Simulation Standard

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Two-dimensional ATLAS Device Simulation of an Organic Ambipolar Lightemitting Field-Effect Transistor

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1. Introduction

Organic semiconductors have been incorporated in a wide range of devices, including organic thin-film transistors (OTFTs) and circuits, organic solar cells, organic non-volatile memories and organic light-emitting diodes (OLEDs). OTFTs also exhibiting light-emission have been demonstrated [1-8]. The light-emitting organic field-effect transistors (LEOFETs) may become an interesting structure in the field of display applications, as they combine the optical output of an OLED and the gate control of an OTFT in a single device.

Recently, results were published on LEOFETs based on an ambipolar polymeric semiconductor [7]. In contrast to unipolar LEOFETs, ambipolar organic field-effect transistors have the ability to conduct holes and electrons at the same time depending on the applied gate and drain voltage. Here, we present some simulation results performed on such an ambipolar light-emitting field-effect transistor. The simulations help to understand the device operation and confirm the experimentally observed behavior.

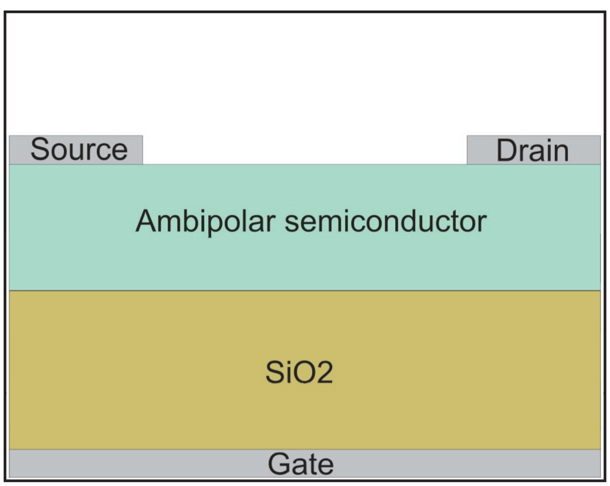

Figure 1. A cross-section of the simulated device structure.

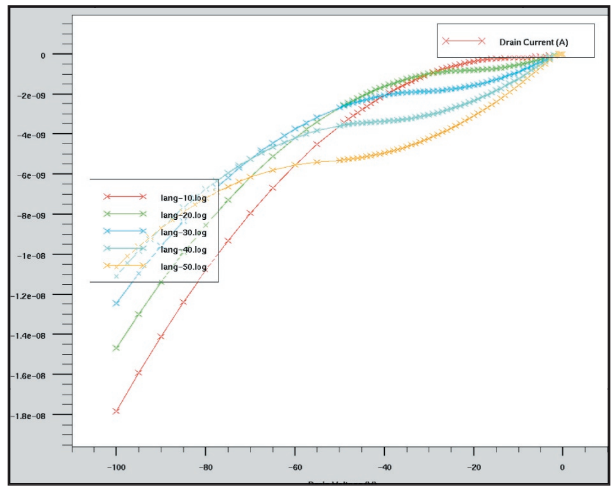

Figure 2. Simulated current-voltage characteristics of the device.

2. Device Structure

The device structure is shown in Figure 1. A top-contact transistor structure is used. The thickness of the oxide is 100nm and the active layer is 60nm thick. Source and drain electrodes are positioned at $x < 1$ μm and $x > 9$ μm, respectively. The material parameters used in the simulations are summarized in Table 1. In order to maximize exciton recombination, the electron and hole mobility are chosen to be equal. The threshold voltage of both materials is assumed to be 0 V, and no interface states were taken into account. Langevin recombination is used during the simulations.

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INSIDE

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	P-type	N-type
LUMO (eV)	2.9	3.4
HOMO (eV)	5.4	5.4
μ (cm^2/Vs)	1 10^{-3}	1 10^{-3}

Table 1. Summary of the material parameters used in the simulations.

3. Results and discussion

Figure 2 shows the simulated output characteristics of the device for negative drain (x-axis) and negative gate voltage. These characteristics can be explained by the fact that holes and electrons are injected at the same time when the applied gate voltage Vg obeys Vs=0V > Vg > Vd, in other words |Vd|>|Vg|. When |Vd| < |Vg|, only holes

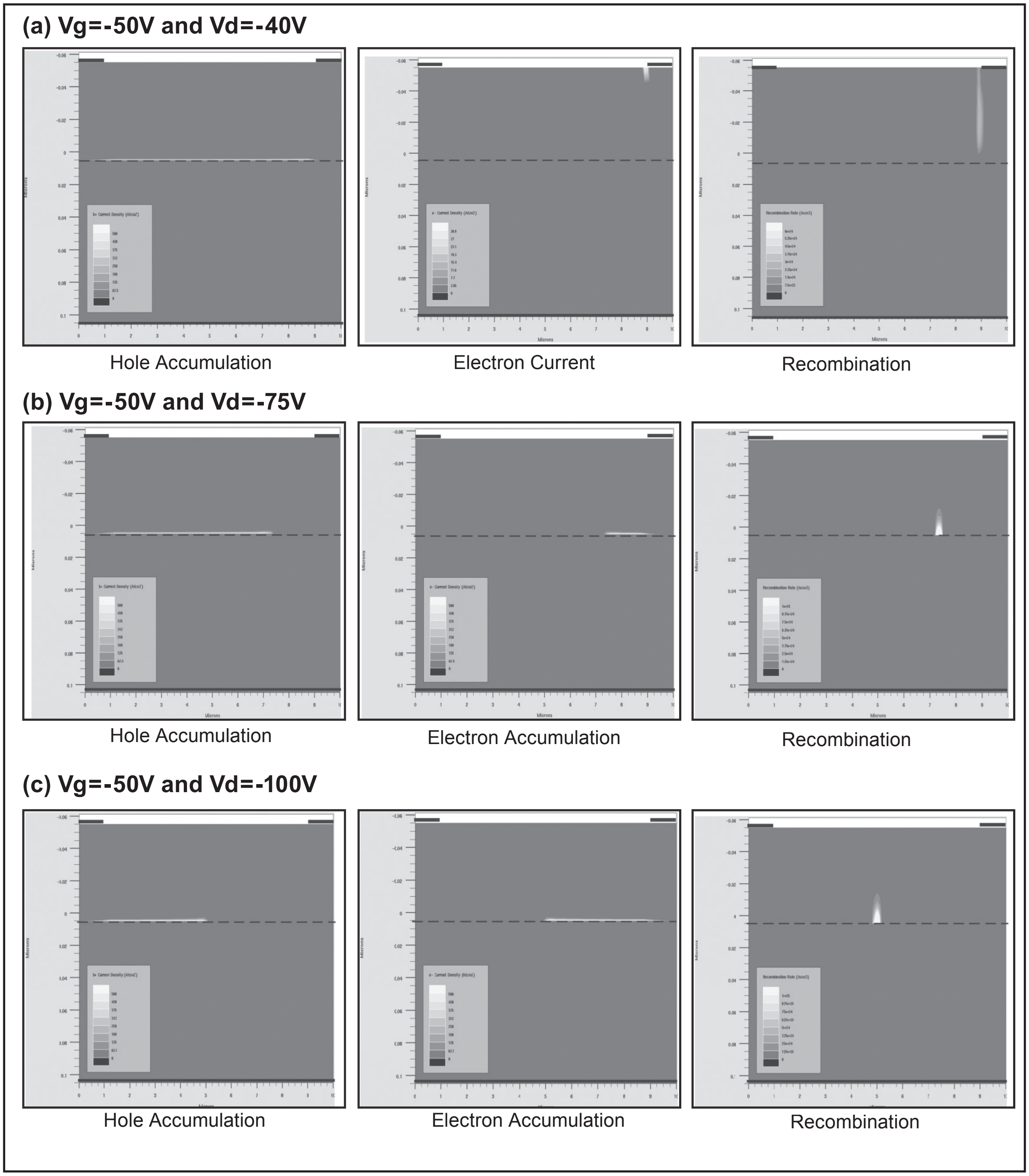

Figure 3. Simulated hole current, electron current and recombination zone for different bias conditions: (a) Vg=-50V and Vd=-40V, (b) Vg=-50V and Vd=-75V and (c) Vg=-50V and Vd=-100V.

can be injected and a hole accumulation layer is formed in the organic layer at the interface with the dielectric. However, when |Vd| > |Vg| ambipolar transport can be observed. Holes as well as electrons are injected and separate accumulation layers of opposite charge carriers are formed in different parts of the channel: holes at the source and electrons at the drain. In this regime electrons and holes are expected to recombine where the two accumulation regions meet, which result in light-emission if the semiconductor is electroluminescent. In this regime the current through the device increases quadratically as can be seen in Figure 2.

By varying the gate voltage or the drain voltage, the length ratio of the two accumulation layers changes. As a consequence the light-emission zone moves within the channel of the transistor. This has been experimentally proven by Zaumseil et al. [7]. Numerical simulations confirm this experimentally observed behavior. Figure 3(a) indicates the situation when Vg=-50V and Vd=-40V. In this case, there is no ambipolar transport, only a hole accumulation layer is formed. Figure 3(b) on the other hand represents the situation where Vg=-50V and Vd=-75V. At this bias condition ambipolar transport occurs. An electron accumulation layer and a hole accumulation layer are formed and recombination occurs where both electrons and holes meet each other. By further increasing the drain voltage, this light-emission zone moves further to the left, as can be verified in Figure 3.

4. Conclusion

An ambipolar light-emitting field-effect transistor has been simulated using ***ATLAS***. These numerical simulations are helpful in understanding the basic operation principle of the device and confirm experimentally observed behavior.

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