Influence of Heavy Ion Induced Columnar Defects on the Vortex Dynamics of High-Temperature Superconductors

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The investigation of vortex dynamics in high-temperature superconductors (HTSC) is always related to the question of defects. In the presence of random disorder the long range order of the magnetic flux line lattice is destroyed and a vortex glass (VG) phase [1] is established below a characteristic glass temperature T_G. In the presence of heavy ion induced columnar defects this correlated disorder leads to a transition from vortex liquid to a Bose-glass (BG) phase [2]. In both cases this transition can be described with the appropriate scaling theory. For the BG case the scaling relation between current density J and electric field E is described by

$$\ell_\perp^{z'-1} E \approx \mathcal{E}_\pm\left(\ell_\parallel \ell_\perp J\right) \qquad (1)$$

with length scales $\ell_\parallel$ and $\ell_\perp$ parallel and perpendicular to the columnar defects that diverge as

$$\ell_\perp \propto \left(T_{BG} - T\right)^{\nu_\perp} \qquad (2)$$

where $\nu_\perp$ and z' are the static and dynamic exponents.

We performed electrical transport measurements on epitaxial $YBa_2Cu_3O_{7-x}$ thin films. Due to their extremely long measurement bridges l=10.9 cm that were patterned photolithographically we were able to measure current-voltage characteristics with an electric field resolution of 10^{-8} V/m and recent results have shown that the dynamic exponent of the VG transition in unirradiated thin films strongly depends on the experimentally accessible range of the electric field [3] which is in contrast to the theory. In order to study the dependence of the critical exponents from the electric field range we have irradiated the samples subsequently with 0.752 GeV ^{209}Bi, B_ϕ = 0.6 T and 0.749 GeV ^{208}Pb, B_ϕ = 1.0 T, ΣB_ϕ = 1.6 T. For this energy both ions have nearly the same electronic energy loss S_e which is responsible for the creation of columnar defects. We performed the same measurements as for the unirradiated case and the obtained data can be scaled well within the framework of the BG model for different magnetic fields. In accordance with the unirradiated case we could show that the dynamic critical exponent z' in the BG case also depends strongly on the electrical field range.

Another consequence of the irradiation is that the number of pinning centers for the vortex system is increased and the glass temperature T_G is shifted . Figure 1 shows the (H,T_G)-irreversibility line for the different irradiation doses and the unirradiated case respectively. For a magnetic field $\mu_0 H$ = 1 T the glass temperature is increased linearly with the irradiation dose as shown in the insert of Fig. 1.

We additionally take advantage of the different vortex dynamics in irradiated and unirradiated parts of HTSC thin films to study the effects at the interfaces between these regions. Different methods can be applied to prepare such a Bose-glass contact. In a first experiment we created a periodic array of strong and weak pinning channels using metal masks or the GSI-microprobe. These channels of width between 10 µm and 800 µm lead to a guided vortex motion (GVM) that can be detected by measuring in a Hall geometry [4]. We have shown that the characteristic fields and temperatures of this GVM are correlated to the BG phase. The second experiment currently is focussed on the electric field profile of a BG contact. Several equidistant (20 µm) voltage probes allow to measure the electric field across the interface between irradiated and unirradiated regions. The measured electric field profile of the weak pinning channel contains information about the characteristic length scales of the interaction between pinned and free vortices.

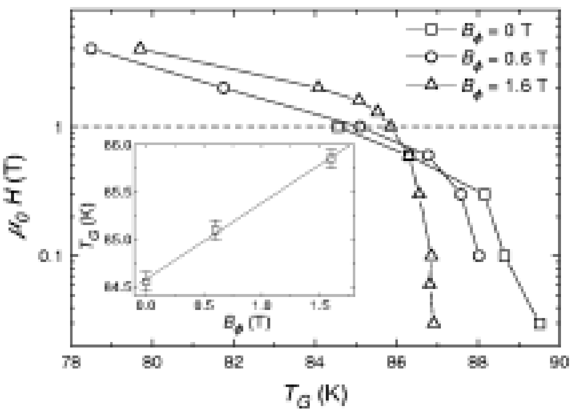

Figure 1: Irreversibility line before and after heavy ion irradiation. For B_ϕ = 0 T the glass temperature is determined using VG scaling, whereas the BG model is used for the irradiated sample. The number of coherent pinning centers is increased and the (H,T_G)-line is shifted. The insert shows the linear dependence between B_ϕ and T_G for a magnetic field $\mu_0 H$ = 1 T.

Thus vortex dynamics at the interface of a BG contact is a new field of investigation to study vortex-vortex interactions in HTSC thin films. Two experimental techniques are necessary to obtain more information: nanolithography and the GSI-microprobe in order to create irradiation patterns on a microscopic scale. This will be realized within the framework of the collaboration.

References

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