Critical points of ternary molybdenum chalcogenides

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The critical current density of ternary molybdenum sulfides with composition $M_xMo_6S_8$ were measured by various methods. The obtained value of j_{cr} reaches 2×10^4 A/cm² in an 80-kOe field at 4.2 K. The relatively large values of the critical currents in strong magnetic fields point to the need for a more detailed analysis of the superconductivity mechanism in ternary molybdenum chalcogenides.

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We have already reported[1] measurements of the critical currents of superconducting samples of ternary molybdenum chalcogenides with lead and tin as the third component. The samples on which the measurements were made in[1] were thin superconducting layers produced in the surface of a molybdenum foil. In some cases these layers were removed from the molybdenum foil and measured in the free state. It followed from the results of[1] that the critical currents of the Mo–Pb–S system are relatively large, for example, the critical current density in a magnetic field $H = 100$ kOe exceeded 5×10^2 A/cm². Since, as already noted in[1], the thin layers investigated there were not perfect enough (they could have, for example, microcracks that decreased the measured critical current), it was of interest to carry out current measurements on bulky samples. The current measurements were performed in the present study both by a contact method and by an inductive method at a temperature $T = 4.2$ K. The samples were prepared by the method described by us in earlier papers (see, e.g.,[2]). Samples of the compound were pressed into cylinders of 5 mm diameter and 10 mm long and were sintered in an oven at 1000 °C.

For the contact measurements, we cut out of these cylinders samples measuring 1.5×8 mm, and the end faces of the samples were electrolytically coated with copper to which current and potential contacts were soldered. The measured current density was of the same order as in[1]. However, the obtained weak dependence of the critical current on the magnetic field pointed to a possible influence of the current contacts.

To eliminate the influence of the current contacts we determined the critical-density by measuring the penetration of the magnetic field in a hollow cylinder[2)]; we also measured the density by the inductive method described in[3]. The critical-current densities determined by both methods made were practically the same and exceeded substantially the values obtained by the contact method.

The inductive method described in[3] makes it possible, by using triangular or trapezoidal modulation of the magnetic field (with amplitude from 20 to 250 Oe and frequency $f \approx 10$ Hz) to obtain on the oscilloscope screen the distribution of the magnetic flux inside the sample. It is thus possible to investigate the dependence of the critical current $j_{cr}(r)$ on the radius and to check on the homogeneity of the investigated sample. To increase the accuracy we used in some cases, in lieu of the oscilloscope, the instrument described in[4], which makes it possible to record periodic voltage signals with an x-y recorder. The inductive method has enabled us also to measure the pressure dependence of j_{cr}. In this case the sample with the receiving coil were placed in the beryllium-bronze bomb described in[5].

In the investigation of critical currents of the molybdenum-chalcogenide samples it was observed that the critical current depends strongly on the sample preparation conditions. Thus, for example, the critical current increases with increasing pressure at which the sample was pressed prior to sintering. The dependence of j_{cr} on the pressure took the form of a curve that tends to saturation. Without dwelling on the results of the investigation of the dependence of the critical current on the sample-preparation technology, it should be noted

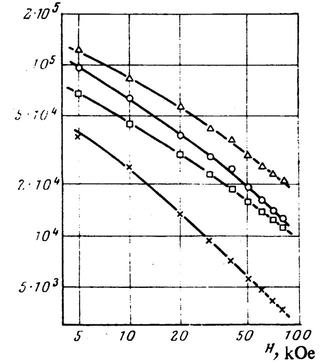

FIG. 1. Critical current density vs magnetic field for molybdenum chalcogenides of several compositions: △—$SnGa_{0.25}Mo_6S_8$, ○—$PbGa_{0.25}Mo_6S_8$, ×—$SnMo_6S_8$, □—$Pb_{1.2}Mo_6S_8$

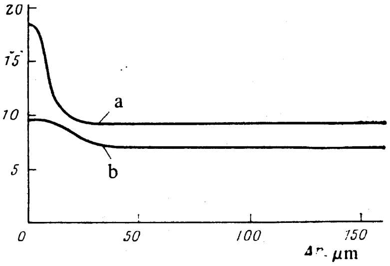

FIG. 2. Critical current density vs distance for the surface for two chalcogenide samples in a magnetic field $H = 80$ kOe: a) $PbGa_{0.7}Mo_6S_8$, b) $PbMo_6S_8$.

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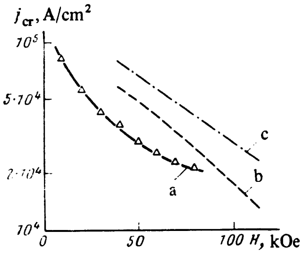

FIG. 3. Comparison of the critical current density of molybdenum chalcogenides with data for Nb_3Sn and V_3Ga ribbons from[6] (the values of j_{cr} in[6] pertain to the total cross section of the ribbon; j_{cr} in the current-carrying layer is approximately four times larger): a) $SnGa_{0.25}Mo_6S_8$, b) Nb_3Sn ribbon, c) V_3Ga ribbon.

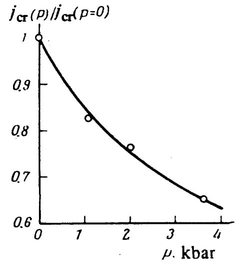

FIG. 4. Relative critical-current density vs. pressure measured for $SnMo_6S_8$ sample in a magnetic field 80 kOe.

that all the results that follow pertain to samples prepared under conditions as close as possible to optimal.

Figure 1 shows the plots of the critical current j_{cr} against the magnetic field H obtained by the inductive method for samples of several compositions. In a number of cases an increase of j_{cr} was observed in the layer next to the surface (see Fig. 2). This indicated that further improvement in the sample preparation technology can yield even larger critical currents than those shown in Fig. 1.

Figure 3 shows the optimal data obtained in the investigation of the critical currents of molybdenum chalcogenide samples in our paper, and also the values of the critical-current density for V_3Ga and Nb_3Sn published in[4]. It is seen from the data that the critical-current density obtained for the investigated chalcogenides (and also for an Mo_6PbS_8 wire) is quite high.

It is difficult to reconcile the high critical-current densities with the point of view of the quasi-zero-dimensional character[7] of the superconductivity of the considered molybdenum chalcogenides. Indeed, although the idea that the superconductivity of these systems is due to the d-electrons of molybdenum clusters is attractive, the localized character of the wave functions of each cluster, which accounts well for the high critical magnetic field, should have two rather low values of the critical-current density precisely because of the weak overlap of the wave functions of the cluster. A "zero-dimensional superconductivity," if it exists at all, should apparently lead to critical currents of the same order as in the case of layered dichalcogenides, when the current is perpendicular to the layer. In accordance with[8] the situation here should be analogous to that in the Josephson effect, and consequently the critical current should be small. It should also be noted that if the wave functions of the molybdenum clusters were indeed to have a local character, then one should expect an increase of the critical current with pressure, in contrast to the decrease we have observed in j_{cr} (see Fig. 4). Thus, the large critical currents call for an additional analysis of the superconductivity mechanism of multicomponent molybdenum chalcogenides.

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2) Since the field frozen in the hollow cylinder underwent no damping, we were able to estimate the upper limit of the sample resistivity at 10^{-16} Ω-cm.

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