MEETINGS AND CONFERENCES

Scientific Session of the Division of General Physics and Astronomy, USSR Academy of Sciences (April 25-26, 1973)

A scientific session of the Division of General Physics and Astronomy of the USSR Academy of Sciences was held in the conference hall of the P. N. Lebedev Physics Institute on 25 and 26 April 1973. The following papers were delivered:

1. L. N. Bulaevskiĭ, Layered Superconductors with Josephson Interaction of the Layers.

2. A. I. Golovashkin and G. P. Motulevich, Electron and Phonon Characteristics of Nb_3Sn.

3. V. M. Galitskiĭ, V. F. Elesin, D. A. Kirzhnits, Yu. V. Kopaev, and R. Kh. Timerov, Possibility of Superconductivity in Nonequilibrium Systems with Repulsion.

4. M. I. Gvozdev, N. A. Dimov, N. L. Zhernokleev, P. D. Kalechev, Yu. L. Kokurin, T. I. Marchenko, E. P. Orlov, and V. A. Sautkin, Multielement Large Optical Telescope with Controllable Mirror Shape.

5. I. A. Viktorov, Ultrasonic and Hypersonic Surface Waves.

6. V. B. Braginskiĭ, A. B. Manukin, E. I. Popov, V. N. Rudenko, and A. A. Khorev, Upper Limit of Gravitational Radiation of Extraterrestrial Origin.

We publish below a brief content of five papers.

L. N. Bulaevskiĭ. Layered Superconductors with Josephson Interaction of the Layers. When layered compounds of the type TaS_2 are intercalated with molecules it is possible to obtain superconductors with Josephson interaction of the layers. In the case of the hopping mechanism of conductivity, an interaction of this type between the layers is realized if the condition

$$\hbar/\tau_\perp \ll \Delta(T) \tag{1}$$

is satisfied, where $\tau_\perp$ is the time between the hops of the electron from one layer to the neighboring layer and $\Delta(T)$ is the superconducting gap at the temperature T. Superconductors in which the condition (1) is satisfied will be called layered superconductors with Josephson interaction of the layers (LSJI). According to data on the electronic specific heat and on the resistivity across the layers of $TaS_2(Py)_{1/2}$, the condition (1) is satisfied in practically the entire temperature interval below $T_c = 3.25°K$, since $\hbar/\tau_1 < 0.2°K$.

Using differential-difference equations of the Ginzburg-Landau type it is possible to obtain the structure of the vortex filament in LSJI. In a magnetic field parallel to the layers, in the center of the vortex filament, the superconductivity inside the layers is not destroyed (unlike the vortex filament of ordinary type-II superconductors), and the magnetic field in the center of the filament is limited because of the nonlinear relation between the Josephson current and the vector potential. For the lower critical field $H_{c1}(\parallel)$ we obtain

$$H_{c1}(\parallel) = \frac{\Phi_0}{4\pi\lambda_L\lambda_J}\ln\frac{\lambda_L}{d}, \tag{2}$$

where λ_L and λ_j are the London and Josephson lengths, respectively, Φ_0 is the magnetic-flux quantum, and d is the distance between the conducting layers. In a field perpendicular to the layers, the structure of the filament and the expression for $H_{c1}(\perp)$ remain the same as usual.

For the mechanism whereby the superconducting phase is destroyed in a magnetic field and for a determination of the upper critical field H_{c2} in LSJI, an important role is played by the fact that the system is quasi-two-dimensional, owing to the Josephson interaction of the layers. If the condition (1) is satisfied, then the field H_{c2} can be obtained without taking into account the motion of the electrons between the layers, and is determined only by the orbital effect in the field perpendicular to the layers and by the paramagnetic effect. In pure LSJI, at field directions close to parallel and at temperatures $T < 0.55\ T_c$, an inhomogeneous state is realized, corresponding in LSJI to the situation in which the Cooper pairs in the field H_{c2} are not on the lower Landau orbit. The dependence of H_{c2} on the angle θ between the direction of the field and the plane of the layers turns out to be very abrupt and nonmonotonic at small θ, and oscillations connected with the realization of the different Landau orbits for the motion of the Cooper pair in the magnetic field appear as $\theta \to 0$ against the background of the increasing H_{c2}. At $T = 0$, the parallel critical field ($\theta = 0$) turns out to be equal to $\sqrt{2}H_p = 2\Delta(0)/g\mu_B$. In dirty LSJI, the inhomogeneous state is not realized, but for field directions close to parallel, the transition from the superconducting state to the normal state turns out to be of first order with increasing field.

The anisotropy of the upper critical field was measured in $TaS_2(Py)_{1/2}$, and the experimental data confirm the hypothesis of Josephson interaction between the layers in $TaS_2(Py)_{1/2}$.

A nonstationary Josephson effect should be observed in LSJI, i.e., when a constant potential difference V is applied perpendicular to the layers, an alternating current should appear in the system at the frequency $\omega = 2eV/\hbar N$, where N is the number of layers between which the voltage V is applied.

The material covered by the paper was published in Zh. Eksp. Teor. Fiz. (64, 2241 (1973); Sov. Phys. JETP 37, No. 6 (1973), and was submitted to "Physics Letters" and to Zh. Eksp. Teor. Fiz. (65 (1973)).

---

[1] A. I. Larkin and Yu. N. Ovchinnikov, Zh. Eksp. Teor. Fiz. 47, 1136 (1964) [Sov. Phys.-JETP 20, 762 (1965)].

[2] P. Fulde, R. A. Ferrell, Phys. Rev. A135, 550 (1964).

[3] L. W. Gruenberg, L. Gunther, Phys. Rev. Lett. 16, 996 (1966).
[4] D. Saint-James et al. Type-II Superconductivity, Pergamon.
[5] I. O. Kulik and I. K. Yanson, Éffekt Dzhozefsona v sverprovodyashchikh tunnel'nykh strukturakh (Josephson Effect in Superconducting Tunnel Structures, Nauka, 1970.
[6] F. R. Gamble, I. H. Osiecki, F. J. Di Salvo, J. Chem. Phys. 55, 3525 (1971).
[7] F. J. Di Salvo, R. Schwall, T. H. Geballe, F. R. Gamble, I. H. Osiecki, Phys. Rev. Lett. 27, 310 (1971).
[8] A. H. Thompson, F. R. Gamble, R. F. Koehler, Jr., Phys. Rev. B5, 2811 (1972).
[9] R. C. Morris, R. V. Coleman, ibid. B7, 991.

A. I. Golovashkin and G. P. Motulevich. Electron and Phonon Characteristics of Nb_3Sn. Optical and tunnel investigations of the superconducting Nb_3Sn, which has high critical parameters, were carried out in the Optics Laboratory of the Lebedev Physics Institute.

1. The Nb_3Sn films were prepared by simultaneous evaporation of Nb and Sn in a vacuum of 5×10^{-6} mm Hg[1,2]. It turned out that an ultrahigh vacuum is essential to obtain Nb_3Sn films with extremely high critical parameters. The film thicknesses were 0.03–2 μ. The main measurements were performed on films 0.5–2 μ thick. The films had mirror surfaces. The surface layer was not distorted by hardening or by oxidation, so that the optical constants and the tunnel characteristics pertain to the undistorted metal. The static characteristics practically coincided with the characteristics of the bulk metal. An x-ray investigation of the samples has shown that they contain only the A-15 phase. The superconducting transition temperature was $T_c = 17.3 - 18.3$°K. The width of the transition was $\Delta T = 0.1 - 0.3$°K. The critical-current density was $j_c \gtrsim 5 \times 10^5$ A/cm² in a zero magnetic field.

2. The optical constants n and κ ($n - i\kappa$ is the complex refractive index) were measured by a polarization method in the wavelength interval $\lambda = 0.4 - 10$ μ[3]. The dielectric constant $\epsilon = n^2 - \kappa^2$ and the optical conductivity $\sigma = 2n\kappa/\lambda$ were calculated.

The contributions to ε and σ from the conduction electrons and to interband transitions were separated. The following characteristics of the conduction electrons were obtained: conduction-electron concentration $N = 1.1 \times 10^{22}$ cm^{-3}, $N/N_{val} = 0.04$ (N_{val} is the concentration of the valence electrons), average electron velocity on the Fermi surface $v_F = 0.48 \times 10^8$ cm/sec, total area of Fermi surface $S_F = 1.1 \times 10^{-37}$ g²cm² sec^{-2}, and effective electron collision frequency $\nu = 1.85 \times 10^{14}$ sec^{-1}. The small value of N is due to the large number of Bragg planes intersecting the Fermi surface. (The Fermi surface is intersected by 102 planes constituting six physically nonequivalent systems).

The characteristics obtained for the interband transitions are listed in Table I. In the table, ω_{max} is the frequency corresponding to the maximum of the interband-transition band, σ_{max} is the conductivity at the frequency ω_{max}, ν_g is a dimensionless relaxation parameter[4], and V_g are the Fourier components of the pseudopotential and correspond to the Bragg planes with indices g. The six principal bands of the interband conductivity were determined experimentally. The number of the bands and the values of V_g point to a hybridization of all the valence electrons and to applicability of the pseudopotential approximation. The optical data show that the density of the electronic states near the Fermi surface is not anomalously large. This seems to contradict the results of measurements of the specific heat, and the reason for the contradiction are discussed below.

Optical measurements have made it possible to determine the electron-phonon interaction constant λ_{ep}.[5,6] For our Nb_3Sn layers we obtained $\lambda_{ep} = 0.46$. Using McMillan's formula for T_c,[7] we obtain $\mu^* = -0.12$. The negative value of the effective Coulomb potential μ^* can indicate the presence of an additional non-phonon superconductivity mechanism, or an appreciable increase of λ_{ep} with decreasing temperature[1], or else that McMillan's formula does not hold for Nb_3Sn.

3. We measured the dependence of I, dI/dV and d²I/dV² on V (I is the tunnel current and V is the voltage) for tunnel junctions of Nb_3Sn with Pb, Sn, Al, and Nb_3Sn. The tunnel barriers were either the natural oxide of Nb_3Sn or Al_2O_3 layers. We investigated both freshly prepared and electrically polished Nb_3Sn films. The electron mean free path in these films was ~ 100 Å. Four values of the energy gap 2Δ were obtained and are given in Tbble II[8]. The maximum of the tunnel density of states occurs in the region of the second and third gaps ($2\Delta_{eff} = 1.9$ meV). The ratios $2\Delta/kT_c$ for all the gaps were smaller than predicted by the BCS theory. One gap was anomalously small. The presence of different gaps is apparently connected with the anisotropy of the Nb_3Sn gap.

Information on the effective phonon spectrum of Nb_3Sn was obtained from the plot of d²I/dV² against V, which is shown in the figure[9]. The minima of d²I/dV² correspond to the maxima of the function α^2F, where F is the phonon density of states and α is the effective electron-phonon coupling constant. It is seen from the figure that the phonon spectrum of Nb_3Sn is complicated and consists of 12 maxima. Some of them are low-

TABLE I. Parameters of interband transitions of Nb_3Sn

Band number	$\hbar\omega_{max}$, eV	ν_g	σ_{max}, 10^{14} sec^{-1}	$\lvert V_g \rvert$, eV	g	Band number	$\hbar\omega_{max}$, eV	ν_g	σ_{max}, 10^{14} sec^{-1}	$\lvert V_g \rvert$, eV	g
1	0.155	0.2	37.0	0.07	110	4	0.95	0.7	10.5	0.32	211
2	0.21	0.3	45.0	0.09	220	5	1.8	0.3	9.0	0.76	210
3	0.40	0.08	8.5	0.19	310	6	3.0	0.25	8.5	1.30	200

TABLE II. Energy gaps of Nb_3Sn at T ≈ 2°K

Gap number	$\frac{2\Delta}{e}$, mV	$\frac{2\Delta}{kT_c}$	Gap number	$\frac{2\Delta}{e}$, mV	$\frac{2\Delta}{kT_c}$
1	4.70±0.04	3.0	3	1.50±0.04	1.0
2	2.24±0.04	1.4	4	0.36±0.04	0.2