Guided vortex motion in Nb films on facetted substrate surfaces

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Abstract

Anisotropy of the pinning force in a superconductor can cause a guiding effect on the vortices, which leads to the appearance of new components in the galvanomagnetic quantities of the sample. In this case one can observe an additional odd magnetoresistive component with respect to magnetic field reversal. Furthermore, an even contribution to the Hall voltage is observed. Guided motion of vortices in Nb films on facetted $\alpha - Al_2O_3$ $(10\bar{1}0)$ was found by measuring the longitudinal and transversal resistivities of three films with transport current directed parallel, perpendicular and at an angle of 45° with respect to the facet ridges. Field inversion was used to separate the even and odd components of the measured magnetoresistivities and thus to obtain the contributions caused by the guided vortex motion.

Key words: Pinning; vortex dynamics; guiding

The influence of anisotropic pinning defects on the vortex dynamics in superconductors attracts much attention from both theoretical [1], [2] and experimental [3], [4], [5] viewpoint. Vortex motion can be influenced by planar pinning structures, a natural example being unidirected twin boundaries in $YBa_2Cu_3O_{7-\delta}$. In the presence of such structures the pinning force is anisotropic: it is much stronger in the transverse direction with respect to the twin boundaries than in the parallel direction. This can result in so called guided vortex motion, when vortices tend to move along the pinning plane even if the external force acting on them is not aligned parallel to this plane. For this case theory predicts the appearance of two 'new' components in the galvanomagnetic response of the superconductor: an odd longitudinal and an even transversal (Hall) voltage with respect to magnetic field reversal. These two components are absent in the isotropic superconductor. This was observed experimentally on twinned $YBa_2Cu_3O_{7-\delta}$ single crystals [4], [5]. In this article we report guided motion in Nb epitaxially grown on facetted $\alpha - Al_2O_3$ $(10\bar{1}0)$. We emphasize the model character of these samples for the study of anisotropic vortex pinning under well-controlled and turnable conditions.

Three Nb-films with thickness of 390$\mathring{A}$ were grown during one deposition process on the facetted $\alpha - Al_2O_3$ substrate using molecular beam epitaxy techniques [6]. The films replicate the facetted substrate surface as shown in the inset of Fig. 1. The facet ridges act as pinning planes [6]. Micro-bridges were patterned by photolithography and ion-beam etching, having different orientations to the facet ridges. Three samples were prepared allowing measurements with the transport current directed at the angles $\alpha = 0°, 45°, 90°$ with regard to the facet ridges. The dependencies of the longitudinal and transversal voltages on temperature were measured simultaneously on the three samples with an average transport current density of 13 kA/cm^2 in fields of +0.030 T and −0.030 T. The magnetic field **H** was aligned perpendicular to the film surface, i.e. parallel to the pinning planes. Odd and even components

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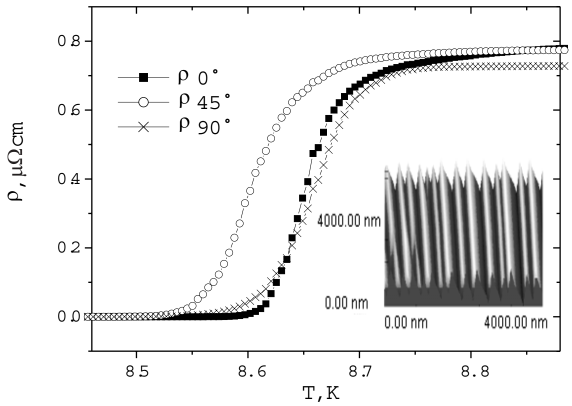

Fig. 1. Superconductive transition of the samples with different transport current orientations in field 0.030 T. Inset: typical AFM picture of the surface of Nb film grown on the facetted $\alpha - Al_2O_3$ substrate. The average height of the facets is about 50 nm.

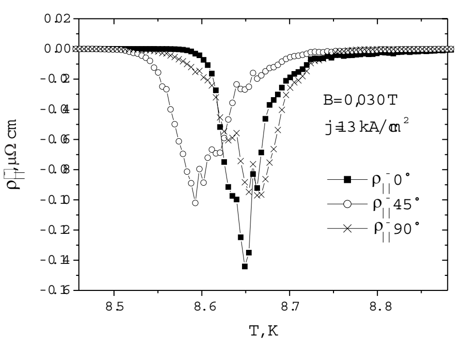

Fig. 2. Temperature dependence of the odd longitudinal magnetoresistivity for the samples with different transport current orientation as indicated.

of the magnetoresistivities were calculated according to the simple relations $\rho^{\pm} = (\rho(H) \pm \rho(-H))/2$.

Fig. 1 shows the superconductive transition for all three samples, i.e. the $\rho(T)$ dependencies in the presence of a magnetic field $\mu_0 H = 0.030$ T. Most likely due to inhomogeneity the sample with $\alpha = 45°$ showed a reduction of the critical temperature by about 0.5 K

In Fig. 2 we plot the temperature dependence of the odd longitudinal magnetoresistivities. These are the 'new' components caused by the guided vortex motion. All three curves show a distinct peak in the region of the superconductive transition. In contradistinction to the theoretical expectation all curves look similar: the shift between the $\alpha = 45°$ and the other two curves corresponds to the differences in critical temperature. Theory predicts response to be maximal for $\alpha = 45°$ and zero for $\alpha = 0°$, $90°$ [2].

In Fig. 3 the even transversal magnetoresistivities are plotted. These components are only present in the case of guided vortex motion due to the existence of an odd (with respect to magnet field reversal) vortex ve-

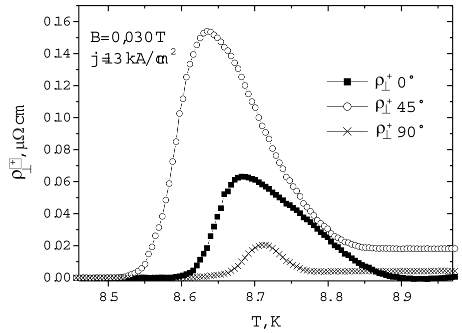

Fig. 3. Temperature dependence of the even transversal magnetoresistivity for the samples with different transport current orientation as indicated.

locity component aligned perpendicular to the transport current direction. In correspondence with the theory the $\rho^+_\perp(T)$ shows the maximum response for the sample with $\alpha = 45°$ [2].

Our results show clear evidence for the guided vortex motion in the Nb films on facetted $\alpha - Al_2O_3$ $(10\bar{1}0)$. Nevertheless, clear discrepancies with regard to the theoretical predictions are observed. In particulars, it is not clear what cause the almost identical behavior of the $\rho^-_{||}(T)$ dependencies for different α(Fig. 2). An analysis of the guiding angle reveals that the pinning anisotropy introduced by the facet ridges is weak. Consequently, a possible influence of isotropic (background) pinning has to be taken into account. Work is in progress to extend the existing theory to systems with an additional isotropic pinning component. On the experimental site we intend to extend our study to the limit of strong anisotropic pinning by means of decorating the facet ridges with pair breaking materials prior to the Nb film deposition.

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