Characteri ation of Density-of-States in olymer-based Organic Thin ilm Transistors and Implementation into TCAD Simulator

Jaehyeong Kim, Jaeman Jang, Minkyung Bae, Woojoon Kim, Inseok Hur, Yongsik Kim, Hyunkwang Jeong, Dongsi k Kong, Jaewook Lee, Yun Hyeok Kim, Sungwoo Jun, Choon Hyeong Jo, Dong Myong Kim, and Dae Hwan Kim [a)]

School of Electrical Engineering, Kookmin University, Seoul, 136-702, Korea [a)]drlife@kookmin.ac.kr

Abstract

In this work, we report extraction of the density-of-states (DOS) in polymer-based organic thin film transistors through the multi-frequency capacitance-voltage method (MFM). Extracted DOS is implemented into a TCAD simulator and obtained a consistent output curves with non-linear characteristics considering the contact resistance effect. We employed a Schottky contact model for the source and drain to fully reproduce a strong nonlinearity with proper physical mechanisms in the output characteristics even under a very small drain biases. For experimental verification of the model and extracted DOS, 2 different OTFTs (P3HT and PQT-12) are employed. By controlling the Schottky contact model parameters in the TCAD simulator, we accurately reproduced the nonlinearity in the output characteristics of OTFT.

I. Introduction

Due to flexibility, uniformity, and cost of organic materials, organic semiconductor thin film transistors (OTFT) have been under active development in last years for improved performance as a material for electronic appliances. It is also known to be easy to fabricate the organic semiconductor materials due to their simple structure and low temperature process. Especially, solution-based process allows printing or coating process for the fabrication. Because of these benefits, OTFT is expected to be very promising devices for e-papers and portable/wearable applications.

In this work, report the density-of-states (DOS) in polymer-based organic thin film transistors extracted through the multi-frequency capacitance-voltage method (MFM) [1]. Extracted DOS is implemented into a TCAD simulator by the C-interpreter method. For the poly (3-hexylthiophene) (P3HT) and poly (3,3''' –didodecyl quaterthiophene) (PQT-12) as organic materials, we obtained a consistent transfer (I_{DS} V_S) and output (I_{DS} V_{DS}) curves with non-linear characteristics and contact resistance effect. In the simulation, we included the effect of contact resistance by the Schottky contact model parameters on the source and drain electrodes.

II. Structure and abrication of OT Ts

The fabricated organic thin film transistor has a bottom gate and bottom source/drain contact as shown in Fig.1(a) and (b).The P3HT or PQT-12 for the active layer is deposited by the ink jet printing process at room temperature. The thickness of the OTFT has a gate insulator (SiO_2) T_o =300 nm, the active layer's thickness T_{active} = 30 nm, the channel width =120 μm, and the channel length L=12 μm.

III. Experimental Result and Discussion

We extracted a donor-like DOS through the multi-frequency C-V method. The extracted donor-like DOS is shown in Fig.2 and summarized in Table 1. In order to verify the result, current-voltage characteristics are simulated by TCAD simulator from Silvaco. Using a C-interpreter, we implemented the extracted donor-like DOS from the OTFTs into the TCAD simulator.

We also note that there is a strong nonlinearity in the output characteristics even at very small drain biases (V_{DS}). This experimental observation of the nonlinear characteristics is common in OTFTs and caused by the large contact resistance at the source and drain[2]. In order to include this experimental nonlinearity of OTFTs in the TCAD simulator, we considered the contact resistance effect.

For the current-voltage characteristics, the channel carrier mobility and current models are also required for the TCAD simulation [4]. We included the hopping mobility model, Poole-Frenkel mobility model, Schottky contact, and Langevin recombination model. We note that the hopping mobility model is dominated by DOS while the electric field-dependent Poole-Frenkel mobility model describes the movement of charges through traps. The Schottky contact is for a physical description of the poor ohmic characteristics at the source/drain contact, the Lagevin model is a well-known recombination model for organic devices.

In order to implement the contact resistance effect in the TCAD simulator of OTFTs, a Schottky contact model is employed for the source/drain contacts. Due to insufficient contact resistance parameters, we controlled the characteristic parameters in the Schottky model described by

$$_{SP} = \upsilon_S \quad _P(p_S - p_e)\exp(\frac{\Delta\phi_b}{T}) \qquad (1)$$

with p_S as a hole concentration at the surface of the contact, p_e as the equilibrium hole concentration, $\upsilon_{sur\,p}$ as the hole velocity. The image force barrier lowering effect $\Delta\phi_b$ is also considered for the Schottky model in the TCAD simulator. For the n-type metal –silicon Schottky contact, υ_{sur} is typically known to be υ_{sur}

=5.2x10^5 cm/s [3]. Controlling υ_{sur} as a fitting parameter, the Schottky contact resistance has been changed to fit to the I-V characteristics especially for the strong nonlinearity in the linear region under a small drain bias.

By implementing the experimentally extracted DOS parameters, shown in Fig.2 and Table I, into the TCAD simulator, transfer and output characteristics of are shown in Fig. 3 for P3HT and Fig. 4 for PQT-12 polymer-based OTFTs. We note that the simulated I-V characteristics with DOS parameters obtained from the MFM agrees well with experimental data. This consistent result for the OTFTs with a strong nonlinearity in the linear region is mainly from inclusion of the non-linear contact resistance effect on the source and drain.

Ⅳ. Summary

In this work, we reported experimental characterization of DOS in polymer-based OTFTs and its implementation into the TCAD simulator through a C-interpreter. We used the MFM method for the extraction of the DOS in OTFTs. We employed a Schottky contact model for the source and drain to fully reproduce a strong nonlinearity with proper physical mechanisms in the output characteristics even under a very small drain biases. We employed 2 different OTFTs (P3HT and PQT-12) for experimental verification of the model and extracted DOS. By controlling the Schottky contact model parameters in the TCAD simulator, we accurately reproduced the nonlinearity in the output characteristics of OTFT. We expect that this approach is very effective and useful for estimation of the electrical properties and practical application of high performance OTFTs to circuits and systems through a TCAD simulation.

Acknowledgements

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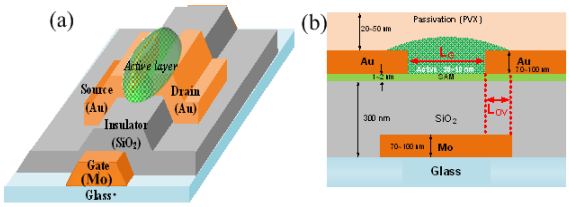

Fig. 1. (a) The 3-D structure of Organic TFT with an bottom gate and Source/Drain contact. (b) The cross-section of Organic TFT structure

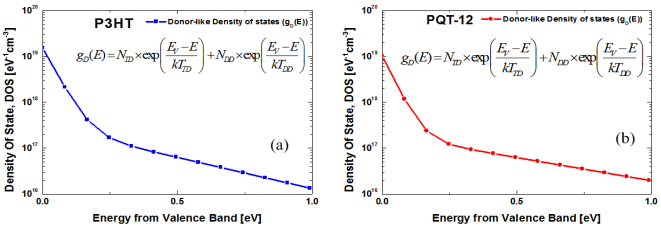

Fig. 2. Extracted donor-like DOS and models for (a) P3HT (b) PQT-12

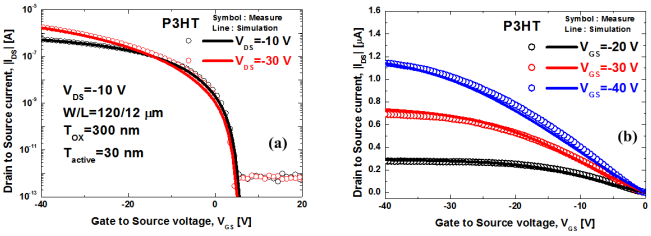

Fig. 3. P3HT OTFT's (a) Transfer curve (V_{DS}=-10 V, V_{DS}=-40 V)

(b) Output curve (V_{GS}=-20 V, V_{GS}=-30 V, V_{GS}=-40 V) open symbol is measurement and the solid line is simulation.

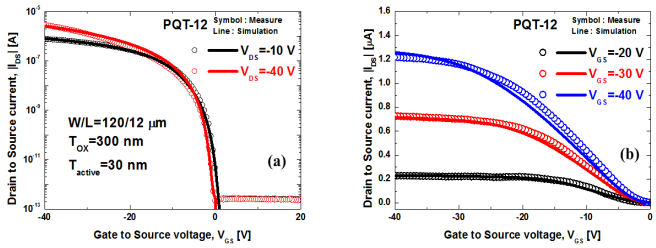

Fig. 4. PQT-12 OTFT's (a) Transfer curve (V_{DS}=-10 V, V_{DS}=-40 V) (b) Output curve (V_{GS}=-20 V, 30 V, 40 V) ; open symbol for measurement and the solid line for TCAD simulation results.

arameter	3HT	T-12
N_{TD} [cm^{-3}eV^{-1}]	1.5x10^{19}	1x10^{19}
kT_{TD} [eV]	0.04	0.036
N_{DD} [cm^{-3}eV^{-1}]	3x10^{17}	2x10^{17}
kT_{DD} [eV]	0.32	0.43

Table 1. Extracted Donor-like DOS values of OTFTs (P3HT,PQT-12).