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CRITICAL MAGNETIC FIELD OF SUPERCONDUCTING CYLINDRICAL LAYERS OF INDIUM

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This paper presents the temperature-dependences of an external (longitudinal) critical magnetic field for cylindrical films of indium of thicknesses from 0.73×10^{-5} cm to $7.06 \times \times 10^{-5}$ cm obtained by evaporation in high vacuum at room temperature. A determination has been made of the penetration depth of the magnetic field at 0 K.

1. *Introduction*

Thin films of superconductors of thicknesses smaller than the penetration depth of a magnetic field in bulk superconductors ($\lambda_0 \approx 10^{-5}$ cm) differ considerably as regards properties from the bulk materials.

The behaviour of superconducting films deposited on flat substrates in an external magnetic field has been presented in very early Refs [1–4]. The results of experiments carried out by Zavaritski for Sn [5], Tl and In [6], and by Szymaszek for Pb [7] proved to be in good agreement with the theory of Ginzburg and Landau [8]. The theory shows that for superconducting layers of thickness $d \leqslant d_c$, where $d_c = \sqrt{5}\,\lambda$, the relation

$$\frac{H_c}{H_{cb}} = 2\sqrt{6}\,\frac{\lambda}{d} \tag{1}$$

holds, whereas for $d > d_c$ we have

$$\frac{H_c}{H_{cb}} = 1 + \frac{\lambda}{d}. \tag{2}$$

Here, H_c is the critical magnetic field for the thin superconducting film, and H_{cb} is the respective value for the bulk superconductor.

For cylindrical superconducting films of thicknesses smaller than the penetration depth λ, but greater than the coherence distance parameter ξ of the theoıy of Pippard

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[9] or Bardeen, Cooper and Schrieffer [10], the magnitude of the critical magnetic field strength is expressed according to Ginzburg [11] by the relation

$$H_c = \frac{\sqrt{6}\,\lambda_0\,\sqrt{T_c}}{d}\left|\frac{dH_{cb}}{dT}\right|(\Delta T)^{\frac{1}{2}} \tag{3}$$

where d is film thickness, λ_0 is the penetration depth of the magnetic field at 0 K, and T_c is the critical temperature.

Investigations of thin superconducting films of Sn deposited on cylindrical substrates are described in papers by Feigin and Shalnikov [12] and Ginzburg and Shalnikov [13].

Our experiments concern the destruction of superconductivity of thin cylindrical indium films evaporated onto substrates in high vacuum at room temperature by an external magnetic field (parallel to the sample axis).

Cylindrical superconducting films have an advantage over flat films in that there are no edge effects which render difficult any comparison of experimental results with theoretical expectations.

2. Measurements

For the measurements fifteen samples of layer thickness from 0.73×10^{-5} cm to 7.06×10^{-5} cm were prepared from 99.999% pure indium. The film thicknesses were determined on the basis of the known mass of evaporated indium and the fixed experimental geometry. The film thicknesses found thus were compared with values calculated from measurements of the sample resistances.

The samples were used for measuring:

a) the temperature of transition from the normal state to the superconducting state in the absence of any external magnetic field, and

b) the critical (external) magnetic field as a function of temperature.

As a point of reference for determining critical values we took 0.5 of the normal resistance of the sample. Sample resistance was measured by the compensation technique. The current-voltage dependences across the samples due to changes in their temperature and changes of an external magnetic field were recorded on a paper tape.

3. Results of measurements

Figure 1 presents the resistance of the sample with a 2.65×10^{-5} cm thick film as a function of magnetic field in the range of temperature differences up to $\Delta T_{\max} = 1.622$ K, where $\Delta T = T_c - T$, T being the temperature of the measurement.

Transitions from the superconducting state to the normal state ($s \to n$) are reversible for this film thickness up to $\Delta T \approx 0.2$ K. The transition curves of Fig. 1 are steep, which is evidence that the quality of the samples is good. "Hysteresis" is observed when the temperature difference is greater, *i.e.* the $s \to n$ transition takes place at a higher value of magnetic field than in the case of the $n \to s$ transition. On the basis of these characteristics the $H_c = f(\Delta T)$ relationships were found for a number of samples of different film thicknesses.

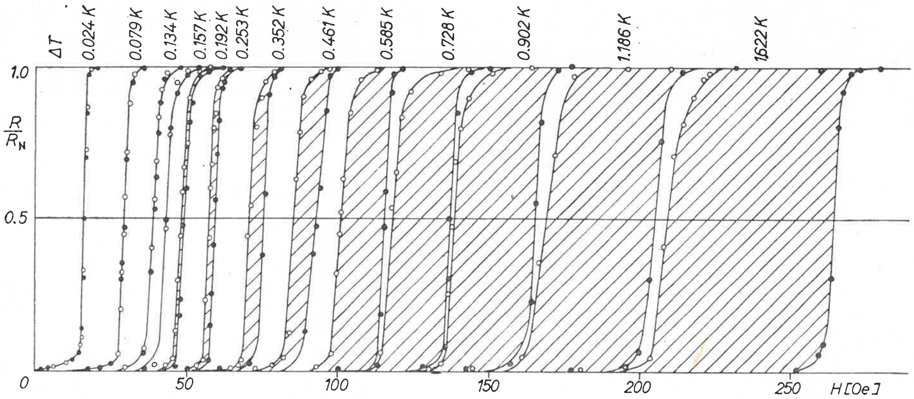

Fig. 1. $\frac{R}{R_N}$ *versus* magnetic field for sample of thickness 2.65×10^{-5} cm. ● — values at rising magnetic field, ○ — values at decreasing magnetic field

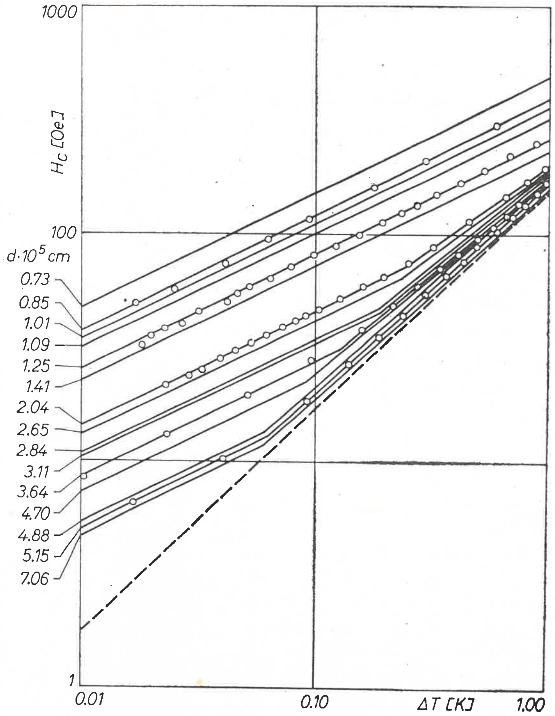

Fig. 2. H_c *versus* ΔT for samples of thicknesses from 0.73×10^{-5} cm to 7.06×10^{-5} cm. Dashed line — $H_{cb} = f(\Delta T)$

These results are shown in Fig. 2. For layers 2.04×10^{-5} cm thick or more there is observed an inflexion in the $H_c = f(\Delta T)$ curves in the range of ΔT from 0.01 K to 1.00 K. Up to the inflexion point the critical value of magnetic field is proportional to $(\Delta T)^{1/2}$, whereas after it the curves become very like the $H_c = f(\Delta T)$ curve for bulk indium. For films of thickness from 0.73×10^{-5} cm to 1.41×10^{-5} cm no inflexion of the curves is observed. Within this range of temperatures H_c is proportional to $(\Delta T)^{1/2}$.

The transition from the superconducting state to the normal state is a second-order phase transition (in the investigated range of temperatures the transition from s to n and back occurs at the same value of magnetic field).

Making use of Eq. (3) the penetration depth of the magnetic field at 0 K was calculated and found to be for indium $\lambda_0 = 0.48 \times 10^{-5}$ cm. According to Zawaritski [6], $\lambda_0 = 0.62 \times 10^{-5}$ cm, whereas Lock [14] gives $\lambda_0 = 0.64 \times 10^{-5}$ cm.

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