ionization relaxation, show that partial equilibrium takes place at $T' > 13000^\circ K$, when $\tau^*/\tau < 1$. Figure 1 shows the equilibrium and non-equilibrium profiles of the layer, and Fig. 2 the brightness temperature of a shock wave in argon. Details of the calculation of the brightness temperature and the results of such a calculation for shock waves in xenon and krypton will be published later.

The author is grateful to M. A. Tskikulin and Yu. P. Raizer for useful discussions.

[1] I. Sh. Model', Zh. Eksp. Teor. Fiz. 32, 714 (1957) [Sov. Phys.-JETP 5, 589 (1957)].

[2] A. E. Voitenko, I. Sh. Model', and I. S. Samodelov, Dokl. Akad. Nauk SSSR 169, 547 (1966) [Sov. Phys.-Dokl. 11, 596 (1967)].

[3] Yu. A. Zatsepin, E. G. Popov, and M. A. Tsikulin, Zh. Eksp. Teor. Fiz. 54, 112 (1968) [Sov. Phys.-JETP 27, 63 (1968)].

[4] Ya. B. Zel'dovich and Yu. P.Raizer, Fizika udarnykh voln i vysokotemperaturnykh gidrodinamicheskikh yavelenii (Physics of Shock Waves and of High-temperature Hydrodynamic Phenomena), Nauka, 1966 [Academic Press, 1966].

[5] Yu. P. Raizer, Zh. Eksp.Teor. Fiz. 33, 101 (1957) [Sov. Phys.-JETP 6, 77 (1958)]

[6] A. N. Zaidel' and E. Ya. Shreider, Spektroskopiya vakuumnogo ul'trafioleta (Spectroscopy of Vacuum Ultraviolet), Nauka, 1967.

[7] E. W. McDaniel, Collision Phenomena in Ionized Gases, Wiley, 1964.

DIFFERENTIAL RESISTANCE OF SUPERCONDUCTORS OF THE SECOND KIND

I. Ya. Fogel', V. G. Volotskaya, L. N. Korovin, and I. M. Dmitrenko
Physico-technical Institute of Low Temperatures, Ukrainian Academy of Sciences

Submitted 16 December 1968
ZhETF Pis. Red. 9, No. 3, 180 - 184 (5 February 1969)

It follows from Abrikosov's theory [1] that a magnetic field penetrates in superconductors of the second kind in the form of vortices. In the form of a transport current, the Lorentz forces cause the vortices to move, and this leads to energy dissipation. If the Lorentz force acting on the vortices greatly exceeds the pinning force, then the vortex motion has the character of a viscous flow. In the region of the viscous flow, the voltage produced in the superconductor depends linearly on the transport current. The differential resistance $\rho_f = dV/dI$ is then connected with the magnetic field by Kim's [2] empirical relation $\rho_f = \rho_n H/H_{c2}(0)$. The value of ρ_f is determined experimentally from the slope of the linear section of the current-voltage characteristic. According to [2], the differential resistance characterizes the volume properties of a superconductor of the second kind.

We have measured the current-voltage characteristics in a wide range of fields, in single-crystal and polycrystalline samples of PbIn alloys with concentrations from 22 to 24 at.% In. The initial components were chosen to be Pb and In of high purity. At these concentrations, the alloys constitute a solid solution with face-centered cubic lattice. The composition of the samples was verified by chemical analysis, and the single-crystal orientation was determined by x-ray diffraction. In all experiments, the long axis of the sample was perpendicular to the direction of the external magnetic field, and the transport current was directed along the sample axis. The measurements were made on samples in the form of round cylinders and plates. The V(I) curves were measured both point-by-point and recorded with a two-coordinate plotting potentiometer.

For all samples, we plotted the critical current I_c and the resistance R against the magnetic field H. It is seen from these plots that surface superconductivity is observed in fields stronger than H_{c2}. The field H_{c2} was determined from the sharp drop of I_c on the $I_c(H)$ curves and from the inflection on the R(H) curves.

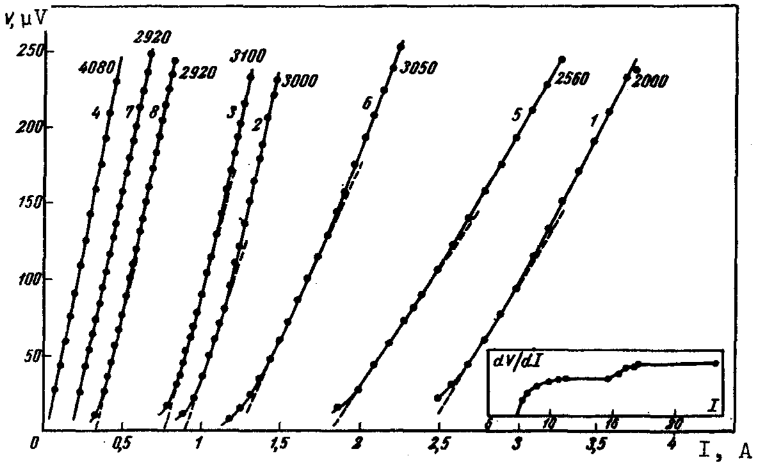

Fig. 1. Current-voltage characteristics for three samples at T = 4.2°K. The dashed lines show extrapolation of the first linear section. Curves 1, 2, 3 4 - single-crystal samples, 24%, In; 5, 6 - polycrystalline sample, 24% In; 7 - plate, 22% In, H perpendicular to the plane of the plate; 8 - pla plate, H at 15° angle to the plane of the sample. The values of the magnetic field (Oe) are shown alongside the curves. The insert on the right shows a plot of dV/dI vs. I in arbitrary units.

Figure 1 shows the current-voltage characteristics of single-crystal and polycrystalline samples (24% In) of cylindrical form at different values of the magnetic field. Judging from the character of the V(I) curves, the resistive state is retained up to the field H_{c3}. On all the current-voltage characteristics plotted in fields weaker than H_{c2}, the initial non-linear region is followed by a linear section, which gives way at larger currents to a second linear section with a somewhat larger slope. In fields exceeding H_{c2}, only the first linear section remains. We have made direct measurements of the derivative dV/dI with the aid of modulation of the transport current by low-frequency alternating current, followed by amplification and detection of the output signal with a synchronous detector. The derivative shows distinctly a plateau parallel to the current axis in the region of the second linear section. However, the first linear section does not appear on the derivative when this differentiation procedure is used. This is caused by the fact that addition of an alternating current, even of the small amplitude necessary to obtain a noticeable signal, leads to a modification of the current-voltage characteristic, whereby the first linear section of the V(I) curve vanishes, and naturally cannot appear on the derivative. In the case of graphic differentiation of the V(I) curves plotted with the aid of the two-coordinate potentiometer ($H < H_{c2}$), a derivative is obtained with two horizontal lines corresponding to the first and second linear sections (insert of Fig. 1).

From the V(I) curves we determined the values of the differential resistance, ρ_{fI} and ρ_{fII} respectively, for the first and second linear sections. The field dependences of ρ_{fI} and ρ_{fII} of a single-crystal sample are shown in Fig. 2. The values of ρ_f are referred to the value of the normal resistance ρ_n. It is seen from the figure that the branches of the differential resistance depend in different manners on the magnetic field. The upper branch, corresponding to ρ_{fII}, terminates in the field H_{c2}, whereas the lower one, corresponding to

ρ_{fI}, continues in the region of fields $>H_{c2}$. Both ρ_f branches depend linearly on the field in weak fields, but the curves do not go to zero, since the demagnetizing factor of the sample does not equal unity. The two ρ_f branches are observed for all cylindrical samples, both single-crystal and polycrystalline.

The character of the dependence of ρ_f on H makes it possible to connected the lower ρ_f branch with surface properties, and the upper one with volume properties. At currents not much higher than critical, the transport current flows apparently predominantly in the surface layer, and the differential resistance is determined by the properties of this layer. When the current increases, the transport current becomes redistributed in the volume (when $H_{c1} < H < H_{c2}$), and the flow of the vortices is determined already by the volume properties of the superconductor. When $H_{c2} < H < H_{c3}$ in the surface layer, according to Kulik [3], if the field is inclined to the surface at a small angle, a vortex structure is produced, and a resistive state connected with the motion of this structure is possible. Such a resistive state is observed indeed in cylindrical samples, for such a geometry always provides for surface sections to which the field is inclined at a small angle. Inasmuch as only one linear section is observed for plates in a perpendicular field [2, 4, 5], it can be assumed that the appearance of a resistive surface layers in fields $<H_{c2}$ is also connected with the existence of an appreciable field component parallel to the sample surface. This assumption is confirmed by our measurements on a flat plate (22% In). Just as in the investigations by others, only one linear section is observed on the current-voltage characteristics when the field is perpendicular to the plane of the sample (curve 7, Fig. 1). At angles 5 and 15° between the plane and the magnetic field ($H \perp I$), we observe again two slopes (curve 8, Fig. 1). We know of only one investigation of the dependence of ρ_f on H at various inclinations of the magnetic field to the plane of the sample [6]. The $\rho_f(H)$ curves given in that paper for small angles are similar to our $\rho_{fI}(H)$ plots. It can be assumed that only the first linear section was observed in that case.

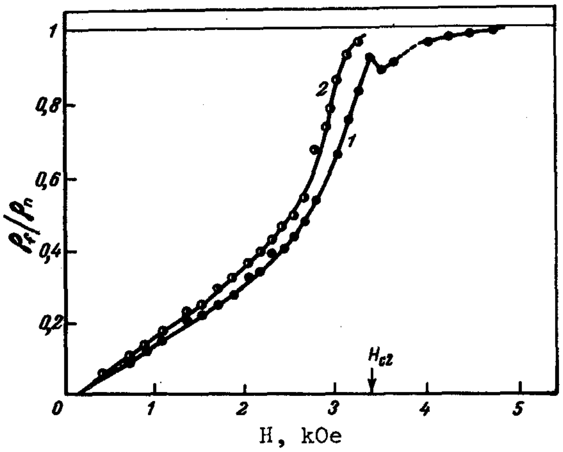

Fig. 2. Plot of ρ_{fI} and ρ_{fII} (curves 1 and 2) vs. the magnetic field for single-crystal sample (24% In), T = 4.2°K.

We can state on the basis of our data not only that the critical current is a surface one, as proposed by Swartz and Hart [6], but also that a current somewhat larger than critical flows in the surface layer. The current flowing in the entire sample greatly exceeds I_c. Thus, the distribution of the transport current in the sample at a fixed external magnetic field depends on the value of the current.

The authors are grateful to I. O. Kulik and V. P.Galaiko for useful discussions.

[1] A. A. Abrikosov, Zh. Eksp. Teor. Fiz. 32, 1442 (1957) [Sov. Phys.-JETP 5, 1174 (1957)].
[2] Y. B. Kim, C. F. Hempstead, and A. R. Strnad, Phys. Rev. 139A, 1163 (1965).

[3] I. O. Kulik, Zh. Eksp.Teor. Fiz. 55, 889 (1968) [Sov. Phys.-JETP 28 (1969)].
[4] W. C. H. Joiner, Phys. Rev. Lett. 19, 895 (1967).
[5] H. Van Beelen, I. P. Van Braam Houckgeest, H. M. Thomas, S. Stolk, and R. deBruyn Ouboter, Physica 36, 241 (1967).
[6] P. S. Swartz, H. R. Hart, Phys. Rev. 137A, 818 (1965).

ANISOTROPY OF POLARIZED-LIGHT ABSORPTION PRODUCED IN GaAs AND CdTe CRYSTALS BY A STRONG ELECTRIC FIELD

V. S. Bagaev, Yu. N. Berozashvili, and L. V. Keldysh
P. N. Lebedev Physics Institute, USSR Academy of Sciences; Cybernetics Institute, Georgian Academy of Sciences
Submitted 18 December 1968
ZhETF Pis. Red. 9, No. 3, 185 - 188 (5 February 1969)

We investigated the light-absorption anisotropy produced by a strong electric field near the intrinsic absorption edge in cubic semiconductors. We shall show that the absorption coefficients $\alpha_{\parallel}$ and $\alpha_{\perp}$ of light polarized parallel and perpendicular to the electric field, respectively, can differ by several times, and that their frequency dependence is also different.

Experimental Results and Discussion

We measured the change of the transmission of polarized light in GaAs and CdTe crystals following application of an alternating electric field. The measured samples were placed in a capacitor so constructed that its electric field was always in a plane perpendicular to the direction of the incident light. After passing through an IKS-12 spectrometer, the light was polarized with a polaroid film. The light polarized either parallel or perpendicular to the electric field was passed through the sample, which was placed in the capacitor. An alternating voltage of 1 kHz frequency was applied to the capacitors. The measurements were made at T = 100°C on high-resistivity ($\rho \sim 10^7 - 10^8$ ohm-cm at 300°K) single-crystal non-oriented GaAs and CdTe samples. We measured directly the change of the intensity ΔI of the transmitted light, due to the shift of the absorption edge in the strong electric field. Simultaneous measurement of the amount of light I_0 passing through the crystal in the absence of the electric field has made it possible to calculate the change $\Delta\alpha$ of the absorption coefficient, using the relation

$$\Delta\alpha \simeq -\frac{1}{L}\ln\left(1-\frac{\Delta I}{I_0}\right), \qquad (1)$$

where L is the crystal thickness.

It should be noted that the values given for the electric field intensity are not exact. The presence of thin air gaps, which were filled with silicone oil in the capacitor, and whose thickness is difficult to measure, may give rise to an error in the estimate of the electric field intensity.

The anisotropy of light absorption and its freqeuncy dependence is best revealed by plotting the ratio of $\Delta\alpha_{\parallel}$ to $\Delta\alpha_{\perp}$ against $\hbar\omega$. Namely, in the case of GaAs (see Fig. 1), $\Delta\alpha_{\parallel}$ may be twice as large as $\Delta\alpha_{\perp}$ for light-quantum energies 0.15 eV away from the edge, and $\Delta\alpha_{\perp}$