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CRITICAL FIELDS OF THE AMBIENT PRESSURE STABLE SUPERCONDUCTING STATE AT 8K OF THE ORGANIC METAL α_t-(BEDT-TTF)$_2$I$_3$

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Crystals of α_t-(BEDT-TTF)$_2$I$_3$ are organic metals with a stable 8K superconducting transition at ambient pressure. The upper critical fields H_{c2} of α_t-(BEDT-TTF)$_2$I$_3$ were determined in dependence of the temperature and of the angle of the magnetic field with respect to the various cristal axes, by measuring the mid-transition of the resistivity as well as of the rf penetration depth (ac-susceptibility). The values obtained by both methodes agree quite well. The data were analised with the anisotropic effective mass model. The highly two dimensional nature of the metal is confirmed, but in the temperature dependence of the critical field with the magnetic field parallel to the ab-plane a crossover from a three- to a two-dimensional behaviour is observed.

1. INTRODUCTION

Since the first observation of superconductivity in an organic metal in 1980 [1] a rather fast development in the field of organic metals and superconductors took place. Today the highest observed transition temperatures of stable superconducting states at ambient pressure in organic materials lie at 8K [2,3] and 10K [4, 5] respectively and are found in radical salts of bis(1,2-ethylenedithiolo)tetrathiafulvalene (BEDT—TTF or often called ET), the α_t-(BEDT-TTF)$_2$I$_3$ crystals and the recently prepared (BEDT-TTF)$_2$Cu(SCN)$_2$ [4]. Here we report measurements of the upper critical fields H_{c2} on crystals of α_t-(BEDT-TTF)$_2$I$_3$.

α_t-(BEDT-TTF)$_2$I$_3$ crystals are prepared by tempering α-(BEDT-TTF)$_2$I$_3$ at about 75°C for several days. This procedure results in a phase transition into a structure which is very similar to the one of crystals of β-(BEDT-TTF)$_2$I$_3$ [3]. The superconductivity in the α_t-(BEDT-TTF)$_2$I$_3$ crystals is a bulk property [3].

2. RESULTS

Figures 1 and 2 show the temperature dependence of the upper critical fields H_{c2} of α_t-(BEDT-TTF)$_2$I$_3$ as obtained by measuring the mid-transition of the resistivity ρ as well as the ac-susceptibility χ_{ac}. The onset temperature for superconductivity lies around 9K, while the superconducting transition temperature evaluated by the center of the resistive transition amounts to 8K. The critical field measurements were done in magnetic fields up to 7.5T and down to temperatures of 1.3K. The data for ρ and χ_{ac} were taken on the same samples and agree quite well. The thermal cycling of the samples had no influence on the data and the transition temperature.

The values for the upper critical fields at zero temperature $H_{c2}(0)$ were obtained by a linear extrapolation of the resistivity data. For the magnetic field perpendicular to the ab-plane $H_{c2\perp}(0)=2.15T$ while for the magnetic field parallel to the ab-plane $H_{c2\parallel}(0)=12T$. The latter value is close to the paramagnetic limit of 14.7T. The anisotropy parameter obtained from this values results to $\varepsilon=H_{c2\perp}/H_{c2\parallel}=0.18$.

The temperature dependence of $H_{c2\parallel}(T)$ shows a dimensional crossover (see figs. 1 and 2) which is characteristic for a layered superconductor and can be understood as the change from the three dimensional anisotropic bulk superconductor to the Josephson coupled two dimensional superconductor [6,7], where the normal cores of the vortices fit between the metallic layers.

Figure 3 shows the angle dependence of H_{c2} at 1.3K. At 0° the magnetic field lies parallel to the c*-axes, that means perpendicular to the ab-plane. The sample was turned around the a-axes.

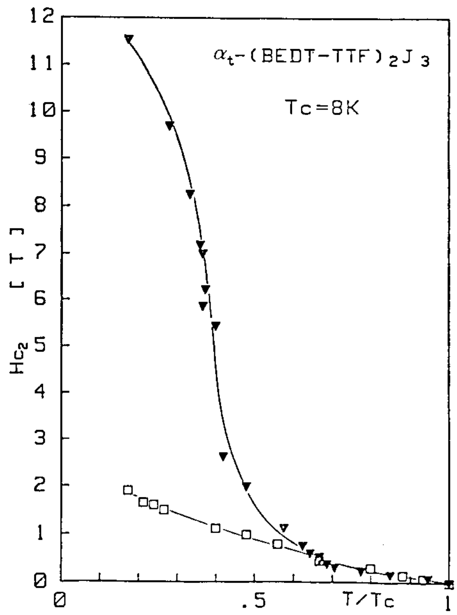

FIGURE 1
Temperature dependence of the upper critical fields H_{c2} of α_t-(BEDT-TTF)$_2$I$_3$ as obtained from the mid transition of the resistivity for the magnetic field perpendicular ([]) and parallel ($\triangledown$) to the ab-plane.

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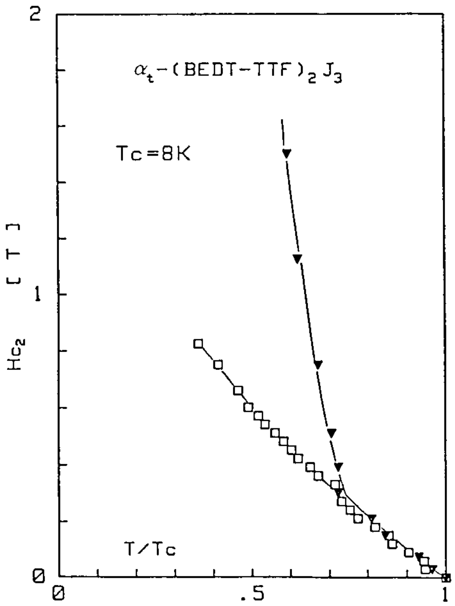

FIGURE 2
Temperature dependence of the upper critical fields H_{c2} of α_t-(BEDT-TTF)$_2I_3$ as obtained from the ac-susceptibility measurement for the magnetic field perpendicular ([]) and parallel (▽) to the ab-plane.

3. DISCUSSION

The results of figs. 1 to 3 were analysed with the anisotropic effective mass model in the picture of the Ginzburg Landau (GL) theory and the assumption that the results found for α_t-(BEDT-TTF)$_2I_3$ are isotropic within the ab-plane (in fact only a very weak anisotropy is observed). Using the extrapolated values of $H_{c2}(0)$ results in coherent lengths $\xi_{\parallel}(0)$ and $\xi_{\perp}(0)$ as obtained from the following equations:

$$\xi_{\parallel}(0)=\left[\frac{\Phi_o}{2\pi\mu_o H_{c2\perp}}\right]^{1/2}; \qquad \xi_{\perp}(0)=\left[\frac{\Phi_o H_{c2\perp}}{2\pi\mu_o H^2_{c2\parallel}}\right]^{1/2}$$

with Φ_o the flux quantum. The Ginzburg Landau parameters $\varkappa_{\perp}$ and $\varkappa_{\parallel}$ are given by

$$\varkappa_{\perp}=\lambda_{\perp}/\xi_{\parallel} \qquad \text{and} \qquad \varkappa_{\parallel}=\left[\lambda_{\parallel}\lambda_{\perp}/\ \xi_{\parallel}\xi_{\perp}\right]^{1/2}.$$

Here the London penetration depths $\lambda_{\parallel}$ and $\lambda_{\perp}$ are defined by

$$\lambda_{\parallel,\perp}=[\,m^*_{\perp,\parallel}/4\mu_o ne^2]^{1/2}$$

with $n=1.24\cdot10^{21}cm^{-1}$, the effective mass $m^*_{\parallel}\approx m_e$ (the free electron mass) and $m^*_{\perp}/m^*_{\parallel}=\varepsilon^2$. In addition the thermodynamical critical field H_c and the lower critical fields H_{c1} were calculated from the equations for the case of a dirty superconductor:

$$H_c=H_{c2\parallel,\perp}/\sqrt{2}\,\varkappa_{\parallel,\perp}\,; \qquad H_{c1\parallel,\perp}=\frac{(\ln\varkappa_{\parallel,\perp}+0.497)H_c}{\sqrt{2}\,\varkappa_{\parallel,\perp}}$$

The extrapolated and calculated parameters for the crystals of α_t-(BEDT-TTF)$_2I_3$ are shown in the table.

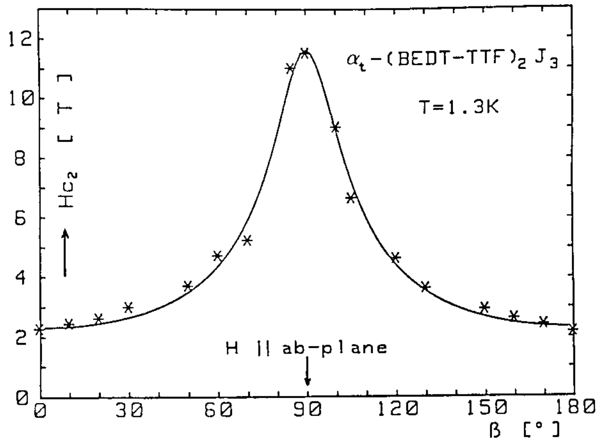

FIGURE 3
Angle dependence of H_{c2} of α_t-(BEDT-TTF)$_2I_3$ at 1.3K. The measured values (*) were fitted by the following function:

$$H_{c2}(H)=H_{c2\parallel}/(\sin^2\beta+\varepsilon^2\cos^2\beta)$$

with ε the anisotropy parameter and β the angle of the magnetic field with respect to the c*-axes.

TABLE
Extrapolated and calculated parameters of the organic superconductor α_t-(BEDT-TTF)$_2I_3$ for T= 0K: Upper critical fields H_{c2} [T], lower critical fields H_{c1} [T], thermodynamical critical field H_c [T], Ginzburg Landau coherence lengths ξ [A], London penetration depths λ [A] and Ginzburg Landau parameters $\varkappa$.

T=0K	H_{c2}	H_{c1}	H_c	ξ	λ	$\varkappa$
∥ ab-plane	12	0.02	0.25	123	4300	35
⊥ ab-plane	2.15	0.066	0.25	22	750	6

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