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## Analysis of luminescence method for determination of Cd<sub>1-x</sub>Zn<sub>x</sub>Te composition

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**Abstract.** A detailed analysis of the method for determination of Cd<sub>1-x</sub>Zn<sub>x</sub>Te composition  $x$  from measurements of 4.2 K peak position of the emission band induced by annihilation of excitons bound with neutral shallow acceptors is given. Found are the conditions fulfillment of which permits to obtain reliable  $x$  values by the above luminescence method.

**Keywords:** Cd<sub>1-x</sub>Zn<sub>x</sub>Te composition, excitons, exciton-impurity complexes, luminescence.

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### 1. Introduction

In the last few years, a luminescence method (measurement of 4.2 K peak position  $h\nu_m$  of the emission band induced by radiative annihilation of excitons  $X$  bound to neutral shallow acceptors  $A^0$ , i.e., by exciton-impurity complexes  $A^0X$ , see Fig. 1 [1]) is used to find the chemical composition  $x$ , namely, the zinc content in Cd<sub>1-x</sub>Zn<sub>x</sub>Te mixed compounds [2-5]. The corresponding 4.2K  $h\nu_m$  vs  $x$  calibration curves are given by the following expressions:

$$h\nu_m = (1.590 + 0.322x + 0.463x^2) \text{ eV} \quad (1)$$

as was found when studying the excitonic luminescence spectra of Cd<sub>1-x</sub>Zn<sub>x</sub>Te films (see Fig. 2a and [6])<sup>1</sup>, and

$$h\nu_m = (1.590 + 0.445x + 0.339x^2) \text{ eV} \quad (2)$$

as was found when studying the excitonic luminescence spectra of Cd<sub>1-x</sub>Zn<sub>x</sub>Te crystals (see Fig. 2b and [8])<sup>2</sup>.

<sup>1</sup> Identification of 4.2 K emission band studied in [6] as induced by annihilation of the exciton-impurity complex  $A^0X$  was made on the basis of its peak position at  $x = 0$  ( $h\nu_m = 1.590$  eV) and  $x = 1$  ( $h\nu_m = 2.375$  eV) [see Fig. 2a] (such  $h\nu_m$  values characterize the 4.2 K  $A^0X$  induced emission band at  $x = 0$  and 1 [7]).

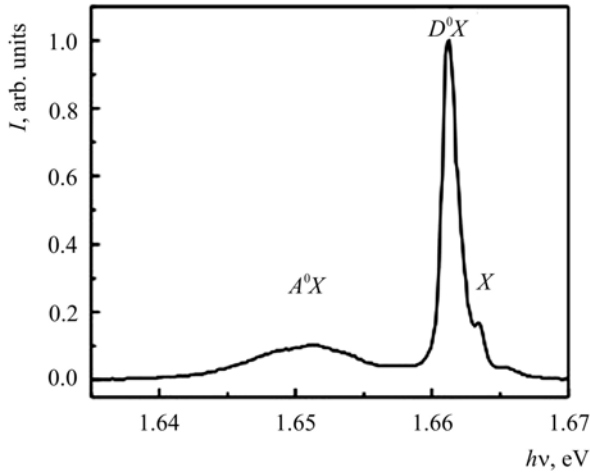
<sup>2</sup> Eq. (2) shows the result of averaging (for details see [8]) somewhat different  $h\nu_m$  vs  $x$  calibration dependencies for Cd<sub>1-x</sub>Zn<sub>x</sub>Te crystals given in [9, 10]. In [10]  $h\nu_m$  vs  $x$  dependency is given for  $T = 1.6$  K; similar to [8] we suppose that this dependency is also valid at  $T = 4.2$  K, as it is known that the peak position of the emission band induced by bound exciton annihilation practically does not depend on temperature at  $T \leq 4.2$  K. In particular, it is valid for Cd<sub>1-x</sub>Zn<sub>x</sub>Te with  $x = 0$  (CdTe) and  $x = 1$  (ZnTe) [7]. Obviously, as one uses the averaged calibration curves a definite inaccuracy in the  $x$  determination appears (it is shown in Fig. 2b). Given in [8] Eq. (A8) needed to construct the calibration curve (2) is the best fit for presented in [9] the experimental  $h\nu_m(A^0X)$  vs.  $x$  dependence made by us.

Earlier [8] a preliminary examination of this method was made. In the present work which is a continuation of [8], some further comment on the discussed luminescence method will be made (for convenience some data given in [8] are repeated in it). Its essence lies in the following.

As known (see, for example, [7, 11] and Fig. 1), in the low temperature (4.2 K) excitonic luminescence spectra of Cd<sub>1-x</sub>Zn<sub>x</sub>Te one could observe not only the discussed emission band [peak position  $h\nu_m(A^0X) \cong 1.590$  eV at  $x = 0$  and 2.375 eV at  $x = 1$ ], but also others, induced by annihilation of excitons bound by neutral shallow donors  $D^0$ , i.e. by exciton-impurity complexes  $D^0X$  [peak position  $h\nu_m(D^0X) \cong 1.594$  eV at  $x = 0$  and 2.3785 eV at  $x = 1$ ], as well as by recombination of free excitons  $X$  [peak position of the emission induced by free excitons in the principal ( $n = 1$ ) state  $h\nu_m(X) \cong 1.596$  eV at  $x = 0$  and 2.3815 eV at  $x = 1$ ]<sup>3</sup>. Further we consider that the pointed  $A^0X$ ,  $D^0X$  and  $X$  induced emission bands could be the only ones observed in the 4.2 K excitonic luminescence spectrum of Cd<sub>1-x</sub>Zn<sub>x</sub>Te. This is valid for Cd<sub>1-x</sub>Zn<sub>x</sub>Te compounds ( $0 < x < 1$ ), see, for example, Fig.1 and [2, 8, 11]. Therefore, to find the  $x$  value by using the discussed luminescence method one must separate the  $A^0X$  induced emission band in Cd<sub>1-x</sub>Zn<sub>x</sub>Te emission spectra.

No problems in separation of the  $A^0X$  induced emission band exists if in Cd<sub>1-x</sub>Zn<sub>x</sub>Te excitonic luminescence spectra all three possible exciton emission bands (induced by annihilation of  $A^0X$ ,  $D^0X$ , and  $X$  excitons) are observed as for them  $h\nu_m(A^0X) < h\nu_m(D^0X) <$

<sup>3</sup> The 4.2 K peak position of the emission band induced by annihilation of neutral shallow donor-exciton complexes  $h\nu_m(D^0X)$  at  $x = 1$  is taken from the reference [11] {somewhat lower the 4.2 K  $h\nu_m(D^0X)$  value at  $x = 1$  (2.3779 eV) is given in a reference [12]}.



**Fig. 1.** Typical 4.2 K photoluminescence spectra (near-band-edge region) of  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  crystal with  $x = 0.1$ [1].

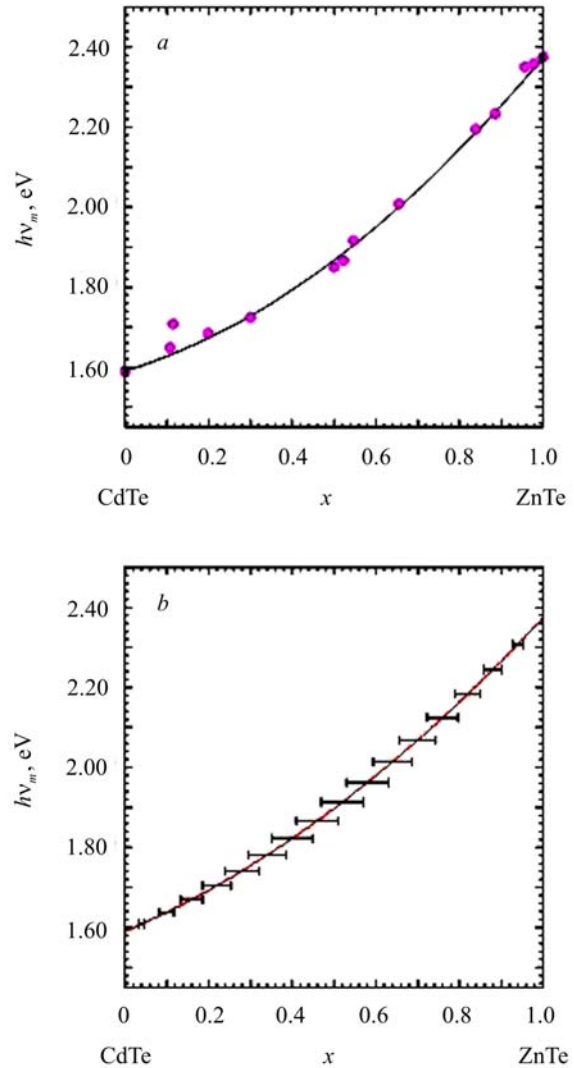
$< h\nu_m(X)$  at any  $x$ , see above and [8]<sup>4</sup>. Evidently, problems in identifying (separation) of the  $A^0X$  induced emission band arise if in the excitonic luminescence spectra of  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  with any value and type of conductivity not all three possible ( $A^0X$ ,  $D^0X$ , and  $X$  induced) emission bands are observed, namely only one or two of them, as  $h\nu_m(D^0X)$  and  $h\nu_m(X)$  vs  $x$  calibration curves are unknown [8]. Obviously, such situation could be realized, for example, due to a substantial difference in the concentrations of shallow acceptors and donors. So below our attention will be paid to an analysis of some peculiarities of determination of  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  composition  $x$  using the low-temperature (4.2 K)  $A^0X$  induced emission band, (its peak position) when  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  exciton luminescence spectrum is an incomplete one, namely, only one or two exciton-induced emission bands are observed in it, in particular, on the conditions of its application.

## 2. Analysis of the method

Let us examine a semiconductor, for example,  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  at helium temperature when no thermally stimulated processes are observed. Its conductivity is determined by photoelectrons and photoholes with concentrations  $\delta n$  and  $\delta p$ , respectively. Let it contain shallow acceptors  $A$  and shallow donors  $D$  with respective concentrations  $N_A$  and  $N_D$ . A majority of shallow acceptors and donors in light-excited semiconductor conductivity of which is determined by

<sup>4</sup> The low-temperature (4.2 K) near-band-edge luminescence of  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  is practically completely induced by radiative annihilation of bound and free excitons [no intrinsic emission band is observed in it (see Fig. 1 and [2, 4]). This could be possible due to a considerable self-absorption of the intrinsic recombination emission or due to a low probability of direct electron-hole recombination compared to that of binding of hole-electron pairs into free excitons.

the excess electrons and holes is in a neutral state where their concentrations are  $N_{A^0}$  and  $N_{D^0}$  accordingly, i.e.,  $N_{A^0} \cong N_A$  and  $N_{D^0} \cong N_D$ . Conditions when these relations hold (their fulfillment is highly probable) are given in [8]. A small number of neutral acceptors  $A^0$  and neutral donors  $D^0$  could bind free excitons (the concentration of free excitons  $n_X$ , the binding coefficient of the electron-hole pairs into free excitons  $b_X$ , the probability of their direct annihilation  $\alpha_X$ ), forming exciton-impurity complexes  $A^0X$  and  $D^0X$  (binding



**Fig. 2.** Dependences of 4.2 K peak positions of the luminescence band induced by annihilation of bound excitons  $A^0X$  in  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  as a function of their composition  $x$ . (a) the data obtained when studying the  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  films; the solid curve is constructed according to Eq.(1) [6]; (b) the data obtained when studying the  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  crystals; the solid curve is constructed according to Eq.(2) [8]; the inaccuracy of  $x$  determination (it is caused by averaging given in [9,10]  $h\nu_m$  vs.  $x$  dependences) is also shown (for details see [8]).

coefficients  $b_{A^0X}$  and  $b_{D^0X}$ ). Evidently, for the examined case intensities of emission bands induced by annihilation of bound  $A^0X$  ( $I_{A^0X}$ ),  $D^0X$  ( $I_{D^0X}$ ) and free  $X(I_X)$  excitons as follows from [8] are given by the following equations written in the assumption that exciton annihilation proceeds mainly with the photon emission (intensities of phonon replicas of exciton induced emission lines in  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  at  $T = 4.2$  K are rather small, see Fig. 1)<sup>5</sup>:

$$I_{A^0X} = b_{A^0X}N_{A^0}n_X \approx b_{A^0X}N_A n_X, \quad (4)$$

$$I_{D^0X} = b_{D^0X}N_{D^0}n_X \approx b_{D^0X}N_D n_X, \quad (5)$$

$$I_X = \alpha_X n_X = b_X \delta p \delta n - (b_{A^0X}N_{A^0} + b_{D^0X}N_{D^0})n_X \approx b_X \delta p \delta n - (b_{A^0X}N_A + b_{D^0X}N_D)n_X, \quad (6)$$

where

$$n_X = \frac{b_X \delta n \delta p}{\alpha_X + b_{A^0X}N_{A^0} + b_{D^0X}N_{D^0}} \approx \frac{b_X \delta n \delta p}{\alpha_X + b_{A^0X}N_A + b_{D^0X}N_D}, \quad (7)$$

and the correlation between the exciton emission intensities is:

$$I_{A^0X} : I_{D^0X} : I_X = b_{A^0X}N_{A^0} : b_{D^0X}N_{D^0} : \alpha_X \approx b_{A^0X}N_A : b_{D^0X}N_D : \alpha_X. \quad (8)$$

Evidently, Eq. (8) is the main one that permits to judge when one or another exciton induced band dominates in the  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  excitonic luminescence spectrum at any excitation intensities  $L$  [naturally, in the adopted model  $I_{A^0X}(L)$ ,  $I_{D^0X}(L)$ ,  $I_X(L) \sim n_X(L)$ ].

When analyzing Eq. (8) one must pay attention to the following.

In  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  compounds, the free exciton induced emission intensity  $I_X$  is of the order or less than the  $A^0X$  emission intensity  $I_{A^0X}$ , i.e.,  $I_X \leq I_{A^0X}$  (see, for example, Fig. 1 and references [1,4,13-15])<sup>6</sup>. So, as it can be easily seen from Eq. (8) if  $I_{A^0X} \gg I_{D^0X}$  (i.e., the  $D^0X$

induced emission band could not be separated from the excitonic luminescence spectrum) one will observe the only emission band – the  $A^0X$  induced emission band in the excitonic luminescence spectrum if  $I_{A^0X} \gg I_X$  (i.e., the free exciton induced emission band could not be separated in the excitonic luminescence spectrum), or two emission bands –  $A^0X$  and  $I_X$  induced emission bands if  $I_{A^0X} \approx I_X$ . In Appendix 1 given are the predominant emission bands in the excitonic luminescence spectrum when any correlation between  $I_{A^0X}$ ,  $I_{D^0X}$ , and  $I_X$  values could exist. Naturally, in both cases when one or two emission bands are observed in the excitonic luminescence spectrum, the  $x$  value could easily be found. To evaluate the  $N_A$  value at which the inequality  $I_{A^0X} \gg I_{D^0X}$  is valid, one must know the  $b_{A^0X}/b_{D^0X}$  value [see Eq. (8)]. It turned out that  $b_{A^0X} \approx b_{D^0X}$  (see Appendix 2). So, the  $A^0X$  induced emission band could be easily separated in the excitonic luminescence spectrum that consists of one or two emission bands, if the inequality

$$N_A \gg N_D \quad (9)$$

is satisfied.

Obviously, the criterion (9) to separate the  $A^0X$  induced emission band from the excitonic luminescence spectrum consisting of one or two emission bands could fulfil: a) in the low resistivity p-type material if its dark conductivity is fixed by shallow acceptors; b) in the high resistive material, if its dark conductivity is fixed by deep donors as shallow acceptors in the pointed material, may be mainly compensated by deep donors (then  $N_A > N_D$ ). Naturally, this criterion is not fulfilled in the high resistive material, if its dark conductivity is fixed by deep acceptors, as in the pointed material shallow donors completely compensate shallow acceptors and possibly partly deep acceptors (then  $N_D \geq N_A$ )<sup>7</sup>. Nevertheless, if the pointed material with deep acceptors responsible for its high resistivity beside deep acceptors and shallow acceptors and donors contains also deep donors then the deep donors could mainly compensate shallow acceptors. So, a role of shallow donors in the compensation of shallow acceptors will not be important, i.e.  $N_D$  may be less than  $N_A$ . Therefore, the relation (9) could fulfil in this material.

Obviously, the above criterion (9) for the  $A^0X$  induced emission band dominance in the  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  excitonic luminescence spectrum is rather rough due to a row of hardly controllable suppositions made when finding the  $b_{A^0X}/b_{D^0X}$  value (see Appendix 2); to define more accurately conditions for the dominance of

<sup>5</sup> Eq. (7) follows from the rate equation for  $n_X$  at low temperatures (thermally stimulated processes are impossible) which takes into account not only the free exciton direct generation and annihilation, but also their capture by neutral acceptors and donors:

$$\frac{dn_X}{dt} = b_X \delta p \delta n - (\alpha_X + b_{A^0}N_{A^0} + b_{D^0}N_{D^0})n_X = 0. \quad (3)$$

<sup>6</sup> Apparently, emission induced by the free exciton annihilation in  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  (as in  $\text{CdTe}$  [13]) may suffer noticeable self-absorption and so could be substantially decreased by the pointed process. Most probably the noted various  $I_{A^0X}/I_X$  values are mainly connected with the different effect of self-absorption on the  $I_X$  value.

<sup>7</sup> Some information about deep acceptors and donors in  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  compounds is given in a review article [15].

the  $A^0X$  induced emission band in the excitonic luminescence spectrum of  $Cd_{1-x}Zn_xTe$  one needs to make more precise determination of the  $b_{A^0X}/b_{D^0X}$  value directly in cadmium-zinc-tellurium mixed compounds.

Evidently, to check the fulfillment of the inequality (9) one needs to know the conductivity type (it must be  $p$ -type) in the low resistive  $Cd_{1-x}Zn_xTe$  (its  $p$ -type conductivity is fixed by shallow acceptors) and  $N_A$  and  $N_D$  values in high resistive  $Cd_{1-x}Zn_xTe$  (its conductivity is fixed by deep acceptors or donors, see above and the footnote 7). This is a serious setback of the discussed luminescence method of  $x$  determination as a rather complex technique is needed to find the above-pointed  $Cd_{1-x}Zn_xTe$  electrical parameters (for example, temperature variations of the equilibrium carrier concentration, if one wants to find the  $N_A$  and  $N_D$  values [16]).

Consequently, if in the excitonic luminescence spectra only one exciton induced emission band is observed, then this band is generated by annihilation of bound excitons  $A^0X$  when the above criterion (9) fulfils. If in the excitonic luminescence spectrum two exciton-induced emission bands are observed, then the  $A^0X$  induced emission band is the low energy one when the discussed above criterion (9) fulfills. In both these cases, it is possible to find  $x$  values using the  $h\nu_m$  vs  $x$  calibration curves given above in Figs 2a and 2b. It is also obvious that in both cases for the effective use of the discussed luminescence method for  $x$  determination in  $Cd_{1-x}Zn_xTe$  one needs to know the conductivity type in low resistive  $Cd_{1-x}Zn_xTe$  and the shallow acceptor and donor concentrations in high resistive  $Cd_{1-x}Zn_xTe$ , which is rather inconvenient.

### 3. Conclusions

Critical examination of the luminescence method for determination of  $Cd_{1-x}Zn_xTe$  composition  $x$  (by measuring the 4.2 K  $A^0X$  induced emission band peak position) was made and showed the following.

- No problems in  $x$  determination exist if in  $Cd_{1-x}Zn_xTe$  excitonic luminescence spectrum all three possible excitonic emission bands are observed.
- Problems in  $x$  determination by using the offered method arise if only one or two (from three possible) exciton-induced emission bands are observed in the  $Cd_{1-x}Zn_xTe$  excitonic luminescence spectra. They are mostly concerned with a necessity to know the conductivity type of the low resistive  $Cd_{1-x}Zn_xTe$  and  $N_A$  and  $N_D$  values in the high resistive  $Cd_{1-x}Zn_xTe$ . The stated makes rather difficult, an effective use of the luminescence method for  $x$  determination based on the fulfillment of the criterion (9), i.e., determination of the zinc content in  $Cd_{1-x}Zn_xTe$  crystals and films. To increase the reliability of  $x$  determination by the discussed luminescence method (by using the separation of the  $A^0X$  induced emission

band), one also needs to raise the accuracy of determination of the  $b_{A^0X}/b_{D^0X}$  ratio and to find the exact  $\alpha_X/b_{A^0X}$  value.

### 4. Appendix

#### 1. Conditions for the dominance of the $A^0X$ induced emission band in the $Cd_{1-x}Zn_xTe$ excitonic luminescence spectrum.

Let us find general conditions when the  $A^0X$  induced emission band dominates in the low temperature (4.2 K)  $Cd_{1-x}Zn_xTe$  excitonic luminescence spectrum. These conditions naturally follow the analysis of Eq. (8). When analyzing Eq. (8) one must pay attention to the following.

If only one emission band is observed in the excitonic luminescence spectrum, (no other emission bands could be separated in it) then this band is induced by radiative annihilation of  $A^0X$  complexes when the following inequality is satisfied:

$$N_A \gg (b_{D^0X}/b_{A^0X})N_D, \alpha_X/b_{A^0X} \quad (A1)$$

$$\begin{aligned} \{ \text{then } I_{A^0X} \approx b_X \delta p \delta n \gg I_{D^0X} \approx \\ \approx (b_{D^0X}N_D/b_{A^0X}N_A)b_X \delta p \delta n, \end{aligned}$$

$I_X = \alpha_X(b_{A^0X}N_A)^{-1} b_X \delta p \delta n$ , see Eqs (4) to (7) [ $I_{A^0X}$  is nearly equal to a generation rate of free excitons  $b_X \delta p \delta n$  as most of free excitons in the discussed case are mainly transformed into  $A^0X$  complexes, see Eqs (4) to (7)]].

If only two emission bands are observed in the excitonic luminescence spectrum, [ $A^0X$  and  $D^0X$  induced (consequently  $I_{A^0X}, I_{D^0X} \gg I_X$ , i.e., the free exciton induced emission band could not be separated from the excitonic luminescence spectrum) or  $A^0X$  and  $X$  induced (consequently  $I_{A^0X}, I_X \gg I_{D^0X}$ , i.e., the  $D^0X$  induced emission band could not be separated from the excitonic luminescence spectrum)] either  $D^0X$  and  $X$  induced (consequently  $I_{D^0X}, I_X \gg I_{A^0X}$ , i.e., then the  $A^0X$  induced emission band could not be separated from the excitonic luminescence spectrum)], the “low-energy” one is induced by radiative annihilation of  $A^0X$  complexes when

$$N_A, (b_{D^0X}/b_{A^0X})N_D \gg \alpha_X/b_{A^0X}, \quad (A2)$$

then  $I_{A^0X}, I_{D^0X} \gg I_X$ , or when

$$N_A, \alpha_X / b_{A^0X} \gg (b_{D^0X} / b_{A^0X}) N_D, \quad (\text{A3})$$

then  $I_{A^0X}, I_X \gg I_{D^0X}$ <sup>8</sup>.

Obviously, the observed high energy emission band in this material (with two emission bands in its spectra) arises due to annihilation of  $D^0X$  complexes (its intensity considerably exceeds the intensity of the free exciton induced emission band (in essence, the latter could not be separated from the excitonic luminescence spectrum), or due to annihilation of free excitons, its intensity considerably exceeds the intensity of the  $D^0X$  induced emission band (in essence, the last could not be separated from the excitonic luminescence spectrum).

So, the emission band induced by annihilation of  $A^0X$  complexes dominates in the excitonic luminescence spectrum, if the inequality (A1) (when only one emission band is observed in the excitonic luminescence spectrum) is fulfilled or could be easily separated if inequalities (A2) either (A3) (when only two emission bands are observed in the excitonic luminescence spectrum) are fulfilled.

To evaluate the  $N_A$  value at which the inequalities (A1)-(A3) fulfil, one must know the  $b_{A^0X} / b_{D^0X}$  and  $\alpha_X / b_{A^0X}$  values. Some estimates of these values are given below in Appendix 2.

## 2. Evaluation of $b_{A^0X} / b_{D^0X}$ and $\alpha_X / b_{A^0X}$ ratios for $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$

As was pointed above, to evaluate the  $N_A$  value at which the inequalities (A1)-(A3) fulfil one must know the  $b_{A^0X} / b_{D^0X}$  and  $\alpha_X / b_{A^0X}$  ratios. Unfortunately, these ratios are not known for  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  mixed compounds. But they could be evaluated from the following considerations arising from the examination of the liquid-helium exciton-induced emission spectrum in CdTe (i.e., in  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  with  $x = 0$ ) given in [13] and in  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  crystals given in [1]. As will be seen, these evaluations are rather rough due to a row of hardly controllable assumptions made when finding the  $b_{A^0X} / b_{D^0X}$  and  $\alpha_X / b_{A^0X}$  ratios.

<sup>8</sup> When writing inequalities (A1)-(A3) we supposed that self-absorption of free exciton induced radiation in  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  crystals did not play a substantial role. If self-absorption of the free exciton induced radiation is important (it decreases the externally emitted free exciton induced radiation, i.e. the intensity of the free exciton induced emission to the value  $I_X^* = \gamma_X I_X$ , where  $\gamma_X$  is a part of the free excitons which does not undergo self-absorption (naturally,  $\gamma_X = 1$  is self-absorption of free exciton radiation is of a minor importance)), then the free exciton contribution to the emission spectra could be neglected if

$I_{A^0X}, I_{D^0X} \gg I_X^*$ . In this case, to take into account the self-absorption on the intensity of the free exciton induced emission in inequalities (A1)-(A3)  $\alpha_X / b_{A^0X}$  should be replaced by  $\gamma_X(\alpha_X / b_{A^0X})$ .

a) *Evaluation of the  $b_{A^0X} / b_{D^0X}$  ratio.* The  $b_{A^0X} / b_{D^0X}$  ratio was found from the relation (valid if  $N_{A^0} \cong N_A$  and  $N_{D^0} \cong N_D$ , we suppose that these relations are fulfilled in investigated in [13] crystals),  $I_{A^0X} / I_{D^0X} \approx b_{A^0X} N_A / b_{D^0X} N_D$  [it follows from Eqs (4) and (5)] using the known (given in [13]) for CdTe  $I_{A^0X} / I_{D^0X}$  and  $N_A / N_D$  values (when calculating the  $b_{A^0X} / b_{D^0X}$  ratio we supposed that given in [13] the  $I_{A^0X} / I_{D^0X}$  value was measured in a region of the same dependence of  $I_{A^0X}$  and  $I_{D^0X}$  on the excitation intensity  $L$ , i.e.  $I_{A^0X} / I_{D^0X}$  is not a function of  $L$ ). It turned out that  $b_{A^0X} \approx b_{D^0X}$  (the  $b_{A^0X} \approx b_{D^0X}$  correlation given in [8] was also found using the data of [13]) {one expects that  $b_{D^0X}$  will be somewhat higher than  $b_{A^0X}$  [17] (in gallium arsenide  $b_{D^0X} / b_{A^0X} \approx 3.75$  [17])}. In the main text, it will be assumed that the found  $b_{D^0X} / b_{A^0X}$  value depends weakly on  $x$ , i.e., is valid for  $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$  with any  $x$  value.

b) *Evaluation of the  $\alpha_X / b_{A^0X}$  ratio.* The  $\alpha_X / b_{A^0X}$  ratio could be found from the relation  $I_{A^0X} / I_X \cong b_{A^0X} / \alpha_X$  valid if  $N_{A^0} \cong N_A$ . It follows from Eqs (4)-(6) using the known  $N_A$  and  $I_{A^0X} / I_X$  values. The  $N_A$  value is of the order  $10^{16} \text{cm}^{-3}$  which is a typical value for the crystals obtained by a modern technology [18]. Unfortunately the known 4.2 K  $I_{A^0X} / I_X$  values differ significantly as given by different authors – for example, from  $I_{A^0X} / I_X \cong 0.03$  [2] up to  $I_{A^0X} / I_X \approx 1$ , see Fig. 1 [1]. In our opinion, this difference is mainly due to a substantial role of self-absorption of the free exciton induced emission, which could differ from crystal to crystal depending on its quality, resulting in a decrease of the  $I_X$  value (see the footnote 6). So, the real  $\alpha_X / b_{A^0X}$  value is of the order or above  $10^{16} \text{cm}^{-3}$  [ $\alpha_X / b_{A^0X} \cong 10^{16} \text{cm}^{-3}$ , if self-absorption of the free exciton induced emission was of minor importance in investigated in [1] high quality crystals, i.e.,  $I_X^* \cong I_X$  ( $\gamma_X \cong 1$ ) and, consequently,  $I_{A^0X} / I_X^* \approx I_{A^0X} / I_X \approx 1$  (see Fig. 1) and  $N_A = 10^{16} \text{cm}^{-3}$  in them<sup>9</sup> (note here that  $\alpha_X / b_{A^0X} \approx 6 \cdot 10^{15} \text{cm}^{-3}$  in gallium arsenide [17])].

<sup>9</sup> When evaluating the  $\alpha_X / b_{A^0X}$  value, we also supposed that

$I_{A^0X} / I_X \neq \phi(L)$  in crystals investigated in [1].

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