi''$ peaks is an indirect measure of the average critical current density of the array.

Fig. 2. Main curve: average critical current of the 3D-DJJA; lower left: dispersion of critical current distribution, $p(T)$; upper right: granular fraction, $f_g(T)$. Line connecting $J_c(T)$ points is a fit of the expression $J_c(T) = J_{c0}(1 - T/T_c)^{2.38}$. Lines on insets are only guides to the eye.
W. A. C. Passos et al. Fig 2

\[ J_c (A/cm^2) \]

\[ T (K) \]

\[ f_c (\%) \]

\[ T (K) \]

\[ p (10^{-2}) \]

\[ T (K) \]