Research organic light-emitting diodes with colloidal quantum dots

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Abstract. In this research we have created light-emitting structures that contain colloidal quantum dots of cadmium selenide in the active layer. To do so, we have used the method of vacuum thermal deposition for the formation of organic layers. This method allowed us to create several OLED structures. We have compared their photo- and electroluminescence spectra, and have revealed necessary conditions for the creation of high quality layers.

1. Introduction

Organic Light Emitting Diodes (OLED) are semiconductor devices created from a number of thin organic films. The structure of OLED consists of a transparent substrate, a transparent anode, transport layers with hole and electronic conductivity, an active layer, and a cathode [1].

Due to the high quantum yield of fluorescence, it is possible to increase the efficiency of the structure by adding colloidal quantum dots (CQD) to the composition of the active layer, as well as to control the emitting range.

2. Experiment

In this work we have created organic light-emitting structures FTO/PEDOT:PSS/TPD/Alq3/Al. To do so, we used glass substrate with an FTO layer on it, deposited transport layers of PEDOT:PSS, TPD and Alq3 on top of it, and finished with aluminium contacts.

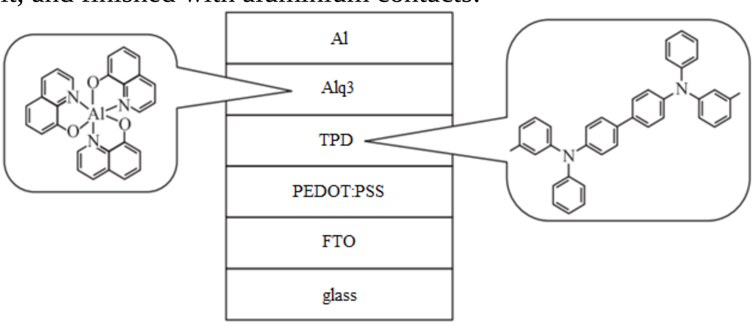

Figure 1. Structure of created OLED [2].

2.1. Change of substrate heating temperature

We have found out that temperature used for heating the glass substrates affected the quality of created structures. To determine the optimum temperature of heating the substrate we have studied the photoluminescence spectra of the TPD and Alq3 layers, deposited at various temperatures of substrate heating.

We have used a scanning excitation laser beam to study photoluminescence characteristics of materials along the entire area of the sample in order to determine homogeneity of created layers. From spectral characteristics we have derived optical emitting power. Thus, for the range of temperatures used for substrate heating we were able to model a surface, which was comprised of values of photoluminescence emission power deviating from the average value. Figure 2 shows this surface model for TPD and Alq3 deposited at the substrate temperature 50 °C and 60 °C. Accompanying data for all measured layers is summarized in table 1.

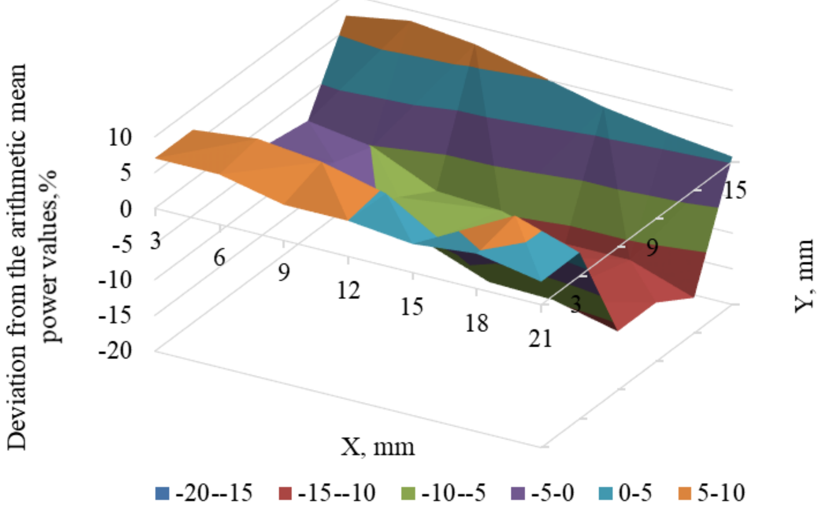

Figure 2. The surface composed of values of photoluminescence emission power of TPD and Alq3 deposited on a substrate at temperature 50 °C and 60 °C deviating from the average value.

Table 1. Relation between layer photoluminescence values and substrate heating temperature.

Material	Annealing temperature, ˚C	The average emitting power over the surface of the structure, rel. units	Deviation from the average power, %
TPD	51	1173	10
TPD	61	967	9.4
TPD	67	320	21
TPD	77	170	17
Alq3	50	690	14
Alq3	60	727	17
Alq3	74	670	16
Alq3	80	477	22
Alq3	88	606	15
TPD + Alq3	51	950	8
TPD + Alq3	TPD at 51 Alq3 at 60	1384	11

It turns out that the most homogeneous layers are obtained when the substrate is heated to 50 °C for TPD, and to 60 °C for Alq3. Therefore, it is better to use same temperatures for spraying these materials in alternation.

There is no necessity to cool the substrate to the room temperature after deposition of TPD. It could immediately be heated to 60 °C and then sprayed with Alq3. This procedure does not affect the uniformity of the layers.
There is a slight increase in deposited material to the edges of the substrate. It is associated with the feature of spraying. The recommendation for creating higher quality layers is to avoid applying contacts near the edges of the substrate.

2.2. Change in a residual gas pressure

A part of this research aimed to compare characteristics of light-emitting structures that were identical in composition. These diodes were created using various degrees of vacuum pumping. To deposit layers we used a method of vacuum thermal evaporation with residual gas pressures of $2 \bullet 10^{-5}$ Torr for one type of structures and 10^{-4} Torr for another.
Created structures FTO/PEDOT:PSS/TPD/Alq3/Al have their own electroluminescence spectrum that is shown in figure 3. This figure clearly demonstrates the need to reduce the pressure of residual gases during creation of organic films. Higher pressures disrupt deposition process, making layers less uniform and material less pure, which consequently affects emitting intensity of created structures.

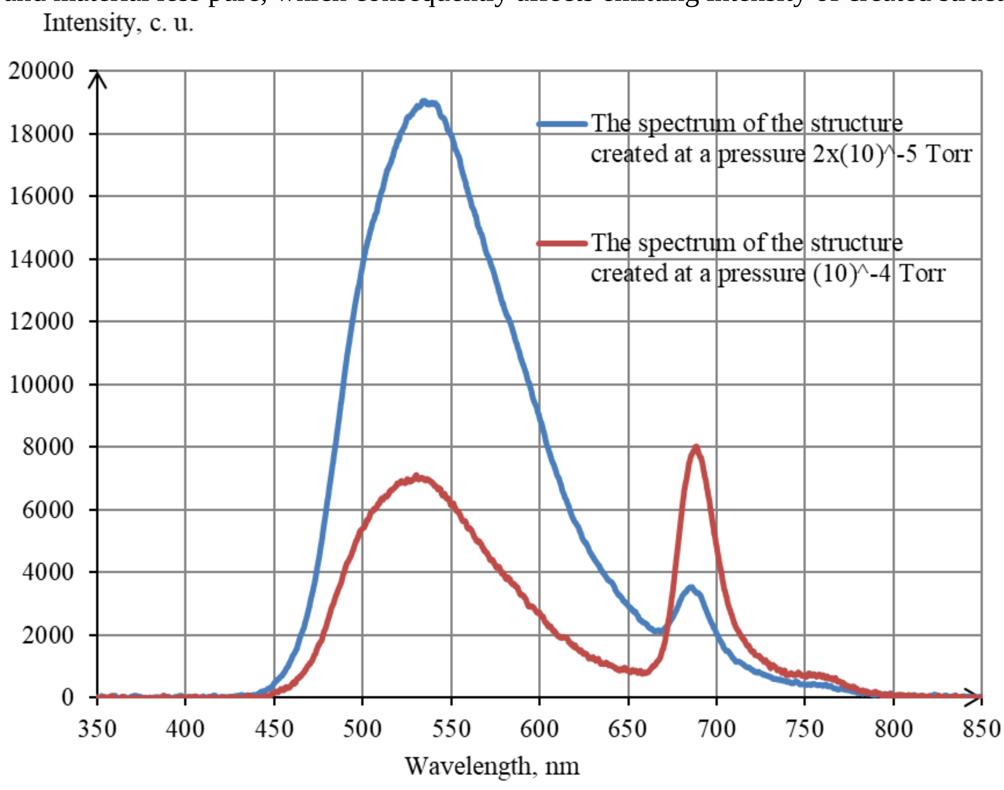

Figure 3. Electroluminescence spectra of structures.

To increase the emitting intensity of the structures, it is possible to fill the working volume of the chamber with an inert gas, such as argon [2]. It is also important to prevent any contact of OLEDs with the environment.

2.3. Change of substrate material

In the next part of this research, we have created two types of structures with same composition but with different substrates. In the first structure we have deposited PEDOT:PSS, TPD, CQD, Alq3 and aluminium contacts on a glass substrate with a layer of indium tin oxide doped with fluorine (FTO). In the second structure we have made the films of these materials on a flexible substrate with a layer of indium tin oxide (ITO).
Relation between emitting efficiency and applied current shown on figure 4 clearly demonstrates distinct properties of structures created on the substrates with anodic contact materials. Taking into

account that the work function of ITO is more than that of FTO, this difference could be explained by disruption of uniformity of the layers created on flexible substrate.

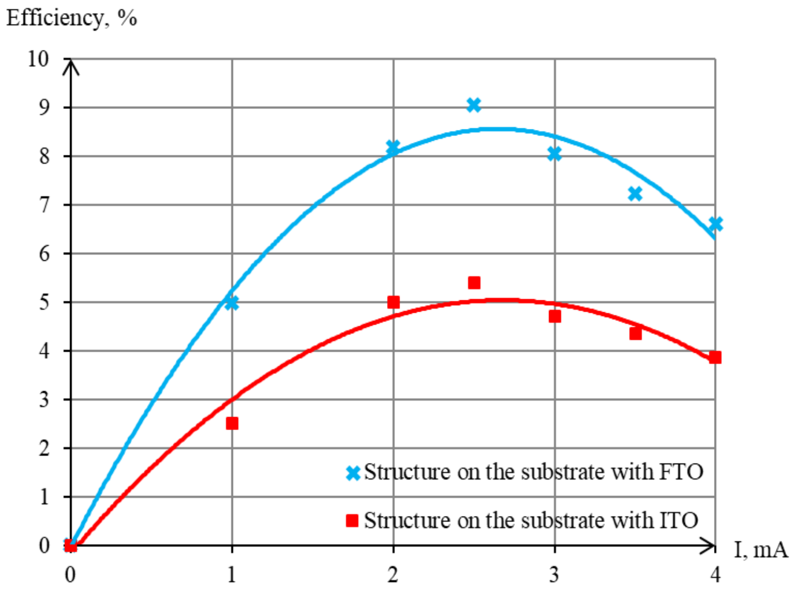

Figure 4. Relation between structure efficiency and applied current.

2.4. The influence of CQD on the spectral characteristic

One of the most important goals of this research was to demonstrate the change in OLED electroluminescence spectrum after the introduction of colloidal quantum dots (CQD) into the active layer. To do this we have created a series of light-emitting structures of FTO/PEDOT:PSS/TPD/Alq3/Al and FTO/PEDOT:PSS/TPD/TPD+CQD(680)/Alq3/Al that contain colloidal quantum dots of CdSe in ZnS shell.

Figure 5 shows spectral characteristics of obtained structures at a voltage of 25 V. The OLED with the CQD has a peak at a wavelength of 680 nm due to electroluminescence of the CQD. The intensity of this maximum depends on applied voltage and on concentration of CdSe/ZnS nanoparticles. In Alq3 electroluminescence peak shifts, which is associated with effects of internal absorption in the array of CQD.

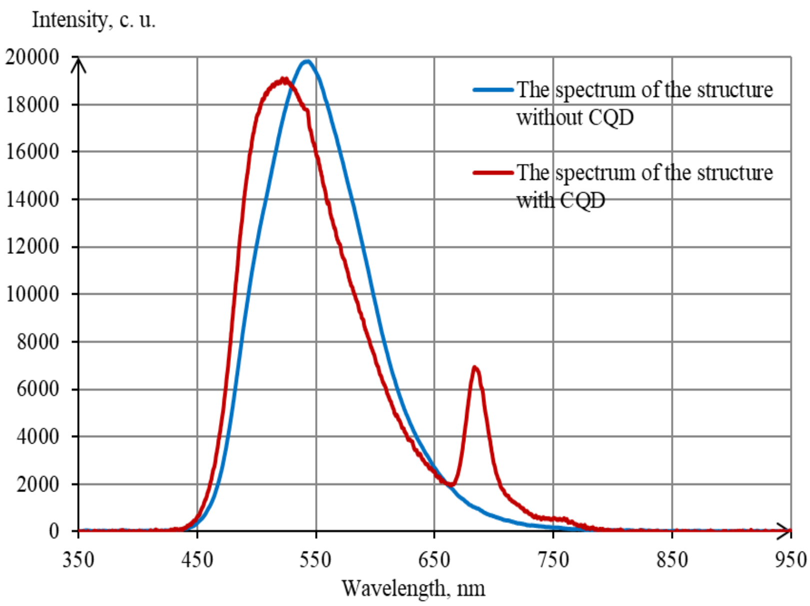

Figure 5. Electroluminescence spectra of structures.

3. Conclusion

In this work we have created organic light-emitting structures FTO/PEDOT:PSS/TPD/Alq3/Al and FTO/PEDOT:PSS/TPD/TPD+CQD(680)/Alq3/Al. We have demonstrated that the inclusion of CQDs in the composition of the active OLED layer leads to a significant change in the spectral characteristics.

In order to ensure high uniformity of layers that are deposited using method of vacuum thermal evaporation, we have found optimal temperatures of substrate heating for organic materials such as TPD and Alq3. Here we have also registered a necessity to reduce residual gas pressure due to the fact that even a slight difference in degree of vacuum pumping leads to significant differences in the efficiency of the light-emitting structure.

We have also showed that a structure created on a substrate with the FTO as anodic contact is more efficient than a similar one on a substrate with the ITO. Emitting efficiency of organic LEDs with former substrate is almost double of that in the latter.

4. References

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