Diamagnetic Resonance in Electronic Conductors

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RECENTLY Dresselhaus, Kip, and Kittel announced[1] the discovery of a new type of quantum resonance effect, namely the diamagnetic (or "cyclotron") resonance. The authors attribute to Dingle[2] the priority of developing the theory of this effect in solid electronic conductors.

I should like to point out that the first theoretical treatment of this new effect, as far as I know, was, in fact, advanced by me already in 1951.[3] In that article, dealing with the diamagnetic resonance in metals and semiconductors, the general features of the effect were accurately predicted and its importance was pointed out as a new means for the direct measurement of the effective mass of the carriers.

[1] Dresselhaus, Kip, and Kittel, Phys. Rev. **92**, 827 (1953).
[2] R. B. Dingle, Proc. Roy. Soc. (London) **A212**, 38 (1952).
[3] J. G. Dorfman, Doklady Akad. Nauk S.S.S.R. **81**, 765 (1951).

Ultraviolet Absorption in Barium Oxide Films

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OPTICAL absorption in BaO films evaporated on quartz tubes from BaO coatings was measured in the wavelength region between 2100A and 3500A. The structure of the experimental tubes used in these measurements is illustrated in Fig. 1. The film was evaporated on one side of the quartz wall from the coating which was activated thermally beforehand for about one hour. Particular caution was taken for the evacuation of the tubes, so the measured absorption curves were almost stable.

Sproull and Tyler[1,2] reported the presence of two distinct absorption bands in BaO; the first one exists in the energy region between 3.8 ev and 4.8 ev, and the second one, of shorter wavelength, begins at 4.8 ev. The former with accompanying photoconduction was assumed by them to be exciton absorption, while the latter was ascribed to band-to-band excitation.

The results of the present measurements were similar to theirs; that is, the threshold energy of the first absorption is 3.95 ev and the second absorption threshold is 4.95 ev. However, precise plotting of the transmittance *versus* wavelength at intervals of 2A or 5A made it possible to distinguish two peaks in the first absorption band, existing at 4.1 ev and 4.4 ev respectively.[3] It is interesting that the wavelength of the former peak shows good agreement with that of the photoconductivity peak obtained by Sproull and Tyler.[2]

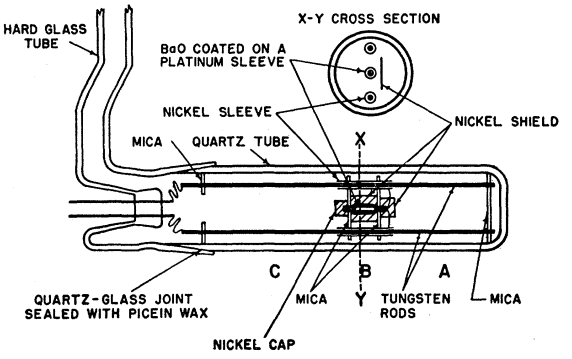

FIG. 1. The structure of the experimental tubes. The tube was evacuated to a pressure less than 1×10^{-5} mm Hg and baked by a gas flame for about one hour except for the wax joint, which was cooled by running water during the baking process; then getter was flashed in a getter chamber. The cathode mount is movable along the tungsten rods. The decomposition and activation of the cathode were carried out at position *A* and evaporation at position *B*. Position *C* was used for the blank in absorption measurements.

It is interesting to compare the absorption in the film in high vacuum, which can be considered as *n*-type BaO, with that in the *p*-type film, which can be produced in an oxygen atmosphere.[4] The absorption in the films deactivated by oxygen gas was measured. The oxygen, which was dehydrated by H_2SO_4, $CaCl_2$, and P_2O_5, was introduced to the tube through two liquid air traps by means of breakable joints. Figure 2 shows the variation of the transmittance in the films evaporated in vacuum when oxygen was introduced. The peaks of the first absorption band were gradually reduced and disappeared at room temperature as a result of the introduction of oxygen, while the threshold energy of the second absorption remained uninfluenced by oxygen.

The effect of oxygen raises a question regarding the origin of the two absorption peaks at 4.1 ev and 4.4 ev respectively. Many experiments indicate the existence of excitons in BaO. However, it is evident that the exciton is not influenced by deactivation of BaO by oxygen. Accordingly, as far as the effect of the oxygen is

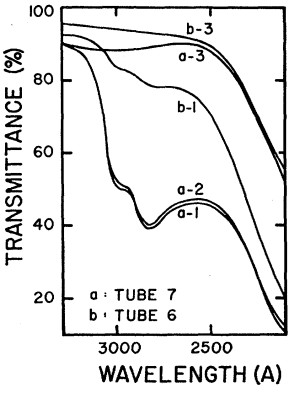

FIG. 2. Variation of the transmittance *versus* wavelength curves in two BaO films when oxygen was introduced at pressure of about 10 mm Hg: $a-1$ and $b-1$ show the curves measured in vacuum; $a-2$ shows the curve measured just after the introduction of oxygen; $a-3$ and $b-3$ show the curves measured after more than 10 hours in an oxygen atmosphere.

concerned, it is more reasonable to attribute these peaks to the electronic transition occurring at the donor energy levels than to the excitons. On the other hand, there are some reasons which make it difficult to consider that these peaks are a structure-sensitive property as was indicated by Sproull and Tyler; that is, large absorption constant and small temperature shift.

The author intends to continue this work. He wishes to express his gratitude to Dr. Y. Ishikawa, Research Laboratory of Nippon Electric Company, under whom this work was undertaken.

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[1] W. W. Tyler and R. L. Sproull, Phys. Rev. **83**, 548 (1951); W. W. Tyler, Phys. Rev. **76**, 1887 (1949).

[2] R. L. Sproull and W. W. Tyler, in *Semiconducting Materials* (Butterworths Scientific Publications, London, 1951), p. 122.

[3] After this work was performed, the author received a communication from Dr. Sproull that R. J. Zollweg of Cornell University has found similar peaks in this region.

[4] Ishikawa, Sato, Okumura, and Sasaki, Phys. Rev. **84**, 371 (1951).

Mechanism for Photovoltaic and Photoconductivity Effects in Activated CdS Crystals

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In previous papers,[1,2] experimental results with activated CdS crystals were reported that could be explained by the Brosser-Kallmann-Warminsky theory of conduction.

Brosser, Kallmann, and Warminsky[3] suggest two possible mechanisms which can explain conduction in activated crystals: (a) They propose that the holes formed by excitation are localized in the filled band and cannot migrate to the electrodes; as long as this is the case, electrons in the conduction band can be in thermal potential equilibrium with the electrodes. This permits a re-supply of electrons from the cathode. The conductivity then depends on the number of bound holes and on the length of time the holes are localized. (b) They apply the Riehl-Schön model. Here it is assumed that part of the excited electrons pass into a band which is somewhere between the conduction band and the filled band and in which the electrons can move freely. The electron density in this band is in thermal potential equilibrium with the electrodes and electrons remain in this band for a relatively long time. As long as there are sufficient electrons in this band, additional electrons can pass from the electrodes. During this period, metallic conduction is possible.

Recent investigation of the spectral response of the photovoltaic effect in activated CdS single crystals[2] shows a response in the red portion of the spectrum. Photoconductivity measurements as a function of wavelength show two peaks: one at the absorption cutoff and the other in the longer-wavelength region. When the photoconductivity is measured from short wavelengths toward long wavelengths and *vice versa*,[1] a shift in the position of the peaks is observed. When the photoconductivity is measured from short to long wavelengths, the peaks are shifted toward long wavelengths because of long-lived electrons in the impurity band; this also causes a tailing out in the long-wavelength region. When the experiment is reversed, photocurrent is not observed until sufficient energy is available to excite electrons to the impurity band; this diminishes the long-wavelength tail.

The energy separation of the bands in CdS would not give rise to the photovoltaic response in the red region mentioned above. The excitation of electrons in impurity levels below the conduction band by light of wavelengths in the red and near infrared could explain the spectral response by allowing a two-step process to the conduction band; however, this would not explain the photoconductivity.

These long lifetimes cannot be explained by the above-mentioned two-step excitation process unless we assume that the holes are fixed. If this were the case, the photovoltaic effect would not be observed. Therefore, to be consistent with both photovoltaic and photoconductivity effects, it appears that the intermediate energy level must be a band. This conforms to the Riehl-Schön model.

[1] Reynolds, Czyzak, Allen, and Reynolds (to be published).

[2] Reynolds, Leies, Antes, and Marburger, Phys. Rev. **96**, 533 (1954).

[3] Brosser, Kallmann, and Warminsky, Z. Naturforsch. **4A**, 631 (1949).

Electronic Susceptibility in Certain Alloys*

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In recent measurements of magnetic susceptibility *vs* composition in the $MgCu_2-MgZn_2$ system (Fig. 1), Klee and Witte[1] have discovered some interesting features in the dependence of susceptibility on electron concentration, and have analyzed the experimental results using the model of nearly free electrons moving in a weak cosine potential. In particular they attribute the two peaks on the left part of the experimental cuve of Fig. 1 to anomalies in the orbital magnetism of the valence electrons associated with the successive touching of the Fermi surface to the two kinds of faces of the