

Data on σ_D^Z are interesting since they serve as an independent source (alongside with σ_t) of information concerning the transverse contributions to the amplitude (σ_D^Z , like σ_t , does not depend on its longitudinal part), and, in particular, can facilitate the separation of the longitudinal cross section σ_l .

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FORBIDDEN OPTICAL AND ELECTRICAL BANDS OF AN AMORPHOUS SEMICONDUCTOR

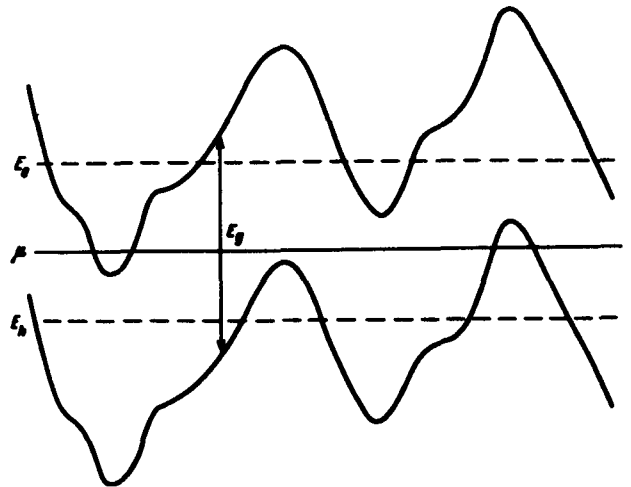
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In amorphous semiconductors, the light absorption coefficient decreases exponentially at quantum energies $\hbar\omega$ that are smaller than a certain value E_g , called usually the optical forbidden band. At the same time, experiment shows that the density of states in the interior of the forbidden band is apparently quite large. Fritzsche [1] noted that these facts can be understood by assuming that in an amorphous semiconductor there exist large-scale fluctuations of the electrostatic potential, which lead to a parallel bending of the energy bands (see the figure). Indeed, in such a model there can exist an appreciable number of electronic states even on a Fermi level μ located deep in the forbidden band. On the other hand, absorption of light with quantum energy $\hbar\omega < E_g$ occurs only as a result of tunneling of the carriers under the humps of the large-scale relief, and is therefore very small.



Energy scheme of an amorphous semiconductor. The wavy lines represent the bottom of the conduction band and the ceiling of the valence band. The solid straight line is the Fermi level, and the dashed lines are the percolation energies of the electrons and holes.

To discuss the conductivity in the Fritzsche model, it can be assumed that the carriers behave like classical particles with respect to the large-scale potential. It is known [2] that for a classical particle in an arbitrary potential-energy relief $V(r)$ there exists a so-called percolation energy E_{perc} , i.e., the maximum value of the particle energy E ,

at which it is still possible to find a connective region of space with $V(r) < E$, which goes off to infinity in all directions. Only by having an energy larger than E_{perc} can a classical particle go through all of space. The percolation levels for electrons E_e and for holes E_h are shown dashed in the figure. Only electrons thrown from the Fermi level above E_e and holes thrown below E_h can take part in the static conductivity. Therefore the conductivity activation energy ΔE is equal to $\min\{E_e - \mu, (\mu - E_h)\}$. The quantity $2\Delta E$ is usually called the electric width of the forbidden band. We wish to call attention to the fact that for a classical potential of general form $E_e - E_h < E_g$, and consequently $2\Delta E < E_g$, i.e., the electric width of the forbidden band is always smaller than the optical width.

To make this statement obvious, let us consider an arbitrary potential relief $V(\vec{r})$ and call regions with $V(\vec{r}) < E$ white, and the remainder of space black. Obviously, at very small E there is percolation only over the black region, and at very large E only over the white regions. Let us consider the arrangement of the critical energies E_{white} and E_{black} , at which percolation over the white occurs and percolation over the black vanishes. It is obvious that a random potential with a finite correlation radius cannot produce an arrangement in which there is no percolation in either the white or the black. Therefore $E_{\text{white}} \leq E_{\text{black}}$. The only basis for satisfying the equality $E_{\text{white}} = E_{\text{black}}$ in an arbitrary potential can be the dimensionality of space. Indeed, in the two-dimensional case ($V(r) = V(x, y)$) we always have $E_{\text{white}} = E_{\text{black}}$, since percolation over the white means absence of percolation over the black and vice-versa. In the three-dimensional case, percolation over one color does not prevent percolation over the other, and therefore generally speaking $E_{\text{white}} < E_{\text{black}}$, i.e., there exists an energy region where percolation over both colors is possible.

Let us consider now the relief of the potential energy of the electron in the conduction band. It is obvious that for this relief $E_{\text{white}} = E_e$, and $E_{\text{black}} = E_h + E_g$. Thus, $E_e - E_h < E_g$ and $2\Delta E < E_g$. The difference between E_g and $2\Delta E$ should coincide in order of magnitude with the amplitude of the bending of the bands. If this amplitude, as in the Fritzsche model, is comparable with E_g , then $E_g - 2\Delta E$ can constitute a noticeable fraction of E_g .

| Substance | E_g , eV | $2\Delta E$, eV | $(E_g - 2\Delta E)/E_g$, % |
|--|-----------------|------------------|-----------------------------|
| As_2S_3 | 2.60 [3] | 2.05 - 2.17 [3] | 7 - 21 |
| | 2.50 [4] | 2.32 [5] | |
| As_2Se_3 | 1.95 - 2.00 [6] | 1.81 [5,6] | 7 - 10 |
| As_2Te_3 [7] | 0.98 | 0.80 | 18 |
| $2\text{As}_2\text{Te}_3 \cdot \text{As}_2\text{Se}_3$ [8] | 1.10 | 1.00 | 10 |
| GeTe [9] | > 0.80 | 0.65 | > 19 |
| $\text{Ge}_{11}\text{Si}_{11}\text{As}_3\text{Te}_{40}$ [10] | 1.17 | 0.90 | 23 |
| $\text{Ge}_{16}\text{As}_3\text{Te}_{28}\text{S}_{21}$ [11] | 1.35 | 1.10 | 18 |

The experimental values of $2\Delta E$ and E_g are gathered in the table. In experiments on the dependence of the conductivity on the temperature T , one usually measures the quantity $2\Delta E$, which is extrapolated to $T = 0$ from room temperature [1]. We therefore compare $2\Delta E$ in our table with the value of E_g extrapolated to $T = 0$ and obtained in the following manner. The dependence of the absorption coefficient α on the frequency at large α was first processed by the formula of Tauc et al. [1] $\alpha(\omega) \sim (\hbar\omega - E_g)^2/\hbar\omega$, and the value of E_g at room temperature was determined. Then, the derivative $\partial E_g/\partial T$ at $T = 293^\circ\text{K}$ was used to extrapolate to $T = 0$. In the cases when we did not know this derivative (GeTe), we determined it from the values of E_g at $T = 77^\circ\text{K}$, assuming by the same token that E_g depends linearly on T in the 77°K interval. Since in fact $|\partial E_g/\partial T|$ always decreases with decreasing T , such an extrapolation method gives only a lower estimate for E_g . In some of the cited papers, the determination and extrapolation of E_g were already performed, and all we had to do was to complete the missing steps. In [11] there are no $\alpha(\omega)$ curves. We therefore determined E_g from the criterion $\alpha(\hbar\omega = E_g) = 10^3 \text{ cm}^{-1}$. Our experience with the reduction of the $\alpha(\omega)$ curves by the Tauc method shows that this criterion is well satisfied for all the substances gathered in the paper.

It is seen from the table that the values of $2\Delta E$ are much smaller than E_g . This can serve as a strong argument supporting the model of curved bands for amorphous semiconductors.

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