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LIFETIMES OF FREE AND BOUND EXCITONS IN CuO_2 CRYSTALS

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Submitted 14 July 1969
ZhETF Pis. Red. 10, No. 5, 219 - 223 (5 September 1969)

The optical properties of an exciton in a cuprous oxide crystal have been investigated in great detail [1]. At low temperatures, two hydrogenlike series of exciton lines, yellow and green are seen on the long-wave edge of the main absorption. The yellow-series absorption line with n = 1 was found in [2, 3] to be due to a quadrupole transition. According to [4], the radiative lifetime of the exciton with n = 1 is of the order of 10 sec.

Following observation of resonance luminescence of the n = 1 exciton in Cu_2O [5], it became possible to investigate the exciton radiative lifetime and to compare it with the calculated value.

The cuprous oxide crystals investigated by us were grown in the same manner as in [5]. The tests were made at temperatures 2 - 4.2°K. The luminescence damping time was determined from the afterglow spectra. The minimum damping time that could be determined in our experiments from the afterglow spectra was 10^{-4} sec.

The edge luminescence of the purest CuO_2 crystals contains only the emission of the free exciton and its background repetitions, and was described by us earlier.

In the investigation of the afterglow spectra of such (purest) Cu_2O crystals, we observed no afterglow of the free electron with a lifetime 10^{-4} sec or longer. From a comparison of this result with the calculated value of the radiative lifetime of the n = 1 exciton ($\tau_{rad} \sim 10$ sec), it follows that the probability of nonradiative transitions for the free electron is at least 10^5 times larger than the probability of radiative transitions.

An entirely different result was obtained with crystals with impurities, for which afterglow of a number of narrow lines and bands was noted. At the same time, all the lines belonging to the emission of a free exciton were missing from the afterglow spectrum. Figure 1 shows microphotographs of the luminescence spectrum of one of the Cu_2O crystals at a temperature T = 2°K, obtained with continuous excitation (curve 1) and in the afterglow (curve 2).

The narrow lines observed in the luminescence spectra of the crystals with the impurities are due to the annihilation of the bound excitons. Luminescence of the bound excitons is observed, with simultaneous excitation of phonons, just as in the case of the emission of the free exciton. In the crystal whose spectrum is shown in Fig. 1, the frequencies of the

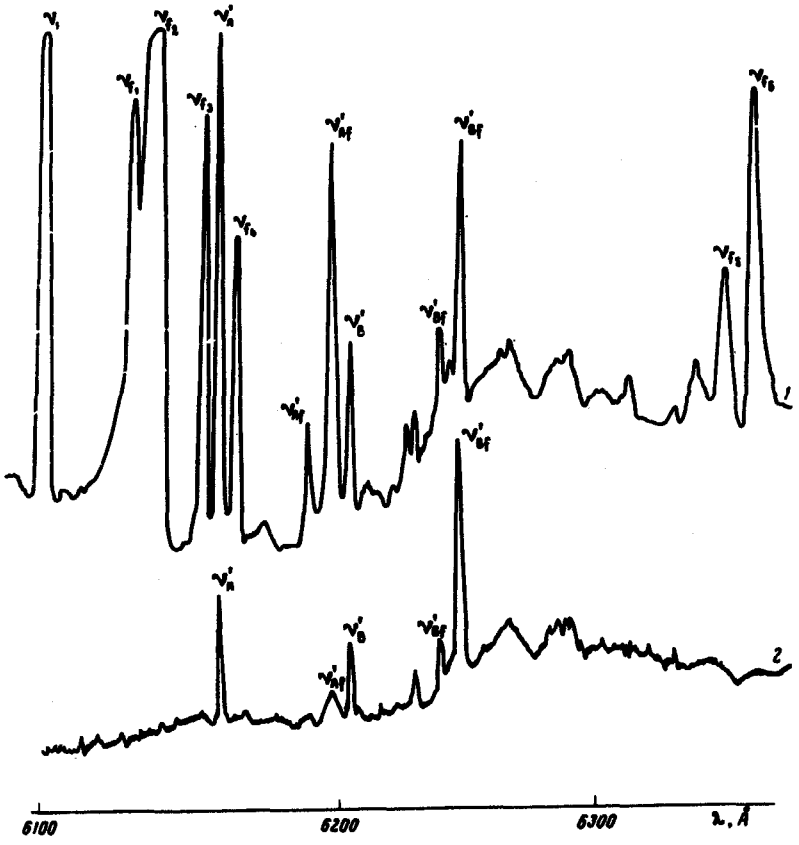

Fig. 1. Microphotograph of the luminescence spectrum of Cu_2O crystal No. 1P in: continuous excitation (1) and in the afterglow (2). T = 2°K. ν_1 - line n = 1; ν_{fi} - its phonon repetitions, ν_A and ν_B - bound excitons, ν'_{Af} and ν'_{Bf} - phonon repetitions of the bound excitons.

phonons interacting both with the bound and with the free excitons are the same. The frequency of the phonon interacting most strongly with the free and bound excitons of this crystal is 105 cm^{-1}. An investigation of the afterglow has shown that the spectrum of this crystal contains two groups of bound-exciton lines, with different lifetimes.

We investigated also Cu_2O crystals with bound excitons, whose phonon spectrum differed from the spectrum of the phonon repetitions of the free exciton. A microphotograph of the luminescence spectrum of such a crystal is shown in Fig. 2. Just as in the preceding case, we see that there are no free-exciton emission lines in the afterglow. The afterglow time of the bound excitons was not less than 10^{-2} sec at T = 2°K in these crystals.

We have thus established that the lifetime of the bound excitons in Cu_2O is much larger (by a factor 10^2 - 10^3) than the lifetime of the free excitons.

The dissociation energy of the bound excitons, which we observe in the Cu_2O crystals, is very small. Therefore, the states of the bound excitons can be described in the effective-mass approximation, i.e., in the case of Cu_2O the transition to the levels of the bound excitons, just as for the free ones, is forbidden. This conclusion is confirmed by the large lifetime of the bound excitons[1].

[1] Additional research is needed to explain the influence of the nonradiative transitions of the bound excitons.

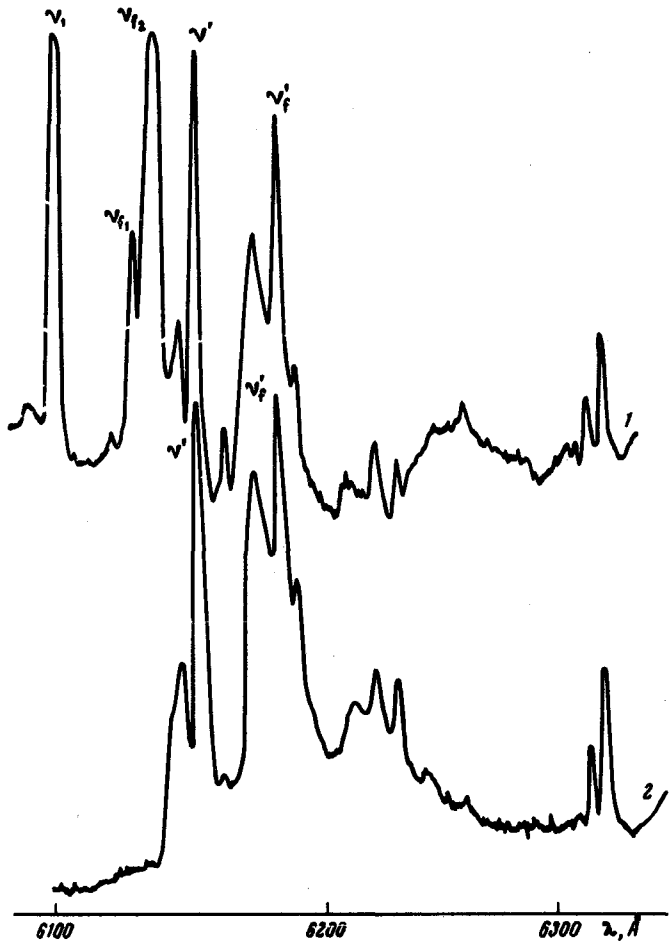

Fig. 2. Microphotograph of luminescence spectrum of Cu_2O crystal No. 1A in continuous excitation (1) and in the afterglow (2). T = 2°K. ν_1 - n = 1 line; ν_{f1} and ν_{f2} - its phonon repetitions, ν' - bound exciton, ν'_f - its phonon repetition..

But then the difference between the lifetimes of the free and bound excitons is due to the difference between their dynamic properties. The main distinction of the free exciton is that it can move through the crystal. The exciton motion decreases its lifetime, owing to collisions with the impurities and defects. The exciton lifetime τ_n relative to capture by impurities is

$$\tau_n = 1/Cv\sigma_n, \qquad (1)$$

where C is the impurity concentration, v the average exciton velocity, and σ_n the cross section for the capture of the exciton by the impurities. Assuming as an estimate $C = 10^{18}$ cm^{-3} and $v = 10^5$ cm/sec, and assuming that the cross section for exciton capture by impurities is of the same order as that for capture of a carrier by a neutral center, $\sigma_n = 10^{-18}$ cm^2, we obtain $\tau_n = 10^{-5}$ sec, i.e., much lower than the radiative lifetime of the n = 1 exciton ($\tau_{rad} \sim 10$ sec).

Thus, the difference observed by us in the lifetimes of the free and bound excitons is a direct consequence of the motion of the free excitons.

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QUANTUM SIZE EFFECTS IN THIN InSb FILMS

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Submitted 14 July 1969
ZhETF Pis. Red. 10, No. 5, 224 - 226 (5 September 1969)

Effects of oscillations of the kinetic coefficients in size-quantized films, observed in semimetallic films [1, 2], can appear also in films of degenerate semiconductors. We have found in [3], from optical measurements, that the energy spectrum of electrons in thin InSb films has a quasi-discrete character. Owing to the small density of states in the conduction band, the electron gas in n-InSb films is degenerate at room temperature. In the present study we investigated the dependence of the resistivity ρ, the Hall constant R, the Hall mobility μ = R/ρ on the thickness L of n-InSb films. The investigation procedure was analogous to that given described in [2]. The samples were long narrow strips (2 x 90 mm) of various thicknesses, with probe leads every 2 mm. The thickness distribution along the thick-film samples was measured with the aid of a microinterferometer. The thickness of thin films was calculated from the weight of the evaporated substance, under the assumption that the distribution of the molecular beam remains the same in the condensation plane. The method of preparing the single-crystal n-InSb film on mica substrates, together with certain data on the structure and electric parameters of the films, is given in [3].

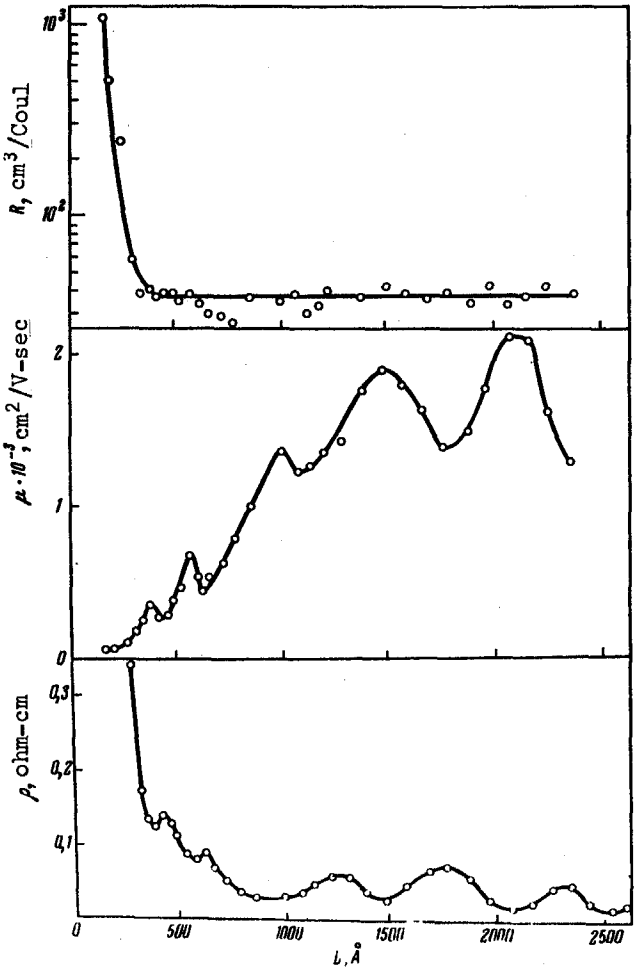

Fig. 1. Hall constant, mobility, and resistivity of InSb films vs. thickness.

The thickness dependences of ρ, R, and μ at room temperature are shown in Fig. 1. A characteristic feature of the dependences of