FEATURES OF OPTICAL CHARACTERISTICS OF BISMUTH FILMS UNDER CONDITIONS OF QUANTUM SIZE EFFECT

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The relatively recently started investigations of the quantum size effect [1 - 3] cover for the most part the features of the kinetic and galvanomagnetic characteristics of Bi and Sb films [4 - 8].

The optical properties of semimetals under the conditions of the quantum size effect have not been investigated[1].

We report in this communication the results of measurement of the spectral dependence of the transmission of bismuth films obtained by vacuum evaporation on a KBr substrate.

The main results discussed here reduce to the following: 1) A shift of the red limit of optical absorption (change in the width of the forbidden band) is observed when the film thickness is varied. 2) The instant at which the metal-semiconductor transition takes place is determined. 3) A nonmonotonic spectral dependence of the optical transmission is noted. 4) An absorption maximum that shifts regularly with changing film thickness is observed near the absorption edge.

1. One of the consequences of the effect of size quantization in semiconductors is the change of the forbidden band as a function of the sample dimension [10].

In bismuth, the extrema of the conduction and valence bands, corresponding to the same value of the wave vector, are separated by the forbidden energy gap. The variation of this gap with varying film thickness d should be manifest in the form of a shift of the red edge $h\nu_{cr}$ of optical absorption for direct optical transitions.

Figure 1 shows the results of measurements of $h\nu_{cr} = f(d)$ at temperatures T = 300°K. The value of $h\nu_{cr}$ was determined by extrapolating the observed linear section of the $k(\nu)$ plot (k = absorption coefficient, ν = wave number; nonquadratic dispersion law) to its intersection with the abscissa axis. The values of the optical constants of bismuth films of different thicknesses were obtained from [13]. The figure demonstrates clearly the presence of an appreciable shift of $h\nu_{cr}$ (up to ∿0.5 eV), which is apparently connected with the increased width of the forbidden band when the film thickness is reduced (to ∿200 Å). At large thicknesses, the curve approaches asymptotically an optical-gap thickness close to that for bulk bismuth (0.07 eV) [11].

2. An important manifestation of the quantum size effect in semimetals is the transition of a metallic film into the semiconducting state at small thicknesses, when the overlap of the valence and conduction bands is eliminated. This circumstance was pointed out by one of the authors of the present note in [12], where a method was proposed to detect the metal-semiconductor transition by measuring the red edge of the optical absorption as a function of the semimetal film thickness.

The gist of the matter is that a singularity in the $h\nu_{cr}$ dependence should be observed

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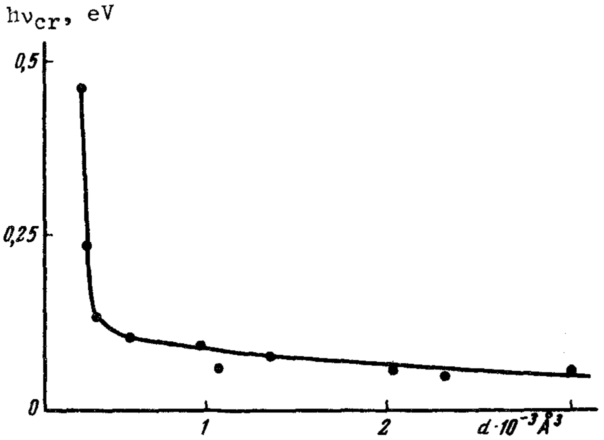
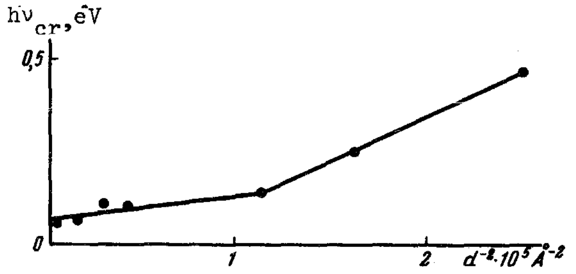
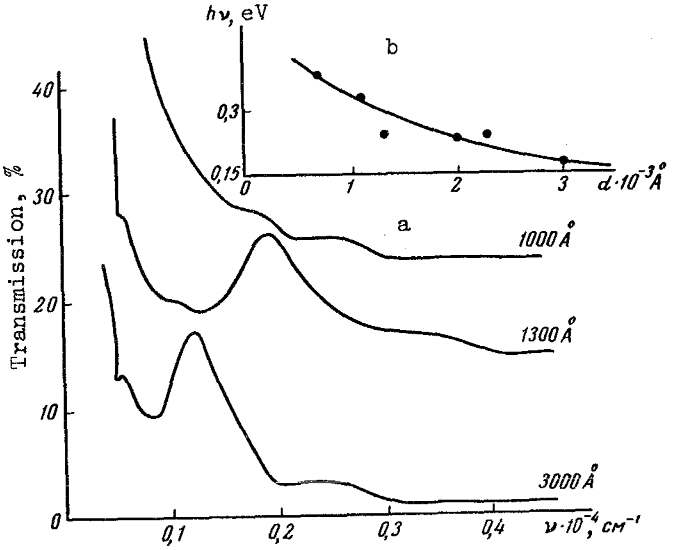
[1] Oscillations of the optical transmission of thin films of aluminum with variation of the thickness were observed in [9].







when the band overlap is eliminated. This singularity is most clearly manifest in the form of a kink on the $h\nu_{cr}(d^{-2})$ curve. Physically, the singularity is due to the fact that when the bands overlap the variation of the optical width of the forbidden gap with thickness is connected with the motion of the bottom of one of the bands (the valence band), and after the overlap is eliminated it is connected with the motion of both bands.

Figure 2 shows the experimental plot of $h\nu_{cr} = f(d^{-2})$, showing distinctly a kink at $d_0 \approx 300$ Å. This illustrates, in our opinion, the thickness at which the band overlap is eliminated.

We note incidentally that an attempt to observe the metal-dielectric transition was made in fact already in the first experimental study [1] in which the quantum size effect was observed.

The sharp growth of the resistivity in the region $d < 400$ Å was interpreted there, in particular, as a possible manifestation of an energy gap. Further searches for this transition were then made by measuring the thickness dependence of the Hall constant and of the temperature coefficient of resistance [4] and of the resistivity [8]. The values obtained in [8] for the critical thickness d_0 coincides with the value of d_0 obtained by us by the optical method.

3. The plots of the spectral dependence of the optical transmission of Bi films (Fig.3a) near the absorption edge are characterized by (i) a nonmonotonic variation and (ii) the presence of a transmission maximum that shifts regularly towards lower energies with increasing film thickness (Fig. 3b). (The curves of Fig. 3a are arbitrarily arranged relative to the ordinates.)

An unambiguous interpretation and establishment of a direct connection between the indicated singularities and the quantum size effect call for measurements in a wider spectral range. Such measurements are now under way.

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EFFECT OF STRONG INCREASE OF ABSORPTIVITY OF A PARTLY IONIZED GAS AT HIGH LIGHT INTENSITIES

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We studied the absorption of light in a plasma. We observed for the first time, in so far as we know, a nonlinear effect of strong increase of absorption with increasing light intensity. A homogeneous plasma with stable parameters was produced in a shock tube similar to that described in [1]. We used a Q-switched ruby laser producing stable pulses of 20 MW power and 50 nsec duration. A lens with f = 3 cm was used to focus the beam in stationary ionized gas behind the reflected shock wave at a distance 1 cm from the end, near the tube axis. The diameter of the focused spot, determined by measuring the intensity distribution over the cross section of the focus, was 1.35×10^{-2} cm.

The radiation passing through the tube (8 cm path) was registered with an FEU-52 photomultiplier, the voltage pulse from which was fed to an I2-7 oscilloscope. A filter with a pass band 6938 - 6948 Å was placed in front of the photomultiplier. To attenuate the incident radiation, neutral filters were used.

A specially developed circuit synchronized the instant of formation of the laser pulse with the instant of passage of the reflected shock wave past the viewing windows of the tube. The synchronization was effected in such a way that the light entered into a plasma region known to be homogeneous, stable, and in thermodynamic equilibrium.

The experiments were performed in xenon under strictly constant conditions, namely initial pressure 10 mm Hg and Mach number of the incident shock wave 10.3. The density of the neutral atoms behind the reflected shock wave was $N_a = 5.5 \times 10^{18}$ cm^{-3}, the electron and ion density was $N_e = 0.97 \times 10^{18}$ cm^{-3}, and the temperature was T = 11000°K (in calculating