A cluster in a granular superconductor

A. P. Perov
M. V. Lomonosov Moscow State University

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An "infinite cluster" has been found to exist in a granular superconductor, a $BaPb_{0.75}Bi_{0.25}O_3$ ceramic, by using the method of local heating. The location of this cluster in the sample has been determined.

In the experiment we used a superconducting $BaPb_{1-x}Bi_xO_3$ ceramic ($x = 0.25$) sample with a critical temperature $T_{cr} = 11$ K. the ceramic sample has a granular structure. The superconducting contacts between the granules are "weak couplings" whose critical parameters J_{cr} and H_{cr} are usually approximately two orders of magnitude lower than those of the granules themselves.[1] At $T < T_{cr}$, these weak couplings determine the current flow through the sample. A theoretical analysis of such systems is based on the percolation theory.[2,3] An "infinite cluster," in which all of the current is concentrated, is formed near the percolation threshold. In other words, a current filament is formed. The percolation theory and its application to the critical phenomena can be tested by measuring the parameters of the cluster upon its breakup.

The position of the infinite cluster in the sample is determined as follows. A concentrated heat source is applied to a superconducting infinite cluster in the precriti-

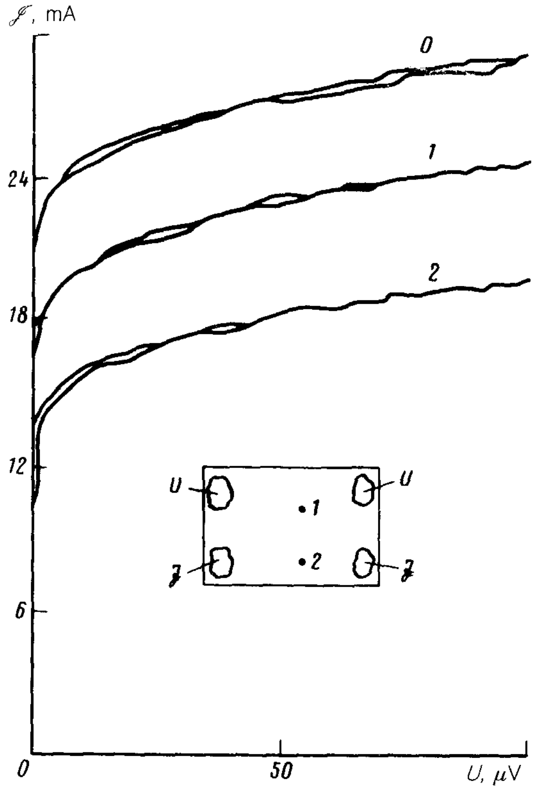

FIG. 1. The *I-V* characteristic of the sample at various positions of the focal point. Curve 0 was obtained in the absence of light; curves 1 and 2 correspond to the positions of the focal point shown in the inset.

cal state, $J < J_{cr}$, in such a way that it breaks up the cluster at this location. A break in the cluster produces a voltage ΔU on the sample. Ignoring the structure of the infinite cluster, we can write this signal in the form

$$\Delta U = JS\rho\delta \,, \qquad (1)$$

where J is the current that flows through the sample, S is the cross-sectional area of the cluster, ρ is the resistivity of the sample in the normal state, and δ is the width of the break.

The sample, a 6×4×0.3-mm plate, is immersed into the cold section of the cryostat in a vacuum. The local heating is achieved by a 2-mW He-Ne laser by focusing its beam onto a spot of up to 25 μm on the sample. The cryostat with the sample is moved relative to the focal point by means of micrometer screws.

Figure 1 shows the current-voltage characteristics of the test sample at $T = 4.5$ K; the critical current is 25 mA. The critical current of the sample is 14.5 mA when the part of the sample containing the infinite cluster is exposed to light. Figure 2 is a plot of the curves for the signal ΔU, when the focal point moves at right angles to the direction which links the current contacts for the sequential current values. The absence of a signal indicates that at a 14-mA current the local heating does not break up

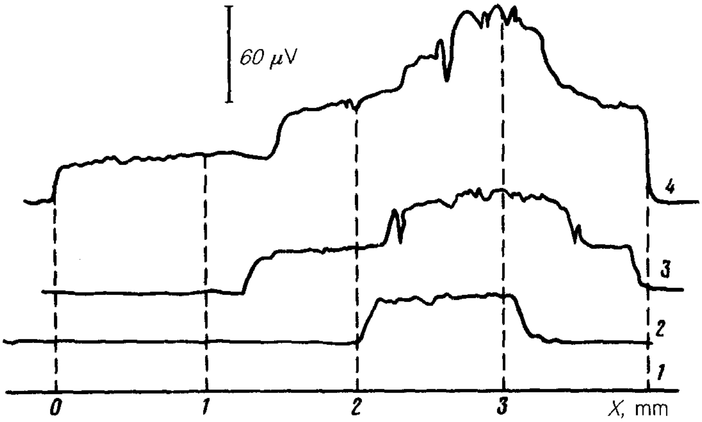

FIG. 2. Voltage on the sample versus the position of the focal point at the consecutive values of the current that flows through the sample. 1—14 mA; 2—15 mA; 3—17 mA; 4—19 mA.

the cluster. The next current value, 15 mA, leads to the appearance of a signal ΔU in the sample when the focal point is situated ~ 1 mm from the sample's edge. The width of the sensitive zone, a part of the sample where the infinite cluster is located, is ~ 1 mm. The appearance of the signal indicates that the temperature peak of the temperature profile of the concentrated heat source coincides with the superconducting infinite cluster, which breaks up in this case. The sensitive zone expands upon further increase in the current because of the approach of the cluster to the percolation threshold—the critical state. As a result, the cluster breaks up at a lower ΔT; i. e., the breakup of the cluster is caused by the peripheral region, rather than the central region, of the local heating, where ΔT peaks, resulting in the expansion of the observable width of the cluster. The appearance on the first plateau of a second break and a third one upon further increase in the current indicates that the cluster undergoes a second and a third breakup, respectively. We can draw a conclusion, therefore, that in the immediate vicinity of the percolation threshold, just before the formation of the cluster, there are large fragments (blocks) which form the infinite clusters as they coalesce.

The width of the break in the cluster, δ, can be determined from the height and width of the voltage plateau (Fig. 2). The resistivity of the sample is $\mu = 0.01\ \Omega$/cm in the normal state, and from (1) we find $\delta \simeq 12\ \mu$m. This value can naturally be compared with the correlation radius

$$r_c = |p - p_c|^{-\nu},$$

where p is the order parameter, and ν is the critical index of the correlation radius. The value of r_c can be estimated from the expression for the critical field $H_{\rm cr}$ of the system of weak couplings, $r_c^2 H_{\rm cr} \simeq \phi_0$, where ϕ_0 is a fluxoid. In our case we have $H_{\rm cr} \simeq 0.7$ Oe, which gives us $r_c \simeq 8\ \mu$m. Since r_c is approximately equal to δ, we conclude that the width of the break in the cluster is determined by the correlation radius r_c and that the measurement of δ is an independent method of determining this quantity. On the other hand, the formation of clusters from blocks of size $R \gg r_c$, whose physical separation is

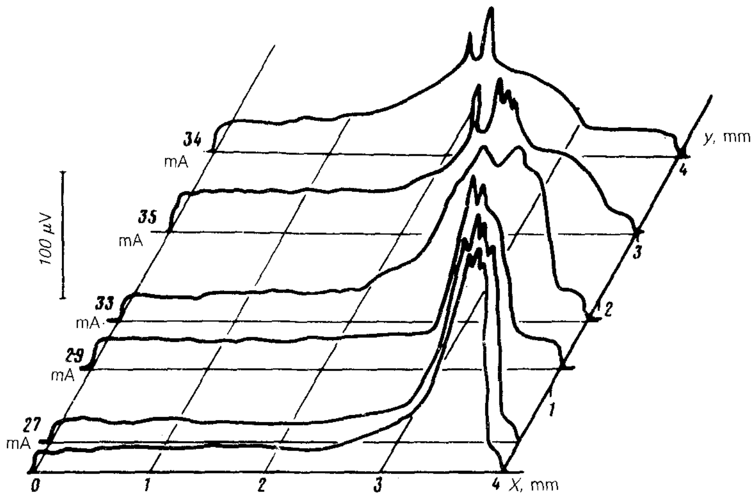

FIG. 3. The position of the infinite cluster in the sample.

on the order of r_c, should be seen in the behavior of the conductivity near the percolation threshold. In the expression for the initial part of the I-V characteristic (Fig. 1),

$$\sigma = \sigma_n \left(\frac{J - J_{cr}}{J_{cr}} \right)^{-t},$$

the critical index t of the conductivity is in the range 0.8–0.9, where σ_n is the conductivity in the normal state. This value is approximately equal to the values of the critical indices which determine the behavior of the infinite cluster, $\beta' \approx \nu \approx 0.8$–$0.9$, where β' determines the total number of cluster couplings, and ν determines the universal index of the correlation radius.

Figure 3 shows the locations of the infinite cluster at various distances from the current contacts. In the immediate vicinity of the percolation threshold, the breaks in the cluster are caused by the parts of the heated region which are situated progressively farther from the center. On the other hand, the width of the break increases, causing the voltage on the sample to increase.

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