A New I-V Equation for Thin Film Transistors and Its Parameter Extraction Method

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Abstract

Based on the device physics, a new I-V equation for TFTs is derived and a simple parameter extraction method is suggested. The new method gives more physically meaningful threshold voltage and mobility, and the obtained values can be directly used for the TFT device modeling.

1. Introduction

The TFT device models and the extracted parameters are important because they become the basis of the evaluation, comparison, and circuit simulation of TFTs. Although many TFT models have been developed [1,2], they still need to be improved to model several kinds of TFTs. Moreover, most researchers still use the simple silicon MOSFET model for their evaluation because the TFT models do not give simple parameter extraction methods. In this paper, a new I-V model along with simple parameter extraction method is suggested.

2. I-V Modeling

For the long channel TFTs, only the channel needs to be concerned neglecting the parasitic resistances. Starting from the gradual channel approximation, the drain current I_{DS} can be expressed as

$$I_{DS} = \frac{W}{L}\int_0^{V_D} \sigma_{sh}(V)dV \qquad (1)$$

where σ_{sh} and V represent the sheet conductivity and the potential of the channel. Assuming that the trap states decay exponentially near the conduction band edge, the equations for the ratio β of the free charge to the total charge can be derived as

$$\beta \equiv \frac{Q_{free}}{Q_{tot}} = \frac{Q_{free}}{Q_{trap}+Q_{free}} \approx [\beta_0(V_G - V_{TH})]^{\gamma-1} \qquad (2)$$

where Q_{free}, Q_{tot}, Q_{trap}, β_0, V_{TH}, and γ represent the free charge per unit area, the total charge per unit area, the trapped charge per unit area, a constant coefficient for β, the threshold voltage, and the power factor for β-V_G relation, respectively. Then, σ_{sh} can be obtained as a function of V_G

$$\sigma_{sh}(V_G) = \mu_{free}Q_{free} = \mu_{free}\beta Q_{tot} \approx \mu_{free}\beta_0^{\gamma-1}C_i(V_G - V_{TH})^{\gamma} \qquad (3)$$

where μ_{free} and C_i represent the free carrier mobility and the insulator capacitance per unit area, repsectively. Because σ_{sh} changes along the channel due to the channel potential V, I_{DS} can be calculated as

$$\begin{aligned} I_{DS} &= \frac{W}{L}\int_0^{V_D} \mu_{free}\beta_0^{\gamma-1}C_i(V_G - V_{TH} - \alpha V)^{\gamma}dV \\ &= \frac{1}{\alpha(\gamma+1)}\mu_{free}\beta_0^{\gamma-1}C_i\frac{W}{L} \\ &\quad \times[(V_G - V_{TH})^{\gamma+1} - (V_G - V_{TH} - \alpha V_D)^{\gamma+1}] \end{aligned} \qquad (4)$$

where α becomes the saturation coefficient because the saturation drain voltage V_{Dsat} becomes $(V_G$-$V_{TH})/\alpha$. For very small V_D, eq. (4) becomes as follows

$$I_{DS,lin} = \mu_{free}\beta_0^{\gamma-1}C_i\frac{W}{L}(V_G - V_{TH})^{\gamma}V_D \qquad (5)$$

and when V_D becomes larger than V_{Dsat}, the equation becomes

$$I_{DS,sat} = \frac{1}{\alpha(\gamma+1)}\mu_{free}\beta_0^{\gamma-1}C_i\frac{W}{L}(V_G - V_{TH})^{\gamma+1}. \qquad (6)$$

3. Parameter Extraction

Conventionally, either the linear region $I_{DS,lin}$-V_G curve or square-root of the saturation region $I_{DS,sat}$-V_G curve has been used to extract V_{TH} and the effective mobility μ_{eff}. For the new method, both of two transfer characteristics, $I_{DS,lin}$-V_G and $I_{DS,sat}$-V_G, are necessary to obtain V_{TH}, γ, α, and μ_{eff}. First, by dividing $I_{DS,sat}$ by $I_{DS,lin}$, one can obtain V_{TH} and $\alpha(\gamma+1)$ with the relation

$$\frac{I_{DS,sat}}{I_{DS,lin}} = \frac{1}{\alpha(\gamma+1)V_D}(V_G - V_{TH}) \tag{7}$$

respectively from the x-intercept and the slope of the $I_{DS,sat}/I_{DS,lin}$ versus V_G plot. Similar dividing techniques can be applied to $I_{DS,sat}$ and $g_{m,sat}$ relation as

$$\frac{I_{DS,sat}}{g_{m,sat}} = \frac{I_{DS,sat}}{\partial I_{DS,sat}/\partial V_G} = \frac{V_G - V_{TH}}{\gamma+1} \tag{8}$$

or to $I_{DS,lin}$ and $g_{m,sat}$ relation as

$$\frac{I_{DS,lin}}{g_{m,sat}} = \frac{I_{DS,lin}}{\partial I_{DS,sat}/\partial V_G} = \alpha V_D \tag{9}$$

to obtain V_{TH}, γ, and α. In this case, two different V_{TH} could be obtained from eq. (7) and (8), but generally the values are not much different. Next, to obtain μ_{eff}, either $I_{DS,lin}{}^{1/\gamma}$ or $I_{DS,sat}{}^{1/(\gamma+1)}$ versus V_G plot can be used. The relation between $I_{DS,lin}{}^{1/\gamma}$ and V_G is given as

$$I_{DS,lin}{}^{1/\gamma} = \left(\mu_{free}\beta_0{}^{\gamma-1}C_i\frac{W}{L}V_D\right)^{1/\gamma}(V_G - V_{TH}) \tag{10}$$

so that $\mu_{free}\beta_0{}^{\gamma-1}$ can be obtained from the slope of $I_{DS,lin}{}^{1/\gamma}$ versus V_G plot as

$$\mu_{free}\beta_0{}^{\gamma-1} = \frac{(slope)^\gamma}{C_i(W/L)V_D}. \tag{11}$$

If $I_{DS,sat}{}^{1/(\gamma+1)}$ is used instead of $I_{DS,lin}{}^{1/\gamma}$, typically the obtained $\mu_{free}\beta_0{}^{\gamma-1}$ is the same as that from $I_{DS,lin}{}^{1/\gamma}$. Because μ_{eff} can be found from σ_{sh}/Q_{tot}, μ_{eff} can be obtained using the obtained $\mu_{free}\beta_0{}^{\gamma-1}$ as

$$\mu_{eff} = \frac{\sigma_{sh}}{Q_{tot}} = \frac{\mu_{free}\beta_0{}^{\gamma-1}C_i(V_G - V_{TH})^\gamma}{C_i(V_G - V_{TH})} = \mu_{free}\beta_0{}^{\gamma-1}(V_G - V_{TH})^{\gamma-1} \tag{12}$$

where μ_{eff} is a function of V_G as expected.

4. Discussion

Described parameter extraction method is applied to the I-V curves of back-channel etched amorphous silicon TFT obtained from TCAD simulation. The thicknesses of SiN_x, a-Si and n^+ a-Si layer are 300, 150, and 30 nm, respectively. To avoid the effects of the series resistance, both the channel width and the channel length are assumed as 1024 μm. Fig. 1 shows $I_{DS,sat}/I_{DS,lin}$ curve from which V_{TH} can be obtained. Other parameters extracted by the new method are summarized in Table I.

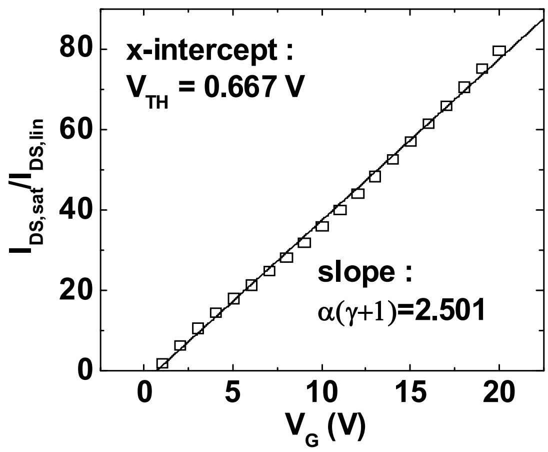
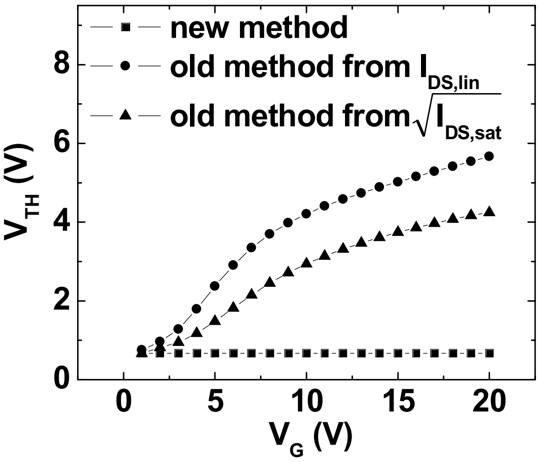


Fig. 1. Parameter extraction using the division of $I_{DS,sat}$ by $I_{DS,lin}$. From the x-intercept, V_{TH} is obtained. From the slope, the product of α and γ+1 can be obtained.

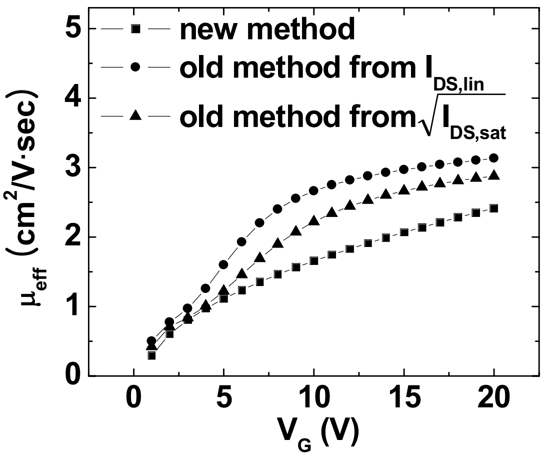
parameter	value	unit
V_{TH}	0.667	V
γ	1.518	-
α	0.993	-
$\mu_{free}\beta_0{}^{\gamma-1}$(lin)	0.521	$cm^2s^{-1}V^{-0.482}$
$\mu_{free}\beta_0{}^{\gamma-1}$(sat)	0.522	$cm^2s^{-1}V^{-0.482}$

Table I. The extracted parameters using the new method. The obtained $\mu_{free}\beta_0{}^{\gamma-1}$ are the same for $I_{DS,lin}$ and $I_{DS,sat}$.

Fig. 2 compares V_{TH} and μ_{eff} obtained from the new method and the conventional method. V_{TH} and μ_{eff} extracted from the conventional method changes depending on the extraction condition, so that the parameters can not represent the characteristics of the device. However, using the new method, V_{TH} and μ_{eff}



(a)

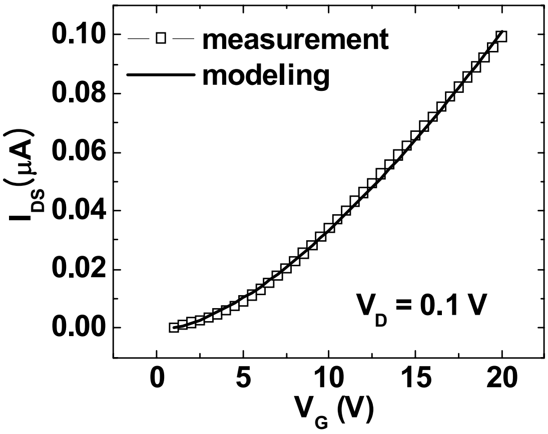


(b)

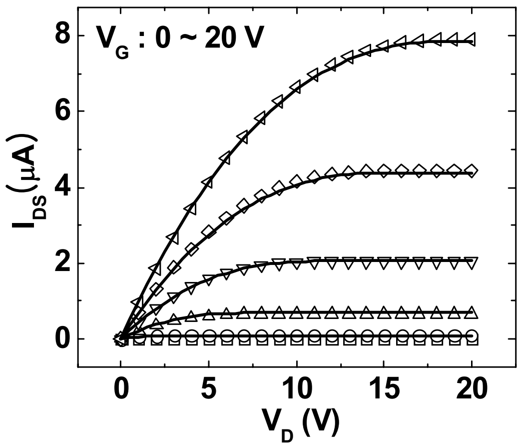
Fig.2 Comparison of extracted parameters. (a) V_{TH} from the new method is constant while V_{TH} from the conventional method changes with V_G. (b) Single μ_{eff} values are obtained from the new method while the conventional method results different μ_{eff} values.

are consistent, so that the physical meaning can be given for the extracted parameters. V_{TH} extracted by the new method indicates the onset of the accumulation layer. When V_G equals to V_{TH}, the total accumulation charge is zero, but the accumulation layer is about to form. Just above V_{TH}, the total accumulation charge is larger than zero, but the current can be relatively very small, because the trapped charges are much larger than the free charges. As V_G becomes larger, the ratio β of the free charges to the trapped charges becomes larger, so that substantial current can be flow through the channel. For μ_{eff}, the coefficient γ is very important because μ_{eff} is proportional to $(V_G\text{-}V_{TH})^{\gamma-1}$. Meanwhile, γ is related to the ratio β, so that the traps can be considered to affect on μ_{eff}.

Fig. 3 shows I_{DS}-V_G and I_{DS}-V_D modeling results using eq. (4) and the extracted parameters in Table I without any optimization. Compared to the modeling results with optimization using RPI TFT model or Leroux TFT model, the new I-V equation shows better modeling results.



(a)



(b)

Fig. 3. Using eq. (4) and extracted parameters, the I-V characteristics can be easily predicted without any additional fitting parameters. (a) I_{DS}-V_G curve (b) I_{DS}-V_D curve

5. Summary

First, the new equation can model the I-V characteristics of TFTs better than previous models because device physics are more carefully applied. Compared to the previous models, the change of the equation seems to be small, but it makes a big difference in the modeling results. Second, the parameter extraction method is easy and the parameters have more physical meaning. Therefore, they can be used for fair evaluation of several kinds of TFTs.

5. References

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