Effect of high-intensity ultrasound on superconducting properties of polycrystalline YBa$_2$Cu$_3$O$_{7-x}$

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Abstract. High intensity ultrasonic irradiation (sonication) of alkane slurries of polycrystalline YBa$_2$Cu$_3$O$_{7-x}$ leads to a significant modification of the grain morphology and, if performed with enforced oxygen flow, results in the increase of the superconducting transition temperature. Sonication with added Fe(CO)$_5$ produces magnetic Fe$_2$O$_3$ nanoparticles deposited on the surface of YBa$_2$Cu$_3$O$_{7-x}$ (YBCO) granules. Upon sintering these nanoparticles should act as efficient pinning centers utilizing both condensation and magnetic contributions to the free energy. The developed method could become a major technique to produce practically useful high-pinning nanocomposite materials based on YBa$_2$Cu$_3$O$_{7-x}$ superconductor.

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YBa$_2$Cu$_3$O$_{7-x}$ 1-6 µm powder from Alfa Aesar) was used as received. Pentane and decane (anhydrous, 99+%, Aldrich) were distilled under argon prior to use. Polycrystalline YBa$_2$Cu$_3$O$_{7-x}$ was ultrasonically irradiated for 120 min at 263 K in 20 mL of decane in an open flask under moderate argon flow (20 mL/min), using direct immersion ultrasonic horn (Sonics VCX-750 at 20 kHz and 50 W/cm$^2$). Various slurry loadings were used. A similar set of slurries was sonicated under ambient atmosphere with the addition of different amounts of Fe(CO)$_5$. Oxygen content in the starting material was probed by the iodometric titration. To maintain the necessary oxygen content during the sonochemical irradiation of YBCO powder, and to explore effects of sonochemical conditions on $T_c$, sonication was performed in 2% (w/w) slurry in ethylene glycol, under 40:20 Ar:O$_2$ flow. All ultrasonically treated materials were collected by filtration, washed with dry pentane, and air-dried overnight. The resulting dry powders were pelletized at room temperature at a pressure of 2 GPa for 24 hours. The figure shows: (A) Commercial powder. (B) YBCO sonicated in 2% (w/w) decane slurry at 263 K. (C) Fe$_2$O$_3$ nanoparticles, distributed over the grains of irradiated YBCO after sonication with 180 µmol of Fe(CO)$_5$.

SEM images of sonochemically treated YBCO powders shown in Fig. 1 (B)(C) reveal substantial fusion, smoothing, and improved interconnecting of individual grains, as compared to the starting material, Fig. 1(C). Figure 2 shows powder XRD spectra of several powders used in this study. Noticeably, material that spent 6 months on the shelf shows significant degradation. However, when sonicated with partial O$_2$ flow, it was not only fully restored, but became better indicating that such treatment is similar to the annealing in oxygen atmosphere.

To further explore this observation and examine the effect on superconducting properties, figure 3 shows the M vs. T curves of sonicated YBCO. Compared to co-sonicated with O$_2$, as received powder shows smaller $T_c$ and superconducting screening.
In Fig. 4, XPS O₁ˢ spectra for several YBa₂Cu₃O₇₋ₓ samples are compared. The starting material.

In conclusion, irradiation with high-intensity ultrasound of alkane slurries containing granular superconductors results in a substantial change of powders’ morphology without affecting its bulk chemical composition. Sonochemical treatment of polycrystalline YBa₂Cu₃O₇₋ₓ high-Tc superconductor showed a dramatic effect on morphology of materials and their superconducting properties. Decane slurries of polycrystalline superconducting materials were ultrasonically irradiated with different slurry loadings and duration of the sonochemical treatment. To maintain the oxygen content in sonochemically treated YBa₂Cu₃O₇₋ₓ, sonochemical irradiation...
of slurries was performed under a partial oxygen flow in decane and in ethylene glycol. Ultrasonic irradiation of decane slurries leads to significant modification of morphology and improved intergrain coupling in polycrystalline superconductors. Effectiveness of sonication increases with the decrease of slurry loading, due to more effective interparticle collisions. Novel composite materials with enhanced pinning properties and increased critical current have been successfully prepared. Materials show enhanced Meissner screening and larger magnetic irreversibility. Critical temperature $T_c$ remains intact, while the pinning properties are improved. The sonochemical method and post-sonochemical annealing are to be further optimized to achieve maximal pinning enhancement in granular YBa$_2$Cu$_3$O$_{7-\delta}$.

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