SOME FEATURES OF THE TRANSITION DUE TO DESTRUCTION OF SUPERCONDUCTIVITY BY A CURRENT IN SUPERCONDUCTING ALLOYS

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The effect of the phase composition and structure of superconducting alloys on the nature of their transition during destruction of superconductivity by a current is investigated. Experimental results of a study of current-induced transitions in a $Pb_{0.83}In_{0.17}$ alloy, thermally treated Zr + 4% Nb alloy, and commercial Nb–Ti–Zr wire are presented.

EXPERIMENTAL PROCEDURE

To plot the dependence of the voltage V on the current I we used a pulsed procedure, making it possible to reduce the influence of heating the samples on the form of the transition curves. The apparatus employed was similar to that described in [1] and used earlier to determine the critical points of a superconducting wire.

A block diagram of the measurements is shown in Fig. 1. A single sawtooth current pulse, of duration ranging from 50 μsec to 100 msec, was passed through the investigated sample 3. The signal from the potential leads of the sample, which was placed in a transverse magnetic field, was fed to the vertical input of an oscilloscope, the signal to the horizontal input being picked off from a shunt 6 and proportional to the current through the sample. Thus, the oscilloscope exhibited curves showing the transition of the sample into the normal state upon destruction of the superconductivity by current.

In the investigation of samples of $Pb_{0.83}In_{0.17}$ and Zr + 4% Nb, the magnetic field was produced by an electromagnet, and for wire samples made of 65 BT alloy it was produced by a superconducting solenoid. The solenoid winding was made of 65 BT alloy wire [2] and produced a magnetic field of 55 kOe in an aperture of 3.5 cm. To increase the field, concentrators of permendur, 6.5 cm long and of 2.7 cm diameter, were placed inside the solenoid [3]. This made it possible to obtain a magnetic field up to 85 kOe in a gap of 1 mm. The magnetic field was measured with a Hall pickup made of InSb [4], which has a linear characteristic in fields up to 100 kOe.

In measurements with pulsed currents it was necessary to prevent mechanical displacement of the samples under the influence of the electrodynamic forces. To this end, samples of $Pb_{0.83}In_{0.17}$ wire were clamped against a brass strip and placed in a test tube with alcohol (which froze when immersed in the liquid helium). The potential leads were soldered to the sample with indium. The Zr + 4% Nb were clamped between strips of brass and bakelite. The current was fed to the sample with the aid of bulky tinned clamps. The potential leads were soldered to small copper-plated sections on the sample.

Samples made of 65 BT wire were prevented from moving by placing them in a narrow slit in the sample holder (insert in the solenoid). The holder was made integral with the concentrators. The ends of the 65 BT sample, emerging from the magnetic field, were coated with copper and soldered with indium to bulky copper busbars. The current was fed to the sample with the aid of superconducting clamps [2]. The potential leads were soldered to narrow sections of the copper coating. In all cases, the part of the sample between the potential contacts and situated in the magnetic field was not covered with copper.

RESULTS OF EXPERIMENT

Figures 2 and 3 show the transition curves of wire samples made of $Pb_{0.83}In_{0.17}$ of 0.35 mm diameter in

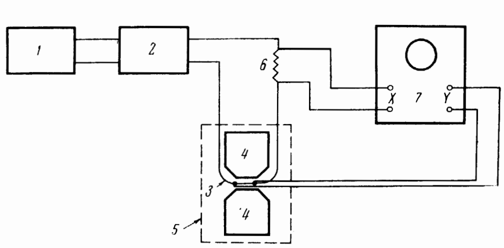

FIG. 1. Block diagram of the measurements: 1 – single sawtooth pulse generator, 2 – current amplifier, 3 – investigated sample, 4 – concentrators of superconducting solenoid, 5 – winding of superconducting solenoid, 6 – measuring shunt, 7 – oscilloscope.

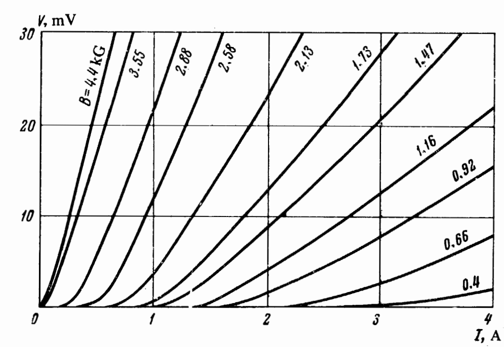

FIG. 2. Transition curves of $Pb_{0.83}In_{0.17}$ sample in magnetic fields from 0.4 to 4.4 kOe, T = 4.2°K.

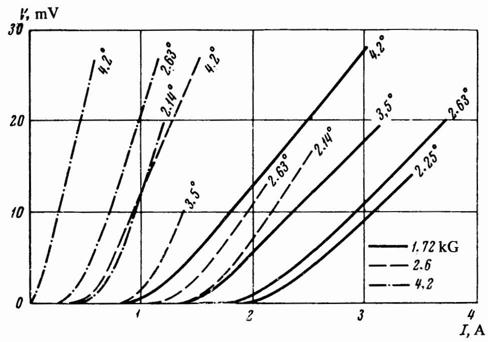

FIG. 3. Transition curves of $Pb_{0.83}In_{0.17}$ sample in magnetic fields from 1.72 to 4.2kOe and temperatures from 2.14 to 4.2°K.

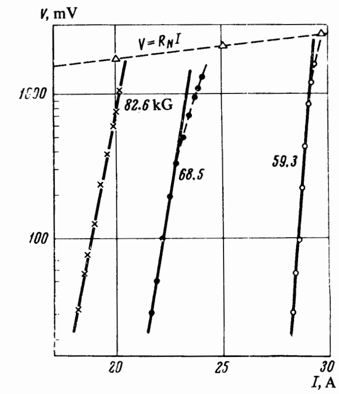

FIG. 6. Dependence of the voltage on the current for samples of cold-drawn wire of 65BT alloy in magnetic fields from 59.3 to 82.6 kOe, T = 4.2°K.

different magnetic fields and at different temperatures. A characteristic feature of all these curves is presence of a clearly pronounced quasilinear section, the slope of which varies with the magnetic field.

Figure 4 shows the transition curves of the Zr + 4% Nb samples, which had an approximately quadratic cross section of 0.5 × 0.5 mm. In this alloy, as shown in[5], mechanical working and heat treatment produces a system of phase segregations enriched with niobium, which are superconducting at 4.2°K, in a matrix which is normal at the same temperature. Figure 4, as well as Fig. 8, shows that these transition curves, unlike the transition curves of $Pb_{0.83}In_{0.17}$ (Figs. 2 and 3) have practically no linear section and can be represented with sufficient accuracy by an exponential.

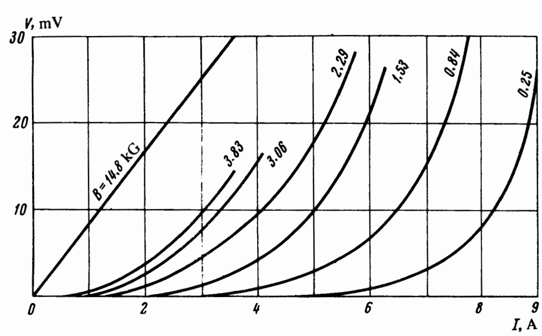

FIG. 4. Transition curves of sample of Zr + 4% Nb alloy in magnetic fields from 0.25 to 14.8 kOe, T = 4.2°K.

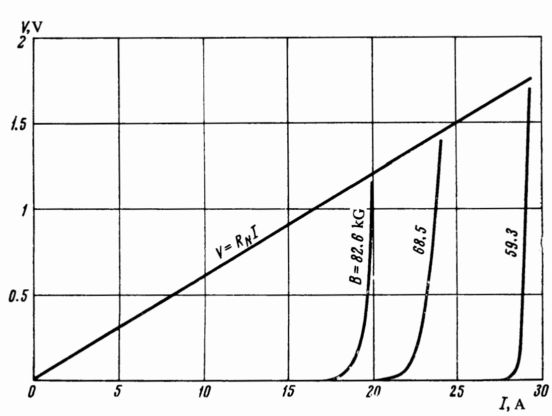

FIG. 5. Transition curves of cold-drawn wire of 0.25 mm diameter of the 65BT alloy in magnetic fields from 59.3 to 82.6 kOe, T = 4.2°K.

Figure 5 shows the transition curves of samples of cold-deformed wire of 65 BT alloy with 0.25 mm diameter. These curves likewise have no linear section (see Fig. 6).

Figure 7 shows the transition curves of the same wire, annealed at 1000°C for 3 hrs. Such an annealing decreases the critical current by a factor 10–20. The transition curves, as seen from the figure, become more similar after such a heat treatment to the curves for the $Pb_{0.83}In_{0.17}$ alloy.

DISCUSSION OF THE EXPERIMENTAL RESULTS

The quasilinear dependence of V on I obtained for the $Pb_{0.83}In_{0.17}$ samples can be explained sufficiently well as being due to the motion of fluxoids in a homogeneous superconductor of the second kind. Thus, for example, the slope of this quasilinear section in weaker fields turns out to be proportional to the magnetic field, as follows from[6,7]. These results agree with the results of analogous measurements by others[8]. Thus, it can be assumed that for such single-phase superconducting alloys as Pb-In, the concept of viscous motion of fluxoids in a superconductor of the second kind is fully applicable in the case of sufficiently strong currents.

Inasmuch as the Zr + 4% Nb alloy is a system of superconducting filaments in a matrix of normal metal[5], a connection can be established between the

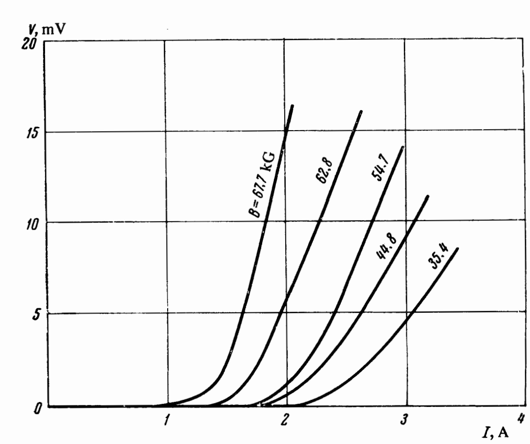

FIG. 7. Transition curves of wire of 65BT alloy, annealed for 3 hr at T = 1000°C, in magnetic fields from 35.4 to 67.7 kOe, T = 4.2°K.

current flowing through the superconducting filaments and the electric field intensity. In the presence of an electric field, the current flows both through the superconducting filaments and through the normal matrix. Therefore the current in the superconducting phase is determined by the relation

$$I_s = I - V/R_N, \quad (1)$$

where R_N is the resistance of the normal matrix. Figure 8 shows a plot of $V(I_s)$. It is seen from the figure that in the case of a small potential difference across the sample, the dependence of V on I_s has an exponential character.

As is well known, an exponential dependence of V on I was obtained[9] in the analysis of the motion of "linkages" of fluxoids secured to defects of the sample under the influence of the Lorentz force and thermal activation. In our case, the sample of the Zr + 4% Nb alloy, which has a filamentary structure, is similar in a certain sense to "synthetic" superconductors[10], to which the model of fluxoid "linkages"[7] is certainly not applicable. Thus, the exponential V(I) dependence observed by a number of authors for hard inhomogeneous superconductors with high critical currents cannot be regarded as an argument in favor of the applicability of the "creep of flux" theory to explain the critical currents of such superconductors[1]. It should be noted that by considering the redistribution of the currents in a system of superconducting filaments under the influence of a current and a magnetic field it is also possible to obtain an exponential V(I) dependence.

It is seen from Fig. 8 that at sufficiently large potential differences across the sample, the current I_s flowing through the superconducting phase and determined from (1) does not increase with increasing voltage but, to the contrary starts to decrease. Such a decrease of the current can be due to the increase of the temperature in the volume of the sample. A similar $V(I_s)$ dependence was observed also in[12] in an investigation of the resistive state of short samples of Nb + 25% Zr wire, stabilized by a copper bus. The authors of the cited paper[12] used for R_N in expression (1) the resistance of the copper bus with allowance for its magnetoresistance[2].

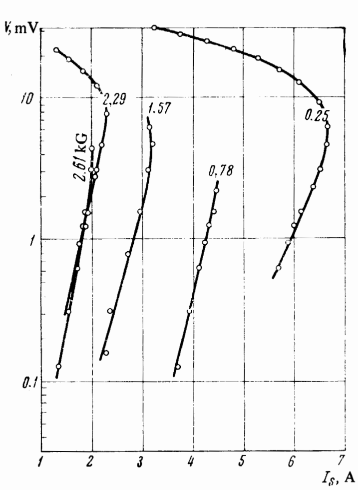

FIG. 8. Dependence of the voltage across a sample of Zr + 4% Nb on the current flowing through the superconducting phase in magnetic fields from 0.25 to 2.61 kOe, T = 4.2°K.

Comparing the form of the transition curves of the 65 BT wire (Fig. 5) and the curves for the Nb + 25% Zr wire from[12] with the transition curves of the Zr + 4% Nb alloy, we see that the properties of the indicated two hard non-single-phase superconductors are very similar to the properties of the superconductor with a stratified-filamentary structure (Zr + 4% Nb). It is therefore quite probable that for such non-single-phase systems it is necessary to use the filamentary model[3] rather than the model of the creep of flux theory.

It should be noted that if it is assumed formally that in the $Pb_{0.83}In_{0.17}$ wire the current in the supercritical region also consists of a current I_{sd} flowing through the inhomogeneities and defects of the lattice, and a current I_f, then it is possible to determine the dependence of V on I_{sd} with the aid of formula (1). In this case I_s is replaced by I_{sd} and R_N is replaced by the resistance R_f corresponding to the viscous flow of the fluxoids, determined from the slope of the quasi-linear section of the transition curve. Within the limits of the measurement accuracy, the voltage across the superconductor V depends exponentially on I_{sd}.

The fact that I_{sd} differs from zero for $Pb_{0.83}In_{0.17}$ in magnetic fields $H > H_{c1}$ is evidence that the samples investigated by us are not ideal superconductors of the second kind. This agrees with the presence of hysteresis on the magnetization curves. It is quite probable that the exponential dependence of V on I_{sd} in the Pb-In alloy is also connected with the stratified-filamentary structure which is conserved in the case of incomplete homogenization.

Summarizing the results, we can note that the behavior of hard non-single-phase superconductors can apparently not be explained with the aid of the fluxoid model of the creep of flux and the viscous flow of fluxoids. More applicable to such superconductors is the filamentary model of the alloy. The exponential dependence of $V(I_s)$, observed for the alloy Zr + 4% Nb, which has a stratified filamentary structure, indicates that such a dependence is not connected with the linked current motion considered in[7]. The V(I) dependences obtained for annealed samples of the Pb-In alloy, which is a homogeneous solid solution, correspond most closely to the fluxoid model. It should be noted, however, that if the current through the sample is represented in the form of a sum of two currents, one of which, I_f, is the current flowing through the

[1]Certain singularities of the filamentary model of hard superconductors were considered in[11].

[2]In the opinion of the authors of [12], the decrease of I_s with increasing potential difference is not connected with heating, since in their experiments the temperature rise of the surface of the copper bus did not exceed several hundredths of a degree. It should be noted that no account was taken here of the temperature jump on the boundary between the superconducting wire and the copper, or of the temperature gradient in the wire itself. It is not excluded that in the case of the Zr + 4% Nb alloy an additional temperature gradient could occur on the boundary of the superconducting filaments.

[3]It should be noted that in [13] the authors reached the conclusion, on the basis of electron-microscope investigations, that Nb + 25% Zr and Nb + 66% Ti alloys have a layered-filamentary structure.

homogeneous part of the alloy, and the other, I_{sd}, is the current flowing through the inhomogeneities and the lattice defects, then an exponential dependence of V on I_{sd} is obtained for the Pb-In alloy. The value of I_{sd} is connected with the magnitude of the hysteresis and should vanish for an ideal sample.

In conclusion we consider it our pleasant duty to thank E. P. Romanov for preparing the samples of the Zr + 4% Nb alloy and Yu. Korbel' for help with the experiment.

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