

09,12

## Optical properties of heterostructure CdTe/CdMgTe doped in various ways

© V.F. Agekyan<sup>1</sup>, S.Yu. Verbin<sup>1</sup>, G. Karczewski<sup>2</sup>, A.Yu. Serov<sup>1</sup>, N.G. Filosofov<sup>1,¶</sup>, I.V. Shtrom<sup>1</sup>

<sup>1</sup> St. Petersburg State University,  
St. Petersburg, Russia

<sup>2</sup> Institute of Physics, Polish Academy of Science,  
Warsaw, Poland

¶ E-mail: n.filosofov@spbu.ru

Received October 28, 2022

Revised October 28, 2022

Accepted November 1, 2022

The reflection and luminescence spectra of a CdTe/CdMgTe heterostructures doped with iodine are studied. Iodine was introduced either into a barrier layer or into a wide CdTe quantum well. It is shown how the doping method and level affect the spectra and the temperature dependence of the quantum well exciton emission intensity.

**Keywords:** heterostructure CdTe/CdMgTe, doping, exciton, luminescence.

DOI: 10.21883/PSS.2023.02.55418.509

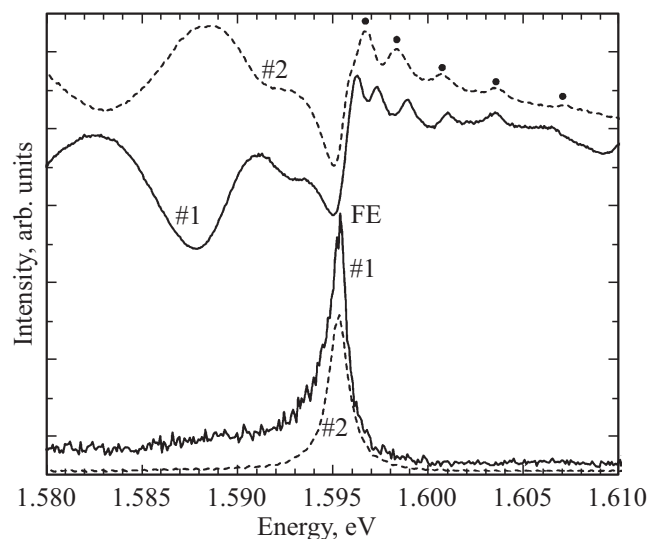
The CdTe/Cd<sub>1-x</sub>Mg<sub>x</sub>Te heterostructures are a subject of numerous research activities (see, for example [1–5]), because a cadmium substitution by magnesium insignificantly changes a lattice parameter and thus make it possible to grow a high quality interfaces. In this study we have investigated reflection and luminescence spectra of a series of CdTe/Cd<sub>1-x</sub>Mg<sub>x</sub>Te heterostructures doped by different methods which contain a single CdTe quantum well (QW) of 100 nm thickness. The energy of the barrier exciton is 2.1 eV, which corresponds to  $x = 0.3$ . Donor doping was carried out using a source of ZnI<sub>2</sub> molecules. In samples #2 and 3 tellurium was replaced by iodine layers with a thickness of 1 monolayer and 5 monolayers, respectively. These iodine layers were formed in a barrier at a distance of 15 nm from the interface. In samples #4–6 the CdTe QW was uniformly doped at temperatures of ZnI<sub>2</sub> source of 130, 140, and 150°C. In the case of doping of CdTe bulk samples, the above-mentioned temperatures correspond to donor concentrations of  $4 \cdot 10^{15}$ ,  $1 \cdot 10^{16}$ , and  $4 \cdot 10^{16}$  cm<sup>-3</sup>. Also, the undoped reference sample #1 was grown.

The exciton ground state radius in CdTe is 6.5 nm, so a weak quantization takes place in the structures under investigation. In this case the restriction in the direction of heterostructure growth has an effect on the motion of the exciton as a whole.

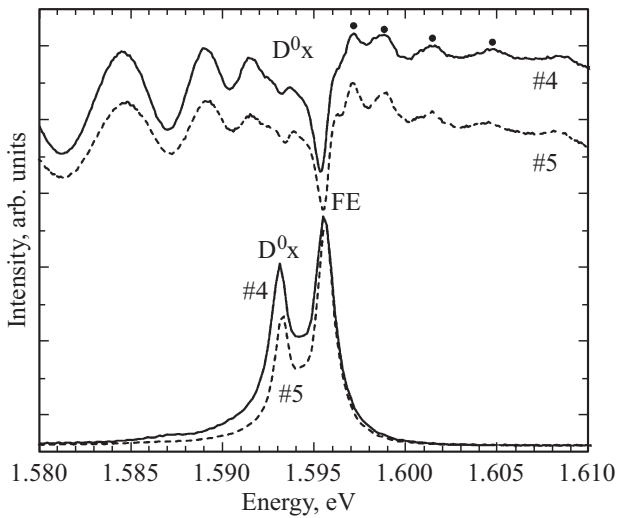
Fig. 1–3 shows reflection spectra of samples #1–5 with the inverted free exciton (FE) resonance contour. This proves that the dead layer near the QW interface has a significant thickness, which results in an effective narrowing of the QW for the exciton. A system of lines is observed at the high-energy side of the FE contour, which corresponds to a quantization of the exciton wave vector. As the level of doping increases, these bands broaden. In reflection spectra of samples #3–5 the features are observed at the low-

energy side of the FE contour, which are manifested in the emission spectra as well.

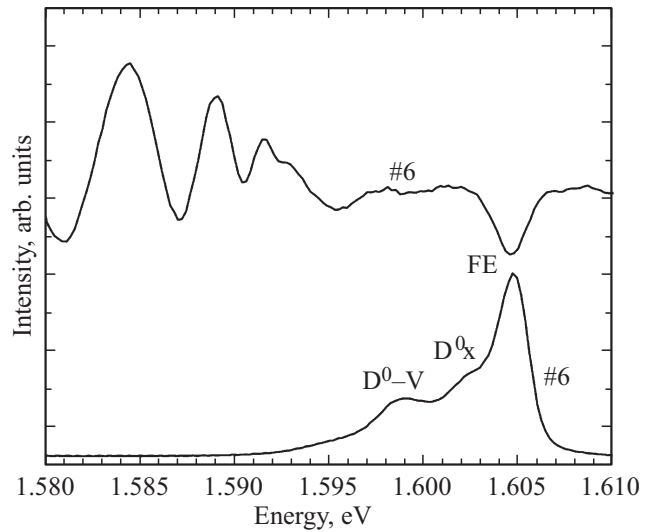
In luminescence spectra of the undoped and lightly doped samples #1 and 2 only the FE band is observed (Fig. 1). In luminescence spectra of samples #4 and 5, along with the FE band a donor bound exciton band is observed, which matches the above-mentioned feature in reflection spectra (Fig. 2). Its position in relation to the FE energy corresponds to the known data for bulk crystals of CdTe:I [6]. In the luminescence spectrum of sample #3 also there is a band that coincides with the weak feature of reflection spectrum, which is noticeably broadened as compared with the bound exciton bands in spectra of



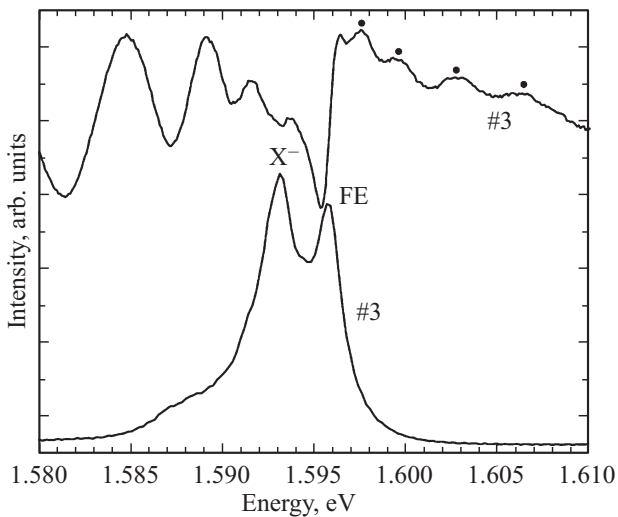
**Figure 1.** Reflection and luminescence spectra of samples #1 and 2,  $T = 5$  K. FE — free exciton, dots in Fig. 1–3 shows the features that arise due to the exciton wave vector quantization.



**Figure 2.** Reflection and luminescence spectra of samples #4 and 5,  $T = 5$  K. FE — free exciton,  $D_x^0$  — exciton bound to a neutral donor.



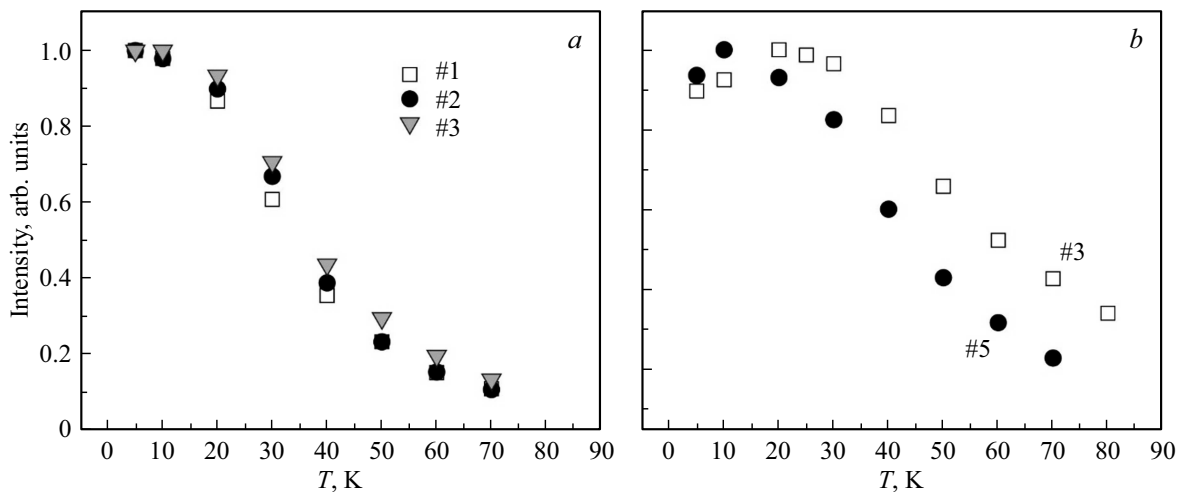
**Figure 4.** Reflection and luminescence spectra of sample #6,  $T = 5$  K. FE — free exciton,  $D_x^0$  — exciton bound to a neutral donor,  $D^0-V$  — presumably the donor-valence band transition.



**Figure 3.** Reflection and luminescence spectra of sample #3,  $T = 5$  K. FE — free exciton,  $X^-$  — trion.

samples #4 and 5 (Fig. 3). Since in the QW of sample #3 there is a considerable number of free electrons from the donors of the barrier layer, this band can be naturally interpreted as a luminescence of the negatively charged trion, which properties were studied in [7–11]. The larger width of this band as compared with the bound exciton bands is explained by mobility of the trion.

The exciton reflection contour in the spectrum of sample #6 is shifted toward high energies by 10 meV as compared to its position in the spectra of samples #3–5 (Fig. 4). A possible cause of this shift is the narrowing of the QW for the exciton due to the increase in thickness of the dead layer in a heavy doped QW. In the luminescence spectrum of sample #6 a weak band of donor bound exciton is observed together with a band that presumably originated from the donor–valence band transition. The doping of



**Figure 5.** Temperature dependence of the free exciton emission band intensities in samples #1, 2, and 4 (a) and in samples #3 and 5 (b).

QW leads to cadmium substitution by zinc. ZnTe is a wide-band component in the CdZnTe solid solution, so no potentials which can localize exciton occur in the case of insignificant relative concentration of zinc. The implantation of zinc atoms results in the scattering centers creation, which can explain the broadening of the exciton structure in the luminescence spectrum of sample #6.

Temperature dependencies of FE band intensities are shown in Fig. 5. For the undoped and lightly doped samples #1, 2, 4 this dependence is monotonous. In luminescence spectra of samples #3 and 5 the FE band increases in a narrow interval of temperatures over 5 K due to the delocalization of donor bound excitons and dissociation of trions.

### Funding

The study was performed with the support of the St.Petersburg University grant No. 93020138 (V.F. Agekyan, S.Yu. Verbin, A.Yu. Serov, N.G. Filosofov and I.V. Shtrom) and grant UMO-2021/41/B/ST3/03651 (G. Karczewski).

### Conflict of interest

The authors declare that they have no conflict of interest.

### References

- [1] M. Deresz, M. Wiater, G. Karczewski, T. Wojtowicz, J. Lusakowski. *Acta Phys. Polonica* **132**, 390 (2017).
- [2] L. Viñ a, R. André, V. Ciulin, J.D. Ganiere, B. Deveaud. *Institut Phys. Conf. Ser.* 171, G4.2 (2003).
- [3] Grigelionis, K. Nogajewski, G. Karczewski, T. Wojtowicz, M. Czapkiewicz, J. Wrobel, H. Boukari, H. Mariette, J. Lusakowski. *Phys. Rev. B* **91**, 075424 (2015).
- [4] A.A. Kiselev, E.L. Ivchenko, A.A. Sirenko, T. Ruf, M. Cardona, D.R. Yakovlev, W. Ossau, A. Waag, G. Landwehr, *J. Crystal Growth* **184–185**, 831 (1998).
- [5] D. Wasik, Z. Adamus, M. Baj, J. Siwiec-Matuszyk, T. Wojtowicz, E. Janik, J. Kossut. *Phys. Status Solidi C* **1**, 751 (2004).
- [6] N. C. Giles, Jaesun Lee, D. Rajavela, C. J. Summers. *J. Appl. Phys.* **73**, 4541 (1993).
- [7] G. Mackh, M. Hilpert, D.R. Yakovlev, W. Ossau, H. Heinke, T. Litz, F. Fischer, A. Waag, G. Landwehr. *Phys. Rev. B* **50**, 14069 (1994).
- [8] E. Vanelle, M. Paillard, X. Marie, T.Amand, P. Gilliot, D. Brinkmann, R. Le'vy, J. Cibert, S. Tatarenko. *Phys. Rev. B* **62**, 2696 (2000).
- [9] J. Tribollet, F. Bernardot, M. Menant, G. Karczewski, C. Testelin, M. Chamarro. *Phys. Rev. B* **68**, 23531 (2003).
- [10] D. Sanvitto, R.A. Hogg, A.J. Shields, D.M. Whittaker, M.Y. Simmons, D.A. Ritchie, M. Pepper. *Phys. Rev. B* **62**, R13294 (2000).
- [11] M.T. Portella-Oberli, V. Ciulin, S. Ilaacke, J.-D. Ganiere, P. Kossacki, M. Kutrowski, T. Wojtowicz, B. Deveaud. *Phys. Rev. B* **66**, 155305 (2002).

*Translated by Ego Translating*