INVESTIGATION OF THE TUNNEL EFFECT IN LEAD AND THALLIUM UNDER PRESSURE

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A study was made of the usefulness of the tunnel effect in investigations of the superconductivity under pressure. Experimental results were obtained for lead and thallium films in superconductor-barrier-superconductor (S-I-S) tunnel systems at pressures up to 14 kbar. Data were obtained on the energy gap and characteristic frequencies of the phonon spectrum. Thick ($d > \xi_0$) films of lead, exhibiting a gap anisotropy, were investigated. It was found that this anisotropy was not greatly affected by the applied pressure.

1. INTRODUCTION

THE principal properties of the superconducting state can be described by the idealized Bardeen-Cooper-Schrieffer model[1] with an isotropic Fermi surface and an isotropic energy gap, which is in good agreement with numerous experimental results. However, there are discrepancies between the experimental data and this model. They include, for example, a structure in the tunnel density of states of some superconductors,[2] an energy gap anisotropy,[3] a departure from the law of corresponding states observed for many superconductors ($2\Delta/kT_c \neq 3.52$), etc. Recently started investigations of the tunneling of electrons through lead under pressure have already resulted in the discovery of a change in $2\Delta/kT_c$, caused by the compression of the lead, which is a superconductor with a strong electron-phonon interaction.[4-6]

The use of the tunnel effect in studies of the superconductivity under hydrostatic pressure opens up new possibilities because the tunneling of electrons can give detailed information on the microscopic properties of a superconductor. It is known that the differential conductivity of a tunnel contact is directly proportional to the density of states in a superconductor:

$$\sigma=\left(\frac{dI}{dU}\right)_S \Big/ \left(\frac{dI}{dU}\right)_N=\frac{N_S}{N_N}=\operatorname{Re}\frac{|\omega|}{[\omega^2-\Delta^2(\omega)]^{1/2}}, \qquad (1)$$

where N_S and N_N are the densities of states in the superconducting and normal states, $\Delta\omega$ is a complex energy-gap parameter,[7] and all the energies ω are measured from the Fermi level. Developments of the theory of tunneling have established[8-10] that the critical points in the phonon spectrum may be resolved easily as singularities in the second derivatives of the conductivity, i.e., in the dependence of $d\sigma/dU$ on U. The influence of the phonon spectrum on the superconducting density of states has been demonstrated convincingly in several experiments.[2, 11-13] Rowell and McMillan[14] demonstrated that the tunnel-effect data can be used to find the function $\alpha^2(\omega)F(\omega)$, where $\alpha^2(\omega)$ is the intensity of the electron-phonon interaction and $F(\omega)$ is the energy distribution function of phonons. Finally, the experiments of Zavaritskiĭ[15] have shown that the tunnel effect approach is fruitful in investigations of the energy gap anisotropy.

The greatest sensitivity to changes in the energy spectrum is exhibited by tunnel systems of the superconductor-barrier-superconductor (S-I-S) type.[7] The present authors investigated such systems and the effect of pressure on the energy gap of superconducting films of lead, tin, indium, and thallium.[4,16,17]

The present paper reports new results obtained in an investigation of the tunnel density of states in lead and the first data resulting from a study of the gap anisotropy of lead and of the phonon spectrum of thallium under pressure.

2. EXPERIMENTAL TECHNIQUE

The technique used in the fabrication of thin-film Al-I-Pb or Al-I-Tl tunnel diodes was described in our earlier papers.[4,17] In contrast to the investigation reported in[4], the lead was evaporated onto a glass substrate kept at room temperature. This was particularly important in the observation of the anisotropy effects which were sensitive to the scattering by grain boundaries. An improvement in the technique of the preparation of the thallium diodes enabled us to store these diodes for a long time (5–10 days) at room temperature. This procedure ensured that the phonon singularities in the tunnel characteristics were clearly revealed; it also improved the quality of a barrier from the point of view of its suitability in investigations under pressure. The initial resistances of the junctions (at P = 0) were within the range 50–500 Ω.

The tunnel density of states and the phonon singularities were investigated using a modulation bridge method, similar to that described in[18]. The phonon effects were recorded at modulation levels amounting to 40–150 μV and the gap phenomena were recorded at levels of 1–10 μV. The modulation frequencies were 383 and 766 Hz. All the characteristics were plotted by an X-Y automatic recorder of the ÉPP-09 type. The static bias across a sample was measured by a high-resistance potentiometer to within ~1 μV.

The high pressures were produced in a bomb filled with a kerosene-oil mixture[19]; they were measured using the shift of the critical temperature of an indium