Coupled Opto-Electronic Simulation of Tandem WOLED Devices

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We demonstrate the full opto-electronic simulation of tandem WOLED including charge generation layers by means of an interface hopping model. This allows the consistent reproduction of the experimental current-voltage characteristics and emission spectra of the blue and yellow units as well as of the tandem WOLED and enables systematic optimization of device characteristics beyond optical cavity design.

Introduction

White organic light-emitting diodes (WOLED) are ubiquitous elements in state-of-the-art AMOLED display technology, as well as in large area OLED lighting applications. Among the device structures proposed for the implementation of WOLED, multi-stack architectures combine high efficiency with excellent device stability and good color stability [1]. In tandem WOLED, adjustment of the desired color characteristics can be achieved via tuning of the sub-unit cavity lengths using optical simulation of the entire layer stack [2,3]. For the electrical properties of stacked OLED devices, however, it is the design of the interlayer region that is central [4]. In our contribution, we therefore demonstrate the full opto-electrical simulation of tandem WOLED using the OLED modelling suite SETFOS, where electrical simulation of charge generation layers is enabled by the inclusion of a hopping model for charge transfer at organic hetero-interfaces [5].

1) Layer stacks and simulation approach

The modelling approach is illustrated on the example of the stacked WOLED devices investigated in [2], which consist of fluorescent blue (MADN:BCzVBi) and phosphorescent yellow [BPhen:Ir(tptpy)$_2$(acac)] units with HAT-CN/TAPC interfaces for both injection and charge generation units (Fig. 1). The full stacks are considered in both optical and electrical simulations. The optical simulation combines a dipole emission model with a transfer-matrix formalism for coherent light propagation in thin films and a net-radiation model for incoherent device layers. The electrical simulation describes charge carrier and exciton populations in terms of continuity equations with drift-diffusion currents. Charge carriers are coupled to the Poisson equation for the

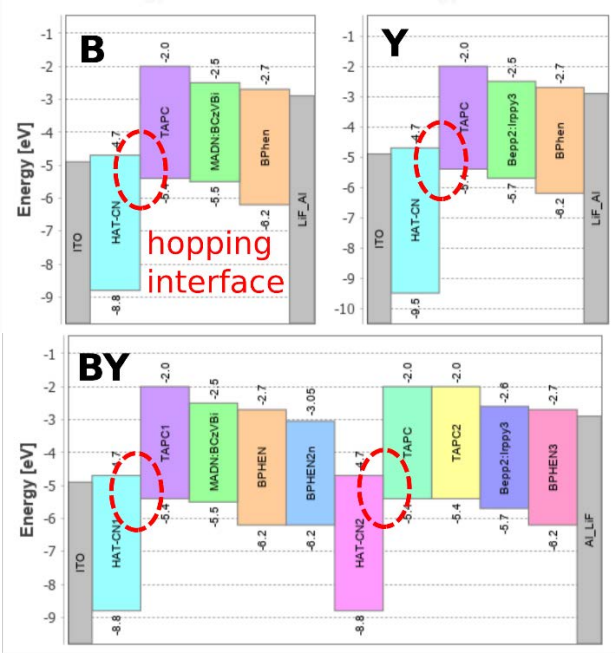

Figure 1: Energy level diagrams of blue (B) and yellow (Y) OLED units and of the stacked WOLED (BY). The charge generation layer interfaces are marked by dashed circles.

Figure 2: steady-state (left) and oscillating (right) hole density profiles for different frequencies.

electrostatic potential and to the exciton population via Langevin recombination, while a multitude of decay mechanisms are considered for the exciton dynamics. Since optical and electrical models are coupled via the exciton population, modification of the electronic properties also affects the optical properties of the device. Hence, optimization of the spectral emission properties beyond the routinely performed optical optimization in terms of cavity design [2] is enabled. In addition to the emission properties, the current efficiency can be targeted thanks to the accessibility of electronic characteristics of the full device, on the one hand, and to the availability of powerful local and global optimization algorithms on the other hand.

Key element of the electrical tandem simulation is the description of hopping charge transfer at the organic-organic hetero-interface formed by the HAT-CN/TAPC junctions [5]. As can be inferred from the alignment of electron and hole quasi-Fermi levels displayed in Fig. 2, both at the injection and at the charge generation layers, largely unhindered current flow can be achieved via optimization of the transfer rates.

2) Fitting of experimental characteristics

The approach outlined above allows to extract consistent material and design parameters that reproduce the experimental current-voltage characteristics (Fig. 2a) and emission spectra (Fig. 2b) of both the single blue (B) and yellow (Y) units as well as of the tandem WOLED (BY). Excellent fits of the experimental characteristics are achieved via simultaneous global optimization of a large range of material parameters for the device geometry defined in Ref. 2. While close agreement is possible for the emission spectra already with simulations using photoluminescence data from literature for the parametrization of the emitter characteristics, this agreement can be further improved by extracting the latter directly from a fit of the electroluminescence data of the single OLED units. For the current-voltage characteristics, the fitting of the tandem data requires adjustment of the hopping transfer rate for the charge generation layer that connects the two sub-units, while no adjustment is required in the injection layer as compared to the single OLED devices.

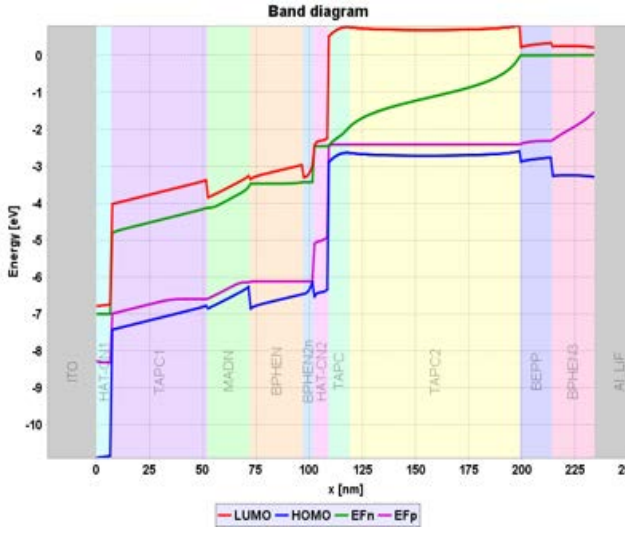

Figure 2: Band profile of the two-stack blue-yellow WOLED device at the operating voltage of 7 V.

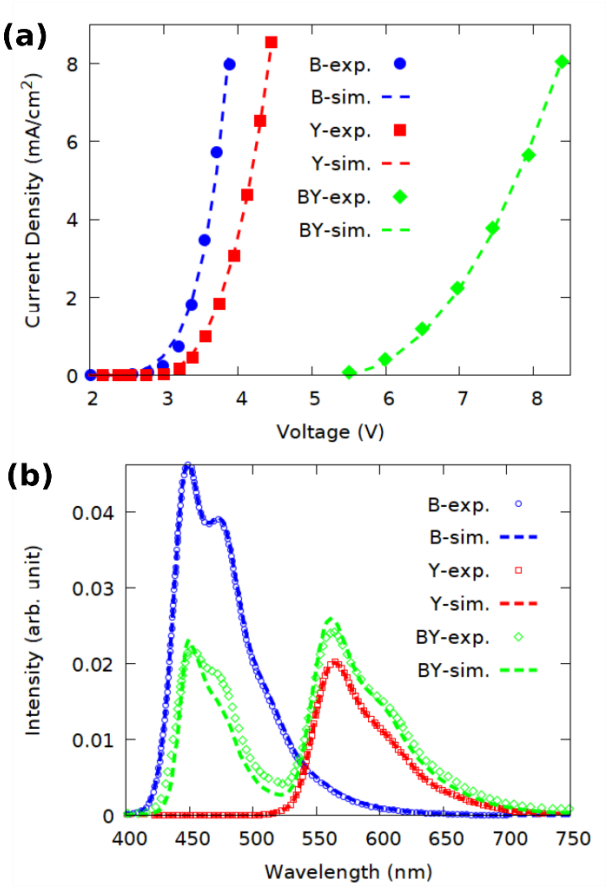

Figure 3: Comparison of experimental data (Ref. 2) and simulation for the single blue (B) and yellow (Y) OLED units as well as for the tandem WOLED (BY): (a) Current-voltage curves, (b) emission spectra.

Conclusion

Inclusion of an interface hopping model for the consideration of charge generation layers into a state-of-the-art OLED device simulation framework enables coupled opto-electronic simulations of tandem WOLED structures and provides device optimization capabilities beyond optical cavity design.

References

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