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Mechanical Effects in Type II Superconductors

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(1. V. 68)

Abstract. Measurements of changes in magnetization curves under pressure and of magnetostriction in an alloy of indium with 14 at. % thallium are presented. Values for the stress dependence of the Ginzburg-Landau parameter are deduced.

Introduction

It has been known for many years that pressure influences the critical temperature and critical field of superconductors, and that there must be changes in dimensions and in elastic properties when superconductivity is destroyed. Such effects have been investigated extensively in type I superconductors [1–4], but for type II materials hardly any data exist [5, 6]. In view of the additional information to be gained from studying such materials we have made a series of observations of the changes in magnetization curves under pressures up to 14000 atmospheres in type II alloys, and we have also measured the magnetostriction occurring in the mixed state. From

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such measurements information on the pressure dependence of the Ginzburg-Landau parameter is obtained in addition to the information normally gained for type I superconductors. In the present work results on an indium alloy containing 14 atomic percent thallium are presented.

Theory

To predict the pressure dependence of the Ginzburg-Landau parameter $\varkappa$ we may use a formula which GOODMAN [7] has derived from a prediction by GORKOV [8]:

$$\varkappa = \varkappa_0 + 7.5 \times 10^3 \, \varrho \, \gamma^{1/2} \, . \tag{1}$$

This gives a relation between $\varkappa$ and the residual resistivity ϱ of the material (in Ω cm). $\varkappa_0$ is the Ginzburg-Landau parameter of the pure material (for In $\varkappa_0 = 0.112$ [9]), and γ is the temperature coefficient of the electronic specific heat in the normal state (in erg cm^{-3} deg^{-2}). For our alloys $\varkappa$ is approximately 0.8, so that $\varkappa_0$ can be neglected. The logarithmic volume derivative of $\varkappa$ becomes

$$\frac{\partial \ln \varkappa}{\partial \ln V} = \frac{\partial \ln \varrho}{\partial \ln V} + \frac{1}{2} \gamma_e \tag{2}$$

where $\partial \ln \gamma / \partial \ln V$, which is the electronic Grüneisen parameter, is denoted by γ_e. This is 2/3 for a free electron gas while recent experiments yield $\gamma_e \approx 3$ for pure indium [2]. $\partial \ln \varrho / \partial \ln V$ cannot be calculated reliably, but may, of course, be determined experimentally.

Effect of High Pressure on the Magnetization Curve

We have plotted magnetization curves of indium alloys under hydrostatic pressures up to 14000 atmospheres. The samples are ellipsoids of rotation with an axial ratio of about 1:7. They are inserted into an oil filled plastic container placed in a hardened beryllium copper cylinder. The hydrostatic pressure is achieved by pressing the sample container between two pistons at room temperature. The pressure remaining after cooling to helium temperature is determined from the depression of the critical temperature T_c. The value of $\partial T_c / \partial p$ is measured separately by direct comparison with pure indium. The magnetization curves are obtained by applying a slowly rising field and integrating the compensated pick-up signal.

Figure 1 shows two magnetization curves with and without pressure. It is clearly seen that the ratio H_{c2}/H_{c1} and the Ginzburg-Landau parameter decrease with

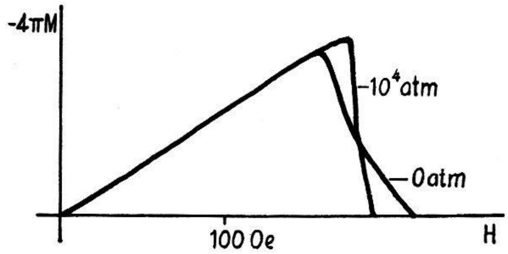

Figure 1

Magnetization curves of In-14 at. % Tl for $p = 0$ and $p = 10000$ atm. The curves were taken at different temperatures to make H_c equal with and without pressure.

increasing pressure. Three different methods may be used for calculating $\varkappa$ from the magnetization curves: one may consider a) the ratio of H_{c2}/H_c, b) $\partial M/\partial H$ near H_{c2} and c) H_{c2}/H_{c1}. The pressure dependences of $\varkappa$ as derived by all three methods were studied and together yield

$$\partial \varkappa/\partial p = -4.6 \pm 0.8 \times 10^{-12}\ \mathrm{cm^2/dyn}$$

at 0.5 T_c.

Using the compressibility of pure indium at absolute zero ($\partial p/\partial V = 2.2 \times 10^{12}$ dyn/cm²) we obtain

$$\partial \ln \varkappa/\partial \ln V = 2.6 \pm 0.5\ .$$

Magnetostriction

The thermodynamically related magnetostrictive change that occurs when the specimen is taken from the superconducting state through the mixed to the normal state in an increasing magnetic field was measured in a capacity cell by a method described by White [10]. The sample had the form of a hollow slit cylinder, and magnetization and magnetostriction were recorded as a function of external magnetic field parallel to the axis of the cylinder at the same time (Fig. 2).

The magnetization M may be written

$$M = -V H_c f(H/H_c, \varkappa) \tag{3}$$

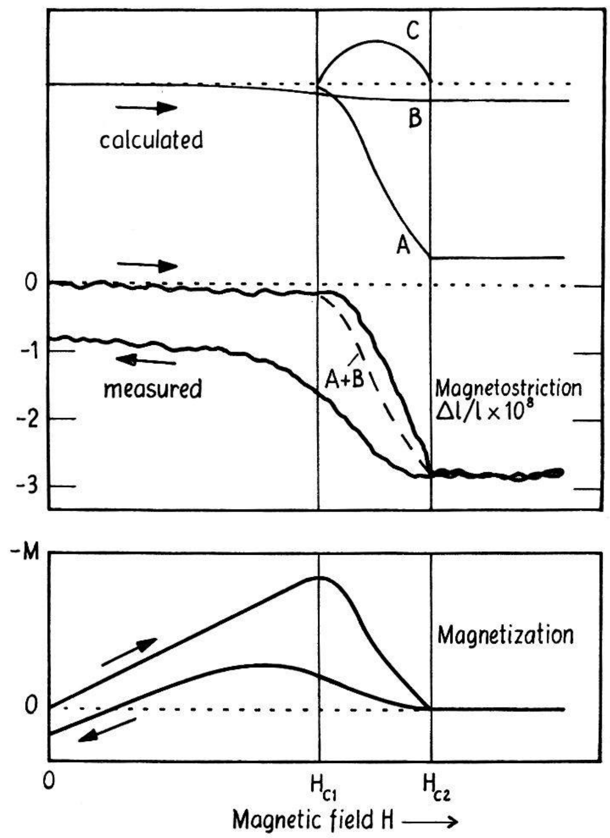

Figure 2

Calculated and observed magnetostriction curves and magnetization curve for an In-14 at. % Tl alloy at 1.28 °K. The calculated values of the three terms A, B and C in (4) are shown separately.

where V is the specimen volume. BRÄNDLI and ENCK [11] have pointed out that the length $l_\theta(H)$ of a specimen in a direction θ for a field H is then given by

$$\frac{l_\theta(H) - l_\theta(0)}{l_\theta(0)} = \frac{\partial H_c}{\partial \sigma_\theta} \int_0^H \left(f - H \frac{\partial f}{\partial H}\right) dH + \frac{1}{V} \frac{\partial V}{\partial \sigma_\theta} H_c \int_0^H f\, dH + \frac{\partial \varkappa}{\partial \sigma_\theta} H_c \int_0^H \frac{\partial f}{\partial \varkappa}\, dH . \qquad (4)$$

$$= \qquad A \qquad + \qquad B \qquad + \qquad C$$

Here σ_θ is a uniaxial stress in the direction θ in which the length is measured. In the present case the direction θ is parallel to the magnetic field. We denote stresses parallel to the field by $\sigma_{\|}$.

There are three terms in this expression for the length change. These are proportional to $\partial H_c/\partial \sigma_{\|}$, $\partial V/\partial \sigma_{\|}$ and $\partial \varkappa/\partial \sigma_{\|}$. In Figure 2 the magnetization curve, the magnetostriction curve and the calculated values of these three terms are shown. It is clear that the terms A and B proportional to $\partial H_c/\partial \sigma_{\|}$ and $\partial V/\partial \sigma_{\|}$ cannot explain the magnetostriction curve. We have to add a term C proportional to $\partial \varkappa/\partial \sigma_{\|}$. The best fit to the experimental curve requires

$$\partial \varkappa/\partial \sigma_{\|} = -5.5 \pm 2.0 \times 10^{-12}\ \mathrm{cm^2/dyn} \quad \text{for} \quad T/T_C = 0.4 .$$

Pressure Dependence of the Resistivity

The decrease of the electrical resistivity under pressure was measured directly in an ice bomb giving ca. 1500 atmospheres at 4.2°K. For In-14 at. % Tl we find

$$\partial \ln \varrho/\partial p = 3.7 \pm 0.7 \times 10^{-12}\ \mathrm{cm^2/dyn} \quad \text{and} \quad \partial \ln \varrho/\partial \ln V = 1.7 \pm 0.3 .$$

Here, too, the low temperature compressibility of pure indium has been used to calculate the volume change.

Discussion

The value of $\partial \ln \varkappa/\partial \ln V$ derived from the magnetization measurements is in good agreement with the predictions of Equation (2) if we use our direct observations of the change in residual resistivity under pressure for $\partial \ln \varrho/\partial \ln V$, together with the published value of γ_e for pure indium [2]. Thus $\partial \ln \varrho/\partial \ln V = 1.7$ and $^1/_2\, \gamma_e = 1.5$ adding up to give $(\partial \ln \varkappa/\partial \ln V)_{\mathrm{calc}} = 3.2$. This is in fair agreement with our observed value of $\partial \ln \varkappa/\partial \ln V = 2.6$.

The magnetostriction measurements give $\partial \varkappa/\partial \sigma_{\|} = -5.5 \times 10^{-12}$ cm²/dyn at $T/T_c = 0.4$. For the dependence of $\varkappa$ upon hydrostatic pressure p we have

$$\partial \varkappa/\partial p = \partial \varkappa/\partial \sigma_{\|} + 2\, \partial \varkappa/\partial \sigma_{\perp} \qquad (5)$$

where $\sigma_{\perp}$ is a stress perpendicular to the magnetic field. If $\partial \varkappa/\partial \sigma_\theta$ is isotropic we should expect $\partial \varkappa/\partial p = 3\, \partial \varkappa/\partial \sigma_\theta$. In fact the observed value of $\partial \varkappa/\partial p$ is only -4.6×10^{-12} cm² dyn⁻¹. This can be reconciled with the value for $\partial \varkappa/\partial \sigma_{\|}$ if $\partial \varkappa/\partial \sigma_{\perp}$ is close to zero. It must, however, be realised that the field pressure on the surface currents may also contribute to the anisotropy of the length change curve in the mixed state.

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Die Beweglichkeit der Ladungsträger in halbleitenden Schichtstrukturen: GaTe und $SnSe_2$

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Zusammenfassung. In Schichtgittern besteht eine starke Wechselwirkung zwischen den freien Ladungsträgern und den normal zu den Schichten polarisierten, nicht polaren optischen Phononen. Der aus Widerstands- und Hall-Messungen bestimmte Temperaturverlauf der Ladungsträgerbeweglichkeiten in GaTe und in $SnSe_2$ wird aufgrund dieser Wechselwirkung interpretiert.

Wir nehmen gerne diese Gelegenheit wahr, Herrn Prof. Dr. G. Busch herzlich zu seinem 60. Geburtstag zu gratulieren, indem wir ihm, dem Lehrer so vieler Schweizer Festkörperphysiker, die Ergebnisse einer Arbeit zueignen, deren Ursprünge im Laboratorium an der Gloriastrasse liegen: die Halbleitereigenschaften von GaTe wurden von einem von uns während seiner Lehrjahre bei Prof. Busch entdeckt und diejenigen von $SnSe_2$ wurden 1961 erstmals von Busch et al. [1] beschrieben.

GaTe und $SnSe_2$ kristallisieren beide in Schichtgittern, die aus losen, nur durch Van-der-Waals-Kräfte zusammengehaltenen Stapeln von in sich kovalent gebundenen, ebenen Atomschichten bestehen. $SnSe_2$ ist isotyp zum hexagonalen CdI_2 [1] und GaTe hat eine komplizierte, monokline Struktur (siehe Figur 1), die auch in GeAs ange-