Compact Capacitance Model for OTFTs from Low to Medium Frequencies

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We present a quasi-static compact capacitance model for organic thin-film transistors (OTFTs), valid not only in the accumulation regime, but also in partial depletion and total depletion regimes. The parameters applied in the model are analytically extracted from the current-voltage characteristics of the devices, using the unified model and parameter extraction method [1].

The total drain-to-source current (I_{DS}) in the OTFT is calculated as the sum of the current in the subthreshold (I_{sub}) and above threshold (I_a) regimes. Using the *tanh* function to join both regions, I_{DS} is expressed as [2]:

$$I_{DS} = I_{sub} \times \frac{1-\tanh\delta}{2} + I_a \times \frac{1+\tanh\delta}{2} \qquad (1)$$

where δ=(V_{GT} - K)$Q1$ and K and $Q1$ are fitting parameters, and

$$I_{sub} = I_a(V_{sub}, V_{DS}) \times \exp^{\frac{2.3}{S}V_{GT}} + I_0 \qquad (2)$$

where I_a is the above threshold regime drain-to-source current, V_{sub} is a gate voltage value near to which the exponential dependence of I_a starts, V_{DS} is the gate-to-source bias, V_{GT}= V_{GS}-V_T where V_{GS} is the gate-to-source bias and V_T is the threshold voltage, and I_0 is the measured off current at a gate voltage sufficiently below V_T. S is the subthreshold slope for the transfer characteristic in linear regime, calculated from experimental data, in the region where the I_{DS} vs. V_{DS} in semilogaritmic plot is linear.

With (1), the expression of the total charge in the channel can be obtained according to [3] as follows:

$$Q_{CH} = \pm \frac{-W^2 C_i^{\,2}}{I_{DS}} \mu_0 \left[\frac{(V_{GT} - V_{FB})^{3+\gamma} - (V_{GT})^{3+\gamma}}{3+\gamma} \right] \qquad (3)$$

where W is the channel width of the device, C_i is the insulator capacitance per unit area, γ is the parameter associated with the disorder within the material of the active layer, dependent on the characteristic temperature (T_0) of the bulk density of states (gd_0) [1] and μ_0 represents the mobility value at V_{GT} = 1 V. The positive (negative) sign describes the total charge in the channel of a p-type (n-type) OTFT.

The extrinsic capacitance effect due to the overlap of the gate with the source and drain regions is added to the calculated intrinsic capacitance above, and it is obtained as C_{OVR}=$WL_{OVR}C_i$, where W is the channel width of the OTFT and L_{OVR} is the overlapping length between gate and drain contacts and between gate and source contacts.

Thus the total gate-to-channel capacitance in the accumulation regime and subthreshold is calculated as $C_{GGa} = C_{GG} + 2C_{OVR}$.

The equivalent capacitance in the depletion regime is then obtained from the sum of the series combination of C_i and C_D, C_{Deq}=(C_D·C_i)/(C_D+C_i).

Finally the complete capacitance model is given by the sum of the capacitances from the accumulation to depletion regimes, joint by a *tanh* function as follows:

$$C_{GGtotal} = C_{Deq} \times \frac{1-\tanh\beta}{2} + C_{GGa} \times \frac{1+\tanh\beta}{2} \qquad (4)$$

where β = (V_{GT} + Δ_T)$Q2$, and Δ_T is the shift in the threshold voltage of the C-V characteristic at different frequencies, and $Q2$ is a fitting parameter of the *tanh* function around 3.

Comparisons between modeled and experimental I-V and C-V characteristics of staggered upper contact p-channel OTFTs based on P3HT-PMMA show the validity of the model at low and medium frequencies, figures 1a and 1b. The extracted parameters are shown in Table I.

Parameter		units
V_T	1.02	V
γ	0.31	
m	3.11	
λ	-6.38×10^{-4}	1/V
μ_{FET0}(V_{GS}= -1 V)	8.20×10^{-4}	cm^2/Vs
μ_{FET} (V_{GS}= -30 V)	1.22×10^{-3}	cm^2/Vs
T_0	318	K
gd_0	9×10^{23}	cm^{-3}
α	0.85	

TABLE I. Model parameters extracted from the I-V characteristics of the OTFTs under study.

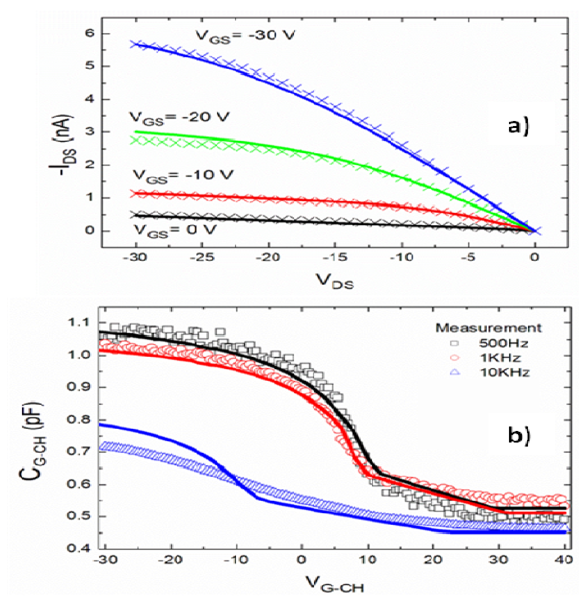

Fig.1. Experimental (symbols) and modeled (solid lines) electrical characteristics of the PMMA/P3HT OTFT with insulator thickness di_{PMMA}=330 nm and ds_{P3HT}=80 nm: a) Output characteristics, and b) Capacitance-Voltage model compared with experimental data.

References

[1] M.Estrada, et. al. *Solid-St Elect.*,vol.52, no.5, pp.787-794, May 2008.

[2] C.H. Kim, et. al "A compact model for organic field-effect transistors with improved output asymptotic behavior", submitted to IEEE Trans. Electron. Dev.

[3] A. Castro-Carranza, et. al., *IET Circuits Devices Syst.*, vol. 6, no. 2, pp. 130-135, Mar. 2012.