Vortices in YBCO thin films with complex pinning structure investigated by AC susceptibility measurements

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We investigated the AC magnetic response of a $YBa_2Cu_3O_7$ film with embedded $BaZrO_3$ (BZ) nanorods and Y_2O_3 nanoparticles in a static magnetic field H_{dc} lower than the matching field H_Φ=4T. AC-susceptibility measurements have been performed using PPMS equipment (Quantum Design) after the sample was cooled down from temperatures $T > T_c$ to 50 K in the DC field H_{dc} perpendicularly oriented to the film surface. The AC-field amplitude h_{ac} was between 0.5 – 6 Oe at frequencies f between 11 and 5555 Hz. The measurements were performed in static DC magnetic fields of 2, 10, and 30 kOe. Complementary zero-field cooling DC magnetic relaxation curves, with the applied DC-magnetic field H_{DC} applied perpendicular to the film surface, were registered with a MPMS (Quantum Design) magnetometer.

The response of the vortex system to the AC excitation is rather complex but extremely useful for the characterization of the vortex dynamics. At small enough amplitude of the AC-field, the slow deformation of the vortex lattice at the surface propagates into the interior and vortices oscillate inside the pinning potentials. In this so-called Campbell regime, with a h_{ac}-independent screening current, it is possible to determine the average curvature of the pinning potential and to investigate the field and temperature dependence of the critical current density [1]. At higher h_{ac}, vortices overcome the pinning well and the flux line system enters into a more dissipative regime with h_{ac}-dependent AC-susceptibility in which the effective vortex activation energy U_{eff} has a logarithmic dependence on the AC field induced current density J.

Current densities and electric fields were extracted from AC and DC magnetic measurements using the critical state model in the Clem-Sanchez approach [2]. Pinning energy U_c(85.5K) obtained from both $E(J)$ characteristics and $J(t=1/f)$ dependence at short time scale is about 900 K (k_B=1), much higher than the ones obtained from DC magnetic measurements. It was found that, for H_{DC} = 2 kOe, the flux velocity during AC measurements is v=0.3 cm s−1 and only 1 nm s−1 in DC relaxation measurements. Thus, the thermal smearing of the potential walls is reduced in AC experiments and the obtained U_c is always higher than U_c determined from DC magnetic measurements.

The dynamic critical current J_d induced for AC driven forces at depinning frequencies was experimentally obtained by measuring the in-phase and out-of-phase magnetic responses (m', m") as a function of T, at various H_{DC}, f and h_{ac}. The depinning frequency f_d extracted by the extrapolation of J to the order of magnitude of $J_d \sim 10^5$ A cm−2 is in agreement with the values obtained from microwave impedance measurements.

References

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