Excitation of resistive domains in a superconducting film

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Penetration of vortices into a current-carrying superconducting film is observed for the first time. The distribution of the transport current over the width of the specimen and temperature distribution in the vicinity of the resistive domains are reconstructed experimentally.

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1. When the superconducting state in a homogeneous or nearly homogeneous film is destroyed by a current, the vortices enter on one of its sides and either move completely across the specimen or annihilate with oppositely moving vortices having opposite sign.[1] The presence of defects or other local formations, which lower appreciably the potential barrier to penetration of the magnetic flux, qualitatively changes the picture. Although vortices enter, as before, predominantly from the edge, since the current density at the edge is higher,[2,3] they can now penetrate into the film. In this case, the vortices appear in (vortex-antivortex) pairs and spread out in different directions under the action of Lorentz force.

Both edge and internal sources of vortices participate in the formation of resistive domains. These domains are overheated sections with an electric field, which are situated across the specimens.[4] The large number of resistive domains (sometimes as large as several hundred) in a specimen, appearing with the passage of a sufficiently strong transport current through real films, also includes domains that arise from internal sources of vortices. However, according to the shape of the I-V curves used for recording the domains, they do not differ from the domains created at the edges.

2. In this work we have recorded for the first time the entry of vortices into a film. The specimens were prepared by sputtering indium or lead on glass substrates in a vacuum of 10^{-4} mm Hg. Their length and width (W) were 15 mm and 6 mm, respectively, and their thickness varied from 400 to 3000 Å. The potential barrier to penetration of vortices was suppressed by the proximity effect. For this, several copper spots with diameter 0.1 mm and thickness 1 μm were simultaneously sputtered on top of the films in a certain order (see Fig. 1).

When a transport current is transmitted, the voltage jumps, which indicate the formation of domains whose number coincided with the number of weak locations created, were reproduced on the I-V curves recorded at thermostat temperature $T_0 \approxeq T_c - T_0$ (T_c is the critical temperature of the film). In this case, the voltage steps with lower current (see Fig. 2) correspond to domains arising on defects that are farther away from the center of the film. To check this fact, an additional voltage lead was used on several specimens (see Fig. 1). In addition, for the indium films, the dependence of the magnitude of the critical currents I_{ci} for the appearance of domains

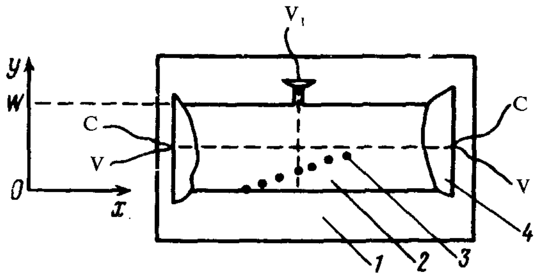

FIG. 1. Typical arrangement of the specimens studied. 1—Substrate, 2—film, 3—copper spots, 4—indium or lead-indium soldered piece. C denotes the current leads, V denotes the voltage leads, V_1 is an additional voltage lead.

on the perpendicular magnetic field $H_\perp$ with magnitude ~ 1 Oe (the dependence $I_c(H_\perp)$ is sensitive to the position of the source of vortices) was measured.

3. Since the spots have identical sizes and structure, they lower the potential barrier by the same amount. Therefore, the magnitudes of the critical currents for creating resistive domains reflect the current density distribution. In addition, if the position of the defects along the OX axis is known (see Fig. 1), it is easy to reconstruct the temperature distribution near a resistive domain from I-V curves recorded by alternately submerging the films in He II and He I and its vapor, assuming that the domains do not affect each other thermally in the superfluid helium (He II). Figure 3 shows the corresponding coordinate dependences for two lead specimens.

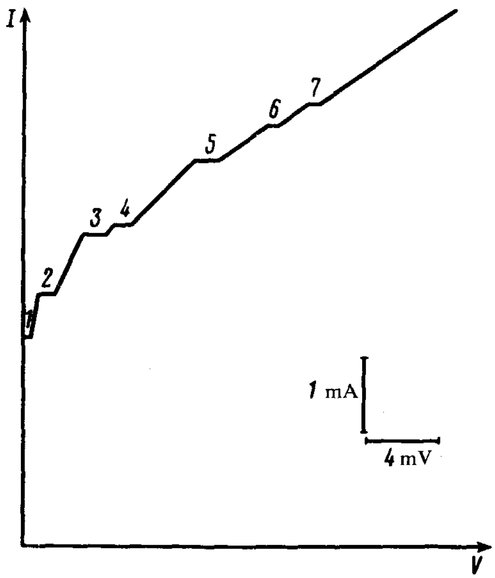

FIG. 2. Seven locations showing a lower potential barrier on the I-V curve of a lead film Pb1. The curve is traced in helium vapor at thermostat temperature 4.9 K. Fixed current regime. A slightly earlier formation of resistance domain No. 4 is related to fluctuation disruption.

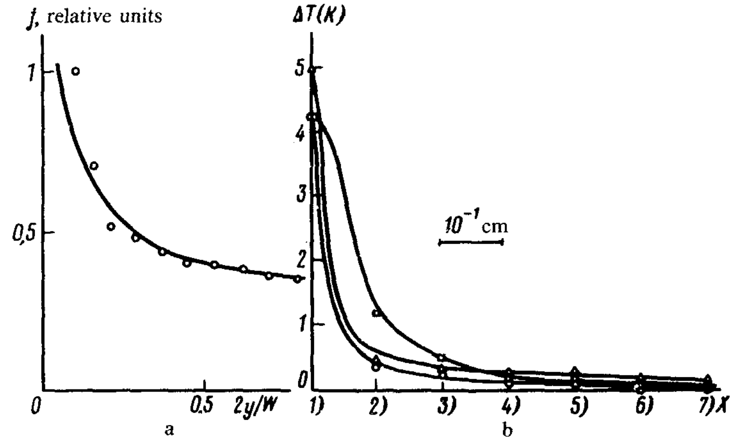

FIG. 3. a) Reconstruction of the transport current distribution (j is the current density) over the film width for the specimen Pb2 (points). The edges of the film correspond to $y = 0$, W. The continuous curves show the theoretical dependence from Refs. 2 and 3. The deviation for small y is related to smearing of the edge of the specimen. b) Temperature profile ($\Delta T = T - T_0$) of resistive domain No. 1 in specimen Pb3 for different conditions of heat removal into the external medium: 1—$T_0 = 2.92$ K, liquid He I; 2—$T_0 = 2.2$ K, liquid He I; 3—$T_0 = 2.92$ K, helium vapor. The numbers 2–7 indicate the position of the neighboring six domains acting as sensors.

It should be noted that the current distribution over the width of the film was previously checked by different methods: according to boiling of helium,[5] according to the magnetic field created near the surface,[6] etc. The most accurate method for reconstructing the current distribution is the method based on direct observation of flux motion using a laser.[1] Its realization, however, requires a complex apparatus. The method proposed here is a direct method which can also be very simply realized. As far as finding the temperature distribution near a resistive domain is concerned, it was possible to perform these measurements in thin films for the first time. The method used is quite promising in such investigations, since it does not require application of special temperature sensors.

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