CYCLOTRON RESONANCE IN POTASSIUM TANTALATE

L. S. Senhouse, G. E. Smith, and M. V. DePaolis

Bell Telephone Laboratories, Murray Hill, New Jersey

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Cyclotron resonance has been observed in the transition-metal oxide potassium tantalate ($KTaO_3$) at a frequency of 70 kMc/sec and a temperature of 1.4°K. This is the first reported cyclotron resonance in any oxide. A tentative model of the band structure has been derived to explain the observed resonances. A classical calculation utilizing this model fails to reproduce all the features of the experimental results, but qualitative conclusions are drawn.

It has been well established[1] that potassium tantalate is a cubic semiconductor (3.5-eV gap) having an extremely high dielectric constant, ϵ, which varies from $\epsilon = 240$ at room temperature to $\epsilon = 4500$ at liquid-helium temperatures. Donors can be introduced in concentrations ranging from $1\times10^{17}/cm^3$ to $2\times10^{19}/cm^3$. Since the ionization energy of a hydrogenlike donor goes as $1/\epsilon^2$, these donor states remain completely ionized even at liquid-helium temperatures. The large dielectric constant also helps to screen out the ionized impurity scattering and results in relatively high mobilities, μ, for the free carriers. Values of 2.3×10^4 cm^2/V sec have been reported[1] at 4.2°K for low-carrier-concentration samples. Such samples were used in the present investigation. This results in the condition $\mu B > 1$ for magnetic fields B in the kilogauss range and makes cyclotron resonance experiments feasible.

The crystal was grown in a platinum crucible by a modified Kyropoulos method[1] and sawed to approximately $0.3\times0.3\times\frac{1}{8}$ in. with each edge along a 100 direction. The surface of the crystal was polished with $0.3\,\mu$ aluminum-oxide grit which was sufficiently smooth since the skin depth for the 70-kMc/sec waves is about 30 μ. The crystal was mounted at the end of a nonresonant rectangular microwave wave guide with the E field in the plane of the sample and along a 100 direction. In a second geometry, the E field was oriented along a 100 direction. The power absorption was detected by a carbon thermometer in contact with the crystal. Details of the experimental apparatus are described elsewhere.[2]

The magnetic field was in the plane of the sample and was rotated with respect to E at an angle θ varying from zero ($B \parallel E$) to 90° ($B \perp E$). At various angles the power absorption of the sample was measured as a function of B from zero to 17 kG. Plots for B along a 100 direction with $E \parallel B$ and $E \perp B$ are shown in Fig. 1. Curves with B along a 110 direction for $E \perp B$ and $E \parallel B$ are shown in Figs. 2 and 3, respectively. The data were reproduced on a second sample.

The classical skin-effect theory[2] was used to interpret the data, and is a reasonable approximation with a skin depth of 30 μ. The plasma frequency, ω_p, is comparable to the microwave frequency, ω, making the observed peaks neither simple cyclotron resonance nor hybrid resonances. Spin-resonance effects can be shown to be negligible.[3] A multiellipsoidal model of the Fermi surface was assumed with the principal axes of the ellipses oriented along a 100 direction. This choice was indicated by the rotational data and is made plausible by band-structure calculations in perovskite titanates.[4]

The absorption as a function of magnetic field was calculated and the parameters varied to fit the data. These parameters are the transverse and longitudinal effective masses (m_t and m_l), the carrier concentration (n), and the relaxation time (τ). The calculation was made only for $B \parallel E$ and $B \perp E$, and not for intermediate values of θ. The values used in the theoretical curves in the figures are $m_t = 0.3m_0$, $m_l = 1.0m_0$, $n = 1.75\times10^{17}/cm^3$, and $\omega\tau = 20$,

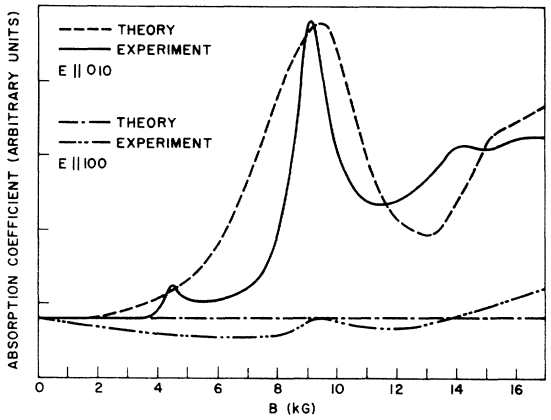

FIG. 1. Microwave absorption coefficient as a function of magnetic field for $B \parallel$ 100 direction.

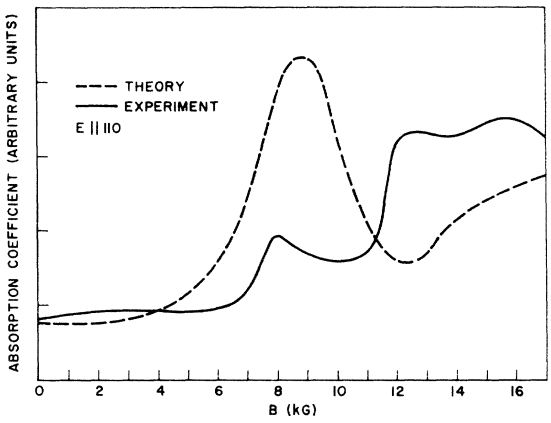

FIG. 2. Microwave absorption coefficient as a function of magnetic field for $B \parallel 1\bar{1}0$ and $B \perp E$.

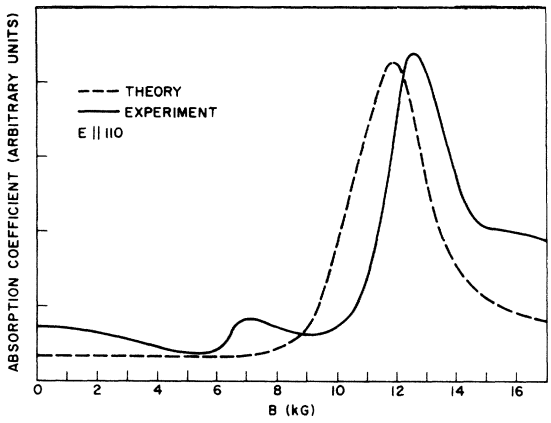

FIG. 3. Microwave absorption coefficients as a function of magnetic field for $B \parallel 110$ and $B \parallel E$.

where m_0 is the free-electron mass. The density-of-states effective mass is in agreement with the thermoelectric-power mass of $(0.8 \pm 0.3)m_0$. It will be noted that the calculated curves follow the general features of the experimental data. A significant feature is the tilted-orbit cyclotron resonance[2] which appears in the $B \parallel E \parallel 110$ data and not in the $B \parallel E \parallel 100$ direction. Such a resonance appears when anisotropy causes the plane of the orbit not to be perpendicular to the magnetic field. This argues for 100 ellipsoids (rather than 110 or 111, for example), since this is the only set which has perpendicular orbits for all ellipsoids when $B \parallel 100$.

The smaller peaks at low magnetic fields could not be reproduced by varying parameters in the calculation. This shows a deficiency in the classical theory calculation and/or model of the band structure. Azbel'-Kaner resonances are improbable since the skin depth is ≈ 30 μ and the electron mean free path ≈ 1 μ. One possibility is a nonellipsoidal Fermi surface. This would generate harmonics at lower magnetic fields, but the inclusion of nonellipsoidal surfaces is beyond the scope of the present calculation. The $B \parallel 110$ data were obtained by placing the edges of the sample at 45° to the rectangular wave guide and could result in misorientation. This could explain the poor fit shown in Fig. 2. The data with $B \parallel 100$ are less susceptible to misorientation, since B is along principal axes of the ellipsoids, and therefore the cyclotron masses as a function of angle are at extrema.

Even assuming that the low-field resonances are a small perturbation, this model and choice of parameters can only be considered tentative. For example, a fair fit can also be achieved with $m_t > m_l$. The principal features which can be considered as conclusive are a multisheeted model to account for the multiplicity of peaks, low anisotropy (from rotation of $\vec{B}$ data), and masses of about $0.5m_0$.

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[1]S. H. Wemple, Phys. Rev. 137, A1575 (1965).
[2]G. E. Smith, L. C. Hebel, and S. J. Buchsbaum, Phys. Rev. 129, 154 (1963).
[3]L. C. Hebel, E. I. Blount, and G. E. Smith, Phys. Rev. 138, A1636 (1965).
[4]A. H. Kahn and A. J. Leyendecker, Phys. Rev. 135, A1321 (1964); L. F. Mattheiss, private communication.