Supplementary Materials: Critical Evaluation of Organic Thin-Film Transistor Models

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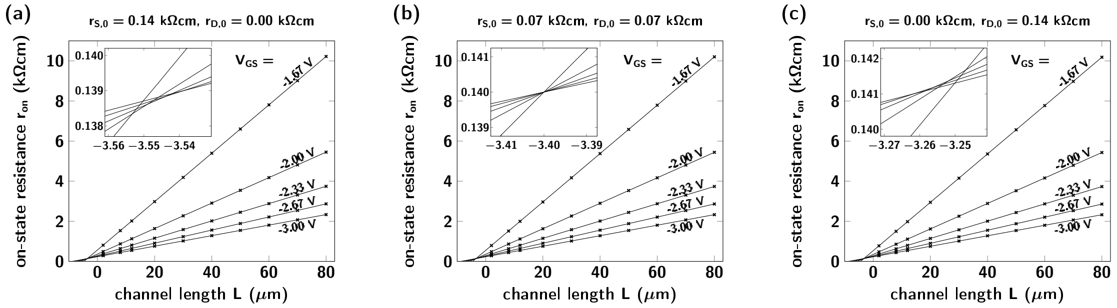

Figure S1. Conventional transmission line method (TLM)[1,2] performed on a simulated set of thin-film transistors (TFTs) with the parameters extracted using TLM for the bottom-gate, bottom-contact DNTT TFTs (intrinsic channel mobility $\mu_{TLM} = 3.2$ cm^2/Vs, threshold voltage $V_T = -1.25$ V, transfer length $L_T = 3.4$ μm and combined contact resistance $r_{C,0} = r_{S,0} + r_{D,0} = 0.14$ kΩcm) assigning $r_{C,0}$ in three different ways to the source and drain resistances $r_{S,0}$ and $r_{D,0}$. The TLM is performed at a non-vanishing drain-source voltage $V_{DS} = -0.1$ V to visualize the generated error caused by not taking $V_{DS} \to 0$ V. For each simulated TFT, the drain current I_D is calculated at $V_{DS} = -0.1$ V and gate-source voltages V_{GS} =-1.67 V, -2.00 V, -2.33 V, -2.67 V and -3.00 V. These drain currents are used to obtain an estimate for the on-state resistance $r_{on} = WV_{DS}/I_D$. The thus-calculated values for r_{on} were used to perform a conventional TLM analysis. The insets show a magnification of the intersect of all fit lines in the region of negative channel lengths L. In (**a**), the entire contact resistance $r_{C,0}$ was assigned to the source side, resulting in an intersect that is smeared out towards more negative channel lengths. The extracted parameters of $\mu_{TLM} = 3.197$ cm^2/Vs, $V_T = -1.300$ V, $L_T = 3.551$ μm and $r_{C,0} = 0.1385$ kΩcm reflect this behaviour by overestimating the transfer length L_T and underestimating the combined contact resistance $r_{C,0}$. The threshold voltage is shifted by $V_{DS}/2$ and the mobility is nearly not affected. In (**b**), $r_{C,0}$ was equally distributed over $r_{S,0}$ and $r_{D,0}$, leading to a precise intersect. The extracted parameters $\mu_{TLM} = 3.200$ cm^2/Vs, $V_T = -1.300$ V, $L_T = 3.400$ μm and $r_{C,0} = 0.14$ kΩcm perfectly match the input parameters except the threshold voltage which is shifted by $V_{DS}/2$. In (**c**), $r_{C,0}$ was entirely attributed to $r_{D,0}$, giving rise to an intersect smeared out towards more positive channel lengths. The extracted parameters are changed in the opposite direction compared to (**a**): $\mu_{TLM} = 3.203$ cm^2/Vs, $V_T = -1.300$ V, $L_T = 3.249$ μm and $r_{C,0} = 0.1414$ kΩcm. Only the threshold voltage is shifted in the same way as in (**a**) and (**b**) by $V_{DS}/2$.

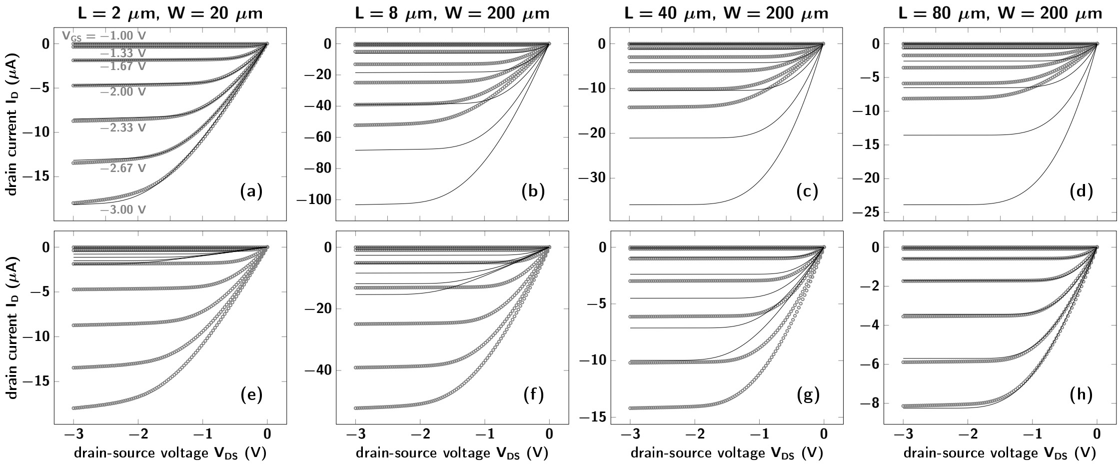

Figure S2. Measured output characteristics of bottom-gate, bottom-contact DNTT TFTs with channel lengths L of 2, 8, 40 and 80 μm plotted as gray symbols and calculated output characteristics as black lines. The TFT with a channel length of 2 μm has a channel width of 20 μm, while the TFTs with channel lengths of 8, 40 and 80 μm have a channel width of 200 μm. Note that the gray symbols appear as an apparent thick line due to the close spacing of the data points. The parameters for the calculated characteristics are the ones fitted using the field- and charge-carrier-density-dependent mobility model, except for the source and drain resistance $r_{S,0}$ and $r_{D,0}$. In the first row, the contact resistances of the TFT with the smallest channel length ($L = 2$ μm) are used, and in the second row, the contact resistances of the TFT with the largest channel ($L = 80$ μm) are used for all calculated characteristics. In (**a**) and (**h**), the contact resistances are the optimized parameters, respectively, resulting in a match of calculated output characteristics and measured output characteristics. For (**b**-**d**), the underestimated contact resistances cause an increasing overestimation of the calculated drain current I_D, and for (**e**-**g**), the drain current is underestimated due to the overestimated contact resistances. Summarizing, the value of the contact resistance has an important influence on the output characteristics, underlining the fact that the channel-length dependence of the contact resistance is indeed important.

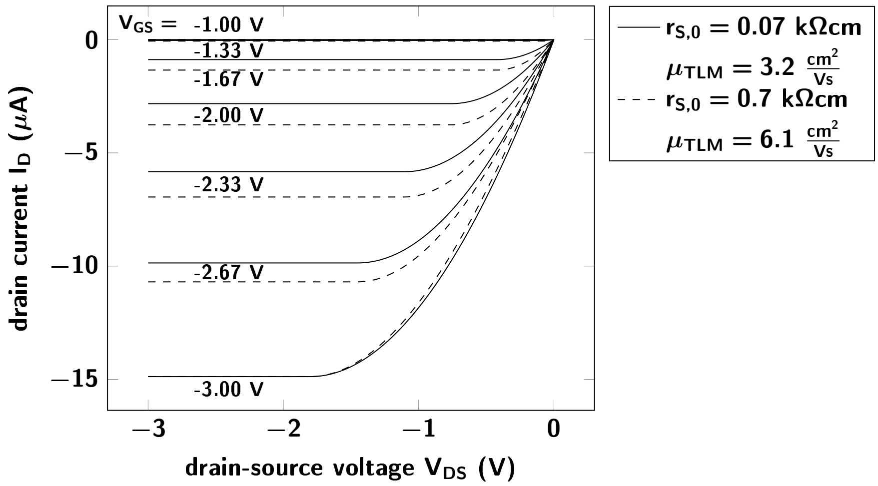

Figure S3. Calculated output characteristics (solid lines) for a TFT with a channel length of L = 40 μm assuming the parameters extracted using TLM for the bottom-gate, bottom-contact DNTT TFTs (intrinsic channel mobility $\mu_{TLM} = 3.2$ cm^2/Vs, threshold voltage $V_T = -1.25$ V, transfer length $L_T = 3.4$ μm and source and drain resistances $r_{S,0} = r_{D,0} = 0.07$ kΩcm). To show the correlation between contact resistance and mobility, a second set of output characteristics (dashed lines) is plotted, for which only the mobility $\mu_{TLM} = 6.1$ cm^2/Vs and the source resistance $r_{S,0} = 0.7$ kΩcm are changed. Simultaneously increasing μ_{TLM} and $r_{S,0}$ results in a nearly perfect agreement between the output characteristics calculated for the largest gate-source voltage $V_{GS} = -3.00$ V, but pronounced differences for smaller gate-source voltages. For a small contact resistance, the saturation current increases quadratically with V_{GS} whereas for a large contact resistance, the saturation current increases linearly with V_{GS}. As a consequence, increasing μ_{TLM} and $r_{S,0}$ makes the spacing between I_D in the saturation regime more uniform, which is able to partly compensate an incorrect mobility model.

References

1. Kanicki, J.; Libsch, F.R.; Griffith, J.; Polastre, R. Performance of thin hydrogenated amorphous silicon thin-film transistors. *Journal of Applied Physics* **1991**, *69*, 2339–2345. doi:10.1063/1.348716.
2. Luan, S.; Neudeck, G.W. An experimental study of the source/drain parasitic resistance effects in amorphous silicon thin film transistors. *Journal of Applied Physics* **1992**, *72*, 766–772. doi:10.1063/1.351809.