Investigation and Analysis of Organic Electroluminescent Heterostructures

Mariya Aleksandrova[1], Georgy Dobrikov[1], Milka Rassovska[1]

Abstract – **In this study organic electroluminescent structures using heteroelectrode have been prepared to increase current density and injection efficiency. Current-voltage characteristics are measured to evaluate the improvement of the electrical behavior. For clarifying and further understanding of the processes in the bulk and at the layer interfaces, additional simulation analysis has been carried out. The charge carriers spatial distribution and electrical field distribution depending on the structure configuration has been investigated.**

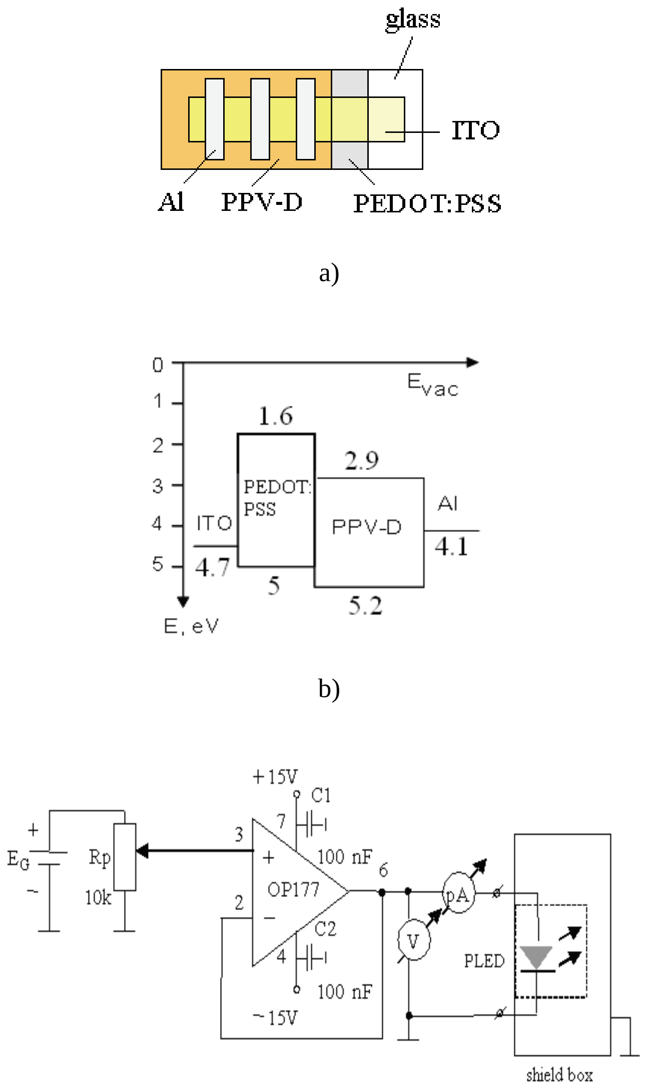
Keywords – **Organic semiconductors, Electroluminescent devices, Heteroelectrode, Heterojunctions.**

I. INTRODUCTION

Organic electroluminescence (EL) is electrically stimulated emission of light from organic semiconductors and finds application in organic light-emitting display (OLED) [1]. There is rapid progress in improvement of the stability of these devices, even for the materials, which produce blue light and require higher energies for charge carrier transitions in the structure [2]. However, for the practice there is one more important parameter except exploitation time. This is device's efficiency and in this case is quantum efficiency, or ratio between numbers of generated photons to numbers of injected charge carriers, which recombine inside the structure. There are many efforts concentrated in this direction [3,4], but most of the explanations about the physical processes in OLED are not full or the knowledge is still poor. Many materials are incorporated in the EL structure between the electrodes and the light emitting organic semiconductor to decrease the height of injection barrier at the layer's boundary [5,6]. Despite of the energy level alignment at the interfaces the charge balance is destroyed after inserting of additional layers, so deeper investigation of this problem is necessary.

In this paper we suggest combine approach of experimental measurements and numerical simulations to get comprehensive information about the behavior and electrophysical properties of OLED structure, which consists of heterojunction for higher efficiency. The investigation aims to reconstruct processes at the layer interfaces and bulks, where it is not possible to receive simple picture about the device only from direct experimental measurements.

II. EXPERIMENTAL SECTION



a)

b)

c)

Fig. 1. Prepared multilayer EL structure (a), energy levels diagram (b) and block diagram of the test circuit for I-V characteristics measurement (c).

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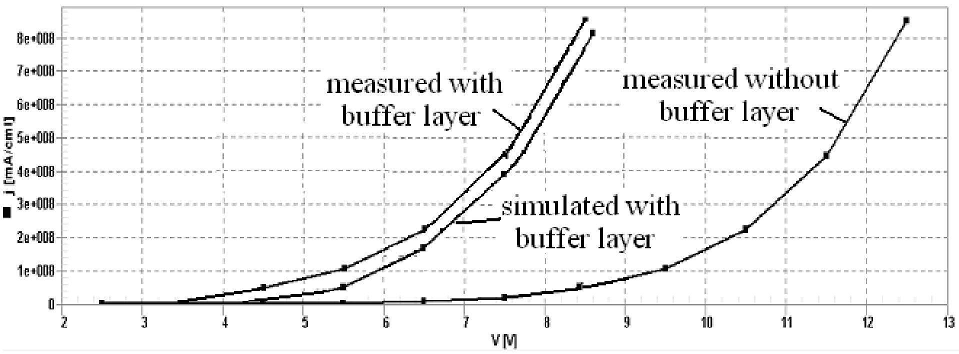

Fig. 2. Current-voltage characteristics of the organic structure with and without heterojunction together with the simulation curve.

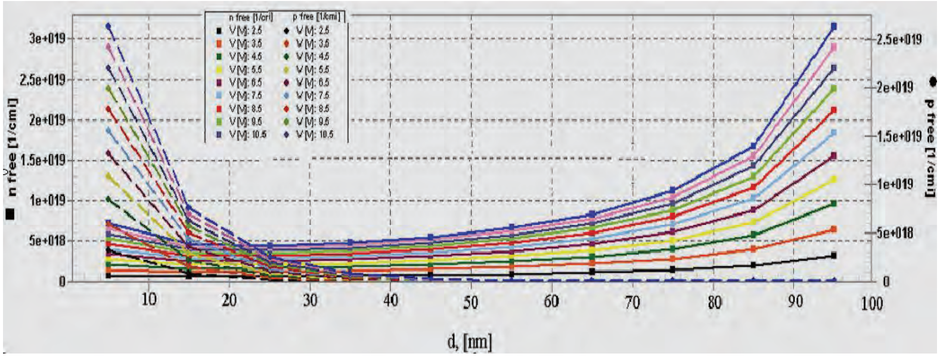

Fig. 3. Spatial distribution of the charge carriers in the bulk of EL structure.

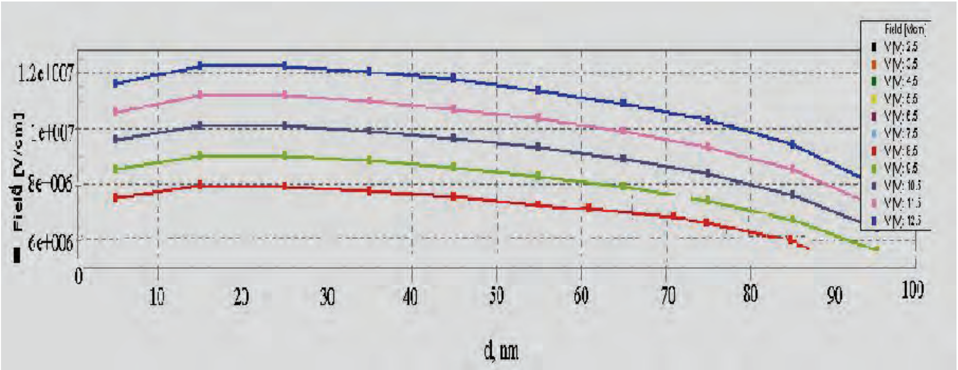

Fig. 4.Electricalfield distribution in depth in the EL structure.

For the fabrication of electroluminescent heterostructure, indium tin oxide (ITO) covered glasses obtained by RF reactive sputtering were used as substrates with anodes. The target was metallic indium tin disk, mounted in vacuum installation model A400VL. Rotary and turbomolecular pumps were used to achieve the desired vacuum level in the system, which is less than 1×10^{-5} Torr. The obtaining of conductive and transparent ITO thin films is described elsewhere [7]. For preparation of hole transporting layer solution of 1 ml poly(3,4-ethylenedioxythiophene) dissolved in 10 ml poly(styrenesulfonate) (PEDOT:PSS) is deposited by spin coating with rotation speed of 1000 rpm for 40s to produce 60 nm thin film. The emissive layer made from poly((9,9-dihexyl-9H-fluorene-2,7-vinylene)-co-(1-methoxy-4-(2-ethylhexyloxy)-2,5-phenylenevinylene)) (PPV-D) is deposited also by spin coating at the same conditions. Important heterojunction is formed between both polymer layers. Finally Al cathode was deposited by vacuum thermal evaporation. Prepared multilayer EL structure is shown on Fig. 1.

The current-voltage characteristics were measured by precise Keythley 6485 picoampermeter.Etalon structure without buffer layer is prepared and its current-voltage characteristics are compared to that with hole transporting layer.

The analysis in this article is based on simulation results achieved with OLED simulation software based onOLEDWin,which consider processes like charge carrier injection and transport, radiative recombination, non-radiative decay, ratio between singlet and triplet states, etc. The program uses experimental measured data as input parameters, so the simulation results complement the data from the real measurement.

III. RESULTS AND DISCUSSION

Measured current-voltage characteristics of the etalon structure and the structure with buffer layer are compared and shown on Fig. 2. In the same plot is presented the result from simulation of the same structure, consisting of the same materials as thin films, with the same thickness and consequence of deposition. As could be seen there is great match between measured and simulated curves (average error of 1.1 %), which give us reason to consider the further simulations as exact representation of the real structure's behavior.

Following assumptions are accepted for the simulated device: trap depth 0.25 eV; singlet and triplet lifetime respectively 1.10^{-8} s and 1.10^{-6} s; efficiency of radiative decay 0.3; charge carriers mobility 10^{-4} $cm^2/V.s$ for holes and 10^{-2} $cm^2/V.s$ for electrons. These acceptances are based on the typical reported values in the scientific literature for the organic semiconductors and concretely for organic electroluminescent devices. One of the main reasons for bad efficiency is the meeting point of both types of charge carriers, namely near one of the electrodes, where high defect concentration exists. This happens, because of the different mobility for electrons and holes and the different injection barriers at the contacts. The defects are caused by electrode deposition processes and they act as luminescence quenching centers. That's why it is necessary the recombination zone to be shifted away from the electrode interfaces and toward the bulk of the organic light emitting layer. Fig. 3 shows spatial distribution of the charges in the bulk and the recombination zone in the case of inserting PEDOT:PSS as buffer layer between ITO and PPV-D. Starting zero value of the "x" axis means the interface between PEDOT:PSS and PPV-D. There is intermediate zone of approximately 5 nm where both layers are partly penetrated to each other. If the whole thickness of the electroluminescent layer is 100 nm the meeting zone of the opposite charge carriers is in the range 25-35 nm, which is not exactly in the middle of the film, but the recombination zone is shifted in comparison with the case without PEDOT:PSS. Charge distribution is independent of the applied voltage in the operational range of 2.5 to 10.5 V, which proves the stability of the prepared device.

Because of the uniform distribution of charges there is no space charge formation and therefore current limitations and field distortions are missing. This can be observed on Fig. 4 where is shown the electrical field distribution inside the EL layer. There are some deflections at the interface with the aluminum electrode (near 100 nm) because in this place there is no cathode buffer layer to improve the conditions for electron injection as this is made for holes. This tendency is preserve with the change of the applied voltage intensity from 2.5 to 12.5 V/cm.

IV. CONCLUSION

In summary hole injection efficiency in organic EL device is found to be enhanced by adding thin PEDOT:PSS layer between the ITO anode and light-emitting layer. Theadvantage of such heteroelectrod (ITO/PEDOT:PSS) and heterojunction (PEDOT:PSS/PPV-D) is energy level alignment at the interfaces and injection barrier decreasing, as well as shifting of the recombination zone inside the structure's bulk and better distribution of the electrical field. It was established that the place of the recombination zone is not sensitive to the voltage applied. We think that this kind of combined research (experimental and simulations) explains well electrophysical behaviour of organic EL devices.

ACKNOWLEDGEMENT

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