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ABSTRACT

From the standpoint of applications, melt-grown (MG) and quench-melt-grown (QMG) bulk YBCO superconductors are of considerable interest. In this paper, we studied the intragranular critical current density (J_c), the apparent pinning potential (U_0), and the irreversibility temperature (T_{irr}) of MG and QMG samples and compared the results to those for conventionally sintered YBCO. A systematic increase in U_0 and a slower drop in J_c with temperature indicate a systematic improvement in flux-pinning properties in progressing from the sintered YBCO to QMG and MG samples. Weaker pinning is observed in the QMG YBCO than in the MG samples.

1. Introduction

Since the discovery of the $YBa_2Cu_3O_x$ (YBCO) superconductor, tremendous efforts have been made to apply this material for practical use. Most applications have been hindered by low critical current density (J_c), especially in the presence of a magnetic field.[1] Various processing techniques have been developed to improve the J_c. Particularly successful are the melt-processing technique developed by Jin et al.[2] for YBCO and the subsequent variations developed by several other groups.[3-5] High J_c values, exceeding 10^4 A/cm^2 at 77 K and 1 T, have been reported by Murakami et al.[3] in quench-melt-grown (QMG) samples. Improvements in J_c are due to preferred alignment of the grains and enhanced flux pinning of the individual grains. The large increase in J_c obtained in QMG samples bring YBCO one step closer to practical applications. The exact mechanism of enhanced flux pinning in melt–processed samples is still not clear and is under investigation;[6,7] although attributed initially to the presence of Y_2BaCuO_5 (211) precipitates embedded in the YBCO matrix,[8] more recent experiments failed to show any correlation between J_c and 211 particle size.[6,7] Thus, the effect of 211 particles on the flux-pinning properties of melt-processed YBCO remains controversial and needs further attention.

Characterizing the superconducting properties of the melt-processed materials can help in understanding some fundamental issues in high–temperature superconductivity. The existence of the so-called "irreversibility line" in high-T_c materials has been established following the pioneering work by Muller et al.[9] Although normal flux–creep theory can explain the irreversibility line as a transition from a flux–creep to a flux–flow regime, several other theories ranging from flux line melting to vortex glass melting have been proposed.[10-12] The important feature that can help distinguish among the various models is whether the irreversibility temperature (T_{irr} for a given field H_{irr}), represents an intrinsic thermodynamic property or an extrinsic property determined by the flux–pinning property of the material. Therefore, the study of T_{irr} in various samples with different flux pinning is of importance. So far, experimental work in this direction has produced contradictory results. In this paper, we present new data on intragranular J_c, apparent pinning potential (U_o), and T_{irr} of melt-grown (MG) and QMG samples of YBCO and compare the results to those for conventionally sintered YBCO samples.

2. Experimental Details

Stoichiometric YBCO powder was prepared by reduced–pressure calcination[13] of Y_2O_3, $BaCO_3$, and CuO in flowing oxygen at ≈850°C for 4 h under a pressure of 2 mm of Hg. Several pellets were prepared from this powder by uniaxial pressing at ≈140 MPa and sintered at 940°C for 4 h and cooled. One pellet was rapidly heated to 1100°C, held for 1 h, cooled rapidly (500°C/h) to 1000°C, slowly cooled (3°C/h) to 900°C, and then cooled to room temperature at ≈60°C/h. This is the melt-grown (MG) sample. Another sintered pellet was heated to 1350°C, held for 2 min, and quenched rapidly between two cold copper plates. The quenched sample was crushed, pelletized, heated rapidly to 1050°C, held for 1 h, slowly (3°C/h) cooled to 900°C, and then cooled to room temperature at ≈60°C/h. This is the quench-melt-grown (QMG) sample. The MG, QMG, and conventionally sintered pellets were oxygenated at ≈500°C for 3 days in flowing oxygen at ambient pressure. During the MG and QMG processing, texturing occurred only locally because none of the samples was subjected to an additional temperature gradient other than that exists unavoidably inside the furnace. All superconducting properties were measured by a superconducting quantum interference device (SQUID) magnetometer equipped with a 5.5 T superconducting magnet.

3. Results and Discussion

The intragranular critical current density of the MG, QMG, and sintered samples was determined from the width of the hysteresis loop (ΔM), obtained while the magnetic field was increased and decreased and by using Bean's critical-state model[14] $J_c = 15\ \Delta M/d$, where d is the average grain size. The plateletlike morphology of the grains is a source of error in calculating J_c because Bean's model is based on cylindrical symmetry of the grains. The grain size and aspect ratio of grains (length/breadth) are much larger in the MG and QMG samples than in the sintered sample. Therefore, a meaningful comparison of the absolute value of J_c among these samples is rather difficult. To avoid these problems, we used the normalized quantity $J_c(T)/J_c(5\ K)$ for the comparisons. The J_c dropped fastest with temperature in the sintered sample and slowest in the MG sample, indicating that flux pinning is strongest in the MG sample and weakest in the sintered sample. Electron microscopy reveals that the 211 particles are smaller and distributed more uniformly in the QMG sample than in the MG sample. If the 211 particles were the prime source of flux pinning, then one would expect higher pinning in the QMG sample than in the MG sample. The present results indicate that 211 particles do not play a significant role in flux pinning.

In the flux-creep measurements, the sample was cooled in zero field to the desired temperature, a magnetic field was applied, and decay of the magnetization with time was recorded over a period of 1 h. Figure 1 shows the temperature dependence of U_0 for the MG, QMG, and sintered YBCO in an applied magnetic field of 0.5 T. U_0 increases systematically from sintered YBCO to the QMG and MG YBCO and is consistent with our earlier statement that flux pinning is strongest in the MG sample and weakest in the sintered sample. The increase in U_0 by more than a factor of 3 in the MG sample over sintered YBCO is remarkable. Measurement of flux creep in sintered YBCO as a function of grain size showed no effect (within an experimental error of about 5%) of grain size on U_0 and therefore, the enhancement of U_0 is not due to the much larger grain size of the melt-processed samples compared to

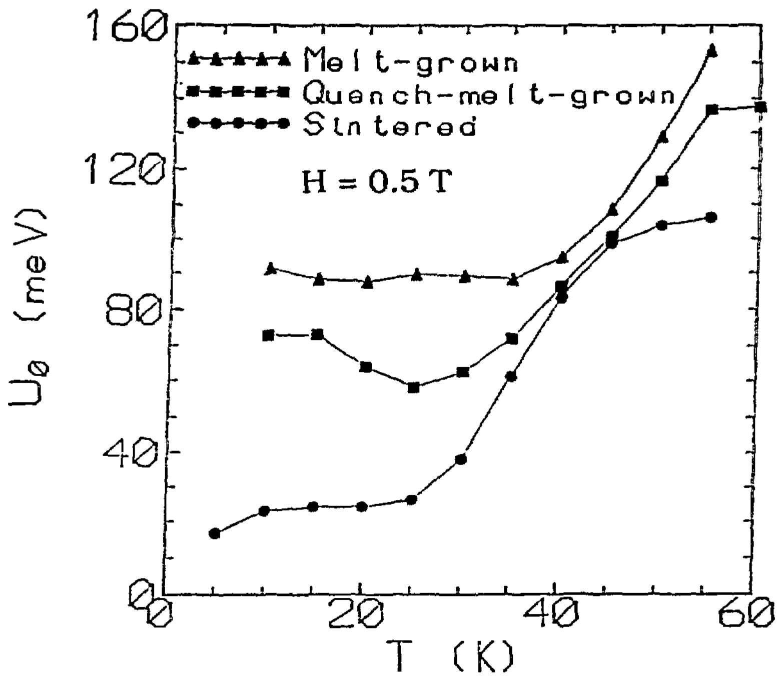

Fig. 1. Temperature dependence of apparent pinning potential (U_0) for melt-grown, quench-melt-grown, and sintered YBCO.

that of the sintered YBCO. The observed enhancement of U_0 truly reflects an improvement in flux-pinning properties in the progression from sintered to QMG to MG YBCO.

The irreversibility temperature (T_{irr}) was determined from DC magnetization measurements. The samples were first cooled in zero field to well below the superconducting transition temperature, the magnetic field was applied, and the data were taken during warmup in steps of 0.1 to 0.2 K up to about 100 K. Subsequently, data were collected during field cooling. The T_{irr} for a given magnetic field (H) was determined from the crossover point of the zero-field-cooled and field-cooled data.

Figure 2 shows a plot of $1-T_{irr}/T_c$ as a function of magnetic field for sintered, MG, and QMG YBCO samples. Single-crystal data from Ref. 15 are also included for comparison (dashed line). As seen in Fig. 2, the T_{irr} changes appreciably from sample to sample and is highest for the MG sample (which has the strongest pinning) and lowest for the sintered YBCO (which has the weakest pinning). This shows that T_{irr} is not an intrinsic property of the material and is basically determined by flux-pinning characteristics;

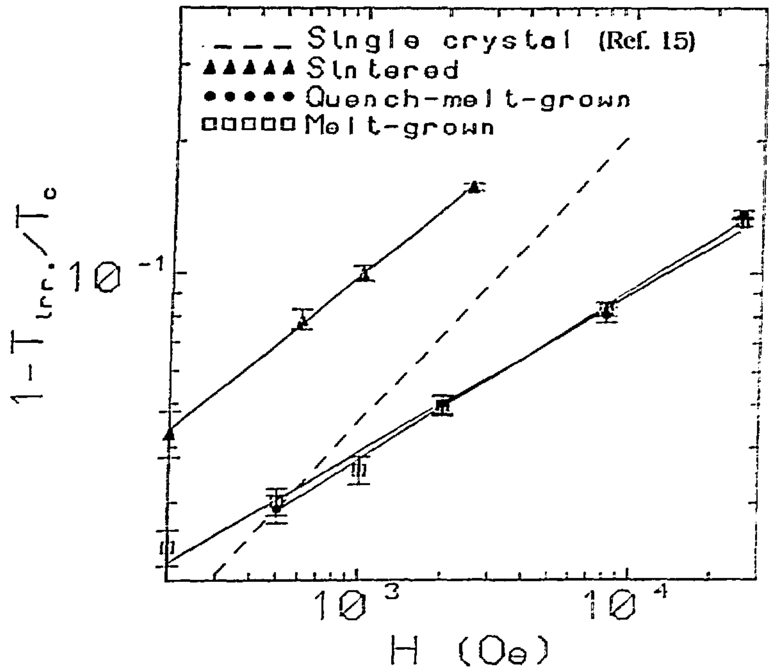

Fig. 2. Irreversibility temperature (T_{irr}) plotted as $1-T_{irr}/T_c$ vs. magnetic field (H) for melt-grown, quench-melt-grown, and sintered YBCO samples. Dashed line represents single-crystal data from Ref. 15.

moreover, T_{irr} is essentially in agreement with earlier data on melt-processed YBCO[16] and more recent data on heavy-ion (Sn)-irradiated single crystals of YBCO.[17] Therefore, association of the irreversibility line with the melting of the crystalline flux line lattice[10,11] seems to be unrealistic because this theory envisages T_{irr} as a sample-independent property. Vortex glass melting[12] or a transition from flux creep to flux flow[15] seems to be a more appropriate description of the irreversibility line.

4. Conclusions

The intragranular critical current density (J_c), the apparent pinning potential (U_o), and the irreversibility temperature (T_{irr}) in melt-grown (MG), quench-melt-grown (QMG), and sintered YBCO were studied. Much lower temperature dependence of J_c and U_o values that are a factor of 3 higher in the MG sample than in the sintered YBCO imply much stronger pinning in the MG sample. Between the QMG and the MG samples, J_c and U_o are higher and hence pinning is stronger in the MG sample. The present results show that the 211 precipitates play a relatively minor role, if any, in flux pinning and are in agreement with some other recent results.[6,7] The present study also shows that T_{irr} is not an intrinsic property and is determined by the flux pinning property of a material.

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