Effects of high-intensity ultrasound on Bi$_2$Sr$_2$CaCu$_2$O$_{8+x}$ superconductor

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Slurries of powdered Bi$_2$Sr$_2$CaCu$_2$O$_{8+x}$ (BSCCO-2212) superconductor in high-boiling alkanes were irradiated with intense ultrasound. Significant enhancements of magnetic irreversibility as well as transport critical current are reported. The effects are dependent on the concentration of the slurry and are optimal for 1.5 wt % slurry loading. Electron microscopy shows that ultrasonic treatment leads to a change in grain morphology and intergrain welding. The observed enhancement of superconducting properties is consistent with the limitations in critical currents in BSCCO superconductor being due to intergrain coupling rather than intragrain pinning strength. © 2004 American Institute of Physics. [DOI: 10.1063/1.1808500]
Transport measurements were performed by using the standard four-point technique. Resistivity curves, normalized by the room temperature values, are shown in Fig. 2. Importantly, the onset of superconductivity and steepness of the transition in sonicated BSCCO remained practically unchanged, indicating that observed morphological changes did not affect bulk chemical composition of initial polycrystalline material. Magnetic measurements were conducted by using Quantum Design MPMS magnetometer. For magnetic and transport measurements, samples were cut into slabs from the central part of sintered pellets, with all at similar sizes, \( \sim 5 \times 2 \times 0.5 \text{ mm} \). All reported measurements were performed with the magnetic field oriented along the long side of a slab in order to minimize the influence of demagnetization. To avoid uncertainty in sample comparison, magnetization curves were normalized by the initial slope, \( |dM/dH|_{H=0} = V(4\pi N)^{-1} \) where \( N \) is the demagnetization factor and \( V \) is the sample volume. At higher magnetic fields the material is characterized by some magnetic susceptibility \( \chi(H) \), and total measured magnetic moment is given by \( M = \chi HV/(1-N) \). The volume of a superconducting fraction and the demagnetization factor are known only approximately. Normalization by the initial slope gives \( 4\pi M(1-N)/V = 4\pi \chi H = 4\pi m \). This has the clear meaning of volume magnetization expressed in gauss—a quantity independent of \( V \) and \( N \), and representing behavior of an infinite slab with ideal initial susceptibility \( 4\pi \chi_{H=0} = -1 \). We stress, however, that since our samples had very similar dimensions (and therefore, very similar volumes and demagnetization factors), raw data show the same trends as reported for normalized quantities. The normalization was used to extract critical current densities using Bean model for a long slab of \( w \times b \) cross-section,

\[
j_c \text{[A cm}^{-2}\text{]} = \frac{40m[G][w[cm]]}{(1-w/3b)}
\]

where \( b \geq w \).

Figure 3 shows normalized magnetization loops measured for samples of different slurry loading and for the reference sample. There is a clear enhancement of magnetic irreversibility in the entire range of magnetic fields for moderate slurry loadings. For larger slurry loading, however, properties deteriorated. This is as expected, since large slurry loadings lead to inefficient low-speed collisions, which only result in deterioration of grains surfaces. The inset shows critical current density evaluated from normalized magnetization at 2000 Oe. There is a significant enhancement of the critical current density (~40%) for sonication of 1% slurries compared to the nonsonicated, initial material.

In another set of experiments, magnetization was measured in a fixed 10 kOe magnetic field at various temperatures. To obtain each point, magnetic field was ramped up to 30 kOe and then reduced to 10 kOe to measure magnetization on a descending branch of the \( M_s(H=10\text{kOe}) \) curve. Then the magnetic field was ramped down to a negative 30 kOe and increased back to +10 kOe, where \( M_s(H=10\text{kOe}) \) was then measured. This procedure was repeated at each temperature shown in Fig. 4.

The advantage of using this method is the ability to estimate irreversible part of magnetization, \( M_{irr} = (M_s - M_f)/2 \). This is a reliable way to estimate the critical current density from irreversible magnetization. Results, shown in Fig. 4, are consistent with Fig. 3 and indicate that observed enhancement of magnetic irreversibility persists over the entire temperature range. Moreover, the enhancement of critical current density at 77 K is about 60%: 55 kA/cm² for sonochemically treated sample versus 35 kA/cm² for nontreated sample.

In order to convincingly demonstrate the enhancement of true critical current, transport properties must be examined. The comparison of voltage–current characteristics measured in reference and sonicated samples is shown in Fig. 5.
There is a clear enhancement of the threshold value of the applied current. Since thick samples were used (the same as for the magnetic measurements), the absolute value for the critical current density is impossible to estimate due to unknown current density distribution throughout the sample. Nevertheless, the ratio of the threshold currents is in a good agreement with the magnetization data, with an enhancement of about 60%.

In conclusion, it is demonstrated that high intensity ultrasonic treatment of slurries of the high-$T_c$ superconductor BSCCO-2212 produces material with significantly enhanced intergrain coupling. This method is effective for moderate slurry loadings. Our results outline a generalizable new direction for the improvement of irreversibility in ceramic superconductors.

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