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…ffect of High Pressure on the Energy Gap of Indium and Thallium Superconducting Films

By

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… effect of high pressure (up to 15000 atm) on the energy gap of In and Tl supercon…g films was investigated by the tunnel effect on superconductor–barrier–superconduc…stems. As directly found in the experiments, the In values $2\,\Delta/kT_c$ indicate a reduc… the electron–phonon interaction under pressure for this metal. In the range up to … the value $2\,\Delta/kT_c$ for Tl remained constant within the experimental error and was … to be 3.64 ± 0.06.

…етодом туннельного эффекта на системах сверхпроводник–барьер–сверх…водник изучалось влияние высоких (до 15000 атм) давлений на энергети…ую щель сверхпроводящих пленок In и Tl. Непосредственно найденные …экспериментах значения $2\,\Delta/kT_c$ для индия указывают на ослабление элек…фононного взаимодействия под давлением для этого металла. Для таллия …ласти давлений до 8 катм в пределах погрешности эксперимента величина …T_c оставалась постоянной и составляла $3{,}64 \pm 0{,}06$.

1. Introduction

The central part of microscopic theory of superconductivity [1] is the presence …an energy gap in the spectrum of elementary excitations:

$$\Delta = \frac{\hbar\,\omega}{\sinh\left(\frac{1}{N\,V}\right)}\,, \tag{1}$$

…here ω and V are cut-off frequency and interaction strength, respectively, … is the state density on the Fermi surface. In this theory the energy gap is …upled with the critical temperature by the universal relation

$$\frac{2\,\Delta}{kT_c} = 3.528\,. \tag{2}$$

…is value characterizes the electron–phonon interaction strength which …ers for real superconductors from 3.528, reaching a maximum value of 4.6 … Hg [2].

It is interesting to investigate the influence of different factors on $2\,\Delta/kT_c$ … one crystal modification. In this respect high pressures as a method are …st perspective.

In all investigations concerning pressure influence on supercondu... main attention is given to the change of the critical temperature T_c and ... magnetic field H_c [3]. In [4] it was considered that $2\,\Delta/kT_c$ does not ch... with pressure.

One of the direct experimental methods for the study of the energy ga... superconductors is the electron tunnelling technique. Possibilities of ... finest instrument allowed to find out a change of $2\,\Delta/kT_c$ with pressure at ... for Pb [5] and then less for Sn [6].

This paper presents results on tunnelling investigations of the energy gap ... In and Tl under pressure.

2. Experimental Technique

2.1 Samples

As is known [7] the best gaps can be obtained on superconductor–barr... superconductor tunnel systems. This made superconducting diodes useful ... investigations under pressure. Of all systems investigated the best are p... prepared on Al base, i.e. an Al–Al_2O_3 superconductor.

Al–I–In and Al–I–Tl samples were prepared by deposition in high (1×10^{-6} T... vacuum on a cooled (up to 80 to 100 °K) glass slide 4×16 mm². There w... three junctions on one slide, each $1_{Al}\times0.5_{In,Tl}$ mm² (Fig. 1). To avoid ed... effects films were deposited through stencils supported by an electromagn... Junction quality in the sense of fitness for their use in pressure measurem... much depended on condensation and oxidation conditions of the Al fi... Aluminium was sprayed from a tungsten U-vaporizer. During deposition th... vacuum did not become worse due to preliminary long annealing (up to vacuu... restoration) of the vaporizer and the hinge. Oxidation took place in the atmo... phere of dry air at a pressure of 0.2 Torr for 5 min. Sample preparation wa... controlled by film and junction resistance measurements both during deposit... and subsequent heating up to room temperatures. Junctions with resistan... 50 to 100 Ω were chosen. Al–I–Tl samples were covered with Si monoxide ... about 1 μm thickness. In and Tl film thickness was determined by Linnik... microinterferometer MII-4 and was equal to (1000 ± 100) Å. For Tl film... $\frac{R_{300}}{R_{4.2}} = 14$ to 18.

Al films had resistivities of 4000 to 6400 Ω mm², and their initial critical temperature varied from 1.65 to 2 °K.

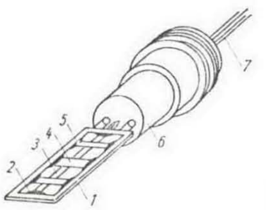


Fig. 1. Tunnel sample and obturator. 1 Sample holder made of getinax, 2 indium contacts, 3 Al film, 4 In and Tl films, 5 cove... glass, 6 obturator, 7 electrical wires

2.2 High pressure technique

...igh pressure bomb with kerosene–oil mixture [8] was used in all investi...s. Pressure was created at room temperature and controlled by a hydraulic ...ure manometer. Here an almost linear change of tunnel junction resistance ...for $R(0) = 100\ \Omega$, $dR/dp = 6\ \Omega$/katm) was a reliable indication. Sensiti...of junction resistance to pressures gave the possibility of rejecting samples ...re immersing into liquid helium. The final pressure in the bomb at low ...peratures was calculated from T_c changes of an In wire [9]:

$$T_c = 4.36\times10^{-5}\,p + 5.2\times10^{-10}\,p^2.$$

...lectrical conductors were introduced into the obturator, this allowed mea...rements to be carried out simultaneously, by means of a 4-probe system, ...the critical temperature of films, the In wire, and corresponding tunnel ...aracteristics.

2.3 Cryogenics and measuring apparatus

Low temperature measurements were carried out in a metal cryostat where ...was possible to get temperatures from 4.2 to 1.15 °K. The bomb with samples ...s in liquid helium.

During the experiments the voltage–current characteristic was measured both ...constant voltage and constant current conditions. Depending on the con...ion dI/dU or (dU/dI)–U at a modulation frequency of 383 Hz were plotted. All tunnel characteristics were recorded automatically on a X–Y coordinate ...PP-09-type register. Constant voltage at a sample was measured by a high-...mic potentiometer to within ≈ 1 μV during recording.

3. Results and Discussion

Indium: After preparation Al–I–In samples were annealed for some days ...t room temperature. The critical temperature of In films practically did not ...ffer from T_c for massive pure indium. The halfwidth of the superconducting ...nsition did not exceed 0.01 °K for all pressures. Table 1 gives the change of ...itical temperature for the film which is found to be

$$\frac{dT_c}{dp} = -\,(3.65 \pm 0.15)\times10^{-5}\,\frac{°K}{atm},$$

Table 1

T_c and $2\,\Delta$ of indium under pressure

p (katm)	T_c (∓ 0.01 °K)	$t = \frac{T}{T_c}$	$2\,\Delta(p,t)$ (∓ 0.01 meV)	$2\,\Delta/kT_c$ (p, t)	$2\,\Delta(p,0)$ (meV)	$2\,\Delta/kT_c$ (p, 0)
0	3.42	0.342	1.090	3.69	1.09	3.69
5	3.23	0.36	1.01	3.63	1.02	3.66
7	3.15	0.372	0.982	3.62	0.99	3.64
7.9	3.13	0.374	0.974	3.61	0.98	3.64
10.5	3.03	0.387	0.930	3.57	0.94	3.60
14	2.91	0.4	0.880	3.51	0.89	3.55

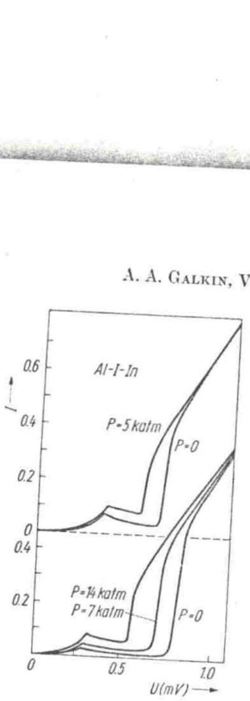


Fig. 2. Current–voltage characteristics of Al–I–In samples at different pressures. $T = (1.17 \pm 0.02)$ °K; normalized units are along the I-axis

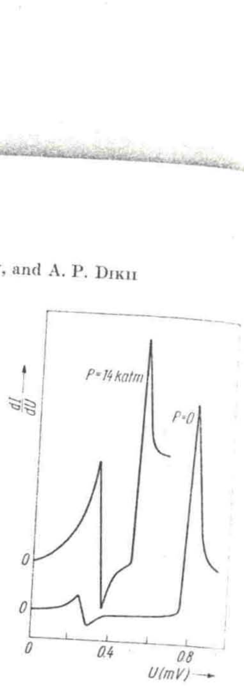


Fig. 3. dI/dU–U characteristics of Al–I–In samples at different pressures. $T = (1.16 \pm 0.02)$ °K

where the error does not include the inaccuracy in pressure measurement. Such T_c change of In films with pressure excellently coincides with Berman, Brandt, and Ginzburg's measurements [10] on massive indium.

Fig. 2 shows voltage–current characteristics for two Al–I–In samples plotted at different pressures. The energy gap was defined from the maxima of the (dI/dU)–U characteristics (Fig. 3).

Fig. 4 shows the result of high pressure influence on the energy gap of indium. For comparison the $2\,\Delta(p) = 3.69\,kT_c$ line is drawn which in fact corresponds to the critical temperature change. The gap values obtained by extrapolating $2\Delta(T)$ to $T = 0$ °K are also included in Table 1. From experiments it is found

$$\frac{d\,2\Delta}{dp} = -(1.43 \pm 0.13)\times 10^{-5}\,\frac{\text{meV}}{\text{atm}}.$$

The energy gap of In at zero pressure, $2\,\Delta(0.0) = (3.69 \pm 0.04)\,kT_c$, is in good agreement with data obtained from precision measurements of critical field curves [11], where the coefficient defining a deviation from the parabola was found to be

$$a_{\text{In}} = 2\,\pi\,\gamma\,\frac{T_c^2}{H_0^2} = 0.985 \quad (3)$$

where

$$\gamma = \frac{2}{3}\pi^2 k^2 N\,. \quad (4)$$

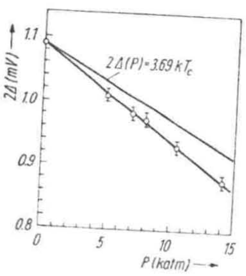


Fig. 4. Change of the superconducting indium energy gap under pressure. o experimental points

the basis of the thermodynamic relation [1]

$$\Delta = k\sqrt{\frac{\pi}{6\gamma}}\,H_0 \quad (5)$$

(3) we have

$$\frac{\Delta}{kT_c} = 1.82\,a^{-\frac{1}{2}}. \quad (6)$$

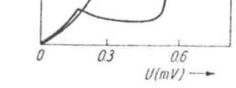
n from our experiments it follows that the parameter a increases with ure from 0.985 to 1.04 ($p = 14$ katm), i.e. it approaches the BCS case. imenta points $\Delta h = h - (1 - t^2)$ given in [10] for indium clearly show dency to the above mentioned increase of a with pressure (see Fig. 6 in In principle on the basis of (5) one may estimate the change of state ty N with pressure. Using our gap data and those of $H_0(p)$ from [10], tate density seems to decrease by no more than 2% at 14 katm.

allium: Because of quick oxidation of Tl films Al–I–Tl samples were ged in the bomb immediately after preparation, and control measurement mall pressure were carried out after some compression cycles. After such cedure the film critical temperature was (2.38 ± 0.01) °K at zero pressure. energy gap here is $2\,\Delta(0.0) = (0.75 \pm 0.01)$ meV $= (3.65 \pm 0.06)\,kT_c$, t is in good agreement with Clark's recent measurements [12].

the small pressure range (2000 to 4000 atm) the anomalous change of al temperature typical of massive pure Tl [13] was not observed. The al temperature linearly decreased up to (2.34 ± 0.01) °K at $p = 8$ katm in qualitative agreement with Gey's data [14] on the dependence of T_c of Tl on residual resistance produced by plastic deformation at different sures.

g. 5 shows I–U characteristics for Al–I–Tl at different pressures. The gap e obtained at 8 katm, $2\,\Delta(8.0) = (0.73 \pm 0.01)$ meV $= (3.64 \pm 0.06)\,kT_c$, ws rather weak dependence in this pressure range. However, this does not lude the possibility that $2\,\Delta/kT_c$ changes for llium at higher pressures. Work in this direc- is in progress.

he main result of gap tunnelling measurements uperconductors under pressure is that the t of $2\,\Delta/kT_c$ decrease initially discovered on which is a representative of superconductors h strong electron–phonon interaction, shows erent dependence on superconductors with rmediate coupling: In, Sn, and perhaps Tl. This umstance makes theoretical investigations essary to obtain a relation connecting the gap



5. Voltage–current characteristics of Al–I–Tl samples at different ures, $T = (1.16 \pm 0.02)$ °K; normalized units are along the I-axis

and critical temperature, taking account of the real energy spectru superconductor, in a manner proposed by Geilikman and Kresin [15 explaining anomalous superconductor properties.

In conclusion we note that in all our experiments dT_c/dp of superfi minium films was always larger than for massive material [16] and varie 3 to 4×10^{-5} °K/atm for different films.[1])

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Subject classification: 10; 22.5.2

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The Dislocation Structure of Glide Bands in LiF Crystals Stressed at $T = 300$ to 1.4 °K

By

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e etch pit density and the shear strain in screw and edge glide bands were measured on crystals, stressed at temperatures of 1.4 to 300 °K, and the temperature dependence of average slip distance of screw dislocations and the probabilities of cross slipping are ated. The slip distance decreases with the temperature down to 78 °K, remaining ant, however, at lower temperatures. The cross slip probabilities increase continuously decreasing temperature.

о величинам сдвига и плотностям ямок травления в винтовых и краевых ах скольжения изучались температурные зависимости средней длины ега винтовых дислокаций λ и вероятности их поперечного скольжения в ессе деформации сжатия кристаллов LiF при $T = 1.4$ до 300 °K. Установлено, что величина λ уменьшается при понижении температуры от 300 до K, а затем остается постоянной вплоть до 1.4 °K. Вероятность поперечного ьжения дислокаций с уменьшением температуры непрерывно возрастает.

A number of phenomena [1 to 3], not being observed near room temperature, e found by birefringence investigations of alkali halide crystals deformed iquid helium temperatures. The phenomena are associated with the kinetics the initiation of elementary slip and slip band growth [4]. The phenomena sist in a strong temperature dependence of the optical elastic limit (observed n at helium temperatures), a decrease of the number of slip events and of ir velocity, the presence of screw dislocation dipoles in the dislocation structure of indentation induced rosettes obtained at liquid helium temperatures, etc. rther understanding of the phenomena, mentioned above, may be gained ly by studying in detail the properties of deformation at liquid helium temperatures. Therefore, the etch pit densities in screw and edge glide bands and e shear strain inside the bands were measured at temperatures in the range m 1.4 °K to room temperature. By the help of the data it was possible to ulate the average slip distance of screw dislocations and the cross slip probilities during the band growth.

The experiments were carried out on lithium fluoride crystals, not being groscopic and therefore suitable for working at room temperature. The ystals, containing about 3×10^{-3} % Mg, were grown by the Kyropoulos technique, then annealed for 48 h at 750 °C, and cooled at a rate of 5°/h. The imens were cleaved from a large block along the cube planes and had a size 5 × 5 × 15 mm³. The initial dislocation density in the specimens did not ed 10^4 cm^{-2}.

The specimens were deformed along the [001] direction at a rate of 0.4 mm n^{-1} at temperatures of 300, 78, 4.2, or 1.4 °K. At all temperatures, the total ain amounted to about 2%. The crystal surface is not completely covered