Exciton luminescence in the field of the Schottky barrier

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A new effect—luminescence of the exciton reflection band in the Schottky-barrier field at the surface of a semiconductor—is discussed. The results of a calculation, in which the Stark energy and the probability of a tunnel dissociation of an exciton were plotted for the first time as functions of the coordinate, are given. The results of the electrical reflection GaAs are confirmed [Phys. Rev. Lett. **29**, 1001 (1972)].

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It is known that the surface of a semiconductor has a strong effect on the reflectivity of light in the region of exciton transitions. In this paper, we discuss the effect of luminescence of the exciton reflection band due to the attraction of an exciton to the surface by the Schottky-barrier field. (The possibility of drawing in an exciton by the electric field was initially pointed out by Gribnikov and Rashba.)[2] If the probability of finding the exciton at the surface is increased, then its interaction with the light incident on the surface of the crystal and the luminescence of the excition band will also increase. This effect apparently can be observed in Fig. 2 of the paper of Evangelisti *et al.*[1] The luminescence in the Schottky-barrier field can be used, for example, in the investigation of weak exciton lines.

To calculate the exciton reflection of light, we used[3]: 1) Formulas for the linear field and for the quadratic potential of the Schottky-barrier as a function of the potential at the surface ϕ_s and of the excess concentration of the donors $N_D - N_A$. 2) The numerical values for the Stark shift and for the probability of tunnel dissociation of an exciton in the electric field. Using the parameters for GaAs (Ref. 4), we calculated them from the values for the hydrogen atom in strong fields.[5] The shift of the resonance frequency of the exciton $\Delta\omega_0$ and the damping Γ are plotted in Fig. 1 as functions of the distance of the exciton from the surface z. 3) A method of calculating the optical properties of excitons for arbitrary $\Delta\omega_0(z)$ and $\Gamma(z)$ based on substituting the step functions for the smooth function.[6] In our calculation we used 40 steps with a

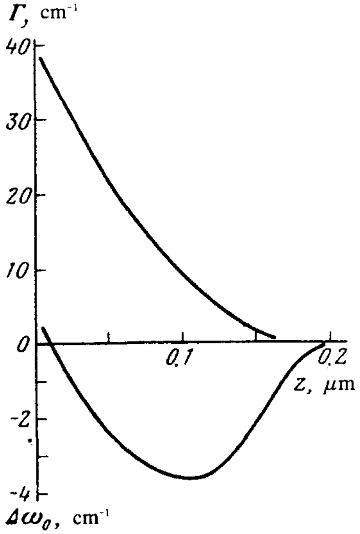

FIG. 1. Damping Γ and resonance-frequency shift $\Delta\omega_0$ of the exciton in the Schottky barrier of the GaAs crystal[4] for $N_D - N_A = 0.9\times10^{15}$ cm^{-3} (Ref. 1) and $\phi_s = 0.025$ B.

width of 10 to 50 Å. As a result of this substitution, the problem was reduced to a calculation of reflectivity from the layered medium with a spatial dispersion. The boundary conditions imposed on the exciton polarization at the inner boundaries re-

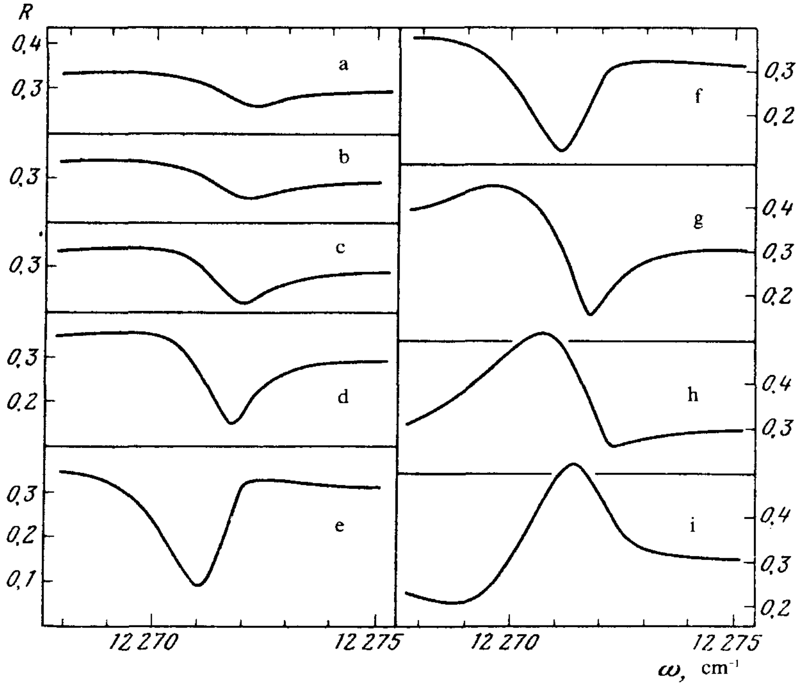

FIG. 2. Reflectivity coefficient of light in the region of the exciton transition at $N_D - N_A = 0.9\times10^{15}$ cm^{-3} (Ref. 1) and ϕ equal to: a, 0; b, 0.001; c, 0.002; d, 0.003; e, 0.005; f, 0.01; g, 0.015; h, 0.02; i, 0.025 B.

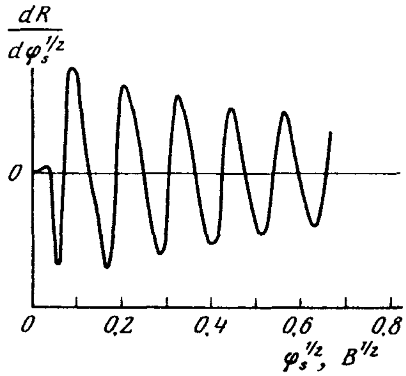

FIG. 3. The derivative of the reflectivity coefficient R of $\phi_s^{1/2}$ as a function of $\phi_s^{1/2}$ at the frequency 12271 cm^{-1}. For best agreement with Ref. 1 $N_D = N_A = 0.144 \times 10^{16}$ cm^{-3}.

quired that the polarization and its derivative should be continuous. In this paper as well as in Ref. 6, it was required that the exciton polarization should be vanishing at the outer boundary.

The results of the calculation with the parameters[4] are shown in Figs. 2 and 3. (The value $\Gamma = 0.8$ cm^{-1} was used for the attenuation constant of the exciton in the bulk.) It can be seen in Fig. 2 that for $N_D - N_A \sim 10^{15}$ cm^{-3} the exciton reflection of light increases by approximately a factor of 4 with increasing ϕ_s. This is attributable to the appearance of a potential well for the exciton at the surface of the crystal (see the curve for $\Delta\omega_0$ in Fig. 1) and hence to an increase in the probability of finding the exciton at the surface.

We also obtained the effect of rotation of the reflection contour with increase ϕ_s, on which attenution was focused by Evangelisti *et al.*[1] It involves conversion of the maximum of the reflectivity of light (Figs. 2a–d) to a minimum (Figs. 2e and 2f) and back again, after which the reflection contour returns to the initial shape (Figs. 2g and 2h) and then again goes through all the phases, etc. The rotation of the contour is caused by the interference of light in the exciton-free surface layer of the crystal whose thickness increases as the curve $\Gamma(z)$ is shifted (see Fig. 1) into the medium as a result of increasing ϕ_s. If we plot the reflectivity as a function of ϕ_s at a specified frequency, then the rotation of the contour will be in the form of oscillations. In Fig. 3 the derivative of the reflectivity with respect to $\phi_s^{1/2}$ at the resonance frequency of the exciton $\omega_0 = 12271$ cm^{-1} is plotted as a function of $\phi_s^{1/2}$. In general it reproduces the experimental curve of Ref. 1—the region of luminescence of the exciton reflection $\phi_s^{1/2} < 0.1\,B^{1/2}$ and that of the weakly damped oscillations $\phi_s^{1/2} > 0.1\,B^{1/2}$ are also shown in Fig. 3. Some differences, however, can be observed upon closer examination. This particularly concerns the highly extended region of low fields on the experimental curve.[1] At present, there is no need for a better agreement, since the effect of complex energy structure of the exciton in GaAs on the reflection spectra, for example, remains unknown, the data on the energy spectrum and on the occupation of the donor and surface states are still missing, etc. As for the calculations, they present no basic difficulty.

In conclusion, we present one more result which concerns the reflectivity spike at the frequency of the longitudinal exciton in the GaAs spectrum. The "dead-layer" model[7] makes it possible to obtain a spike only at very small damping $\Gamma - < 0.4$ cm^{-1}.[4] The model, which has a potential well near the surface and a Schottky barrier, greatly reduces the requirements for Γ.[3,6] For $N_d - N_A \sim 10^{14}$ cm^{-3} in GaAs (Ref. 4), the spike can be obtained for the values of Γ up to 1.2 cm^{-1} in the bulk of the sample. Moreover, the appearance of a spike in the dead-layer model is accompanied by a strong decrease of the main reflectivity spike, i.e., a slight rotation of the contour. This has not been confirmed experimentally.[4] As for the Schottky barrier, it produces a spike without a noticeable rotation of the reflection contour. Thus, this model describes one more, heretofore unexplainable experimental observation.

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