Critical Current Distributions in Multifilamentary $Bi_2Sr_2CaCu_2O_{8+x}$ Round Wires

Abstract

$Bi_2Sr_2CaCu_2O_{8+x}$ (Bi-2212) is a promising candidate for ultra-high field magnets (>25 T) because of its round wire geometry, twisted multifilamentary architecture, and macroscopically isotropic electromagnetic properties. However, in composite superconductors, the local critical current may vary due to variable vortex pinning interactions and variations in filament connectivity arising from filament shape variation and grain-to-grain connectivity variations, particularly in high-temperature superconductors. The critical current density (J_c) in Bi-2212 round wires is high [J_c (30 T, 4.2 K) = 4600 A/mm^2], but can fluctuate by 30–40% between wires, due to a complex interplay of powder quality, filament uniformity, and the conditions of overpressure heat treatment (OP-HT), especially the highest temperature of the OP-HT. We here report on an extensive study of the critical current distributions in ~1.5 m long samples of wire manufactured in km lengths by Bruker-Oxford Superconducting Technology (Bruker-OST) using d^2V/dI^2 analyses of the *V-I* curves measured on ITER-like barrels. The transitions are well-fitted by Gaussian distributions characterized by their relative standard deviations (σ/μ).

This dissertation details experiments characterizing the influence of OP-HT parameters, filament separation, powder quality, and oxygen doping on the supercurrent path connectivity. We show that the highest J_c values occur for minimum time-in-the-melt (t_{melt}) and lower maximum temperature (T_{max}) during OP-HT and they also correspond to significantly lower σ/μ values. We attribute the degradation of properties that occurs with higher T_{max} to decreasing filament connectivity associated with deteriorating texture due to filament merging during the melt step of the OP-HT. Having obtained systematic results on the variation of σ/μ as a function of heat treatment conditions, we then applied this analysis to short sections cut from both ends of test magnets wound with about 200 m of wire, to understand the extent of systematic variations in the ~1 km length wires being delivered by Bruker-OST. We found that recent Engi-Mat fine-particle powder wires have significantly higher J_c and significantly lower σ/μ than found in earlier Bruker-OST wires made with milled Nexans granulate powder. We find it interesting that (i) there are clear trends that J_c rises as σ/μ declines and (ii) that the σ/μ values are only about twice as high as fully optimized Nb-47 wt.%Ti wires, which unlike Bi-2212 are isotropic, fully connected and

with only one single value of irreversibility field (H_{irr}). Furthermore, our investigation into the long-length uniformity of a 10 Kg Bi-2212 billet reveals that a kilometer-length conductor is macroscopically uniform with a σ/μ ratio almost independent of position along the ~1.2 km conductor. We attribute this to good fabrication practice by Bruker-OST and by the averaging effects of ~1000 filaments that render the complex critical current path functionally uniform along the wire length, in spite of many local percolation paths within each filament.

Finally, we report on the nature of the current path after deoxygenation of an initially overdoped wire in its highest J_c state. We find that the current path did not change significantly by deoxygenation, at least at the relatively high and broad range of electric field (E) accessed by d^2V/dI^2. However, gradual deoxygenation reveals two separate current paths that become evident in transition temperature (T_c) measurements. We attribute these two transitions either to dissipation due to flux flow within the *ab*-planes and also to flux flow at grain boundaries. Within a model that ascribes high J_c in polycrystalline Bi-2212 to its strong biaxial texture, we see the current-limiting obstacles as either occurring at grain boundaries obstructing *ab*-plane supercurrent or to the *c*-axis current flow required to transfer supercurrent from grain to grain when the *ab*-plane paths are blocked. The very special microstructure of Bi-2212 in which long [100]-oriented grains stack with other well-oriented [100] grains confers a large grain boundary (GB) area for *c*-axis current flow. A plausible interpretation of our deoxygenation experiments is that this *c*-axis transport is markedly degraded by underdoping that drives the *c*-axis from the SNS or even SS'S state when overdoped into a strongly Josephson-coupled SIS state, with degraded *c*-axis I_c. These experiments show that much can be learned about current flow in complex Bi-2212 wires even though we believe that many independent characteristics control the current flow. We are hopeful that having such analytical tools for identifying the distribution of critical currents and the way that the dominant dissipation mechanisms change with doping will enable further J_c enhancement in what are already very high J_c conductors.