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Three-terminal light-emitting device with adjustable emission color

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ABSTRACT

A three-terminal organic light-emitting device with a periodic interrupted middle electrode is developed to allow for an adjustable emission color. The emission results from three independent light-emitting diodes with one diode utilizing exciplex emission. An equivalent electrical circuit is suggested taking the current–voltage characteristics and the direction of current flow through the organic structure into account. Two diodes are formed between the embedded middle electrode and the LiF/Al top and ITO bottom electrode, respectively, and the third diode utilizes that part of the device without the middle-electrode exhibiting exciplex emission. It will be shown that the spectrum of the emitted light can be tuned from blue to orange by controlling the applied potentials to the device terminals.

1. Introduction

Modern organic light-emitting diodes (OLEDs) are mainly realized of two or more organic thin-film layers sandwiched between a transparent ITO anode and a metallic cathode [1]. These devices have already found wide industrial applications in displays and lighting [2]. In addition, new optoelectronic device structures such as light-emitting field-effect transistors (OLETs) [3,4] or vertical organic light-emitting transistors (VOLETs) [5] have been introduced allowing for the possibility to obtain a three-terminal control over the intensity, location and color [6,7] in case of the OLET and a large area emission in case of the VOLET [5]. In addition, a new device structure has been suggested recently combining a one- and two-layer OLED in a single device. It mixes an orange exciplex emission generated at the organic interface of the two-layer partition of the device and the blue excitonic emission of the starburst carbazole derivative tri(9-hexylcarbazol-3-yl) amine (THCA) (see Fig. 1a) of the one-layer partition of the device [11]. The exciplex emission results thereby from the charge carrier recombination at the interface formed by the tris(quinolin-8-olato) aluminum (Alq_3) layer and THCA layer and the blue emission from the THCA layer alone.

In the present article based on the above results a novel three-terminal device is suggested that allows for an easy color tuning utilizing a structure similar to a three-terminal VOLET combined with the exciplex emission [9,10]. This is realized by embedding spatially periodic slit-like electrodes in a two layer OLED in the spatial region of exciplex formation. Thereby, three light-emitting diodes are combined in a single device. It will be shown that such a

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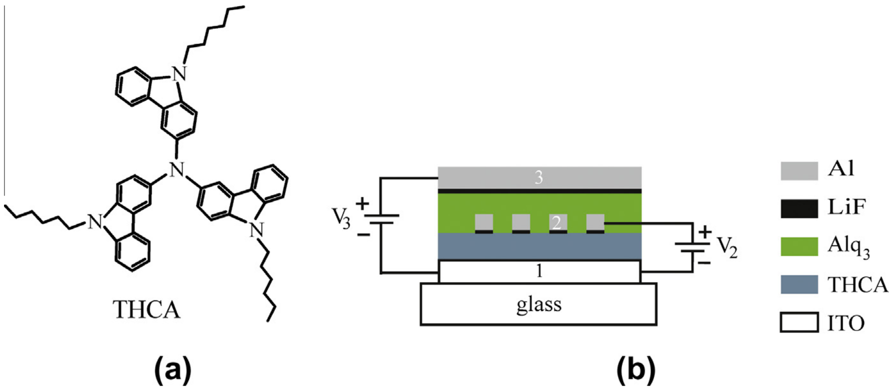

Fig. 1. Chemical structure of THCA (a) and layer structure of the prepared organic light-emitting device (b). The contact pad to the middle electrode **2** can be found outside the actual light-emitting diode either in front or in the rear of the displayed device cross section.

device can be driven by two independent voltages resulting in a color tunable range from blue to orange. Thus, the general problem of color tuning as, e.g., in white OLEDs fabricated by mixing of three dyes into a single layer can easily be overcome [8].

2. Experimental

The electroluminescent three-terminal device (Fig. 1b) was fabricated by means of vacuum deposition of organic semiconductor layers and metal electrodes onto pre-cleaned ITO-coated glass substrates under a vacuum of 10^{-6} mbar. The pre-cleaning consisted of an ultrasonic treatment in different solvents and a subsequent irradiation in an UV–ozone chamber. The layer of THCA acts thereby as hole-transporting and blue light-emitting layer, the Alq_3 layer as electron-transporting layer, which above the central electrodes emits in the green and in combination with the THCA layer (in between the middle electrodes) leads to the appearance of the above mentioned orange exciplex emission at the organic–organic interface [11]. The device was fabricated by a step-by-step deposition. At first a 70 nm THCA layer was deposited on the full area of ITO (labeled **1**). Then a slit mask with slit widths of 100 μm or 200 μm, respectively, was used to deposit the LiF (0.7 nm)/Al (50 nm) middle electrodes (labeled **2**) which were interconnected via an additional ITO pad outside the light-emitting area. Subsequently, a 70 nm thick Alq_3 layer was deposited followed by a second LiF (0.7 nm)/Al (100 nm) cathode (labeled **3**), both on the full device area (5.4 mm^2).

The electrical characteristics were measured using a semiconductor parameter analyzer (HP 4155A) and two source measure units (SMUs). One SMU was used to apply the voltage V_2 to electrodes **1** and **2,** the other one to supply the voltage V_3 to electrode **3**. Electrode **1** was the reference electrode that was kept at ground potential for all measurements. The electroluminescence spectra were recorded with an Ocean Optics spectrometer. All measurements were performed in a glove box in inert nitrogen atmosphere.

3. Results and discussions

Consequently, the three terminal device consists of three light-emitting diodes: In the regions between the metallic electrodes **1** and **3** with no intermittent electrode **2** diodes with an ITO/THCA/Alq_3/LiF/Al structure are formed and named D1 in the following. In the regions where the center electrode **2** exists two additional diodes are located, namely an ITO/THCA/LiF/Al diode, named D2, and an Al/Alq_3/LiF/Al one, named D3. An equivalent circuit of the device is depicted in Fig. 2. By application of the voltages V_3 and V_2 at least two diodes will be driven simultaneously. Consequently, measuring the current I_2 the contribution of D2 and D3 will be taken into account whereas the current I_3 will show contributions from diode D1 and D3. The emission spectrum of the whole device, however, will contain contributions from all three diodes unless one is deliberately switched off by setting one of the voltages equal to zero. The relative contribution of the three diodes will change according to the magnitude of the applied voltages V_3 and V_2. As was shown previously [11] diode D1 is an exciplex-type OLED characterized by an electroluminescence spectrum with a maximum at 595 nm and Diode D2 is a blue OLED with an emission maximum at 465 nm. Diode D3 utilizes Alq_3 which exhibits a green emission peaking at 530 nm.

In Fig. 3a the dependence of the current flowing between the electrodes **1** and **3** is shown as a function of the applied voltage V_3 for different values of V_2. The

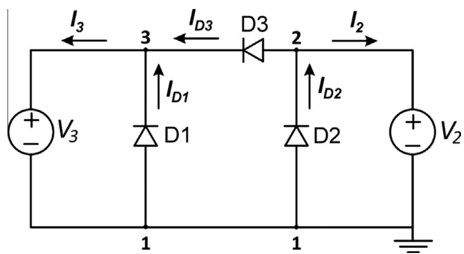

Fig. 2. Equivalent electric circuit for the three-terminal device.