Time-Resolved Magnetic Flux and AC-Current Distributions in Superconducting YBCO Thin Films and Multifilament

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Abstract

Time-resolved magneto-optical imaging (TRMOI) technique allows dynamic ac trans-port measurements on superconductors. The high time and spatial resolutions of the measurements also offer good quantitative data analysis of the MO images. $YBa_2Cu_3O_{7-8}$ (YBCO) was discovered as a high-temperature superconductor (HTSC) which has wide applications due to its high critical temperature of $T_c = 91$ K, and high critical current density J_c in the order of 10^{6-7} Acm^{-2}. Many of the applications require high ac current load and a high magnetic field. We study the interaction behavior of YBCO thin films in an ac transport current and a dc magnetic field by the TRMOI technique.

In this dissertation, I first introduce the applications of high-temperature superconductors with focus on YBCO and describe the advantages of the TRMOI technique we developed over other methods to map the magnetic flux distribution of superconductors. The theories to understand the magnetic properties of HTSC are presented, followed by a theoretical model proposed by Bean in the 1960s and its modified version to fit our special experimental cases. I also introduce a newly developed finite elemental model (FEM) simulation which is proved to be a better theoretical guideline to our data analysis.

The TRMOI experimental setup and the procedures are discussed in detail. I show step-by-step the calibration of light intensity profiles averaged from MO images to determine magnetic field distribution, and a numerical inversion of the Biot-Savart law to calculate the current density distributions from the calibrated field profiles.

The current density evolution in YBCO thin films is studied by TRMOI as a function of the phase of an ac current applied simultaneously with a perpendicular dc magnetic field. The measurements show that an ac current enables the vortex matter in YBCO thin films to reorganize into two coexisting steady states of driven vortex motion with different characteristics: a quasi-static disordered glassy state in the interior of the film and a dynamic state of plastic motion near the sample edges. Both our TRMOI data and the FEM simulations reveal such vortex behavior. To study the transport current effects in YBCO thin films, we present a new empirical method to separate the total current distribution into a circulating shielding current and a transport current, which has asymmetric profile with pronounced peaks at the edges.

Furthermore, we performed TRMOI measurements on multifilamentary YBCO thin films with six superconducting filaments. Several sets of measurements with different experimental parameters are compared to find optimized measurements especially fitting the TRMOI technique for best quantitative results. The integrated transport current in the optimized measurements agrees fairly well with the current we applied. Nearly half of the transport current flows in the most outer two filaments while the rest of the current flows roughly evenly in the inner four filaments. We compare the measured data with the FEM simulation results and find that the multifilamentary film has higher critical current than the single bridged TBCO thin film. At last we present a TRMOI study of YBCO coated conductors in ac current regime. The MO images show a finger-like inhomogeneous flux penetration due to the large amount of grain boundaries in the coated conductors. A quantitative analysis of the images show how the grain boundary network affects the overall behavior of the flux and current density evolution.