pinching, the oscillations exhibit no growth [Fig. 4(a)]. Their attenuation times are exponential and increase with current until growing oscillations occur (Fig. 3). Their amplitude also increases with current (Fig. 3), whereas the frequency remains constant at 30.8 ± 0.2 Mc/sec.

Further increase in current beyond ~7 A produces oscillations that grow in time and then decay [Fig. 4(b)]. A semilog plot of the amplitude A vs time t yields the curve $A = \operatorname{sech} t$ from which exponential growth and decay times are deduced. The oscillations of Fig. 4(b) have symmetric growth and attenuation times which are 0.49 μsec. At 13.0 A, as noted in Fig. 3, the growth and attenuation times are somewhat different. The amplitude of the growing oscillations increases very rapidly with current to extremely large values, even larger than the potential difference.

The frequency remains constant over the entire range of current for which either decaying or growing oscillations are observed. The frequency does not change when different contacts are used for the injection of the plasma, nor is it influenced by shunting the sample with either a 50-ohm resistance or a 10^{-9}-F capacitance.

The behavior of both types of growing oscillations in the presence of magnetic fields will be discussed elsewhere.

All the conditions necessary for producing either of these two types of growing oscillations are not known as yet, nor is it understood why a particular type occurs in a particular sample, but when either is observed its behavior is highly reproducible. It seems probable that the constant-frequency growing oscillations are related to acoustic electron waves.

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EXPERIMENTAL DETERMINATION OF EFFECTIVE MASSES IN A BISMUTH-ANTIMONY ALLOY

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(Received November 2, 1962)

Hybrid and "tilted-orbit" cyclotron resonance has been observed in an alloy consisting of 5 atomic percent antimony in bismuth. Such resonances have previously been studied in pure bismuth[1] and proved to be an effective means of determining effective masses. It is found in the present work that in $Bi_{95}Sb_5$, the electron effective masses are smaller by about a factor of two than those measured in pure bismuth, and the hole masses are essentially unchanged.

A model of the band structure of bismuth-antimony alloys has been derived by Jain[2] from galvanomagnetic studies by assuming that the band structure changes continuously from that of pure bismuth with the addition of antimony. According to Jain's model, the addition of antimony reduces the band overlap E_0 but does not change effective masses or the energy gap E_g between the conduction band and the next lower band. Measurements of the de Haas–van Alphen effect[3] in the 0-1 wt.% range show no change in effective mass.

The experiment reported here was performed on material grown by the zone-leveling technique described elsewhere.[4] A sample was cut with the bisectrix axis perpendicular to the surface. Linearly polarized microwaves ($\nu = 70$ kMc/sec) were used with the electric field oriented along either the binary or trigonal axis. The magnetic field was in the plane of the sample and could be rotated either parallel or perpendicular to the microwave E field. The measurements were carried out at 1.3°K and the absorbed microwave power was measured by a calorimetric method.[1] Experimental plots of absorption coefficient vs magnetic field are shown in Figs. 1 and 2.

The model for the band structure was assumed to have the same form as that for pure bismuth. This model consists of three electron ellipsoids, one of which is given by

$$E_e = (\hbar^2/2m_0)(\alpha_{11}k_1^2 + \alpha_{22}k_2^2 + \alpha_{33}k_3^2 + 2\alpha_{23}k_2k_3), \quad (1)$$

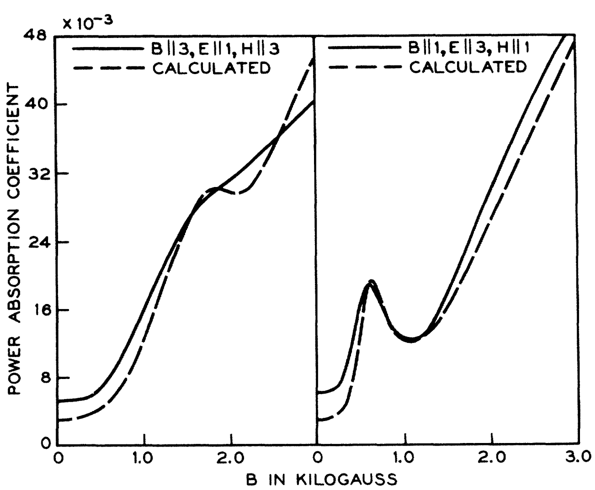

FIG. 1. Theoretical and experimental plots of absorption coefficient vs field with the microwave E field perpendicular to the static magnetic field B.

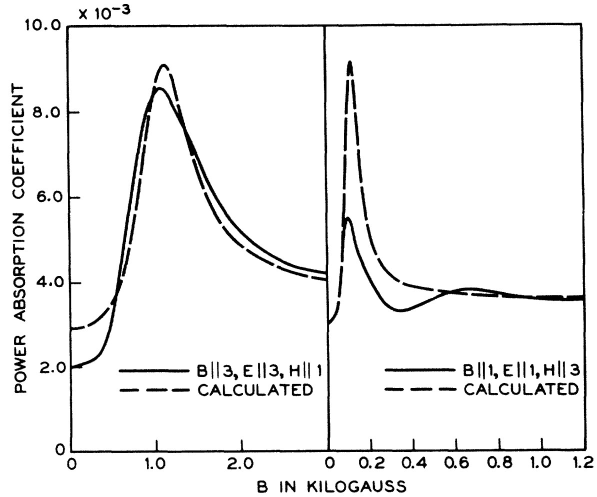

FIG. 2. Theoretical and experimental plots of absorption coefficient vs field with the microwave magnetic field H perpendicular to the static magnetic field B.

where $\alpha_{ij}=(m^{-1})_{ij}$ are the inverse effective-mass components, E_e is the electron Fermi energy, and k_1, k_2, and k_3 are wave vector components along the binary, bisectrix, and trigonal axes. The other two ellipsoids are obtained by rotations of $\pm120°$ about the trigonal axis. There is one hole ellipsoid of revolution given by

$$E_h=(\hbar^2/2m_0)(k_1^2/M_1+k_2^2/M_1+k_3^2/M_3).$$

The number of electrons is set equal to the number of holes. Theoretical curves are calculated from Maxwell's equations and a conductivity tensor derived by assuming that classical skin effect conditions prevail. Under these conditions, hybrid resonances[1,5] associated with longitudinal plasma modes and tilted orbit cyclotron resonances are observed. To obtain a fit to the data, effective masses were varied to fit the positions of the resonances, and relaxation times, τ, for electrons and holes varied to fit the line shapes. The number of carriers could not be determined directly since absolute values of the absorption coefficient were not measured. A value of $N=0.15\times10^{17}/\mathrm{cm}^3$ was used and will be justified below. The lattice dielectric constant was assumed to be 100, the same as in pure bismuth.

Plots of the experimental results and calculated curves are shown in Figs. 1 and 2. The experimental curves were fitted to the calculated ones by an arbitrary scale factor. The electron effective masses used to fit the data are for electrons $m_{11}=0.0025$, $m_{22}=0.75$, $m_{33}=0.0065$, and $m_{23}=-0.040$, and for holes, $M_1=0.10$ and $M_3=0.50$. The values used for $\omega\tau$ are for electrons, $\omega\tau_e=3$, and for holes, $\omega\tau_h=6$. For comparison, the corresponding mass parameters[1] in pure bismuth are for electrons, $m_{11}=0.0062$, $m_{22}=1.30$, $m_{33}=0.017$, and $m_{23}=-0.085$, and for holes, $M_1=0.057$ and $M_3=0.77$. The agreement between the experimental and calculated positions of the resonances is felt to be reasonably good. The relaxation times used may be fictitiously small since inhomogeneities in the sample will cause a broadening of the resonances if the masses are changing rapidly with composition.

These values of effective-mass components for electrons are about a factor of two smaller than those measured for pure bismuth. This change in effective mass can be explained with the nonquadratic model of the band structure[5-8] in which Eq. (1) becomes

$$E_e(1+E_e/E_g)=(\hbar^2/2m_0)(\vec{k}\cdot\alpha_b\cdot\vec{k}), \tag{2}$$

where α_b is the inverse effective-mass tensor at the bottom of the conduction band. The cyclotron mass at energy E_e is then

$$m_c=m_b(1+2E_e/E_g).$$

Using the measured mass values m_c and assuming that the energy gap E_g and the cyclotron mass m_b at the bottom of the band are the same as those in pure bismuth, a Fermi energy in $Bi_{95}Sb_5$ is calculated to be $E_e = 0.007$ eV. The values for the Fermi energy and E_g in pure bismuth are taken to be those measured by Brown, Mavroides, and Lax in magnetoreflection measurements.[9] They are $E_e = 0.025$ eV and $E_g = 0.015$ eV. The number of electrons per ellipsoid is derived from Eq. (2) to be

$$N_e = (8\pi/3h^3)[2E_e(1+E_e/E_g)m_0(\det\alpha_b)^{-1/3}]^{3/2},$$

where $m_0(\det\alpha_b)^{-1/3}$ is the density-of-states effective mass at the bottom of the band. In pure bismuth, N_e is calculated to be $N_e = 0.8\times10^{17}/\text{cm}^3$ and in $Bi_{95}Sb_5$, $N_e = 0.05\times10^{17}/\text{cm}^3$. A three-ellipsoid model for the electrons in $Bi_{95}Sb_5$ gives the total number of electrons $N = 0.15\times10^{17}/\text{cm}^3$ quoted earlier.

The occurrence of a long relaxation time in such a nondilute alloy is somewhat surprising. This is plausible, however, since the electron wavelengths are of the order of 1000 Å and will not be strongly scattered by individual solute atoms.

The author is grateful to B. Bingham for technical assistance and to J. J. Schott for growing the crystal.

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HIGH-FIELD SUPERCONDUCTIVITY IN NIOBIUM

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Many superconductors, including niobium, maintain zero resistance when exposed to magnetic fields substantially higher than their thermodynamic or bulk critical fields, H_{cb}. In this sense niobium is a high-field superconductor, and explanations of its behavior may be applicable to more complex materials such as alloys or compounds. Present explanations of high-field superconductivity invoke, directly or indirectly, the thermodynamic argument[1] that if a superconducting region is thin enough to permit substantial field penetration, it will remain superconducting for $H > H_{cb}$. These theories fall into two classes:

(A) Inhomogeneities such as fine filaments exist which have a higher H_{cb} than the surrounding material. In a strong field the current flows along these filaments, which may be dislocations.[2] As the applied field is increased these filaments shrink in size, raising their critical fields. A model of this type has been used[3] to explain the observed dependence of current-carrying capacity on the direction of the applied field.

(B) In the presence of a magnetic field the sample can lower its free energy by breaking up into normal and superconducting regions thin enough to allow field penetration into the superconducting regions. This increases the normal-superconducting surface area, and may be thought of as resulting from a negative surface energy. Abrikosov[4] and more recently Goodman[5,6] and Yntema[7] have proposed theories of this type.

This Letter describes and interprets a number of experiments on Nb wires in magnetic fields. The main points may be enumerated as follows:

(1) The resistance of current-carrying Nb wires behaves in a very unusual manner in some regions;