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Flux profiles in $Bi_2Sr_2CaCu_2O_8$ crystals containing columnar defects.

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The magnetic flux profiles in $Bi_2Sr_2CaCu_2O_8$ crystals containing columnar defects were measured using a Hall-sensor array placed on the sample surface. Double slope profiles with abrupt drop of persistent current $J \approx dB/dx$ above the matching field B_Φ were observed, in agreement with the predictions of the Bose-glass model (B_Φ is the field of complete filling of columnar defects by flux lines). Disapearence of this feature at 50-60K can be identified as crossing the depinning temperature T_{dp}.

Critical current due to columnar-defect pinning is expected to exhibit a rapid drop when the magnetic field exceeds the matching field B_Φ.[1] This leads to the shrinking of the magnetic hysteresis loops above B_Φ in the conventional magnetization experiments. However in presence of high critical current, the large field gradients lead to a spread in the local magnetic induction and smeare the features related to the crossing of B_Φ. A new experiment technique, measurement of the flux profiles by Hall-sensor array, overcomes this difficulty and allows the direct observation of $J \propto dB/dx$ versus local B variation.

Rectangular shape samples were cut from $Bi_2Sr_2CaCu_2O_8$ crystal and irradiated with 5.8 GeV Pb ions in the heavy ion accelerator GANIL at Caen (France). This kind of irradiation is known to produce damage in the form of normal amorphous tracks embedded in a superconducting matrix.[2] The ion fluence defines corresponding matching field B_Φ, at which each rod is filled by one flux line. We investigated the low B_Φ range: 200-1000G. Magnetic field profiles were measured with an array of 11 Hall sensors of $10x10\mu m^2$ active area each separated by $10\mu m$ constructed in a two-dimensional-electron-gas of a GaAs-AlGaAs heterostructure.

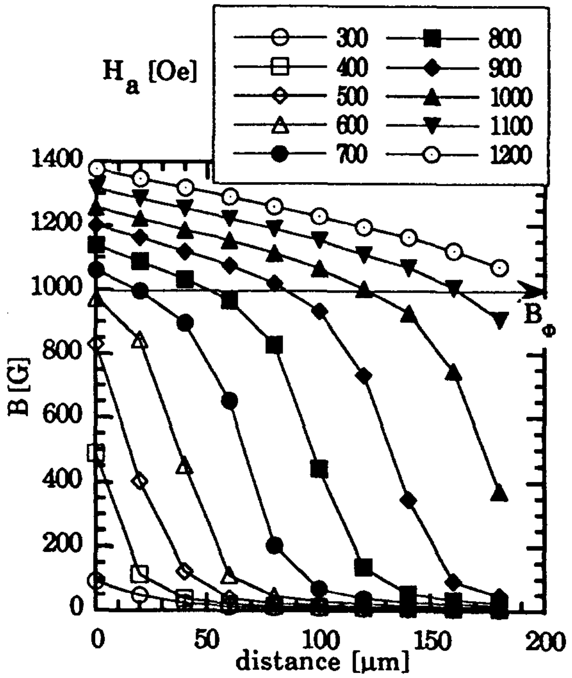

Figure 1. Field profiles in $Bi_2Sr_2CaCu_2O$ crystal irradiated with 5.8 GeV Pb ions (B_Φ=1kOe) at 30K after zero-field-cooling.

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The sample was fixed on the top of the sensor. Sensor 1 measured the field on the edge of the sample while the remaining sensors 2-11 probed the normal component of magnetic induction $B_z(x)$ across the width of the sample.

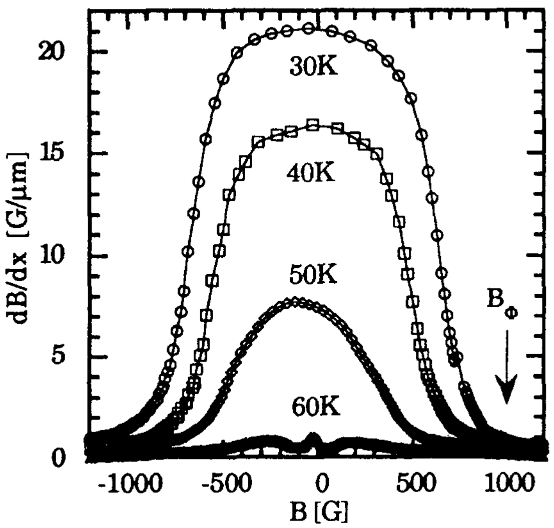

Figure 2. Field gradient dB/dx vs. local B at several temperatures recorded in $Bi_2Sr_2CaCu_2O_8$ sample with columnar defects (B_Φ=1kOe).

After calibration of the Hall-sensor array at a temperature above T_c, the sample was field cooled and magnetic hysteresis loops were recorded at a constant temperature. Typical field profiles recorded at 30K in $Bi_2Sr_2CaCu_2O_8$ sample irradiated with 5×10^9 Pb ions/cm^2 (B_Φ=1000 G) are presented in Fig. 1. The penetration of the field starts from the edges unlike the pristine sample.[3] With increasing applied field the front of the flux front moves toward the center of the sample. In region where $B<B_\Phi$ the slope dB/dx assumes a high value. In contrast, lower inductions gradients are obtained for $B_z(x)>B_\Phi$. Close to the edges $B_z(x)>B_\Phi$ is obtained at applied fields smaller than B_Φ due to damagnetization factor.

Fig. 2 shows the dependence of dB/dx on the local B. The induction gradient was obtained by differentiating the signals of sensors 3-5 (40-80μm) while B is the induction at sensor 4. The decreasing field branch from the maximum field in one direction to the maximum in the opposite direction was used in this procedure.

Step-like dB/dx vs. B variations with the rapid drop of dB/dx close to B_Φ are observed at temperatures below 40K. At 50K, dB/dx vs. B variations smears and the edge field at which dB/dx goes to the low value becomes smaller than B_Φ. Above 60K the enhancement of dB/dx does not exhibit any particular feature related to B_Φ.

Field profiles in Fig. 1 are consistent with the Bean critical state model[4] with specific J vs. B ($J\propto dB/dx$) dependence. The step-like drop of J at the accommodation field B* is predicted by the Bose-glass model of pinning by columnar defects.[1] At low temperature B* coincides with B_Φ while above the depinning temperature T_{dp}, the decrease of B* is expected. Experimental data fit closely this scenario and we estimate the value of T_{dp} to be between 50 and 60K.

The interpretation of the magnetic hysteresis measured by conventional techniques on samples containing columnar defects is not straightforward because of nonuniform current and field distributions.

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