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Temperature dependence of luminescence pecularities in oxygen doped ZnTe films

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Abstract. Temperature dependence of luminescence intensity inherent to zinc telluride films prepared by the method of vacuum deposition and containing an oxygen impurity was investigated. The model explaining non-monotonous behaviour of curve temperature dependence for the "oxygen" band (λ_{max} = 650 nm) is offered. According to this model, during quenching luminescence, the centers of a luminescence and those of the majority carriers capture participate. Determined are the values of the activation energy and concentration of the appropriate centers at which abnormal dependence of luminescence intensity on the temperature is observed.

Keywords: luminescence, quenching, centre of luminescence, centre of capture, temperature dependence.

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1. Introduction

Zink telluride is promising material for creation of light sources in the visible spectrum. Optimisation of its radiative characteristics requires data about parameters of emission centers. One of the methods of determination of energy centers position is based on the measurement of dependence of irradiation on the temperature. The existing models are well applicable to describing the classical temperature quenching of luminescence when with increasing temperature the light intensity exponentially decreases [1]. This paper introduces the model that describes non-monotonous behavior of the temperature dependence of luminescence intensity detected in oxygen doped ZnTe films [2, 3].

2. Experimental results and discussion

The luminescence of oxygen doped ZnTe with λ_{max} = = 650 nm is observed around 77 K. Fig. 1 shows temperature dependence of the luminescence "oxygen" band in ZnTe films grown by vacuum deposition method in quasi-closed volume under different technological conditions. One can see that with increasing temperature,

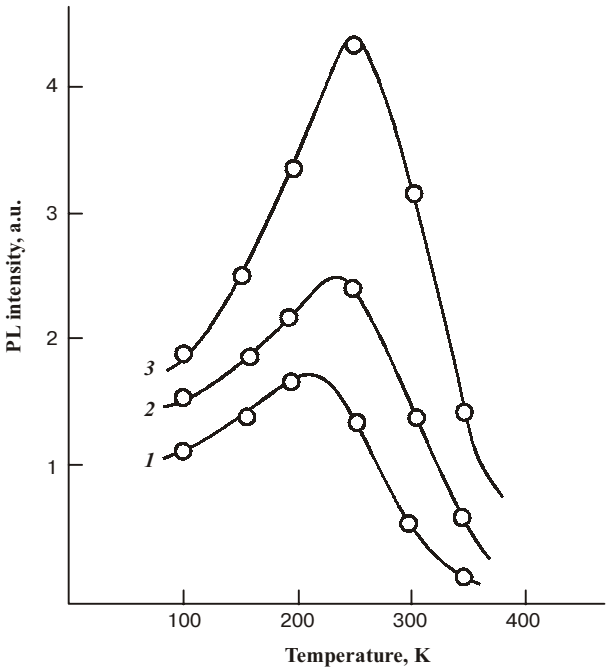

Fig. 1. Temperature dependence of photoluminescence with λ_{max} = 650 nm of ZnTe films obtained under different condensation temperatures (T_k), K: 570 (*1*); 600 (*2*); 670 (*3*).

the flaming up of the luminescence is observed instead of typical quenching. After reaching the maximum, the value of the luminescence intensity falls down, and the value of temperature corresponding to the peak intensity depends on the temperature of film condensation.

It is known [2] that oxygen creates O_{Te} defect while replacing the Te atom in ZnTe lattice, which is the deep donor of the luminescence center. It is remarkable that in the luminescence spectrum of ZnTe:O only one elementary band is observed, and as implication there are luminescence centers of only one type. It is obvious that for explanation of luminescence quenching mechanism it is necessary to consider the influence of other centers. The role of other centers that take part in the quenching can be played by acceptors located near the valence band. The centers of this kind were observed in ZnTe under different methods of its preparation. To provide *p*-type of semiconductor conductivity, these centres have different nature and play the role of capture centers for major carriers. The depth of levels of such centers varies from 0.05 to 0.25 eV.

In order to explain the temperature dependence of intensive "oxygen" luminescence of the considered ZnTe samples, the following model was selected.

The presence of two groups of levels in the gap is supposed: acceptor and donor ones with concentrations of respective centres N_1 and N_2, and depths E_1 and E_2. Under stationary excitation, such system will be described with the following equations

$$\gamma_{n_1} np_1 + \gamma_{p_1} p_1 F e^{-\frac{E_1}{kT}} = \gamma_{p_1} p(N_1 - p_1), \quad (1)$$

$$\gamma_{p_2} pn_2 + \gamma_{n_2} n_2 F e^{-\frac{E_2}{kT}} = \gamma_{n_2} n(N_2 - n_2), \quad (2)$$

$$Z = \gamma_{n_1} np_1 + \gamma_{p_2} pn_2, \quad (3)$$

$$(N_2 - n_2) - n = (N_1 - p_1) - p, \quad (4)$$

where $\gamma_{n_1}, \gamma_{p_2}$ – recombination coefficients of acceptor and donor; $\gamma_{p_1}, \gamma_{n_2}$ – coefficients of thermal dumping for holes from acceptor and electrons from donor; p_1, n_2 – concentrations of carriers localized on corresponding levels; *p, n* – concentrations of free electrons and holes; *Z* – intensity of stationary photoexcitation; *F* – effective density of states in the bands.

The model supposes the equality of coefficients of thermal dumping and capturing the carriers on corresponding centers as well as equality of state effective densities for holes and electrons.

In the system of equations (1–4), the first two equations explain the dynamic equilibrium of the carriers exchange process between impurity centers and zones. The equality (3) represents the condition of equilibrium between processes of generation (*Z*) and recombination of carriers during stationary excitation. The latter equation in the system is the electroneutrality condition.

The system was solved with the following values:

$\gamma_{n_1} = 10^{-8}\,\mathrm{cm^3c^{-1}}$ $E_1 = 0.05 \div 0.25$ eV $F = 2.5 \cdot 10^{19}\,\mathrm{cm^{-3}}$

$\gamma_{p_2} = 10^{-13}\,\mathrm{cm^3c^{-1}}$ $E_2 = 0.1 \div 0.5$ eV $Z = 10^{15}\,\mathrm{cm^{-3}c^{-1}}$

$\gamma_{n_2} = 10^{-7}\,\mathrm{cm^3c^{-1}}$ $N_1 = 10^{15} \div 10^{16}\,\mathrm{cm^{-3}}$

$\gamma_{p_1} = 10^{-6}\,\mathrm{cm^3c^{-1}}$ $N_2 = 10^{14} \div 10^{16}\,\mathrm{cm^{-3}}$

The calculated temperature dependence of luminescence intensity can be expressed with the formula

$$I_L(T) = \gamma_{p2} p_{(T)}\, n_{2(T)}.$$

As expected, at the specific values of E_1, E_2, N_1 and N_2, the calculated dependence $I_l(T)$ is non-monotonous. The calculation show that the depth of acceptors bedding – E_1 and concentration of donors (N_2) have the most considerable influence the temperature curve.

Calculated family of temperature dependence curves at the different values of E_1 is shown in Fig. 2. One can see that decrease of the value of E_1 causes the low-temperature-side shift of the maximum of temperature curve. Indeed, the concentration of free carriers increases due to thermal release of acceptor centers, and the closer is this center to the V-band the smaller are the temperatures of the thermal exchange start in this zone.

As a result of donor centers being deep, their energy position does not influence the kind of dependence $I_l(T)$. Increasing donor center concentration leads to the following results (see Fig. 3). At the small concentration of N_2, the dependence $I_l(T)$ has the classical shape (curve 1), and the energy of activation of the quenching process

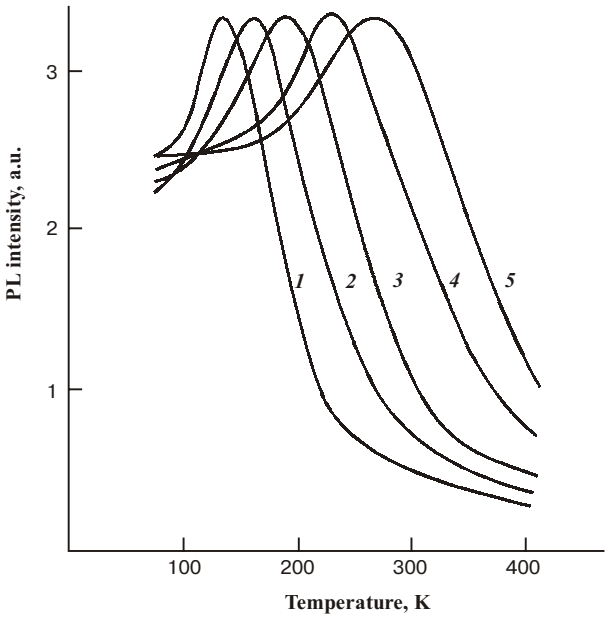

Fig. 2. Theoretical curves of temperature dependences of the luminescence intensity at the different values of E_1, eV: *1* – 0.1; *2* – 0.12; *3* – 0.14; *4* – 0.17; *5* – 0.2.

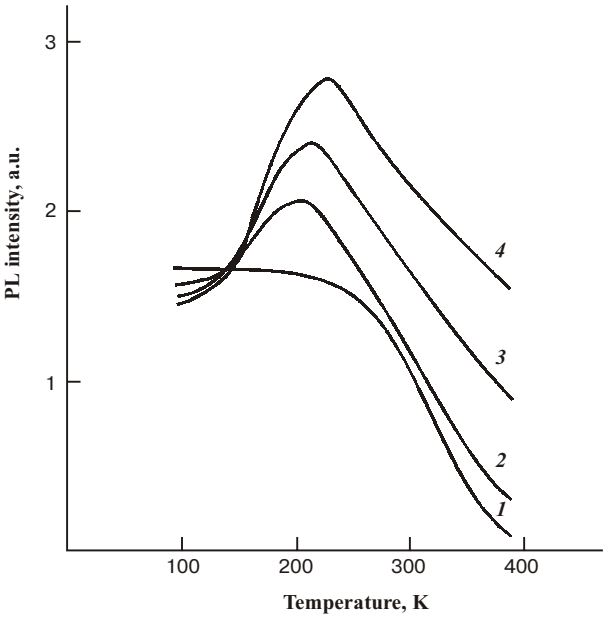

Fig. 3. Theoretical curves for temperature dependences of the luminescence intensity at different concentrations of donor centers N_2: *1* – $2 \cdot 10^{14}$ cm^{-3}: *2* – $6 \cdot 10^{14}$ cm^{-3}.

equals 0.45 eV, what correlates with the "oxygen" luminescence center activation energy. Starting from some specific value of N_2, the temperature dependence of luminescence intensity has a maximum, position of which shifts to the area of high temperatures (curves 2 and 3). This is clear from the following considerations. At the small donor concentration, increase of the free hole concentration caused by their thermal release from acceptor levels influences the temperature dependence only a little, because the intensity of luminescence is controlled by the value N_2. This influence starts to be noticable at higher values of donor centers. It is also clear that with increase of their concentration luminescence quenching stimulated by thermal release of electrons from donor centers starts at the ever increasing temperatures, what determines the shift of the peak position on the curve $I_l(T)$.

In a general case, the peculiarities of temperature dependences $I_l(T)$ obtained in the calculations are determined by temperature dependencies of values included in the expressions (5). As computations show, in the temperature interval 100–400 K, the concentration of free holes increases with the temperature, reaching the saturation. In the same temperature interval, with the increase of the temperature, the concentration of electrons on the donor centers in the beginning does not depend on the temperature and then decreases as a consequence of thermal injection in the conductivity band. Superposition of these two processes results in the maximum on the curve $I_l(T)$.

3. Conclusions

Thus, the proposed model explains the observed temperature dependence of "oxygen" luminescence intensity, and as a result of comparing with theoretically calculated dependence one can determine parameters of centers, which participate in its quenching. For example, for grown ZnTe films the anomaly temperature dependence can be observed at the values: E_1 = 0.15–0.20 eV; E_2 = = 0.45 eV; $N_1 = 10^{16}$ cm^{-3}; $N_2 = 5 \cdot 10^{14}$–$15 \cdot 10^{15}$ cm^{-3}.

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