sorption was conjectured in an earlier paper. See. T. H. Stix, Phys. Fluids 3, 19 (1960).

[2]P. L. Auer, H. Hurwitz, Jr., and R. D. Miller, Phys. Fluids 1, 501 (1958).

[3]I. B. Bernstein, Phys. Rev. 109, 10 (1958).

[4]G. Landauer, in Proceedings of the Fifth International Conference on Ionization Phenomena in Gases, Munich, 1961 (North-Holland Publishing Company, Amsterdam, 1962), Vol. 1, p. 389.

[5]W. Wasow, Ann. Math. 52, 350 (1950).

[6]M. V. Babykin, P. P. Gavrin, E. K. Zavoiskii, L. I. Rudakov, and V. A. Skoryupin, Zh. Eksperim. i Teor. Fiz. 43, 411 (1962) [translation: Soviet Phys.-JETP 16, 295 (1963)].

[7]E. Canobbio and R. Croci, in Proceedings of the Sixth International Conference on Ionization Phenomena in Gases, Paris, 1963, edited by P. Hubert (S.E.R.M.A., Paris, 1964), Vol. 3, p. 269.

[8]H. Dreicer, private communication.

[9]T. H. Stix, Bull. Am. Phys. Soc. 10, 230 (1965).

[10]A. F. Kuckes and J. M. Dawson, Phys. Fluids 8, 1007 (1965).

PLASMA RADIATION FROM THIN SILVER FOILS EXCITED BY LIGHT

J. Brambring and H. Raether

Institut für Angewandte Physik der Universität Hamburg, Hamburg, Germany

(Received 18 October 1965)

If electrons (some 10-keV energy) traverse a thin metal film (some 100 Å) they excite a radiative plasma oscillation of energy $\hbar\omega_p$ (ω_p = volume plasma frequency), which emits a peak of electromagnetic radiation around the frequency ω_p. This radiation, predicted by Ferrell,[1] has been observed by Steinmann[2] as well as by Brown, Wessel, and Trounson[3] in silver and later by Arakawa, Herickhoff, and Birkhoff in aluminum and some other metals.[4]

In the following an experiment in silver is described in which this radiative plasma mode is not excited by electrons, but by electromagnetic radiation. Since the radiative plasma oscillation consists of electrons vibrating perpendicular to the surface, a light emission is expected with an intensity peak around ω_p as in the electron experiment, if the electric field of the exciting radiation has a component normal to the foil. The emitted radiation should be polarized, its electric field vector vibrating in the plane given by the foil normal and the direction of observation, and show the angular dependence of intensity calculated by Ferrell.

These considerations are verified by the experiments: If one irradiates a silver foil with polarized white light at a nonzero angle of incidence (α), one observes at the angle θ relative to the foil normal (see Fig. 1) a strong intensity maximum at $\lambda_p = 3275 \pm 15$ Å ($\hbar\omega_p = 3.77 \pm 0.02$ eV) (see Fig. 2), if the electric vector of the exciting light lies in the plane given by the direction of the incoming beam and the foil normal. This maximum does not appear if the incoming light is polarized perpendicularly to this plane. The wavelength of the intensity maximum agrees with $\lambda_p = 3300$

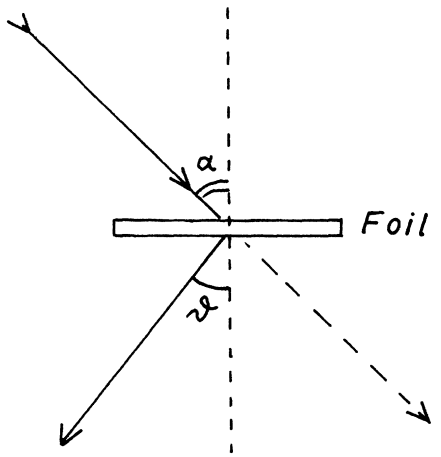

FIG. 1. A polarized light beam hits a thin silver foil at the angle α. The light emitted by the excited surface plasma oscillation at the angle θ relative to the foil normal is detected by a photomultiplier.

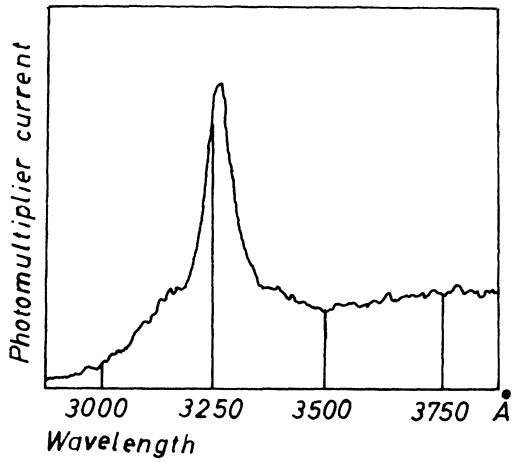

FIG. 2. Recorder traces of the photon emission from Ag foil (at room temperature) at $\alpha = 30°$ and $\theta = 45°$. The peak intensity is observed at $\lambda_p = 3275$ Å corresponding to $\hbar\omega_p = 3.77$ eV.

Å (at room temperature) measured in experiments with electron excitation. The emitted light is fully polarized in the plane given by the normal of the foil and the direction of observation. The maximum of intensity is obtained if the angle θ approaches 25-30° in agreement with Ferrell's calculation and with the electron experiment. The emitted intensity is zero, if one observes in the direction of the foil normal ($\theta = 0$). The intensity of the emitted light increases with the thickness of the silver foil and passes through a maximum at a thickness of nearly 300 Å. The intensity maximum shifts to higher frequencies if the foil temperature is decreased, in agreement with the experiments of Arakawa, Davis, and Birkhoff[5] with the silver radiation excited by electrons.

The excitation of the plasma oscillation leads to an additional absorption of the light traversing a thin film of silver, known as plasma resonance absorption, if its frequency equals the plasma frequency ω_p and if the electric field vector has a component perpendicular to the foil surface.[6] In the experiment described here the excitation of the plasma mode is observed by its emitted radiation.

Unpublished measurements of D. Schulz in our institute have shown that the frequency of the plasma resonance absorption (minimum of the intensity of the transmitted, p-polarized light[6]) is temperature dependent: Its energy ($\hbar\omega_p = 3.76 \pm 0.025$ eV $\Rightarrow \lambda_p = 3280 \pm 20$ Å at room temperature) grows with decreasing temperature as $\Delta\hbar\omega_p/\Delta T = -3.8\times10^{-4}$ eV/deg. This figure is in good agreement with the dependence of the emission peak on temperature excited by electrons or by electromagnetic radiation mentioned above.

[1]R. A. Ferrell, Phys. Rev. 111, 1214 (1958).
[2]W. Steinmann, Phys. Rev. Letters 5, 470 (1960); Z. Physik 163, 92 (1961).
[3]R. W. Brown, P. Wessel, and E. P. Trounson, Phys. Rev. Letters 5, 472 (1960).
[4]E. T. Arakawa, R. J. Herickhoff, and R. D. Birkhoff, Phys. Rev. Letters 12, 319 (1964).
[5]E. T. Arakawa, N. O. Davis, and R. D. Birkhoff, Phys. Rev. 135, A224 (1964).
[6]A. J. McAlister and E. A. Stern, Phys. Rev. 132, 1599 (1963).

ELECTROREFLECTANCE AT A SEMICONDUCTOR-ELECTROLYTE INTERFACE*

Kerry L. Shaklee, Fred H. Pollak, and Manuel Cardona

Physics Department, Brown University, Providence, Rhode Island
(Received 28 October 1965)

We have measured the modulation of the spectral reflectivity by an alternating electric field for several group IV, III-V, and II-VI semiconductors at the interface with an electrolyte. The results are very similar to those obtained recently for germanium, silicon, and GaAs,[1] in which case the electric field is applied by means of a transparent conducting electrode separated from the semiconductor by a thin insulating foil. In addition to its greater simplicity, the electrolyte-semiconductor configuration[2] offers the possibility of extending the measurements of Seraphin and co-workers to shorter wavelengths (the short-wavelength cutoff is determined by the electrolyte and is 1700 Å for water). Modulations in reflectance as high as 0.2% can be obtained with an applied ac voltage of 2 V peak to peak. Furthermore, while accurately flat and smooth samples are required for the transparent-electrode method, samples obtained by irregular cleavage or fracture can be used for the electrolyte technique. It is also possible to measure samples cleaved within the electrolyte without exposing the surface to air. The transparent-electrode configuration is preferable at low temperatures, but measurements far below 0°C can be performed with the electrolyte method by using suitable low-temperature electrolytes.[3] The electrolyte technique also makes it possible to measure accurately the effects of uniaxial stress. It is also believed that this technique can be used for studying the electrochemistry of semiconductor-electrolyte interfaces.

A dilute solution of KCl in water was used for the room-temperature measurements. A platinum plate was used as one electrode while the other was the material to be measured. The sample was dc biased so as to form a blocking contact and an ac voltage was superimposed