TCAD Laboratory

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# IMPROVED RPI TFT COMPACT MODEL : EXTRINSIC AND WITH CORRECT ACCOUNT OF POSITIVE DIFFERENTIAL CONDUCTANCE AFTER SATURATION

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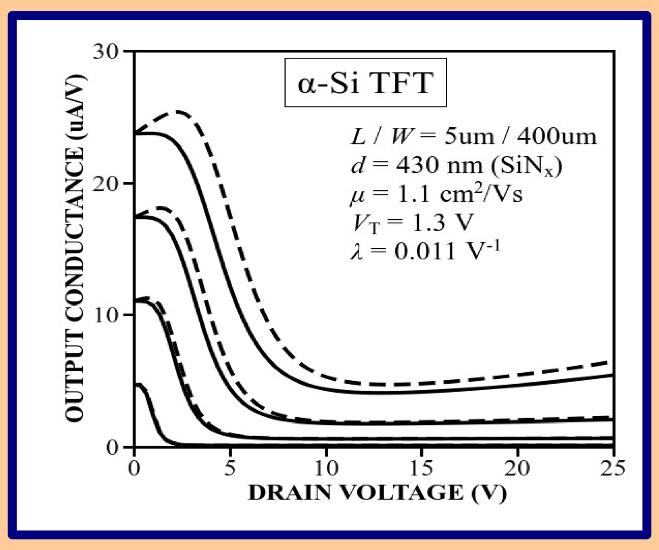
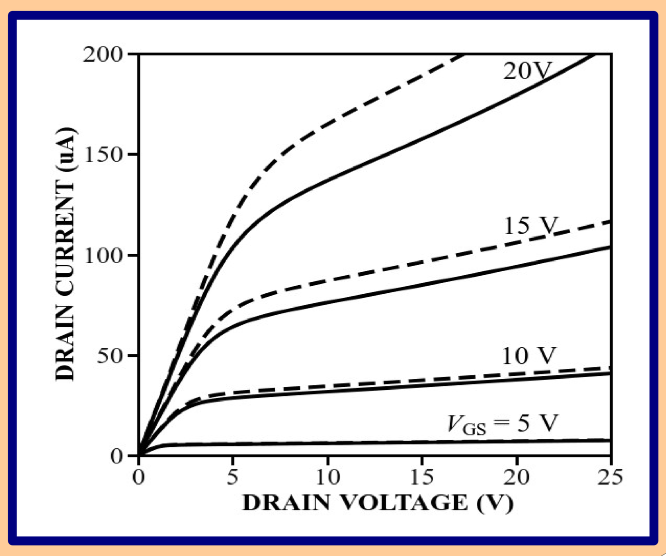
*The RPI TFT and MOSFET Level 1 models, based on the simplest quadratic Shockley's MOSFET model, are used, for example, in AIM-Spice, Cadence PSPICE, Synopsys HSPICE, and Silvaco SmartSpice circuit simulators. These models use channel-length modulation parameter λ to account for non-zero differential conductance after saturation due to Channel Length Modulation (CLM), Drain Induced Barrier Lowering (DIBL), and self-heating (SH) effects. This is done by multiplying the expression for the drain current by the $1+\lambda V_{DS}$ factor, where $V_{DS}$ is the drain-to-source bias. However, this traditional approach suffers from non-monotonic behavior of the differential conductance with increasing drain-to-source bias. For example, we found that if the differential conductance after saturation equals 25% or 50% of its value in the linear regime, the maximum differential conductance reaches 108% or 124% of its value in the linear regime, respectively. However, to be useful in analog circuit simulations, the compact model should accurately reproduce the output conductance. To overcome this disadvantage of traditional models, we offered a new approach that gives the correct monotonic decrease of the differential conductance. This new approach can be applied also to BSIM3 and BSIM4 models. In addition, we have generalized the improved model into the extrinsic compact model that accounts for the source and drain series resistances analytically.*

## Problems :

- *Non-monotonic behavior of the differential conductance in the case of the a-Si RPI TFT model*
- *The RPI TFT model is intrinsic initially and doesn't account for the source and drain series resistances analytically.*




*Dashed lines are for the traditional a-Si RPI TFT model with account of the self-heating effect. Solid lines are for the improved model [1]*

## Basic equations of the MOSFET theory :

- *Linear regime:*

$$I_{1L}=g_{1L}V_{DS} \qquad g_1=\beta V_{GT}$$
$$\beta=\mu\frac{\epsilon}{d}\frac{W}{L} \qquad I_1=I_{1L}-\beta V_{DS}^2/2\alpha$$

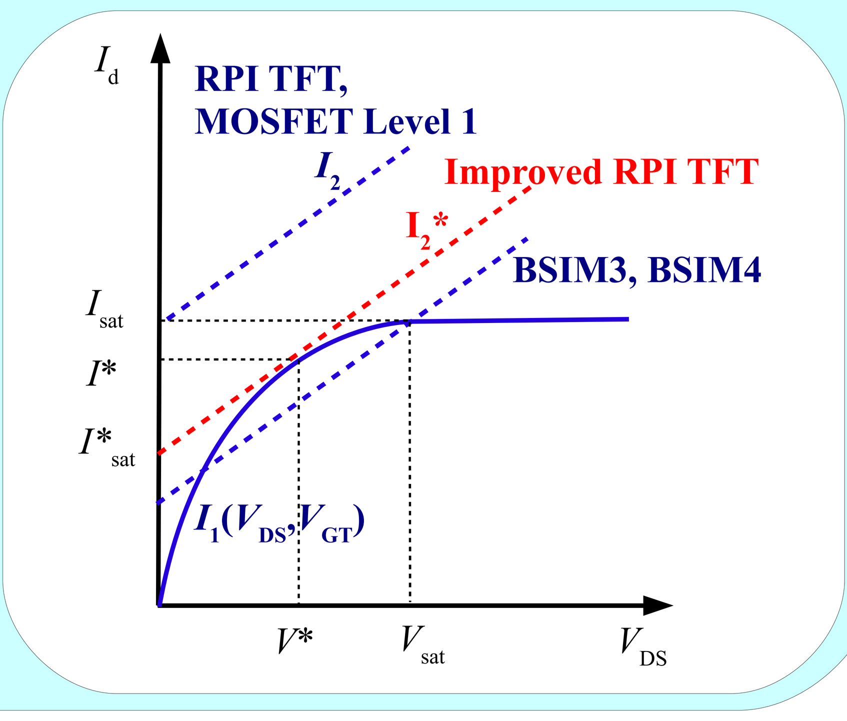
- *Saturation regime:*

$$I_2=I_{sat}+g_2V_{DS} \qquad I_{sat}=\frac{\beta V_L^2}{\alpha}\left(\sqrt{1+\left(\frac{\alpha V_{GT}}{V_L}\right)^2}-1\right) \qquad V_L=\frac{v_S L}{\mu}$$
$$g_2=\lambda I_{sat}$$

## Improved model:

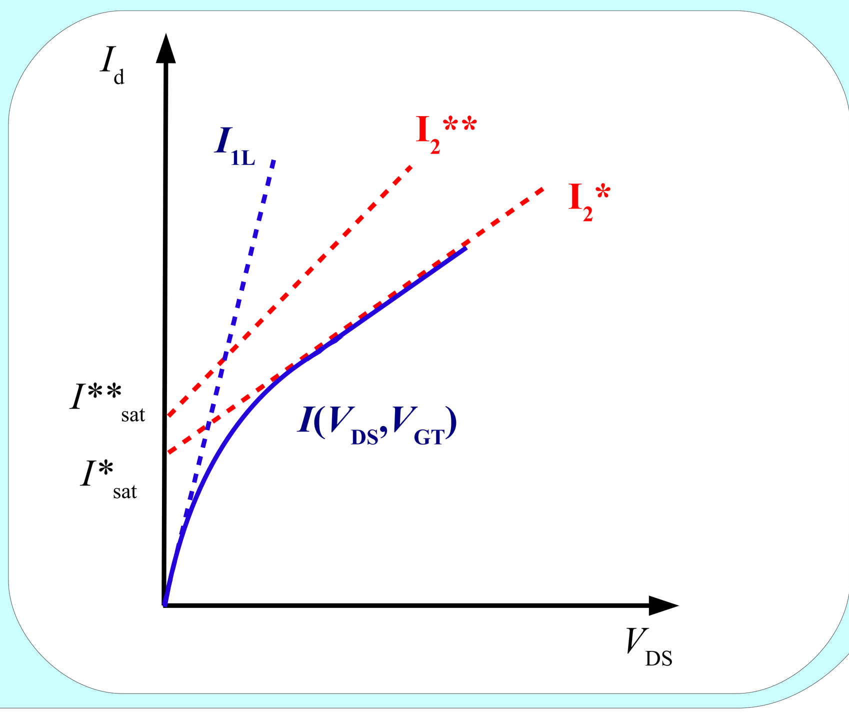
- *Intrinsic case. We introduce a new asymptotic "after saturation" equations for the drain current:*

$$I_2^*=I_{sat}^*+\lambda I_{sat}V_{DS}$$
$$I_{sat}^*=I^*-\lambda I_{sat}V^*$$
$$\begin{cases} I^*=\dfrac{\alpha}{2}\left(\beta V_{GT}^2-\dfrac{\lambda^2}{\beta}I_{sat}^2\right)\\ V^*=\alpha\left(V_{GT}-\dfrac{\lambda}{\beta}I_{sat}\right)\end{cases}$$




- *Intrinsic case. Equations for the drain current in the Improved RPI TFT Model:*

$$I=\frac{I_{1L}I_2^{**}}{\left[I_{1L}^m+\left|I_2^{**}\right|^m\right]^{1/m}}$$
$$I_2^{**}=I_{sat}^{**}+g_2^{**}V_{DS}$$
$$I_{sat}^{**}=\frac{g_{1L}}{\left[g_{1L}^m-\left|g_2\right|^m\right]^{1/m}}\ I_{sat}^*$$
$$g_2^{**}=\frac{g_{1L}}{\left[g_{1L}^m-\left|g_2\right|^m\right]^{1/m}}\ g_2$$




- *We have convenient for calculations equation for the drain current for both, Intrinsic and Extrinsic cases:*

$$I=\frac{I_{1L}I_2^*}{\left[I_{1L}{}^m+I_2^*{}^m-\left(I_2^*-I^*+\lambda I_{sat}V^*\right)^m\right]^{1/m}}$$

- *Extrinsic case. Relations between extrinsic and intrinsic drain-to-source and gate-to-source voltages [2]:*

$$\begin{cases} V_{ds}=V_{DS}+IR_T\\ V_{gt}=V_{GT}+IR_S\end{cases} \qquad R_T=R_S+R_D$$

- *Extrinsic case. Linear regime:*

$$I_{1L}=\frac{1+\beta\left(V_{gt}R_T+V_{ds}R_S\right)}{2\beta R_S R_T}\left(1-\sqrt{1-\frac{4\beta^2R_SR_TV_{gt}V_{ds}}{\left(1+\beta\left(V_{gt}R_T+V_{ds}R_S\right)\right)^2}}\right)$$

$$I_{sat}=\frac{\alpha\beta V_{gt}^2}{1+\alpha\beta R_SV_{gt}+\sqrt{1+2\alpha\beta R_SV_{gt}+\left(\alpha V_{gt}/V_L\right)^2}}, \qquad V_{sat}=V_{SAT}+I_{sat}R_T$$

- *Extrinsic case. Saturation regime:*

$$I^*=\frac{\alpha\beta R_SV_{gt}+1}{\alpha\beta R_S{}^2}\left(1-\sqrt{1-\frac{2\alpha\beta R_S{}^2\left(\dfrac{\alpha\beta}{2}V_{gt}{}^2-\dfrac{\alpha\lambda^2}{2\beta}I_{sat}{}^2\right)}{\left(\alpha\beta R_SV_{gt}+1\right)^2}}\right)$$
$$V^*=\alpha\left(\left(V_{gt}-I^*R_S\right)-\frac{\lambda}{\beta}I_{sat}\right)$$

- *If $I^* < I_{sat}$ :*

$$I_2^*=\frac{\left(1+\alpha\beta R_SV_{gt}-\lambda\left(\alpha R_S-R_T\right)I_{sat}\right)}{\alpha\beta R_S{}^2}\times\left(1-\sqrt{1-\frac{\alpha\beta R_S{}^2\left(2\lambda\left(V_{ds}-\alpha V_{gt}\right)I_{sat}+\alpha\left(\beta V_{gt}{}^2+\dfrac{\lambda^2}{\beta}I_{sat}{}^2\right)\right)}{\left(1+\alpha\beta R_SV_{gt}-\lambda\left(\alpha R_S-R_T\right)I_{sat}\right)^2}}\right)$$

- *If $I^* > I_{sat}$ : $I^*=I_{sat}$, $V^*=V_{sat}$*

$$I_2^*=I_{sat}\frac{1+\lambda\left(V_{ds}-\alpha V_{gt}\right)+\dfrac{\lambda\alpha}{\beta V_L}I_{sat}}{1+\lambda I_{sat}\left(R_T-\alpha R_S\right)}$$

## References:

[1] Turin, V.O., Sedov, A.V., Zebrev, G.I., Iniguez, B., and Shur, M.S. "Intrinsic compact MOSFET model with correct account of positive differential conductance after saturation" Proc. SPIE 7521, 75211H, pp. 1-9, (2010).
[2] Shur, M.S., Turin, V.O., Veksler, D., Ytterdal, T., Iñiguez, B., and Jackson, W., "Compact Iterative Field Effect Transistor Model", NSTI-Nanotech 2006, ISBN 0-9767985-8-1, 3, 648-651(2006).
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