Photoluminescence and electroluminescence from tailored Alq3:DCM nanolayers

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Introduction

Advances in the development of organic light emitting diodes (OLEDs) have so far only partially unleashed the potential of these devices and pointed out new major scientific and technological challenges. One of the most pressing tasks is the obtaining of diode structures with the polarized nature of the emitted light. The development of effective methods for fabricating such light-generating structures with specified color characteristics, high dichroic ratio, sufficient energy efficiency and time stability based on organic nanolayers can significantly optimize the design of LEDs. Technology costs can be reduced by eliminating the need for additional polarizing filters, while increasing brightness and contrast and widening viewing angles.

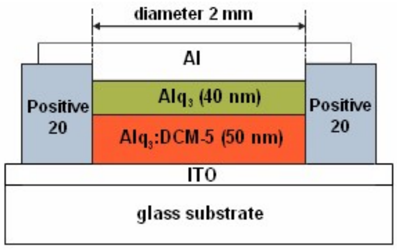
From a scientific point of view, the main task on the way to solving the described problems is to find the best matching between the inorganic nanostructure and the layer of organic luminescent molecules that both form the light-generating element. So the aim of this work is to obtain and study organic-inorganic light-emitting structures, on which innovative OLED-devices with polarized emission for modern optoelectronic systems can be based. Research involves the matching of initial organic and inorganic compounds in multilayer configurations with different hierarchies to create new organic-inorganic structures with polarized luminescence. An important aspect of the work is the use of newly synthesized highly luminescent organic molecules tested in recent studies, which will allow to create light-generating layers of different colors in LED structures.

The possibility of combining specific substrate materials with different organic molecules for light emission with different wavelengths may be considered as a way to create hybrid nanostructures that emit white light. The possibility of facilitating the charge carriers injection processes between the cathode and the transport layer by introducing metal impurities is also worth to be considered.

From research perspective, the purpose of the present work is to study the mechanisms of the formation of hybrid nanostructures and electronic processes in such structures that lay the background for energy efficient and controlled methods of creating promising functional materials for optoelectronics, as well as for flexible prediction of how external factors influence on the characteristics of light-generating structures.

Experimental

DCM-5, Alq3 and Alq3:DCM-5 (10 wt. %) organic films with the thickness less than 50 nm were thermally deposited in 10−4 Pa vacuum on optical glass substrates, transparent for wavelength above 300 nm or on transparent conductive indium-tin-oxide (ITO) glass (purchased from Sigma-Aldrich, surface resistivity – 70–100 ohm/sq) for OLED fabrication. Thickness control during the process was provided by quartz crystal deposition rate controller. To produce OLED, the contact as the top electrode – cathode to the Alq3 was formed using thermally evaporated Al. The Al was evaporated through the shadow masks in a circular area of diameter ~ 3 mm. A liquid photo-positive resist based on o-naphto-chinon-diazide and novolack (a type of phenol-formaldehyde resin) "Positive 20" KONTAKT CHEMIE was used as the photoresist-insulator. The schematic image of the OLED is shown in Fig. 1.



1 Schematic structure of organic light emitting diodes based on Alq3 and Alq3:DCM (10 wt. %) thin films

The ex situ ellipsometry measurements were performed with a serial null ellipsometer LEF-3 M in PCSA (polarizer–compensator–sample–analyzer) arrangement. The light source was He–Ne (633 nm) laser .

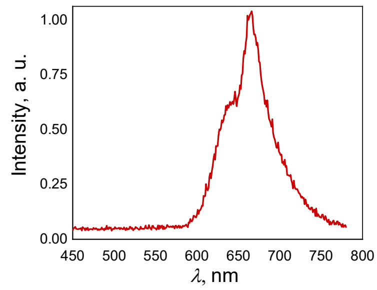
The photoluminescence spectra (PL) were measured using automated monochromator/spectrograph M266 (SolarLS JSC, Minsk, Belarus) connected with CCD camera, based on Hamamatsu S7030-1006S sensor. The samples were excited by GaN laser (405 nm). The sample was placed in a closed loop helium cryostat, equipped with a cryocooler DE-202A (Advanced Research Systems, Macungie, USA) and a temperature regulator Cryocon 32 (Cryogenic Control Systems Inc., Rancho Santa Fe, USA).

The electroluminescence (EL) spectra were measured using a portable fiber optic spectrometer AvaSpec-ULS2048L-USB2-UA-RS (Avantes BV, Netherlands) with an input slit of 200 nm, a diffraction grating of 300 lines/mm and a resolution of 9 nm. The accumulation time was 200 msec. The detection of light in a spectrometer is carried out by a 2048 pixel CCD detector. Special software for automated computer control of the spectrometer and processing was used.

Results

The ex situ ellipsometry measurements with employment of a single-layer model of DCM-5 thin films on the optical glass substrates, were performed. It was found that the effective refractive index of the DCM-5 thin films are approximately equal to 2.26.

We used a low temperature studies, because in pure evaporated DCM thin film photoluminescence very weak [14], due to large intermolecular interaction, which quench luminescence. As can be seen from Fig. 2, the PL spectrum of the DCM-5 thin film, measured at T = 96 K, is exhibit two overlapping bands with the maxima at 635 nm and 665 nm in the visible region.

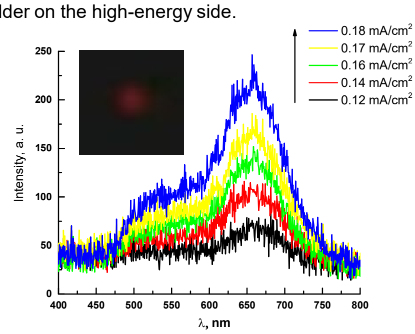


2 PL spectrum of the DCM-5 thin films measured at T = 96 K.

It was found that the decay kinetics of these two overlapping bands of photoluminescence at T = 96 K consists of two components – fast and slow:

Emission band, nm	Decay time of the fast component τ_1, ns	Amplitude of the fast component A_1	Decay time of the slow component τ_2, ns	Amplitude of the slow component A_2
635	3.2	543	7.4	44
665	3	571	7	40

Fig. 3 presents the EL spectrum of the our heterostructure with the configuration ITO/Alq3:DCM-5 (10 wt. %)/Alq3/Al. The EL emission clearly seen by a naked eye in the dark (see the snapshot in Fig. 3). The emission intensities of the EL spectra increase with the increase in applied voltage. The wide band in the range from approximately 600 nm to 750 nm has a clear shoulder on the high-energy side.



3 Room temperature EL spectra of our OLED under different injected currents. Inset shows a snapshot of light emission