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[6]Such waves can reduce the characteristic relaxation time from the local value $\tau \sim 1/k^{2/3}$.

[7]The energy spectrum is $E(k) \propto k^3 \exp(-ck/k_d)$ where $k_d = (\epsilon/\nu^3)^{1/4}$. A similar spectrum was found by Kraichnan,[2] from equations which left the scaling of k_d unspecified. It is shown in this analysis that the terms retained by Kraichnan are of the same order of magnitude as those involved in the "exact" equations. However, Kraichnan's "direct interaction" contribution seems to be just a part of the complete interaction in this range.

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ABSORPTION EDGE OF GaAs AND ITS DEPENDENCE ON ELECTRIC FIELD

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The effect of strong electric fields on the absorption edge (Franz-Keldysh effect) of gallium arsenide has been measured previously by Moss[1] and by Lambert[2] using bulk material and by Penchina, Frova, and Handler[3] using p-n junctions. The results to be reported in this Letter are bulk effects obtained using semi-insulating gallium arsenide held at a temperature of 77°K. The observations are new in three respects: (1) They extend up to an absorption coefficient (K) of 1.2×10^4 cm^{-1} and so include measurements well above the absorption edge. (2) Polarization dependence has been investigated. (3) Effects have been found to be specimen dependent. These observations were made on crystals which were mechanically polished and mounted on either glass or sapphire substrates. Square-wave voltage pulses were applied to the crystal producing electric fields of up to 60 kV cm^{-1} perpendicular to the light beam. The transmission was measured during and after the voltage pulse, the latter measurements enabling changes from the zero-field absorption due to heating of the sample to be detected. Uniform electric fields were produced within the samples despite their inhomogeneous resistivity by applying the voltage pulses at a repetition frequency of 100 cps, which is much greater than typical reciprocal dielectric relaxation times for the material (~1 sec^{-1}).

Figure 1 shows the absorption edge and its field dependence obtained from a set of specimens of various thicknesses, the data from which showed agreement in regions of overlap. It will be seen that there is considerable "structure" in the zero-field absorption but that this becomes less evident as the electric field strength is increased. As a consequence, some regions of the spectrum show a particularly high sensitivity to field; however, at fields in excess of 20 kV cm^{-1} the whole spectrum becomes relatively insensitive to field.

As the photon energy is increased, a point on the edge is reached where the effect of the field changes from one of increasing K to one of decreasing K. This inversion point for a field of 12 kV cm^{-1} is shown for three different crystals in Fig. 2. A pronounced dependence on specimens of the zero-field absorption and

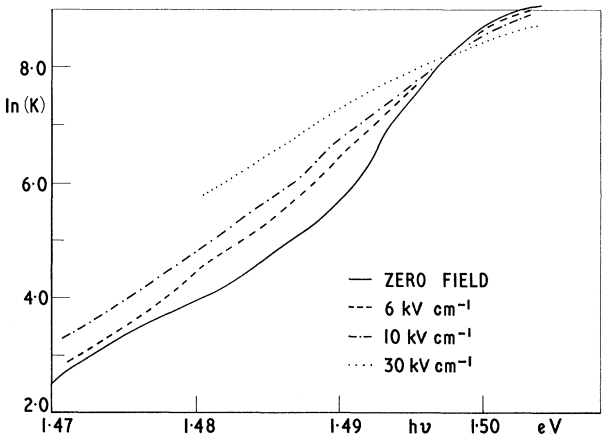

FIG. 1. Absorption edge of GaAs from a set of crystals showing good agreement in regions of overlapping data. Zero-field, 6-, 10-, and 30-kV cm^{-1} curves are derived from approximately 200, 100, 100, and 50 points, respectively. Estimated standard error in ln(K) for each point is typically 0.03. Optical resolution 500 μeV.

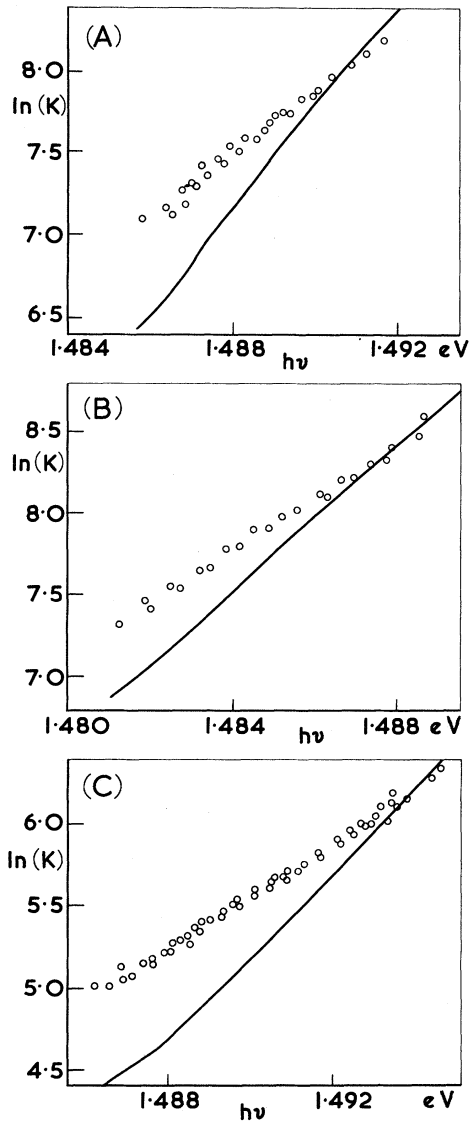

FIG. 2. Zero-field (full lines) and 12-kV cm^{-1} absorption spectra near the lowest inversion of the electroabsorption for three different crystals of GaAs. Optical resolution 500 μeV.

the electroabsorption spectrum can be seen. There is a trend in which the less steep edges show lower sensitivity to electric field.

A preliminary investigation of polarization dependence showed that the effects were small. The electroabsorption spectrum for plane-polarized radiation with electric vector perpendicular to the applied field was greater than that parallel by up to 20%. No distinction between polarizations has been made in the results presented here; they are strongly weighted to the parallel orientation by the optical system employed.

Above the band-gap transmission, measurements have been made on one crystal. An oscillatory electroabsorption spectrum has been observed over a range of electric field strength (20-60 kV cm^{-1}) and is shown in Fig. 3 for a field of 40 kV cm^{-1}. The absence of a well-defined exciton peak[4] in the zero-field absorption is attributed to crystal defects, the majority of which may have been introduced in the preparation of the very thin (2.7 μm) sample.

There are three factors which contribute to prevent a direct comparison between our observations and the theoretically predicted effects of field on the absorption edge.[5,6] Firstly, as Sturge's[4] analysis of the absorption edge has shown, strong effects of Coulomb interaction between electron and hole pervade the region of absorption we have investigated. Such effects are not incorporated in current theories though Duke[7] has shown the effect of field on the line shape of the lowest energy exciton peak. Secondly, existing theories do not take into account the degeneracy of the valence band edge at the center of the zone. And thirdly, there

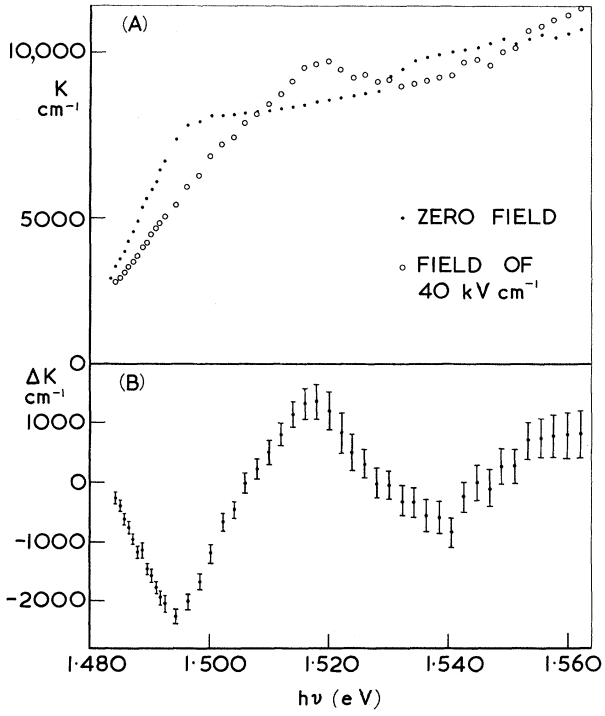

FIG. 3. (a) Absorption spectra of GaAs at zero field and 40 kV cm^{-1}. (b) Difference between spectra. Optical resolution 1 meV.

is no provision for the strong specimen dependence we have observed.[8] Since the impurity concentration in the semi-insulating GaAs we have used is known to exceed 10^{16} cm^{-3}, we attribute the specimen dependence in Fig. 2 to impurity effects.[9] At this concentration, impurities can be expected to contribute to broadening of exciton structure to extend the fundamental edge by production of tail states as well as to give rise to observable absorption bands. Qualitatively, the first two effects are similar to that produced by an electric field. It follows that samples showing the least effects due to impurities will be most sensitive to electric fields and also that at sufficiently high field strengths the effect of field will dominate and the resulting absorption spectrum will be specimen independent. This is consistent with the trend of our observations. As seen from Fig. 1, at high fields (30 kV cm^{-1}), the absorption edge becomes approximately exponential in agreement with Callaway's predictions[5] and can be fitted to his theory if a reduced mass of $0.03m_0$ is chosen. While this value is close to the electron–light-hole reduced mass,[10] it would be surprising if the neglect of excitonic effects in Callaway's treatment were unimportant although it should be noted that the field strength is sufficient to remove exciton structure.[7]

The oscillating electroabsorption we have observed above the band gap is a manifestation in the absorption spectrum of an effect observed by Seraphin and Hess[11] in the reflection spectrum of germanium. It has been predicted by Callaway[5] and Tharmalingam[6] and our data can be fitted to theory using a single reduced mass of $0.06m_0$. However, detailed interpretation of these results must await incorporation in the theory of the effect of the Coulomb interaction between electron and hole and the degeneracy of the valence band edge.

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