The author wishes to express his thanks to Professor Ferrell for helpful advice and important suggestions, and to Professor Rollwagen, director of this institute, for his constant interest in this work. He is also indebted to Mr. Fischer and Mr. Otto for their performance of the energy-loss experiments.

*A more detailed report of this work will be submitted to the Zeitschrift für Physik.

[1]R. A. Ferrell, Phys. Rev. 111, 1214 (1958).

[2]L. Marton, L. B. Leder, and H. Mendlowitz, Advances in Electronics and Electron Physics, edited by L. Marton (Academic Press, Inc., New York, 1955), Vol. 7, p. 183.

[3]R. A. Ferrell (private communication).

[4]H. Fröhlich and H. Peltzer, Proc. Phys. Soc. (London) A68, 525 (1955).

[5]H. Watanabe, report submitted to the Gatlinburg Conference on Penetration of Charged Particles in Matter, 1958 (unpublished).

[6]The measurements of the loss spectra were performed by J. Fischer and A. Otto of this institute with a Möllenstedt-type analyzer.

PLASMON RERADIATION FROM SILVER FILMS

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A straightforward application of the free electron theory of metals would indicate the possibility of a plasma oscillation of the valence electrons at a frequency dependent on their density. It has been conjectured[1] that the characteristic losses of energy suffered by high-energy electrons traversing thin metallic films can be attributed to the excitation of these plasmons with a characteristic frequency determined through $\Delta E = \hbar\omega_p$.

However, this explanation of the losses is not universally accepted.[2] For this and other reasons stated in his paper, Ferrell[3] has suggested a crucial test of the plasmon theory. He states that, at certain ratios of film thickness to incident electron velocity, plasmons would be excited which could be expected to decay through photon emission at a frequency ω_p. Although the level of this radiation is expected to be small, it differs from anticipated background in its dependence of intensity on electron velocity and its angular distribution about the normal to the film. The width of the line should also depend strongly on angle of observation, through the relation

$$\tau_\gamma^{-1} \propto \sin\theta \tan\theta, \qquad (1)$$

where θ is the angle from the normal and τ_γ the radiative mean life.

Although we originally planned to work with sodium films, we found it impossible to keep them continuous and clean in our apparatus. We now are working with thin silver films, in which the predictions of the free electron theory are less clear-cut but the experiment itself more simple. We deposit films of the order of 500 A thick and transfer them to cover a slit 1 mm wide at the target end of an electron gun structure providing 22-kev electrons normally incident on the film. The entire gun structure is capable of rotation about a slit serving as the input to a diffraction spectrometer which, with the exception of input lenses and a quartz window, is located entirely outside the vacuum system. The signal is taken from a photomultiplier and read beyond an amplifier and phase detector, which eliminates noise having no relation to the modulated beam.

As shown in Fig. 1(a), we find a peak in the spectrum taken at 30° from the film normal; it has

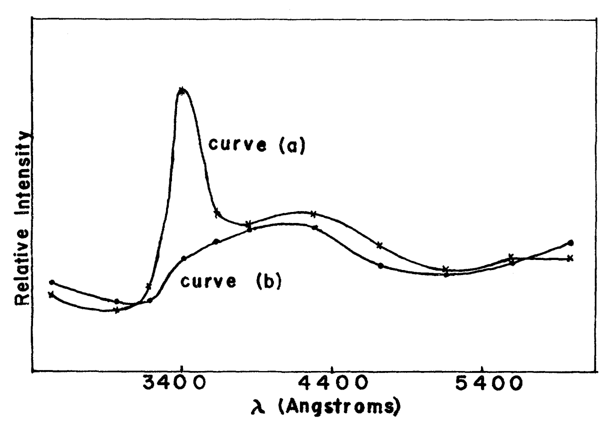

FIG. 1. Intensity of radiation vs wavelength at two different angles from normal of silver film. Thickness of film 500 A; beam voltage 22 kv. (a) $\theta = 20°$. (b) $\theta = 75°$.

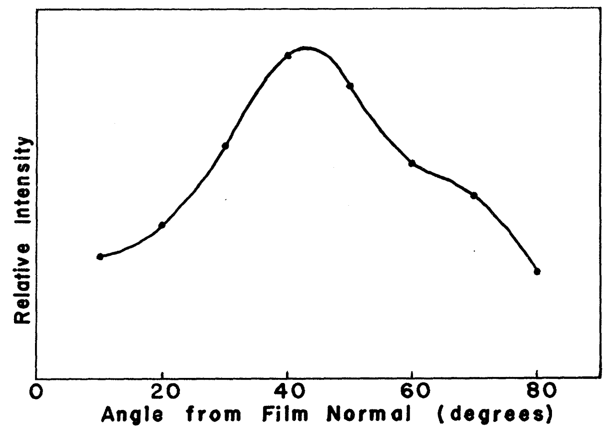

FIG. 2. Angular dependence of radiation at 3400 A under identical conditions of voltage and film thickness to those of Fig. 1.

disappeared into the background of the spectrum taken at 70° [Fig. 1(b)]. We attribute its disappearance to the expected broadening via shorter lifetime [Eq. (1)] and the expected angular dependence (Fig. 3 of reference 3). The peak in the spectrum occurs at 3400 A and coincides with the 3.7-ev loss in silver[4] and the well-known optical transparency in that metal.

An additional indication that we are indeed observing plasmon decay is provided by the angular distribution shown in Fig. 2, taken at 3400 A. This peaks around 40° to the normal to the film and appears to go to zero both at the normal and in the plane of the film, although we do not have access to those points with our equipment. This behavior is to be compared with Fig. 3 of reference 3. Comparison runs on the low-level background from gold have indicated an isotropic angular pattern.

We are attempting polarization measurements of the 3400A line from silver, but have no definitive results as yet.

[1]D. Pines, Revs. Modern Phys. 28, 184 (1956).

[2]L. Marton, Advances in Electronics and Electron Physics (Academic Press, New York, 1955), Vol. 7.

[3]R. A. Ferrell, Phys. Rev. 111, 1214 (1958).

[4]Unpublished work of H. Watanabe, as reported privately by R. Ferrell.

ADDITIONAL SPIN RESONANCE SPECTRUM IN ANTIMONY-DOPED GERMANIUM

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Pontinen and Sanders[1] have recently reported a spin-resonance spectrum for antimony-doped germanium which exhibits a striking new feature. In addition to the resonance of electrons bound to antimony donors which was observed by Feher, Wilson, and Gere,[2] they observe a set of four lines each of which apparently represents a g tensor of the type observed by Wilson and Feher[3] for electrons bound to donors in germanium subjected to a large elastic shear strain. We believe that the additional resonance observed by Pontinen and Sanders[1] may be accounted for by the strains normally present in germanium crystals and present our reasons in this note.

An electron bound to a donor will show a resonance line of the type observed by Wilson and Feher in strained germanium if the local strain is such as to depress the energy of one of the valleys below any other valley by a separation of at least several times Δ_c. The donor wave function then is derived from the states of that valley alone, and is insensitive to additional strain.[4] All donors satisfying this condition therefore contribute to one of the four anisotropic g tensors of the type observed by Wilson and Feher. The crucial point is that the g value is stationary with respect to other strain components, and the condition is therefore satisfied for a finite range of the ratios of strain components.

In the case of an antimony donor Δ_c is very small, and the critical strain, ϵ_c, required to separate the valleys by an amount $4\Delta_c$ is correspondingly small. It can be estimated by the relation $\Xi_u\epsilon \approx 4\Delta_c$. Using recent values[5] for Δ_c for an antimony atom and for Ξ_u, it is found that $\epsilon_c \approx 3\times10^{-5}$. Even in a relatively good germanium crystal, strains of this magnitude may exist in an appreciable part of the crystal. For example, strains larger than ϵ_c are encountered up to 10^{-4} cm from a dislocation.

Thus we divide the antimony donors into three classes: (1) those subject to a strain with a