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# Precise Parameter Extraction for Organic Thin-Film Transistors Operating in the Linear Regime

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We discuss the application of a precise parameter extraction technique [1] for organic thin-film transistors (OTFT) operating in the linear regime. Unmatched precision is achieved by utilizing Y and H functions in a proper sequence, resolving the parametric interference in other characterisation techniques [2]. The $Y_{VG}$ function compensates for the first order degradation in the current-voltage (I−V) characteristics of the OTFT that is caused by contact resistance $R_C$. The $Y_{VG}$ function is inferred from the Y-function of MOSFET [3], and for OTFT with mobility enhancement factor $\gamma>0$ is

$$Y_{VG} \equiv \frac{I_D}{\sqrt{g_m V_D}} \approx \sqrt{\frac{K}{1+\gamma}} \times (V_G - V_T)^{1+\gamma/2}, \quad (1)$$

where the current $I_D(V_G)$ and transconductance $g_m(V_G)=\partial I_D/\partial V_G$ are experimental quantities and functions of the gate bias voltage $V_G$ at given drain bias voltage $V_D$ (source $V_S=0$); $V_T$ is the threshold voltage of the OTFT; $K=(W/L)\mu_o C_I$ is the OTFT "constant" at low bias $V_G \sim V_T$, at which the carrier mobility is $\mu_o$; $C_I$ is the unit-area gate insulator capacitance; and W/L is the ratio of the channel width W to channel length L. For OTFT, $Y_{VG}$ is a power-law function of $V_G$, compensated for $R_C$, which allows for precise determination of $\gamma$ from the slope of $HY_{VG}$ function, given by

$$HY_{VG} \equiv \frac{\int Y_{VG}\, dV_G}{Y_{VG}} \approx \frac{V_G - V_T}{2+\gamma/2}, \quad (2)$$

and then for compensation of $\gamma$ in $Y_{VG}$, thus, obtaining linear $\gamma Y_{VG}$ function, given by

$$\gamma Y_{VG} \equiv \sqrt[1+\gamma/2]{Y_{VG}} \approx \sqrt[2+\gamma]{K/(1+\gamma)} \times (V_G - V_T). \quad (3)$$

Linear regression of $\gamma Y_{VG}$ vs. $V_G$ yields precise values for K (thus, mobility) and $V_T$ (Table 1). Knowing precisely the values of $V_T$, K and $\gamma$, one also extracts precise value for $R_C$, and consequent use of these parameters in the TFT compact DC model [4, 5] yields very good fit for $I_D$ and also for $g_m$ (Fig. 1). The TFT compact DC model is arranged as

$$I_D = K\frac{V_{GTS}^{2+\gamma} - V_{GTD}^{2+\gamma}}{2+\gamma} + I_{off}, \quad (4)$$

including interpolation with effective overdrive voltages for sub-threshold regime of operation of the OTFT, given by

$$V_{GTS} = V_{SS} \ln\left[1+\exp\left(\frac{V_G - V_T - V_{SI}}{V_{SS}}\right)\right]$$
$$V_{GTD} = V_{SS} \ln\left[1+\exp\left(\frac{V_G - V_T - V_{DI}}{V_{SS}}\right)\right] \quad (5)$$

where $V_{SS}$ is a voltage parameter for the subthreshold regime ($V_{SS}$ is approximately the subthreshold slope $SS=\partial V_G/\partial \log_{10}(I_D)$ at $V_G \ll V_T$ or $V_{SS} \approx ½SS$ at $V_G \approx V_T$, see [4, 5]). The potentials $V_{SI}=V_S+I_D\times R_S=I_D\times ½R_C$ and $V_{DI}=V_D-I_D\times R_D=V_D-I_D\times R_C$ of the intrinsic channel at the source ($V_S=0$) and the drain sides, respectively, account for the voltage drops on contact resistances $R_D=R_S=½R_C$. Leakage current $I_{off}$ is also included in eq. (4). The values of the subthreshold parameters $V_{SS}$ and $I_{off}$ are varied, until a good fit to the measured $I_D$ was achieved at the subthreshold and off regions in semi-logarithmic plot of the $I_D-V_D$ characteristic (not shown). The parameters of the OTFT are given in Table 1.

The proper use of the characterization technique is discussed, as well as possible second-order degradation mechanism in the I−V characteristics of the OTFT, which we are able to observe (Fig. 1), owing to the high precision of the parameter extraction technique.

Table 1. Values of extracted and other parameters of the OTFT, also used in the re-simulation of the measurement

| Parameter | Unit | Value |
|---|---|---|
| $K=(W/L)\mu_o C_I$ | $nA/V^{2+\gamma}$ | 155±3 |
| $-V_T$ | V | -12.08±0.4 |
| $\gamma$ | numeric | 0.304±0.005 |
| $R_D=R_S=½R_C$ | kΩ | 9.762±0.09 |
| $V_{SS}$ | V | 1.48±0.1 |
| $I_{off}$ | nA | 0.127±0.05 |
| W=5000μm, L=90μm, $C_I$=17nF/cm² (200nm $SiO_2$+OTS)<br>Top contact (gold), bottom gate (degenerated Si wafer),<br>30nm organic semiconductor film of diketopyrrolopyrrole<br>β-unsubstituted quaterthiophene (DKPP-BT) | | |

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## References

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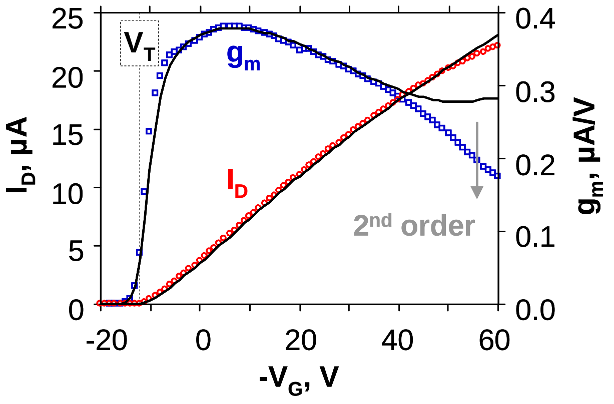

Fig. 1. Experimental (symbols) and re-simulated (lines) $I_D-V_G$ (circles) and $g_m-V_G$ (squares) characteristics of an OTFT (Table 1). Unsupported by models second order degradation in the characteristics is observed at high $V_G$.