Organic Electronics 15 (2014) 2505–2512

Contents lists available at ScienceDirect

Organic Electronics

journal homepage: www.elsevier.com/locate/orgel

# The color change in polychromatic organic light-emitting field-effect transistors: Optical filtering versus reemission

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ARTICLE INFO

*Article history:*
Received 7 March 2014
Received in revised form 2 July 2014
Accepted 5 July 2014
Available online 27 July 2014

*Keywords:*
Organic semiconductor
Organic field-effect transistor
Organic light-emitting field-effect transistor
Polychromatic organic field-effect transistor

ABSTRACT

In this contribution the color conversion process of a polychromatic organic light-emitting field-effect transistor (OLET) is revisited on the basis of an analytic device model. The device of interest consists of a color conversion layer out of rubrene on top of a monochromatic light-emitting transistor based on poly(9,9-di-*n*-octyl-fluorene-alt-benzothiadiazole) (F8BT). The model describes the relation of color coordinate and emission intensity – set by the applied drain and gate biases – linking the optoelectronic response of the employed monochromatic OLET to the optical processes occurring in the color conversion layer. The model shows that the color shift is rather due to partial absorption of the F8BT emission by rubrene than, as was claimed earlier, due to a color conversion process by absorption and reemission in the conversion layer. In addition to the earlier publication, it will be demonstrated that such a device allows for an independent electrical tunability of emission intensity and color coordinate within the color span of the F8BT and the rubrene spectrum being a unique feature of such a polychromatic light-emitting field-effect transistor.



## 1. Introduction

The useful property of ambipolar field-effect transistors namely that the position of the narrow recombination region within the transistor channel can be controlled by the applied biases [1], opens novel aspects for applications. In recent contributions it was demonstrated that such controlled movement of the emission zone can be used to develop polychromatic organic light-emitting field-effect transistors (organic light-emitting transistor, OLETs). Those transistors provide a bias controlled adjustability of the color of emission [2–4]. E.g., by combining an monochromatic light-emitting transistor with an electrically decoupled color conversion layer on top of the transistor, such tunable OLETs are easily achieved [4]. It was suggested that the color conversion in such a device results from the mixing of the transmitted light emitted from the transistor with the reemitted light of the photo-excited conversion layer (see Fig. 1A). Due to a wedge like form of the conversion layer, the mixing depends on the position of the recombination zone within the channel providing the color adjustability aimed at.

In the present article the color conversion of the polychromatic OLET introduced in Ref. [4] will be disclosed. Newer inspection of the former results [4] have shed doubt on the initial explanation that the experimentally observed color change is caused by a simple mixing of light from the monochromatic poly(9,9-di-*n*-octyl-fluorene-alt-benzothiadiazole) (F8BT) based OLET and light reemitted from the rubrene conversion layer. On basis of an analytical device model linking the electrical quantities of the employed transistor to the final emission color and intensity, it will be demonstrated that the device operates

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http://dx.doi.org/10.1016/j.orgel.2014.07.007
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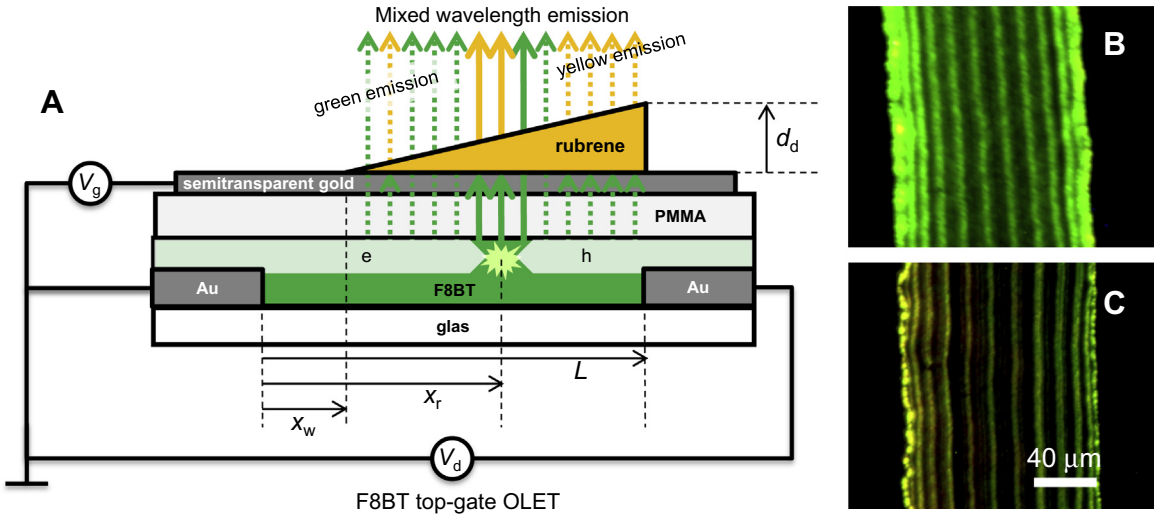


**Fig. 1.** (A) Schematics of a color tunable OLET using a color conversion layer in form of a rubrene wedge. The OLET is based on a F8BT OLET introduced in [14]. Continuous emission arrows mark the actual electroluminescence (EL) while dotted emission arrows indicate possible mixed emission by change in $x_r$. $L$ is the channel length, $x_r$ is the position of the recombination zone, $x_w$ is the distance of the rubrene wedge onset from the source and $d_d$ is the rubrene layer thickness at the drain. Micrographs of the transistor channel of a neat F8BT based OLET (B) and a corresponding OLET with rubrene based color conversion layer (C) under operation. The transistors were operated at $V_d$ = 100 V and the gate voltage was increased from 0 V to 100 V in 5 V steps. The evolution of the position of the recombination region within the channel and the emission color can thus be compared [4]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

mainly in a filter mode rather than in a reemission mode which explains the experimentally observed emission spectra. This modus operandi keeps the conversion losses small while yet inducing a substantial color shift explaining the measured external quantum efficiencies (EQEs). The loss mechanisms induced by the color conversion process will be discussed in detail. Moreover, it will be demonstrated experimentally and theoretically that the emission color and the intensity can be independently adjusted within the color coordinates of F8BT and rubrene.

## 2. Results and discussion

The polychromatic device, considered here, was introduced and characterized by an earlier publication [4]. As exciting light source, a bottom-contact, top-gate ambipolar transistor based on a poly(9,9-di-*n*-octyl-fluorene-alt-benzothiadiazole) (F8BT) bipolar semiconductor was fabricated and evaluated. This transistor was first introduced by Zaumseil et al. [5] and consists of a poly(methyl methacrylate) (PMMA) gate insulator and all Au electrodes. The

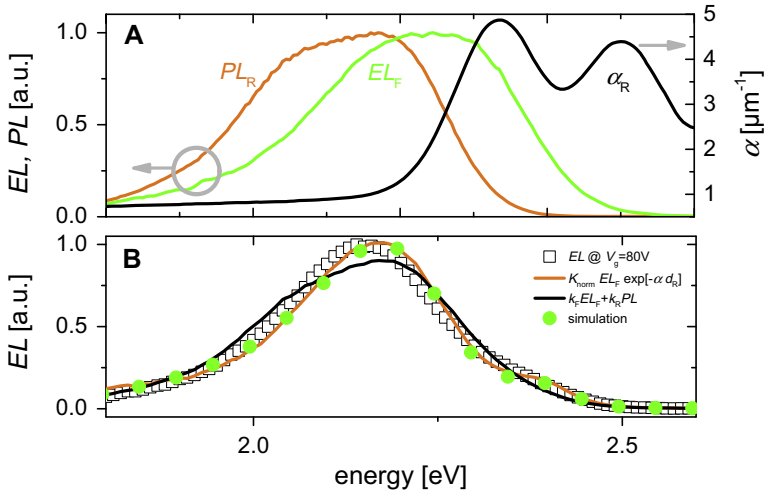


**Fig. 2.** (A) Extinction coefficient (black line) and photoluminescence spectrum of rubrene (orange line) excited at a wavelength of 314 nm and the electroluminescence spectrum of F8BT (green line). (B) The measured electroluminescence spectra (□) of a polychromatic OLET operated at $V_d$ = 100 V and $V_g$ = 80 V where strong color conversion occurs. The spectrum was fitted by a superposition of the neat EL spectra of F8BT and the neat PL spectra of rubrene (black line). $k_F$ and $k_R$ are fitting parameters. The spectrum was fitted by a F8BT emission spectrum deformed by rubrene absorption (orange line). $K_{norm}$ and $d_R$ are fitting parameters. Moreover, the model simulation at the given operation conditions is presented (green dots). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)