Student Paper

Investigation of the Influence of the Source/Drain Barrier Height on the I/V Characteristics of OFETs by Using a 2D Analytical Model for the Injection Current

Franziska Hain[a,b], Michael Graef[a,b], Thomas Holtij[a,b], Alexander Kloes [a], Benjamin Iniguez[b]
Corresponding author: Franziska.hain@ei.thm.de

[a] *Technische Hochschule Mittelhessen – University of Applied Sciences, Competence Center Nanoelectronics and Photonics, Giessen, Germany*
[b] *Universitat Rovira i Virgili, Department of Electronic, Electric and Automatic Engineering, Tarragona, Spain*.

The interest in organic semiconductors, especially organic field-effect transistors has grown enormously during the last years. They feature properties far beyond these of their inorganic counterpartners essential for devices like flexible displays or printable electronics. However, analytical compact models of organic semiconductors are rarely to find and mostly not able to describe the physical and chemical facts clearly. In the most cases they just exist for semiconductors with a well matching HOMO level.

In dependence of different source and drain materials, varying workfunctions, HOMO-, LUMO- and trap-levels the parasitic contact resistance effects became a major problem in organic transistors [1], [2]. So the source semiconductor junction was considered to be the limiting factor for the charge carriers. Exemplarily for the case of bottom-contact, bottom gate OFETs we present an analytical model for the electrostatic potential, the electric field as well as the source and drain injection current which is able to describe typical characteristics in the output and transfer curves. These are, for instance, an s-like shape in the output characteristic or kinks in the transfer characteristic (Fig. 2,4) especially of devices fabricated with organic semiconductors whose HOMO level does not match well with the electrode's workfunction.

In general the charge injection into organic semiconductors is described by the thermionic drift-diffusion theory. Mostly tunneling processes are neglected. In our model we combine thermal diffusion and tunneling processes to describe the injection into a random hopping system. The organic semiconductor data set is leaned on Pentacene but kept variable regarding the barrier height for holes Φ_{Bp}. A band-like transport within the semiconductor is assumed in this step, as well as a gate-bias dependent mobility [3]. As it is most commonly used, we assumed gold as source and drain electrode's material.

In accordance with the different charge transport mechanisms we separated the whole device into different subparts: The source semiconductor contact, whose properties highly influence the charge carrier injection, the transistor channel itself and the drain semiconductor contact. Each of these parts can limit the total device current.

We assumed three operational states clearly to be separated and influenced just by the barrier height Φ_{Bp} (Fig. 1). At first if the gate and drain biases are low and the bands at the source-channel and the channel-drain junction are bent upwards (p-semiconductor). Secondly when the drain bias raises the bands at the source-channel junction bend downwards and finally the bands on both junctions bent downwards for high V_{GS} and comparatively low V_{DS}. If we assume that the injection current consists of a diffusion and a tunneling contribution the band bending has to be derived at the junctions. This is done by computing the electric field on the basis of a 2D potential solution analytically by solving the Poisson equation via the conformal mapping technique [4], [5].

The total device current is calculated by superposition, where I_{sTE}, I_{sTU}, I_{dTE}, and I_{dTU}, are the source or drain related thermionic and tunneling currents, respectively (Fig. 3):

$$I_{ds} = \left(\frac{1}{I_{sTE} + I_{sTU}} + \frac{1}{I_{ch}} + \frac{1}{I_{dTE} + I_{dTU}}\right)^{-1}.$$

To our knowledge this model is one of the first and simplest to correctly predict kinks in the transfer as well as an s-like shape in the output characteristics of an organic field-effect transistor just on the basis physical processes at the interface. In case of a well matching HOMO level of the semiconductor and a barrier height of less than 0.2eV the intrinsic channel itself limits the device current. If the barrier height increases the different operational states can be clearly identified.

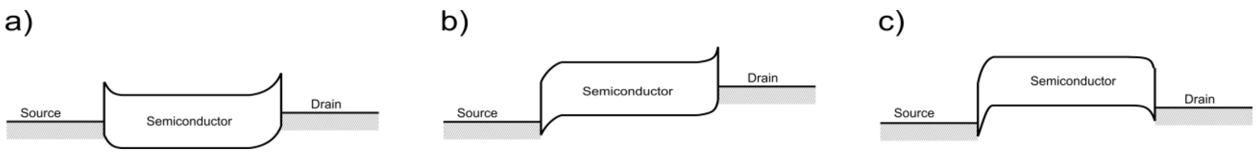

Figure 1: Three possible operational states. a) Thermionic Emission (TE) at both junctions, b) TE and tunneling (TU) at the source and TE at the drain junction, c) an additional tunneling barrier at the drain junction.

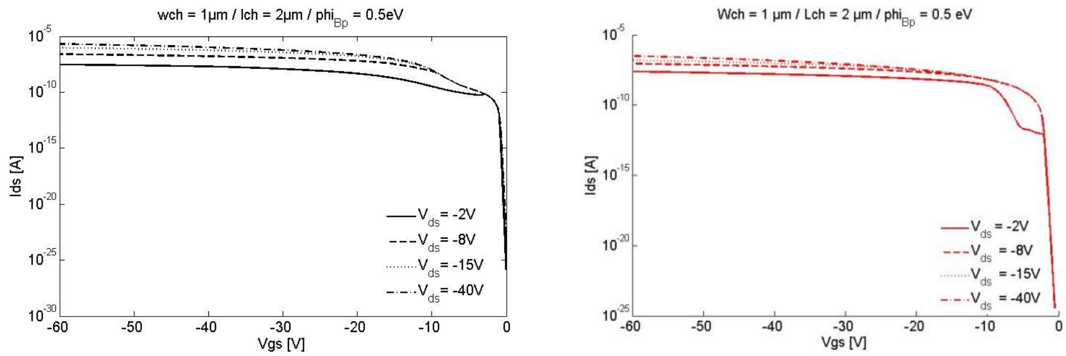

Figure 2: Simulated (TCAD sentaurus) (left) and modeled (right) transfer characteristic with a barrier height of 0.5eV. The kinks can be clearly related to the transport mechanisms at the source and drain junctions.

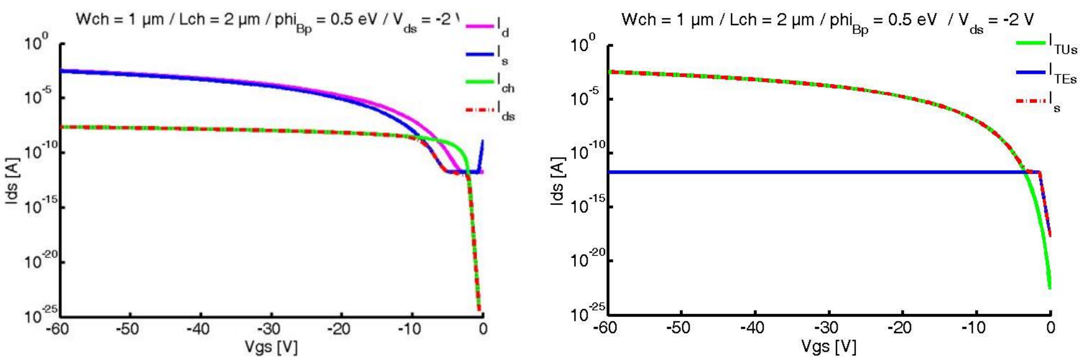

Figure 3: Total current limitation by either the source drain injection current or the channel current (left). The source current consists of a TE and a TU part. At higher barriers the source contribution develops a kink.

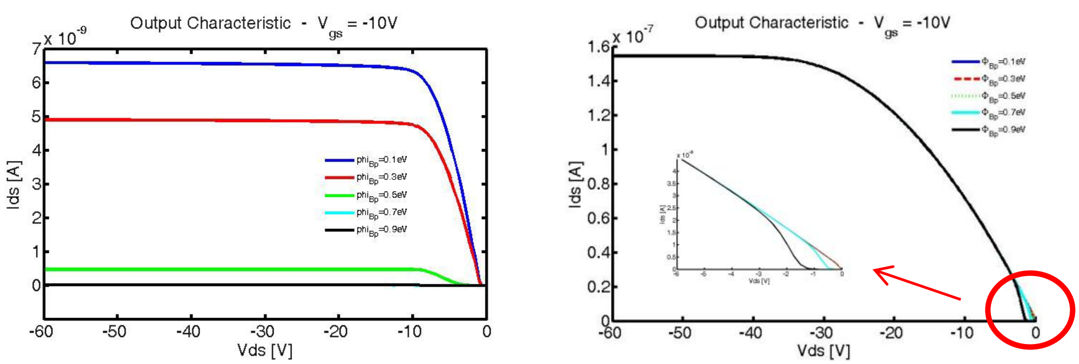

Figure 4: Simulated (left) and modeled (right) output characteristic for various barrier heights.

References

[1] Horowitz, G., “Organic Transistors”, *Organic Electronics*, Wiley-VCH (edited by Hagen Klauk), 2006

[2] Panzer, M. J., Frisbie, D. „Contact Effects in Organic Field-Effect Transistors“, *Organic Field-Effect Transistors*, CRC Press (edited by Zhenan Bao and Jason Locklin), 2007

[3] Estrada, M., et al., "Mobility model for compact device modeling of OTFTs made with different materials." *Solid-State Electronics* 52.5 (2008): 787-794.

[4] Hain, F., et al., “Analytical model for the potential in bottom contact OFETs and approach for the tunneling/thermionic source/drain injection current”, *ICOE proceedings*, June 2013

[5] Hain, F., et al., “Two dimensional analytical modeling of non-linear charge injection in bottom-contact organic field-effect transistors”, *SPIE proceedings*, *Organic Field-Effect Transistors XII*, paper no. 8831-142, August 2013