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Luminescence kinetic of $CsPbBr_3$ quantum dots

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Abstract. $CsPbBr_3$ quantum dots have been studied as a luminophore for scintillators that could be used in technology of ionizing radiation detectors. The main optical process that characterizes luminophore parameters is the kinetic of luminescence. In order to study optical parameters one phase of $CsPbBr_3$ quantum dots was isolated from the solution by using 400 nm filter and placed in toluene. Time resolved photoluminescence was measured for received sample by using ultraviolet laser diode (λ = 372 nm) as a source. Empirical expression from decay time plot was obtained. The expression described model of luminescence kinetic for $CsPbBr_3$ quantum dots. According to the magnitude of empirical parameter received from the expression it was concluded that the recombination mechanism of luminescence on traps predominated for the studied samples of $CsPbBr_3$ quantum dots. The expression could be used for modeling optical proprieties for nanosized $CsPbBr_3$.

Keywords: $CsPbBr_3$, quantum dots, luminophore, scintillator, kinetic of luminescence

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Кинетика люминесценции квантовых точек $CsPbBr_3$

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Аннотация. Была измерена разрешенная по времени фотолюминесценция для образцов квантовых точек $CsPbBr_3$, получено эмпирическое выражение из графика времени затухания. Выражение описывает модель кинетики люминесценции квантовых точек $CsPbBr_3$. По величине эмпирического параметра, полученного из выражения, сделан вывод, что для исследованных образцов квантовых точек преобладает рекомбинационный механизм люминесценции на ловушках.

Ключевые слова: $CsPbBr_3$, квантовые точки, люминофор, сцинтиллятор, кинетика люминесценции

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Introduction

Perovskite materials are manufactured using low-temperature technologies and have properties suitable for optoelectronic devices [1]. One of perovskites applications can be creation of a scintillator based on them [2, 3]. The most promising materials for this application are quantum dots (QDs) like $CsPbBr_3$ QDs, since there is no self-absorption problem for structures smaller than the luminescence wavelength. $CsPbBr_3$ QDs are manufactured with temperature lower than 100 °C, using $PbBr_2$ as a precursor and a cesium precursor, for example, CsBr or Cs_2CO_3. The solvent is selected depending on the cesium precursor. Carboxylic acids or octylamine (OA) are added to stabilize the solution [4–6].

Despite technology results the mechanism of luminescence process is unknown and highly depends on perovskite composition [7]. The luminescence kinetic is characterized by the dependence of the light output intensity (I) on the decay time (t). Measuring time resolved photoluminescence and approximation results on model of luminescence kinetic will help to understand mechanism of luminescence process for $CsPbBr_3$ QDs.

Materials and Methods

$PbBr_2$ and CsBr were used as precursors in dimethyl sulfoxide solvent to obtain $CsPbBr_3$ QDs. The ratio of 3 parts of OABr to 5 parts of $CsPbBr_3$ QDs was taken to stabilize solution. During the process of QDs production the phases, that are too large to have quantum proprieties, could appear. These phases have self-absorption issue that could have impact on time proprieties and misrepresent the result of time resolved photoluminescence measurement. Due to this reason $CsPbBr_3$ QDs were filtered by 400 nm filter and then were placed in toluene which is anti-solvent for $CsPbBr_3$ QDs. Outwardly, there was a strong difference in the wavelengths of filtered and unfiltered samples (Fig. 1, *a*). Photoluminescence (PL) specters of filtered and unfiltered samples were measured by using Agilent Cary Eclipse spectrophotometer with excitation wavelength $\lambda = 370$ nm (Fig. 1, *b*).

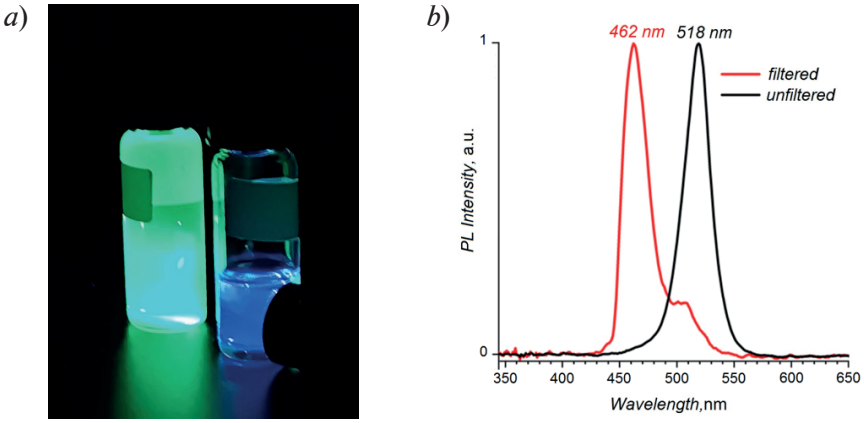

Fig. 1. Photograph of $CsPbBr_3$ QDs samples in toluene (*a*) and PL specter of the samples (*b*)

Time resolved photoluminescence was measured for filtered sample by using ultraviolet laser diode ($\lambda = 372$ nm) as a source and a streak camera. Laser diode was connected to a driver and to a time-to-digital converter; width of laser pulse was 40 ps. Measuring bench was used in integrated mode. According to a form of PL specter the contribution in decay time measurement of all wavelengths except maximum of PL specter ($\lambda = 462$ nm) could be neglected. The resulting decay time function was normalized. The model from resulting plot was made by using Becquerel theory [8]. According to this theory there are monomolecular and recombination types of luminescence kinetic. Monomolecular luminescence is described by the probability of a radiative

transition in a separate center independent from other luminescence centers. The equation for monomolecular model is written below:

$$I = I_0 \exp(-kt), \tag{1}$$

where I_0 is initial intensity of luminescence, k is the process rate coefficient.

There are two competitive processes in the recombination mechanism: the capture of charge carriers by traps caused by defects, and recombination on ionized centers. Recombination mechanism depends on the rates of these processes. Empirical equation for recombination model is written below [8]:

$$I = \frac{I_0}{(1+Mt)^p}, \tag{2}$$

where M is the recombination parameter, p is an empirical parameter that determines the function hyperbolicity.

Magnitude of p parameter could be between 1 and 2. If magnitude of p parameter is close to 1 mechanism of recombination with ionized center will be dominant, if it is close to 2 trapping mechanism will be dominant.

Results and Discussion

The resulting decay time function is not linearized in exponential coordinates. The recombination model should be used for approximation. The normalized function of the decay time was approximated by a hyperbolic function of time using the least squares method (Fig. 2).

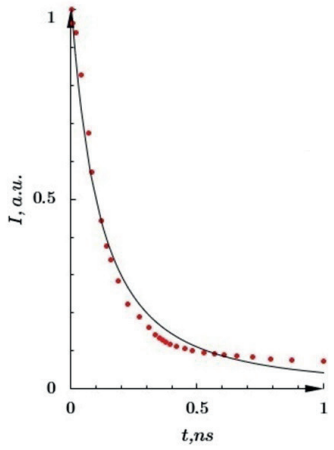

Fig. 2. Approximation of decay time data by a hyperbolic function

By selecting the constants, the function can be approximated by the expression:

$$I = \frac{1}{(1+5.12t)^{1.78}}, \tag{3}$$

The hyperbolic nature of the dependence of intensity on time describes the recombination type of luminescence kinetic. It could be postulated that recombination mechanism of luminescence on traps is predominated for $CsPbBr_3$ QDs according to the value of the empirical parameter ($p = 1.78$).

Conclusion

An expression describing the kinetic of luminescence was obtained for $CsPbBr_3$ QDs from time resolved photoluminescence measurement. According to Becquerel theory it could be concluded that recombination mechanism on traps is predominated due to magnitude of empirical parameter. This result could be used in future modeling tasks. Also, the result describes traps issue by solving which, decay time should be even less and that could meet more applications for $CsPbBr_3$ QDs.

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