MEASUREMENTS OF THE MICROWAVE CONDUCTIVITY OF THE ORGANIC SUPERCONDUCTOR ET₂ (IAUI)

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ABSTRACT

The microwave conductivity of $\text{ET}_2(\text{IAuI})$, which is superconducting below 4 K, has been measured between 20 and 300 K. The measurements were done by cavity perturbation at 35 GHz for electric field along the highly conducting direction. The samples were in the skin-depth limit. The room temperature conductivity is quite low, approximately 6 Ω^{-1} cm⁻¹. With decrease in temperature the conductivity increases as T^{-2} , reaching nearly 900 Ω^{-1} cm⁻¹ at 20 K. These values are rather close to extrapolations of the frequency-dependent conductivity determined from far-infrared experiments.

INTRODUCTION

The 35 GHz microwave conductivity of the 2:1 β-phase compound of bis(ethylenedithio)-tetrathiafulvalene (BEDT-TTF or "ET") with the diiodoaurate anion (I-Au-I) has been measured from 20 to 300 K. This material is extremely interesting on account of its having the highest ambient pressure, unstrained transition temperature of any organic superconductor. The conductivity has a very small magnitude and varies as the inverse square of the temperature over the entire range investigated.

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EXPERIMENTAL DETAILS

The measurements were made using the cavity perturbation technique. The apparatus, described by Guldbranson <u>et al</u>. [1], is an interferometer or bridge, which can measure both the transmission and the phase shift upon transmission of the cavity. By making measurements at (typically) five frequencies near the cavity resonant frequency (where the transmission is a maximum), the portion of the detected signal caused by reflections from the many components in the microwave system may be estimated. As discussed in Ref. 1, correcting for these reflections improves the accuracy of the measurements of the cavity resonant frequency, ω_0 , and quality factor, Q. We found that the corrected values for Q differed from the uncorrected ones by 10%-15%, although both had a reproducibility of ±0.5%.

The cavity was attached to the cold end of a Cryodyne continuous flow helium cryostat. The heat conducted down the waveguide limited the minimum temperature to 20 K.

We measured ω_0 and Q with the electric field along the highly-conducting crystallographic a-axis of the (ET)₂ IAuI sample. Measurements of ω_0 and Q for the empty cavity were also made.

The single-crystal sample was prepared by electrocrystalization as previously described [2,3]. The length (a-axis direction), width, and height were respectively L=1.5 mm, W=0.4mm, and H=0.4 mm. With these dimensions, the skin depth is smaller than the sample size, so long as the conductivity exceeds $0.02 \ \Omega^{-1} \text{ cm}^{-1}$.

In the skin-depth limit, [1,4] the change in Q and $\omega_{\rm Q}$ caused by introducing the sample are given by:

$$\Delta\left(\frac{1}{2Q}\right) = \frac{9\varepsilon_0\sqrt{\mu_0}}{64\sqrt{2}} \quad \frac{W + H}{\alpha} \left(\frac{\alpha}{N_z}\right)^2 \sqrt{\frac{\omega_0^3}{\sigma_1^3}} \tag{1}$$

$$\frac{|\Delta\omega|}{\omega_0} = \frac{\alpha}{N_z} + \Delta(\frac{1}{2Q})$$
(2)

where

$$\Delta(\frac{1}{2Q}) \equiv \frac{1}{2} \left| \frac{1}{Q}_{\text{sample}} - \frac{1}{Q}_{\text{empty}} \right|$$

$$\frac{|\Delta\omega|}{\omega_0} = \frac{|\omega_0 \text{ empty} - \omega_0 \text{ sample}|}{\omega_0 \text{ empty}}$$

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The other quantities in Eqs. 1 and 2 are the conductivity, σ_1 ; the volume filling fraction, $\alpha = 2V_{sample}/V_{cavity}$; the depolarization factor (for the long axis), N_z ; the dielectric constant (permability) of empty space, $\varepsilon_0(\mu_0)$; and the angular frequency, ω_0 . Introduction of the sample reduces the cavity Q and lowers the resonant frequency. In the skin depth limit, $|\Delta \omega|/\omega_0$ and $\Delta(1/2Q)$ determine the geometric quantity α/N_z . We estimate that the accuracy of our values for the conductivity from Eqs. 1 and 2 was approximately $\pm 10\%$, governed largely by errors in the geometrical quantities α , W, and H. Were it necessary to calculate the depolarization factor N_z from a sample geometry, then the errors would be much larger, being perhaps as much as a factor of two.

RESULTS

Fig. 1 shows the microwave conductivity versus temperature. On cooling, the conductivity increases from 6 Ω^{-1} cm⁻¹ at 300 K to almost 900 Ω^{-1} cm⁻¹ at 20 K, with most of the increase occurring below 50 K.



Fig. 1. Temperature dependence of the conductivity of (ET)₂ IAuI.

DISCUSSION

Fig. 2 shows the temperature dependence of the resistivity, $p=1/\sigma_1$ on a log-log scale. The resistivity follows

$$\rho \sim T^2 \tag{3}$$

over the whole temperature range. The straight line in Fig. 2 is a plot of Eq. (3). We note that if the resistivity is assumed to follow Matthiessen's rule, with a temperature-dependent intrinsic term and a temperatureindependent residual term, then the residual part must be substantially below $0.001 \ \Omega$ -cm, or we would observe curvature in Fig. 2.



Fig. 2. Temperature dependence of the resistivity of (ET)₂ IAuI. Note the logarithmic scales. The line shows a quadratic temperature dependence.

The room-temperature conductivity is rather small for an organic "metal." It is, however, of the same order of magnitude as the conductivity of other 2:1 β -phase ET salts. Values between 10 and 33 Ω^{-1} -cm⁻¹ have been reported for the I₃, PF₆, and C10₄ salts [5-9]. Only the ReO₄ salt has been found to have a higher value, being 200 Ω^{-1} cm⁻¹ at room temperature [10]. Finally, we note that the microwave conductivity is rather close to the extrapolation to dc of the far-infrared conductivity as determined by Kramers-Kronig analysis of the reflectance [11]. Thus there seems to be no need to invoke narrow low-frequency collective-mode contributions to the conductivity. This is a significant difference from what is seen in TTF-TCNQ and the Bechgaard salts, [12-14] even though the temperature dependence of the conductivity (in the high-temperature, highly conducting regime) is rather similar in all three compounds [15,16].

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