(6) The fact that the extrapolated main resonance and the mode numbering scheme can be determined unambiguously in a series of films of different thicknesses deposited simultaneously has been reported previously,[7] and the physical basis of the variation of position of the main resonance has been discussed at length.[3] Furthermore, film properties (including the position of the high-field mode) do not necessarily change with time.[8]

(7) As far as the Kittel model[9] is concerned, very few films ever strictly obey the idealized spin-pinning model for a homogeneous magnetic film in a homogeneous rf magnetic field. Nevertheless, many films follow the quadratic behavior according to the spin-wave dispersion relation even though the mode intensities can be highly variable, depending, among other things, on the method of excitation and on the film surface state and film homogeneity. Thus SWR can be successfully employed as a spectroscopic tool to investigate the more fundamental Bloch-Dyson spin-wave dispersion relation[3] (on which the Kittel model is of course based), even though deviations from the idealized model can occur and may be of interest in studying the nature of thin films per se.

In summary, no one questions that compositionally invariant films are invaluable and that many of the anomalies previously observed can be attributed to films not representative of uniform bulk material; however, no evidence has been presented which shows that the flash-evaporation method eliminates these potential difficulties any better than other evaporation methods, nor is there any reason to believe that flash-evaporated films will even approach the physical results that have already been obtained by SWR.

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OBSERVATION OF INTERBAND TRANSITIONS IN ARSENIC*

Martin Maltz†
Electrical Engineering Department, Massachusetts Institute of Technology, Cambridge, Massachusetts

and

M. S. Dresselhaus‡
Lincoln Laboratory,§ Massachusetts Institute of Technology, Lexington, Massachusetts
(Received 7 March 1968)

In this communication, we report the observation of a series of oscillations in the infrared magnetoreflectivity of arsenic.[1,2] From a study of these oscillations, we have been able to obtain much useful information about the electronic band structure of this material. In particular, we have been able to associate these oscillations with an interband transition across a small, direct energy band gap of 0.346 eV between bands having either the $T_{2'}$ and T_1 or the T_2 and $T_{1'}$ symmetries, using the symmetry notation of Lin and Falicov.[3] Our results are therefore in direct disagreement with the pseudopotential calculations of Lin and Falicov,[3,4] which do not display any small direct gaps between bands of the symmetries required by our experiment.

In our experiment, we have used a somewhat improved version[2] of the equipment previously used to study the magnetoreflectivity of bismuth,[5] antimony,[6] and graphite.[7] The experiment is done in the Faraday geometry, with both the magnetic field and the propagation vector of the light perpendicular to an optical face of the liquid-helium-cooled, single-crystal sample. The arsenic boule from which these samples were cut was grown using a modified Bridgman technique[8] and had a resistivity ratio, $R_{290^\circ\mathrm{K}}/R_{4.2^\circ\mathrm{K}}$, greater than 300. The trigonal faces of the sam-

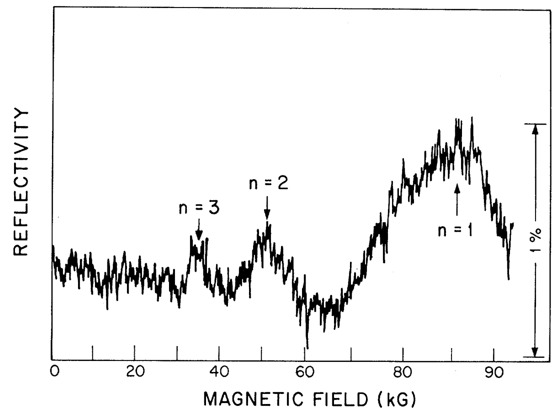

FIG. 1. Reflectivity from a binary face of arsenic as a function of magnetic field at a constant photon energy of 0.410 eV. The amplitude is given as a percentage of the zero-field reflectivity, and the resonant fields for three interband transitions are indicated by arrows.

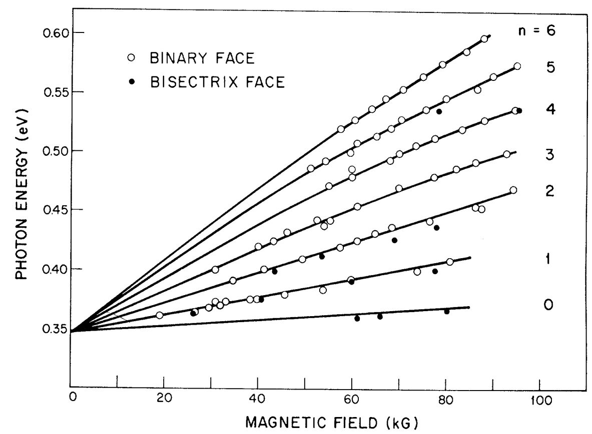

FIG. 2. Summary of experimentally observed resonant fields for interband Landau-level transitions from the binary and bisectrix faces of arsenic. The solid curves are constructed to fit the binary data.

ples were cleaved, and the binary and bisectrix axes were spark cut and chemically polished. When not in use, the samples were kept coated with Krylon to prevent oxidation.

A typical experimental trace showing the variation of the optical reflectivity with magnetic field at a fixed photon energy, $\hbar\omega = 0.410$ eV, is given in Fig. 1 for a binary face and unpolarized incident radiation. The resonant field for an interband transition between two Landau levels of quantum number n is determined from the peak in the reflectivity as is shown in Fig. 1.[9,10] In analyzing our results, we have assumed the selection rule $\Delta n = 0$. The reason that the peak in the reflectivity is the feature of the oscillation line shape which corresponds to the resonant field is that the photon energy at which the data were taken is well above the plasma frequencies of the material.[10] These plasma frequencies were found to be 0.26 and 0.30 eV for the optical electric field $\vec{E}$ perpendicular and parallel to the trigonal axis, respectively.[2]

In Fig. 2, we plot the resonant fields as a function of photon energy for data taken on a binary face (open circles). The solid lines are smooth curves drawn through the data for the binary face. For photon energies near the energy gap of 0.346 eV, the spacing of the lines is what one would expect for nondegenerate parabolic bands with no spin splitting[9,10] and a reduced effective cyclotron mass of 0.023. At higher energies, the lines become decidedly curved indicating that the energy bands are no longer described by simple parabolic dispersion relations.

It was found that the magnetoreflection oscillations were extinguished when the light was polarized perpendicular to the trigonal axis, which implies that the component of the interband velocity matrix element perpendicular to the trigonal axis is zero, and that the component parallel to the trigonal axis is nonzero. To use this information, one now looks at the high symmetry points in the Brillouin zone and tries to find a pair of bands which have the proper symmetry such that these selection rules are satisfied.[6] The only points in the Brillouin zone which have bands with these properties are found to lie along the trigonal (Λ) axis.[3] To restrict further the possible critical-point locations, we note that the simplicity of the observed magnetoreflectivity spectrum implies that the two band extrema are located at the same point in the Brillouin zone, since if they were displaced from each other, the simple interband Landau-level selection rules would break down,[11] and one would expect to see a more complicated oscillation pattern. The simplicity of the magnetoreflection spectrum therefore implies that the band extrema are both at either T or Γ, where energy bands are required to exhibit extrema by symmetry.[3] We conclude that the band extrema are probably at T because all band calculations show that there are no small band gaps at Γ.[3,4,12] Therefore, using the symmetry notation of Lin and Falicov,[3] we find that the transitions we have observed must be between bands of symmetries T_1 and $T_2{}'$ or $T_1{}'$ and T_2. This result disagrees with the results of the pseudopotential calculation of Lin and Falicov,[3,4] which predicts that the smallest energy gap between bands of these symmetries is about 1 eV, which is considerably greater than the measured band gap of 0.346 eV. Since the experimental situation seems to be quite unambiguous, it would be interesting to vary the pseudopotential parameters in order to bring the calculated band structure into agreement with our data.

Experiments were also performed with the magnetic field parallel to the bisectrix and trigonal axes. For the bisectrix sample orientation, we find that the resonant fields are almost exactly the same as they were for the binary orientation, and that the data can be fitted by a spinless parabolic two-band model, with a reduced effective cyclotron mass of 0.026 and an energy gap of 0.346 eV. To illustrate this similarity, data taken on a bisectrix face are included as closed circles in Fig. 2. These bisectrix data are moderately well fitted by the solid curves which were constructed for the binary (open-circle) data. This similarity of the binary and bisectrix data is also consistent with the identification of the interband Landau-level transitions with the T point in the Brillouin zone. Due to the threefold rotation symmetry about T, the reduced cyclotron effective masses for the binary and bisectrix sample orientations are required to be equal.[3] We therefore conclude that the reduced cyclotron effective mass for magnetic fields perpendicular to the trigonal axis is 0.0245 ± 0.0015 for this series of interband transitions. For the trigonal sample orientation, no oscillations associated with this series are observed, in agreement with the observed polarization effect.

There is also some evidence that there might be a very small pocket of carriers associated with one of the bands under consideration. The evidence for this is presented in Fig. 3, where we show the relationship between the photon energy and the amplitude of the $n=0$ oscillation, as observed for the bisectrix face. The amplitude goes to zero for a photon energy of 0.360 eV, which is 0.014 eV above the energy gap. A similar cutoff was also observed in the binary data.

Generally, such a cutoff implies that the Fermi level lies within one of the bands associated with the interband transition,[10] and not in the energy gap between them, and that there is therefore a small pocket of carriers associated with one of the bands. We do not have enough information about this carrier pocket to estimate the carrier density involved, but from the very small Fermi level, it seems reasonable to assume that it is no more than a percent of the total carrier density of the material.[13] It is not surprising, therefore, that this carrier pocket has not been previously observed experimentally.[13-15]

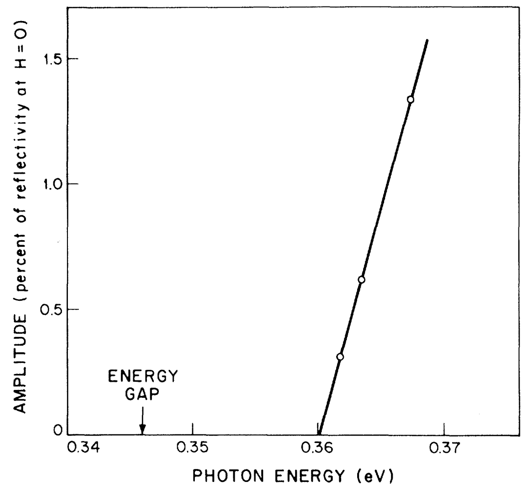

FIG. 3. The amplitude of the $n=0$ interband oscillation observed for the arsenic bisectrix face, displayed as a function of the photon energy.

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‡Currently on leave of absence at the Electrical Engineering Department, Massachusetts Institute of Technology, Cambridge, Mass.

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"CURIE-WEISS" BEHAVIOR AND FLUCTUATION PHENOMENA IN THE RESISTIVE TRANSITIONS OF DIRTY SUPERCONDUCTORS*

Myron Strongin, O. F. Kammerer, J. Crow, R. S. Thompson, and H. L. Fine
Brookhaven National Laboratory, Upton, New York
(Received 6 March 1968)

By making very small mean-free-path films we have been able to measure the intrinsic nature of resistive transitions as a function of mean free path. Analysis based on the concepts of Anderson and Josephson leads to an estimate of the smearing of the transition near zero resistance.

Very recently, experimental studies of the nature of the superconducting transition temperature[1] have shown "Curie-Weiss" behavior above T_c and the possibility of a critical region about 3 mdeg away from T_c. The usual estimates for the natural widths of the superconducting transition have ranged from[2] 10^{-14} to 10^{-8}°K in pure superconductors, and in view of these estimates little hope was given to observing the nature of the transition in ideal superconductors. However, Glover,[1] following a suggestion of Anderson,[3] was able to achieve a measurable transition region by studying amorphous Bi, a system with a very small mean free path (l). In these films l was about two atomic spacings, which is about as small an l as can be achieved in pure metallic systems. Hence the study of the transition region as a function of l is difficult in these films, since larger l's would make the width prohibitively small.

In this note we wish to report measurements on thin Al films[4,5] prepared in vacua of $\sim 10^{-6}$ Torr at room temperature and then exposed to air. In this type of system the film is probably composed of grains of metal surrounded by oxide, or possibly weakly linked to each other through Josephson barriers or fine metallic links. The crucial points we wish to make are the following:

(a) The effective mean free path ($l_{\rm eff}$) can be made much smaller in a "granular" system than in pure metal systems, thereby leading to a larger intrinsic transition region. This is because of the high resistance of the tunneling barriers between particles, or the fine metallic links.

(b) The dependence of the transition width on $l_{\rm eff}$ can therefore be studied.

(c) Towards the end of this paper a model is given which discusses the smearing of the transition near $R/R_n \sim 0$.

In Figs. 1 and 2 the data are shown for two different films with mean free paths of about 0.2 and 5 Å, respectively.[6] The heavy line in both cases is a fit at high temperatures, near 4°K, to the function $R/R_N = (1+\tau_0/\tau)^{-1}$. τ is defined as $(T-T_c)/T_c$ and τ_0 is the value of τ at $R/R_N = 0.5$. The fact that this "Curie-Weiss" dependence might describe the nature of the resistive transition above T_c has been suggested by Schmidt[1] and discussed by Glover.[1] Although the data are fitted extremely well by this dependence, it is not clear why this analogy to the magnetic case holds. (See Note added in proof.) From our measurements it is clear that τ_0, which differs by about a factor of 10 in the two films, goes inversely as $l_{\rm eff}$.