Flux profiles in Bi$_2$Sr$_2$CaCu$_2$O$_8$ crystals containing columnar defects.

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The magnetic flux profiles in Bi$_2$Sr$_2$CaCu$_2$O$_8$ 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 $J = dB/dx$ above the matching field $B_\Phi$ were observed, in agreement with the predictions of the Bose-glass model ($B_\Phi$ is the field of complete filling of columnar defects by flux lines). Disappearance 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 $B_\Phi$. This leads to the shrinking of the magnetic hysteresis loops above $B_\Phi$ 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 smears the features related to the crossing of $B_\Phi$. A new experiment technique, measurement of the flux profiles by Hall-sensor array, overcomes this difficulty and allows the direct observation of $J = dB/dx$ versus local B variation.

Rectangular shape samples were cut from Bi$_2$Sr$_2$CaCu$_2$O$_8$ 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. The ion fluence defines corresponding matching field $B_\Phi$, at which each rod is filled by one flux line. We investigated the low $B_\Phi$ range: 200-1000G. Magnetic field profiles were measured with an array of 11 Hall sensors of 10x10μm$^2$ active area each separated by 10μm.

Figure 1. Field profiles in Bi$_2$Sr$_2$CaCu$_2$O$_8$ crystal irradiated with 5.8 GeV Pb ions ($B_\Phi=1kOe$) at 30K after zero-field-cooling.
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.

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 $B_{\Phi}$ 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 $B_{\Phi}$. Above 60K the enhancement of $dB/dx$ does not exhibit any particular feature related to $B_{\Phi}$.

Field profiles in Fig. 1 are consistent with the Bean critical state model\textsuperscript{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.\textsuperscript{1} At low temperature $B^*$ coincides with $B_{\Phi}$ 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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