ELECTRONIC MODULE WITH ORGANIC TRANSISTORS MODELLED USING THE SLPS INTERFACE

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Lucrarea se referă la noi posibilităţi de cosimulare oferite de interfata PSpice SLPS cu modulele MATLAB Simulink. Scopul este de a face investigaţii cu privire la comportamentul unor dispozitive electronice care fac parte din modulul optoelectronic prezentat. Pentru a simula cu acuratete circuitul, un model PSpice a fost dezvoltat în conformitate cu măsurătorile efectuate pentru tranzistoare organice. Prin intermediul interfeţei SLPS, circuitul este modelat în MATLAB. Modelul a fost, de asemenea, realizat propriu-zis cu componente clasice şi masuratorile corespund rezultatelor obţinute în simulare.

The paper elaborates on the new integration offered with the PSpice SLPS interface and the MATLAB Simulink toolboxes. The aim is to make multi-domain investigations on the behavior of the optoelectronic devices of the proposed electronic module. In order to have an accurate circuit simulation a PSpice model has been developed in accordance to measurements performed on top gate bottom contacts organic transistors. By means of the SLPS interface the circuit is modeled in MATLAB, where accurate models for photovoltaic cells are available. The module itself has also been implemented in a prototype with classic components and it matches the results obtained in the simulation.

Keywords: optoelectronics, MATLAB, PSpice, organic semiconductors

1. Introduction

Organic components' performance has improved in the recent years in terms of mobility and stability due to better fabrication techniques and the new organic and polymeric compounds utilized for the fabrication of these components.[1-4] Still their performances are far from rivaling the performances of the classical transistors and this is in part due to the fact that the conduction mechanism is not properly controlled in the technological process[5,6].

It is necessary to realize better simulation models in order to optimize these devices. Given that the actual behavior of the OTFT [7-11] is still an

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actively researched topic, the mathematical models which are developed for calculation pose significant difficulties for adapting to circuit simulators such as PSpice and MATLAB. Analytic models as well as finite element models are presented in

[12-14]. In this paper, the model proposed is a very basic one which leads to increased flexibility. The fact that the needed parameters are few proves it is sufficient to match the physical equations to measurements for a variety of geometric layouts and materials.

A variety of applications have been envisioned [8-20] for electronic devices using organic semiconductor materials due to flexibility, low cost, and applicability of low temperature processing.

2. Co-simulation possibility of electrical and physical systems

The PSpice SLPS interface also known as Simulink PSpice interface program, is a link between two commonly used design products, Cadence PSpice and Mathwork's Simulink simulator. The SLPS simulation environment supports the substitution of an actual electronic block with an "ideal model", which is the mathematical Simulink model.

The interface integrates these two simulators to provide a simulation flow that can be used to design various systems with electronic circuits / sub-systems. Thus, circuits with PSpice models can be included in the system model. The SLPS interface allows substituting blocks in MATLAB with electronic circuits simulated in PSpice, while the rest of the system is simulated using MATLAB/Simulink. This interaction can be observed in Figure 1. As a result, we can use a single prototype to co-simulate the electrical and physical systems, using accurate models for the electronic circuits instead of ideal models.

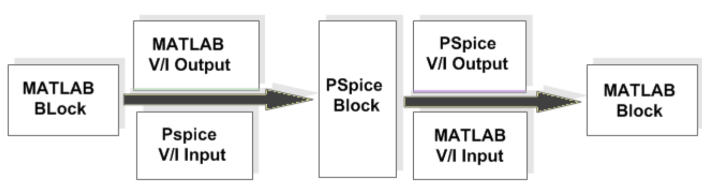

Fig. 1 Block diagram of the working principle

The simulation of the optoelectronic module is achieved using the PSpice circuit simulator engine, while the simulation of the interactions with the measured quantity is done with MATLAB/Simulink. Such a Simulink-PSpice (SLPS) co-simulation between an electrical and a physical modeling tool is particularly useful because it extends simulation beyond the limit of the actual system.

3. Equations

The simulations were based on the classical MOSFET equations with a model in which only parameters resulting from geometry and material properties were maintained. Some of the relevant parameters of the PTAA organic transistors which were taken into account are threshold voltage, gate oxide capacitance and mobility.

The simulations were based on the standard transistor equation (1) for the linear regime:

$$I_{DSlin} = \frac{W}{L} \mu C_i \left(V_{GS} - V_T\right) V_{DSlin} \tag{1}$$

where W and L are the channel width and length respectively, Ci is the capacitance per unit area of the gate insulator, μ is the field effect mobility, V_T is the threshold voltage. Other parameters could be taken into account as described in. The transistor equivalent model is represented in Fig. 2:

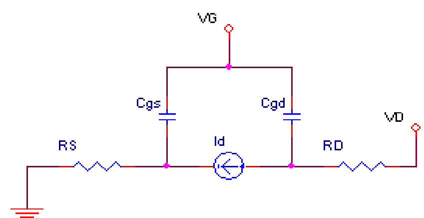

Fig. 2 Equivalent circuit of the organic transistor.

4. OTFT model

In this paper results are provided from measuring top gate bottom contacts organic transistors. The S-D electrodes were patterned by photolithography. Then organic materials, commercially available from Merck were spin coated, in air, onto the electrodes. The thickness of the semiconductor SP300 is approximately 60nm and the thickness of the insulator D320 is 1um. Consequently, the gate was deposited by chemical vapor deposition and it is approximately 20nm thick. This thickness is sufficient for the gate because of the low currents. The structure, whose layout was designed within the FP7 FlexNet Consortium, can be observed in Fig. 3, below:

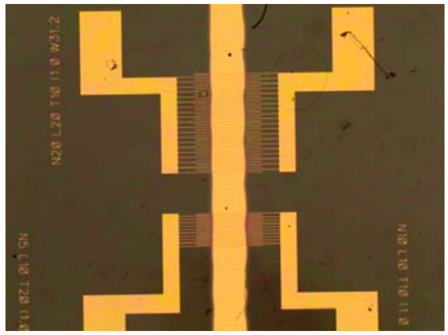

Fig. 3 Layout of a measured structure.

The electrical characteristics were obtained, as shown in Figure 4 and Figure 5, from measurements performed with an Keithley 4200 Semiconductor Parameter Analyzer with the settings presented in Table 1. It can be observed that the transistor enters saturation and the reverse and direct curve don't exhibit large hysteresis.

Table 1

Measurement conditions and parameters

Measurement conditions	
Atmosphere	air
Temperature	25
Relative humidity [%]	<2%
Delay time [s]	0.1
Integration time [s]	0.02
Hold time [s]	1

Electrical Parameters	
V_G (start) [V]	0
V_G (stop) [V]	-20
Mobility [cm^2/Vs]	0.016
Threshold voltage[V]	-4.6
On-Off ratio	300
Id(max) L/W [A]	20E-06

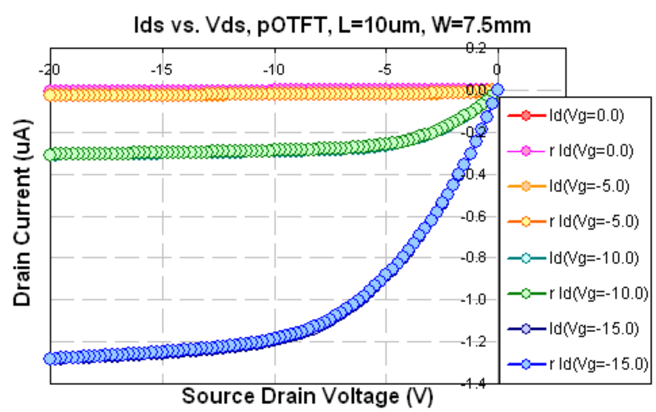

Fig. 4 Output characteristic of the structure from measurements

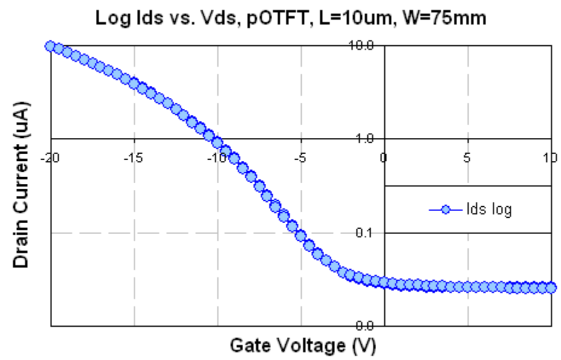

Fig. 5 Transfer characteristic of the structure from measurements

The simulation combines the linear DC sweep of the drain source voltage with a parametric analysis of the channel length as a model parameter. In Figure 7 the output characteristics can be observed for transistors with varying channel length, for which the drain voltage is swept from 0V to -30V.

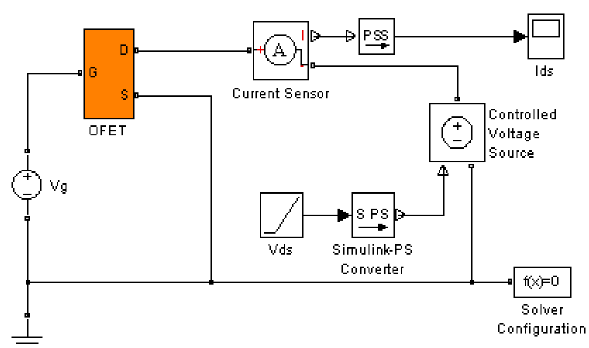

Fig. 6 MATLAB circuit

The output characteristic resulted from the PSpice – MATLAB co-simulation. A fitting procedure to relevant parameters, such as mobility, would yield even closer results to the measured values. This OTFT model takes into account only equation (1) and the following parameters: mobility, threshold voltage, Kp factor, channel length, channel width, capacitance of the gate oxide and contact resistance.

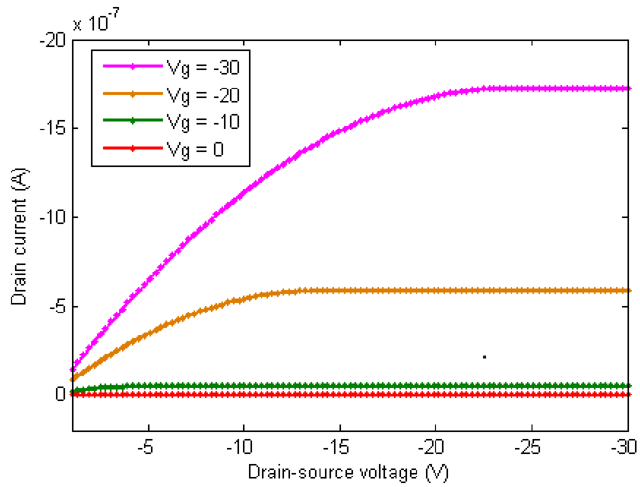

Fig. 7 Output characteristics for MATLAB simulation

5. Electronic circuit simulation

The proposed circuit, shown in Figure 9, has in view the integration of several active and passive devices. Based on the fact that the drain source current is rather low, it is evident that a single organic transistor would not be sufficient to drive the LED.

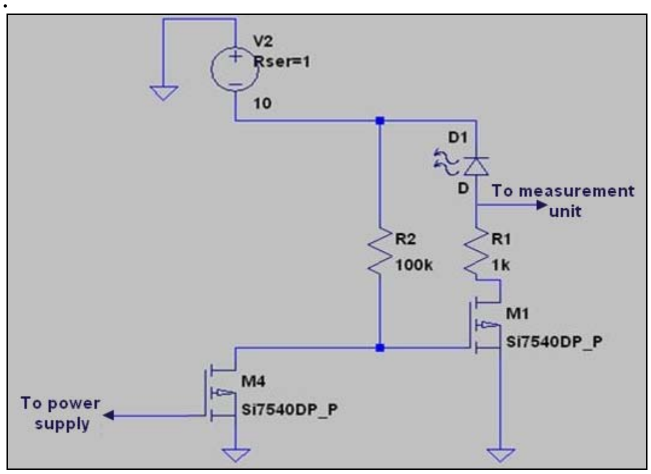

Fig. 8 Circuit implemented within the SLPS block

As the photovoltaic cell is exposed to light the LED is switched off. Reversely, when the photovoltaic cell is not exposed to light and kept in the dark, the LED is switched on the current passing from the source through the transistor towards the LED. In the latter case the transistor is in saturation regime allowing current flow.

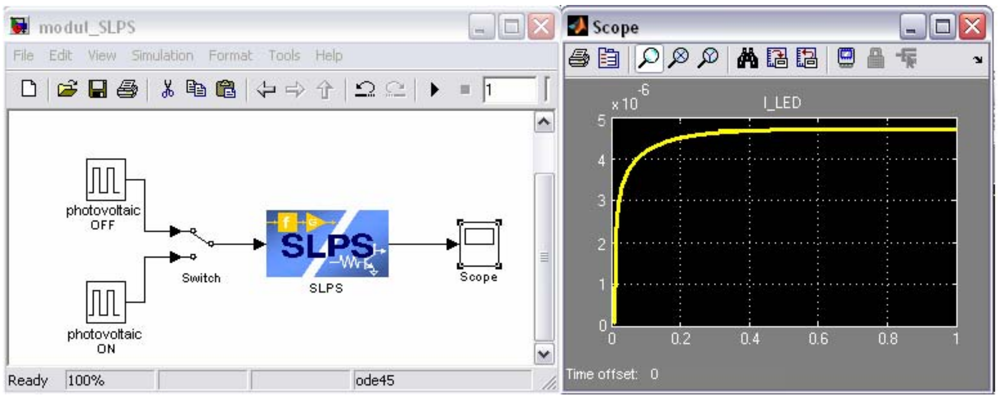

Fig. 9 Co-simulation for the photovoltaic cell in OFF (ie. 0V) state, the current through the LED being of the order of μA

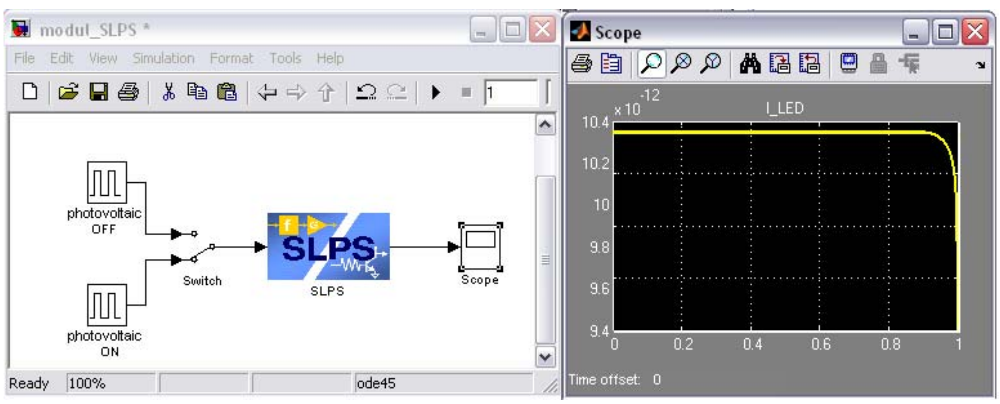

Fig. 10 Simulink Co-simulation for the photovoltaic cell in ON (ie. -18V) state, exhibiting a current through the LED of the order of nA

When the photovoltaic cell is exposed to light, state ON, the LED is switched off. Reversely, when the photovoltaic cell is not exposed to light in state OFF, the LED is switched ON the current passing from the source through the transistor towards the LED

In Figure 9, when the photovoltaic cell or the photodiode model is in state ON, the current on the LED is around 10pA in both the PSpice and the Simulink simulation. Similarly, in Figure 10, where the photodiode is in state OFF, the current has the value of around 5uA for both simulations, with the result displayed on the oscilloscope.

In the given approach, a single SLPS block that includes the electrical circuit is used and the procedure is described in [20]. The MATLAB blocks are used to simulate the behavior of the photovoltaic cell as it is exposed to light. The SPLS block included in MATLAB system diagram, provides the connection with the electronic circuits in PSpice. The obtained results for the simulation show the same values which proves that indeed the SLPS block interface does not distort the data, while allowing greater flexibility in terms of electrical and physical systems interaction.

Even though the simulation was done with a simple switch, an extended MATLAB Toolbox would offer the possibility to use a solar cell, which has more physical parameters. Values for the energy gap, temperature dependence parameters or irradiance could also be set, as shown in Figure 11, below:

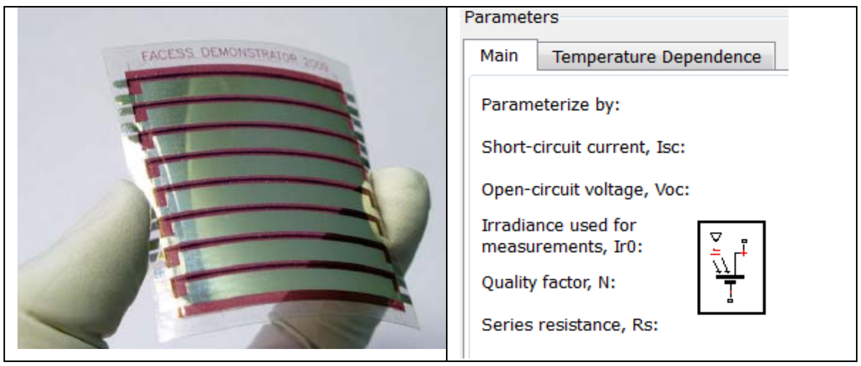

Fig. 11 Gravure printed OPV (left) [21] and MATLAB model for solar cell (right) [22]

Authors' previous work [23, 24] focused on making a test module on FR4 substrate with classical components and the measurements were performed for that case when the photovoltaic cell was not illuminated. It resulted a current through the LED of 5uA similarly to the results obtained in the simulation. For the opposite case, when the cell was illuminated the observed dark current through the LED was of 110pA for a measurement performed at 3.5 V from the voltage source. This simulation takes the results one step forward as the PSpice models of the components are updated in accordance to the characteristics of the organic components.

6. Conclusions

The conclusion of our study is that a co-simulation environment allows simulating whole systems with more realistic element models before prototyping in terms of behavior. It is recommended to use appropriate models for each stage of designing process, because the proper modeling makes optimizing the system parameters easier.

The paper presents analytic organic transistor simulations and measurements directed towards determining the contact effects. The simulations show a good match to measurement data for high gate voltages, even though the number of parameters taken into account is rather limited. Regarding the parameters, the extraction of the contact resistance is done under the assumption that the drain and source resistances are equal, in accordance to the TLM method. Further measurements could be performed to better define the dependence on gate voltage of the mobility and threshold voltage.

The simulated and measured results are similar when the LED is ON, while in the OFF state the slight differences in the measured case may be due dispersion in comparison with the model, or due to the rise in temperature of the photovoltaic cell due to operation, leading to the existence of a dark current.

The authors have in view the implementation of the module with organic flexible components. Due to the specific characteristics of these components in terms of performance it is expected to obtain vales similar to the results obtained in the simulation.

Acknoledgements

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