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Critical current density measurements in high-field superconductors described using wave-particle duality

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Abstract

We report extensive measurements of the critical current density J_C as a function of magnetic field B, field angle θ, temperature T, and applied strain ε_{app} for a (RE)BCO coated conductor with nanorod artificial pinning centres (APCs), together with the effective upper critical field $B_{c2}^{*\rho}(\theta, T, \varepsilon_{app})$ measured resistively down to ~ 60 K. We show that the J_C data are not properly described using the standard universal flux pinning scaling approach for the volumetric pinning force $F_p \propto F_{p,max} b^p (1-b)^q$ because it leads to non-physical values (> 1000 T) of the effective upper critical field $B_{c2}^{*\rho}$ at low temperatures, although such fits indicate that a single mechanism and the anisotropy in $B_{c2}^{*\rho}$ broadly describe the J_C data.

Here the J_C data are parameterised using an in-field Superconducting-Normal-Superconducting (SNS) Josephson-junction (*J-J*) model which includes the wave-particle nature of the superelectrons. J_C shows power law behaviour at intermediate fields with free-parameter values giving enhanced $B_{c2}^{*\rho}$ and very thin barriers - consistent with the APC (RE)BCO's insulating pins enabling enhanced internal surface barrier currents, and its strongly textured microstructure. We also show fits to J_C data for a (RE)BCO tape without APCs, and an ITER bronze route Nb_3Sn strand. J_C for Nb_3Sn obeys the well-known Kramer-like high-field dependence, with free-parameter values that specify ~ 3 nm thick barriers that are ~ 450 nm wide - consistent with the grain-size of optimised polycrystalline Nb_3Sn, strong triple-point pinning and the flow of distorted fluxons along the grain boundary channels. Although more complex, the *J-J* analysis offers better strategies to optimise these three materials than standard flux pinning, because it describes flux pinning and the critical state more accurately and provides physically reasonable values for the free-parameter microscopic properties, including $B_{c2}^{*\rho}$ at low temperatures.

Keywords: superconductivity, critical current, flux pinning, Josephson junction, grain boundaries