A simple model and parameter extraction method for the description of ON-current of LT-PS TFT

Dewill Chung, Junyoung Park, Sang-Gyu Park*
Div. of Electronics and Computer Engineering, Hanyang University, Seoul, KOREA
Phone: +82-2-2220-0375 , E-mail: sanggyu@hanyang.ac.kr

Abstract

A simple SPICE model for the description of the on-current of low-temperature poly-silicon thin film transistors is proposed. By employing constant mobility, V_{GS} dependent alpha parameter, and exponential kink effect, very good agreements between the model and measurement were obtained.

1. Introduction

Low Temperature Poly-Silicon (LT-PS) Thin Film Transistors (TFTs) are expected to play an important role in the next generation flat-panel display technology[1]. In order to use the LT-PS TFTs in semiconductor circuits, an accurate modeling of device characteristics is essential. The most widely used model of LT-PS TFTs are by Jacunski et al which is implemented as HSPICE MOSFET Level 62 (or AIM-SPICE Level 16) [2,3]. Although this model is quite accurate, at least for the description of the DC characteristics, the parameter extraction for this model is quite involved.

In this paper, we propose a very simple analytical model to describe the ON-current behavior of LT-PS TFTs and the parameter extraction technique for the model. By employing V_{GS}-dependent α-parameter, and exponential kink effect, very good agreements between the model and measurement were obtained for the ON-current behavior of short channel devices, where channel length is as short as 4 μm.

2. Results

Above threshold, the drain current in the linear region of poly-silicon TFT can be expressed as

$$I_a = \mu C_{ox} \frac{W}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2\alpha}\right], \quad (1)$$

where μ is the carrier mobility, $C_{ox} = \varepsilon_{ox} / t_{ox}$ is the gate-oxide capacitance per unit area, where ε_{ox} is the dielectric permittivity and t_{ox} is the thickness of the gate oxide. W and L are the channel width and length, respectively. V_{GS} and V_T are gate-source voltage and the threshold voltage, respectively. α is the body-effect related parameter.

If we assume that α, μ and V_T in Eq. (1) are independent of V_{DS}, we can fit the measured I_{DS} (V_{DS}) to the quadratic function of Eq. (2)

$$I_{DS} = AV_{DS} - BV_{DS}^2 . \quad (2)$$

when compare Eqs (1) and (2), we can establish following relationship.

$$A = \mu C_{ox}\frac{W}{L}(V_{GS} - V_T), \quad (3a)$$

$$B = \mu C_{ox}\frac{W}{L}\frac{1}{2\alpha}, \quad (3b)$$

$$\frac{A}{B} = 2\alpha(V_{GS} - V_T). \quad (3c)$$

Figure 1 shows the result of the quadratic fitting. We observe that the fitting is very good for small V_{DS}. As the device goes into saturation with large V_{DS}, the quadratic curves diverge from the measured curves.

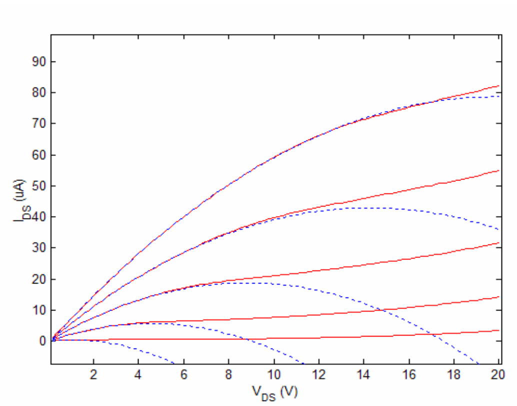

Figure 1. Comparison of the $I_D - V_{DS}$ curves by measurement (solid) and quadratic fitting curve (dotted)

Fig. 2 shows the parameters A and B in Eq. (2) extracted for Fig. 1. From Fig. 2 (a), we can observe that $A(V_{GS})$ is almost straight line. This implies that the carrier mobility can be considered to be a constant for this device. We can extract this constant mobility μ from the slope of the line and V_T from the intercept of this line with the V_{GS}-axis. Next, from Fig. 2 (b), we can observe that α is a strong function of V_{GS}. This is illustrated again in Fig. 2 (c) where $\alpha = (A/2B)/(V_{GS} - V_T)$ is shown (solid line). We can fit α to a quadratic function of V_{GS} as shown in Fig. 2 (c) (dotted line).

In the saturation region, the drain current can be described as,

$$I_{DS} = \alpha \cdot \frac{1}{2} \mu C_{ox} \frac{W}{L} (V_{GS} - V_T)^2 . \qquad (4)$$

The Eqs (1) and (3) can be combined into one equation as follows[4],

$$I_{DS} = \mu C_{ox} \frac{W}{L} \left[(V_{GS} - V_T) V_{DSe} - \frac{V_{DSe}^2}{2\alpha} \right], \qquad (5)$$

where V_{DSe} is effective intrinsic drain-source voltage defined as[5,6]

$$V_{DSe} = \frac{V_{DS}}{\left[1 + \left(\frac{V_{DS}}{V_{sat}} \right)^{M_{SS}} \right]^{\frac{1}{M_{SS}}}}, \qquad (6)$$

where V_{sat} is above-threshold saturation voltage given as[7],

$$V_{sat} = 2^{\frac{1}{M_{SS}}} \cdot \alpha \cdot V_{GT}, \qquad (7)$$

and M_{SS} is the fitting parameter which controls the transition between the triode region and the saturation region. For long-channel devices, we typically have $M_{SS} >> 1$ in which case $V_{sat} \approx \alpha \cdot V_{GT}$.

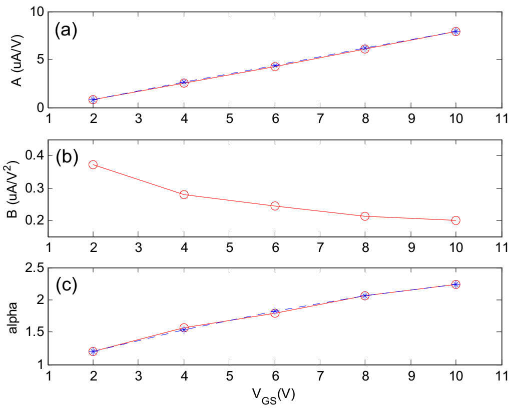

Figure 2. Parameters extracted by parabolic fitting to the linear region $I - V$ curves. (a) A (solid: measurement, dotted: linear fit) (b) B (c) $\alpha = (A/2B)/(V_{GS} - V_T)$ (solid: measurement, dotted: quadratic fit)

Figure 3 shows modeled $I_{DS} - V_{DS}$ curves which calculated with takes the saturation effect into consideration[3]. We can observe that the agreement between the measurement (solid line) and the model (dotted line) is quite good in the linear region. However, for large V_{DS} , the agreement betweens poor. This is due to kink effect.

We define multiplication factor M due to kink effect as the ratio of measured I_{DS} to the calculated I_{DS} not including the kink effect.

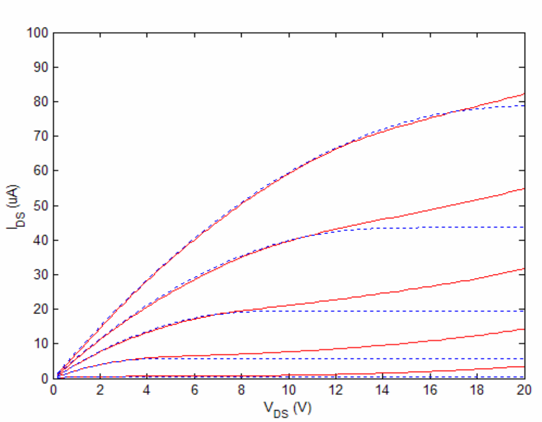

Figure 3. Comparison of the $I_D - V_{DS}$ curves by measurement (solid) and the modeling not including the kink effect (dotted)

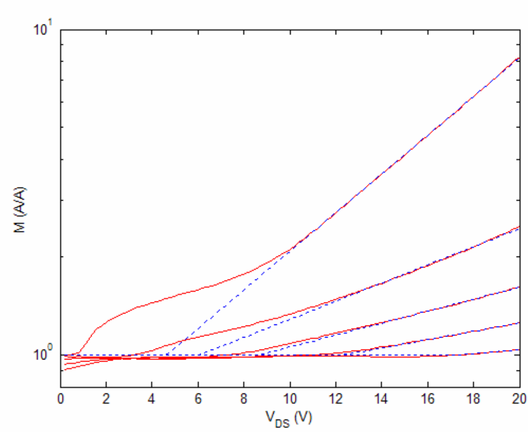

Figure 4. Current multiplication factor M defined as the ratio of measured I_{DS} to the modeled I_{DS} not including the kink effect (solid). Dotted lines represent exponential fit in the large V_{DS} region.

Figure 4 shows the multiplication factor M obtained from the I_{DS} curves in Fig. 3. We can observe that M is a strong function of both V_{GS} and V_{DS} , and for large values of V_{DS} , M can be modeled as

$$M = C \exp(D \cdot V_{DS}), \qquad (8)$$

where C and D are functions of V_{GS} . The dotted lines in Fig. 4 represent the result of this exponential function fitting.

Figure 5 (a) compares the I_{DS} curves calculated using the above kink effect model with the measured curves. We can observe excellent agreements between the curves. Fig. 5 (b) shows the output conductance of the TFT defined as $g_{DS} = \partial I_{DS} / \partial V_{DS}$. The output resistances obtained by numerically differentiating the measured data and modeled one agree very well both in the linear region and the saturation region.

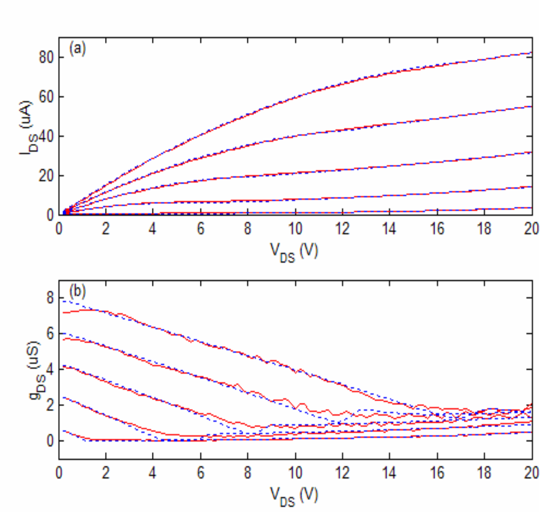

Figure 5. (a) Comparison of $I_D - V_{DS}$ curves from measurement (solid) and modeling (dotted) (b) Output resistance by numerically differentiating the $I_D - V_{DS}$ curves from the measurement (solid) and modeling (dotted)

3. Conclusions

In conclusion, we proposed a very simple model for the description of on-current behavior of LT-PS TFTs. The parameter extraction technique is very straightforward and does not involve any nonlinear optimization. By employing constant mobility, V_{GS} dependent α - parameter, and exponential kink effect, a very good agreement between the model and measurement was obtained.

4. Acknowledgements

This research was supported by a grant (F0004110) from the Information Display R&D Center, one of the 21st Century Frontier R&D Program funded by the Ministry of Commerce, Industry and Energy of the Korean Government.

5. References

[1] C. R. Kagan, P. Andry, *THIN-FILM TRANSISTORS*, Marcel Dekker, New York, U.S.A, 2003.

[2] M. Jacunski, M. Shur, M. Hack, IEEE Trans. Electron Devices, **43**, 1433 (1996).

[3] M. Jacunski, M. Shur, A. A. Owusu, T. Ytterdal, M. Hack, B. Iniguez, IEEE Trans. Electron Devices, **46**, 1146 (1999).

[4] Y. Tsividis, *Operation and Modeling of The MOS Transistor*, McGRAW-HILL, 1999

[5] K. Lee, M. Shur, T. A. Fjeldly and T. Ytterdal, *Semiconductor Device Modeling for VLSI*, Prentice-Hall, 1993.

[6] T. A. Fjeldly, T. Ytterdal and M. Shur, *Introduction to Device Modeling and Circuit Simulation,* New York : John Wiley & Sons, 1998.

[7] M. D. Jacunski, M. Shur, T. Ytterdal, A. Owusu, and M. Hack, *1996 Mater. Res. Soc. Spring Meet,* San Francisco, Apr. 1996.