Semiconductors, 2025, Vol. 59, No. 7

UDC 621.315.592

Temperature Dependence of Exciton and Free Carrier Contributions to the Luminescence of CdTe/CdMgTe Heterostructure

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Received May 5, 2025
Revised June 24, 2025
Accepted September 18, 2025

The luminescence spectra and luminescence excitation spectra under the above-barrier excitation of the CdTe/Cd$_{0.6}$Mg$_{0.4}$Te heterostructure with a single quantum well were studied at temperatures of 5−100 K. The luminescence at the maximum of the barrier band is determined by the relaxation of the hot excitons over the entire temperature range, whereas free carriers make the main contribution to the luminescence of the low-energy side of the barrier band and the luminescence of the quantum well at low temperatures.

Keywords: quantum well II−VI, cadmium telluride, luminescence, energy transfer.

DOI: 10.61011/SC.2025.07.62466.7841

1. Introduction

The luminescence spectra of bulk semiconductors and semiconductor heterostructures at low temperatures and low levels of optical excitation exhibit only transitions associated with the lowest electronic levels. Information about the energies of the excited levels can be obtained from the luminescence excitation spectra (LES), which are sometimes called pseudoabsorption spectra. When studying heterostructures with quantum wells (QW), LES are usually related to the under-barrier region of the spectrum, where discrete excited levels of QWs are located [1,2]. It is of interest to study the LES, as well as the barrier layer related to the above-barrier excitation, which provides information about the contribution of excitons and free carriers to the relaxation process of excitation depending on the parameters of the heterostructure and temperature. It should be noted that studies of the optics of heterostructures largely focuse on excitons and their complexes, however, the study of the contribution of free carriers on the optical properties of heterostructures is also of considerable interest [3–5]. If we turn to the optics of semiconductors of group II−VI, then CdTe-based heterostructures along with ZnO-based heterostructures are attracting the most attention (see, for example, [6–9]), they are promising in applications, in particular as a material for solar cells [10].

2. Experiment and discussion

The object of the study is the CdTe/Cd$_{0.6}$Mg$_{0.4}$Te heterostructure with a single QW thickness of 9.6 nm, fabricated by the MBE method. The luminescence and reflection spectra and the LES were studied in the energy range of 2.2−3.0 eV, and they were recorded at the maximum and at half the maximum of the emission band contour.

Figure 1 shows the luminescence, reflection, and LES spectra of the heterostructure. It can be seen that at $T = 5$ K there is a noticeable Stokes shift between the exciton resonance in the reflection spectrum and the CdTe luminescence band. This means that at low temperatures, exciton localized in widenings of QW are responsible for light emission.

2.1. LES of the barrier layer

At low temperatures, the low-energy tail of the barrier luminescence, which is a solid solution with cationic substitution, is formed mainly by the luminescence of shallow bound excitons. The luminescence of excitons localized at deep potentials of the solid solution is superimposed on the same region, this contribution remains even at higher temperatures, however, it should be borne in mind that the concentration of deep random potentials is low. A sharp rearrangement of the luminescence excitation spectrum already at low temperatures in the region of 15−20 K indicates that at low temperatures the long-wavelength edge of the emission band is formed by excitons bound on shallow impurities.

The maximum LES when registering a signal on the low-energy tail of the luminescence band of the barrier at $T = 5$ K is about 2.6 eV, which is 0.25 eV higher than the free exciton (FE) energy level of the barrier (Figure 2). This means that the main mechanism of formation of bound excitons is not the capture of FE, but the sequential capture of carriers of different signs. The energy position of the LES maximum is determined by two factors. With an increase in the energy of free carriers, the process of

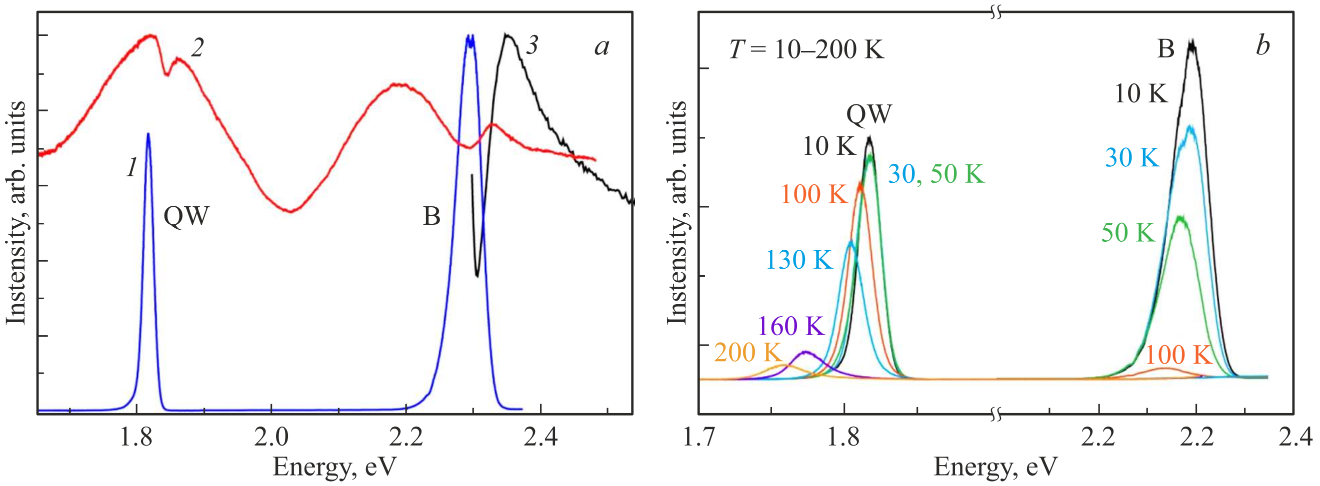

Figure 1. *a* — luminescence spectra (*1*), reflection (*2*), and barrier LES (*3*) CdTe/$Cd_{0.6}Mg_{0.4}Te$ heterostructure at $T = 5$ K; QW and B — emission of the QW and barrier. *b* — luminescence spectra in the temperature range of 10–200 K.

their cooling becomes more complicated, which reduces the efficiency of their capture to shallow impurity levels. At the same time, carriers born near the extremes of the bands have small impulses, they easily bind in the FE, and this reduces their contribution to the formation of bound excitons. It can be seen from Figure 2 and 3 that the shape of the LES changes dramatically in the temperature range of 10–30 K, so that at $T = 20$ K the maximum of the spectrum already coincides with the FE level of the barrier. This transformation of the LES correlates with the temperature decay of bound excitons. The contribution of free carriers is already insignificant at $T > 30$ K, and the shape of the LES does not change with a further increase in temperature.

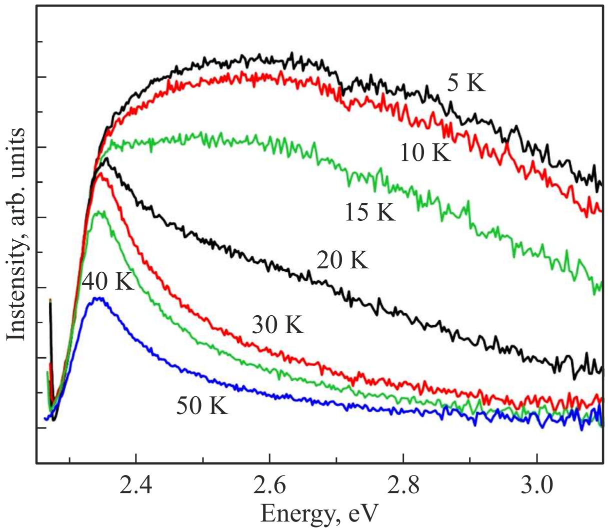

Figure 2. LES in the temperature range of 5–50 K when registering a signal on the low-energy tail of the luminescence band of the barrier layer.

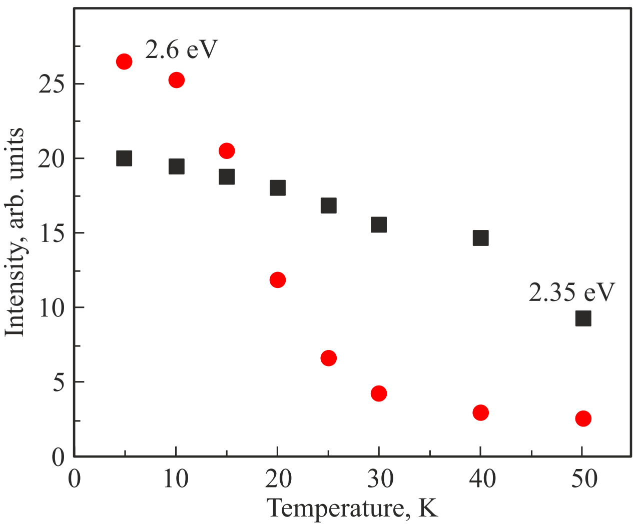

Figure 3. The temperature dependence of the signal intensity in two regions of the LES when registering a signal on a low-energy tail of the luminescence band of the barrier layer.

The center of the luminescence band of the barrier at low temperatures corresponds to the emission of excitons localized at random potentials, which arise due to statistical fluctuations in the relative concentrations of the components of the barrier solid solution [11]. When measuring the signal in the center of the band, the maximum LES coincides with the barrier layer FE level over the entire temperature range of 5–70 K (Figure 4, *a*). In contrast to the previous case, the contribution of free carriers is insignificant even at low temperatures, and it decreases relatively as the sample temperature increases. It can be concluded that localized exciton states characteristic of the solid solution are formed through relaxation of the FE as a whole.

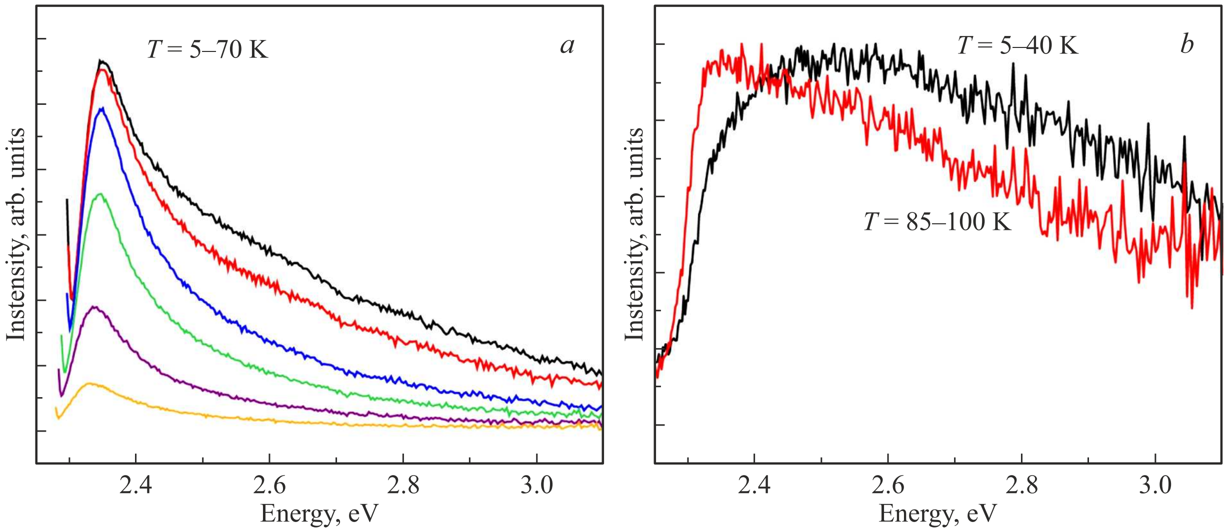

Figure 4. *a* — LES in the temperature range of 5–70 K when registering a signal in the center of the emission band of the barrier layer. *b* — normalized in the maximum LES of CdTe QW in the temperature range of 5–100 K.

2.2. Quantum well LES

The contribution of free carriers dominates in QW LES at $T = 5-40$ K, and the maximum of the spectrum is shifted relative to the barrier layer FE level by 0.25 eV, the shape of the LES is almost the same in this temperature range (Figure 4, *b*). The spectrum changes in the temperature range of 40–85 K, and its maximum coincides with the barrier FE level at $T > 50$ K. It can be concluded that at low temperatures, the contribution of excitons to the transfer of excitation from the barrier layer to QW is suppressed by their localization at random potentials in the barrier layer. For this reason, QW is predominantly populated by free carriers. An increase in temperature transfers the excitons of the barrier layer to a free state, as a result of which their contribution to the population of the QW becomes predominant.

3. Conclusion

Thus, the LES analysis shows that excitons bound on shallow impurities are formed when carriers of different signs are sequentially captured, whereas FE are localized on random potentials of the barrier solid solution. The temperature change in the shape of the LES makes it possible to trace the decay of exciton-impurity complexes and the transition of localized barrier excitons to the free state, as a result of which excitons dominate the energy transfer at high temperatures.

Funding

The work was supported by a grant from St. Petersburg State University, No. 129360164.

Conflict of interest

The authors declare that they have no conflict of interest.

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Translated by A.Akhtyamov