A New Model for Kink-Effect in Poly-Silicon Thin-Film Transistors

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Abstract: *In poly-Si TFTs, the kink-effect much more pronounced than in bulk crystalline devices because of the floating body effect and the large voltage drops at the grain boundaries. In this paper, we propose a new kink effect model which expresses the multiplication factor as exponential functions of V_{DS}. Using the model, we obtained excellent agreements between the measured and calculated characteristics for TFT with channel lengths as short as 4um.*

Keywords: LTPS TFT; I-V characteristics; Kink effect.

Introduction

Low Temperature Poly-Silicon (LTPS) Thin-Film Transistors (TFTs) are expected to play an important role in the next generation flat-panel display technology. In order to use LTPS TFTs in circuits, an accurate modeling of device characteristics is essential. In poly-Si TFTs, the kink effect is much more pronounced than in crystalline devices because of the large voltage drops at the grain boundaries. Therefore, proper modeling of the kink effect is very important for the accurate description of the I-V characteristics of poly-Si TFTs.

In this paper, we propose a new empirical model for the kink effect in poly-Si TFTs. The kink effect is expressed by defining a multiplication factor $M = I_{DS} / I_a$, where I_{DS} and I_a are drain currents with and without kink effect, respectively.

Model Formulation and Results

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

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

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.

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

$$I_D = \alpha \cdot \frac{1}{2}\mu C_{ox}\frac{W}{L}(V_{GS} - V_T)^2, \qquad (2)$$

The Eqs (1) and (2) can be combined into one equation as follows[1],

$$I_D = \mu C_{ox}\frac{W}{L}\left[(V_{GS} - V_T)V_{DSe} - \frac{V_{DSe}^2}{2\alpha}\right], \qquad (3)$$

where V_{DSe} is effective intrinsic drain-source voltage defined as[2,3]

$$V_{DSe} = \frac{V_{DS}}{\left[1 + \left(\frac{V_{DS}}{V_{sat}}\right)^{M_{SS}}\right]^{\frac{1}{M_{SS}}}}, \qquad (4)$$

where V_{sat} is above-threshold saturation voltage given as[4],

$$V_{sat} = 2^{\frac{1}{M_{SS}}} \cdot \alpha \cdot V_{GT}, \qquad (5)$$

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 $V_{sat} \approx \alpha \cdot V_{GT}$.

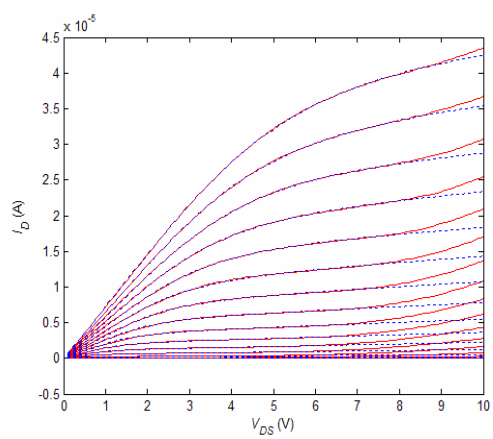

Figure 1. Comparison of the I_{DS}-V_{DS} curves by measurement (solid) and the modeling not including the kink effect (dotted)

Figure 1 shows modeled I_{DS}-V_{DS} curves which calculated with takes the saturation effect into consideration [5]. 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.

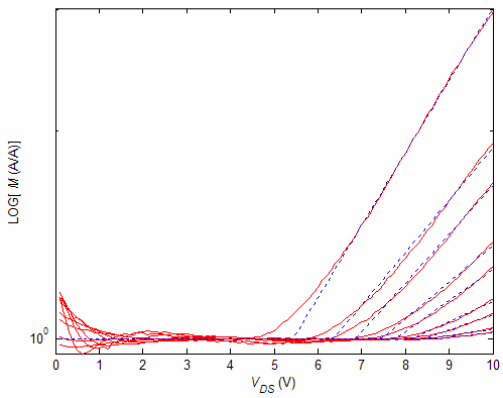

Figure 2. Current multiplication factor *M* defined as the ratio of measured I_{DS} to the modeled I_{DS} not including the kink effect (solid). Dotted lines represent exponential fit in the large V_{DS} region.

Figure 2 shows the multiplication factor *M* obtained from the I_{DS} curves in Fig. 1(solid lines). 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

$$M = K_1(V_{GS})\exp[K_2(V_{GS})V_{DS}], \qquad (6)$$

where K_1 and K_2 are V_{GS}-dependent parameters. The dotted lines in Fig. 2 represent the results of this fitting.

Figure 3 shows the extracted K_1 and K_2. We can see that K_2, which is responsible for the large increase of current at large V_{DS}, is almost a linear decreasing function of V_{GS}. The solid lines in Fig. 3 (a) and (b) represent fittings to the extracted parameters.

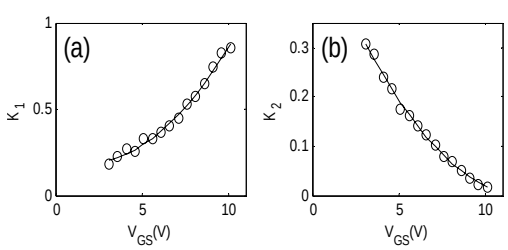

Figure 3. Extracted kink effect parameters (a) K_1 (b) K_2

Figure 4 shows experimentally measured (circles) and the calculated (solid lines) I_{DS}-V_{DS} characteristics. We can observe excellent agreements between them, which is difficult to obtain with existing models. The relative error which is defined as $|I_{meas} - I_{calc}|/I_{meas}$ is less than 5% in the entire region. Or the absolute error in the same range is less than 1.1μA, which is less than 2.5% of the maximum current shown in Fig. 4. The dotted lines in Fig. 4 represent calculated characteristics without kink effect.

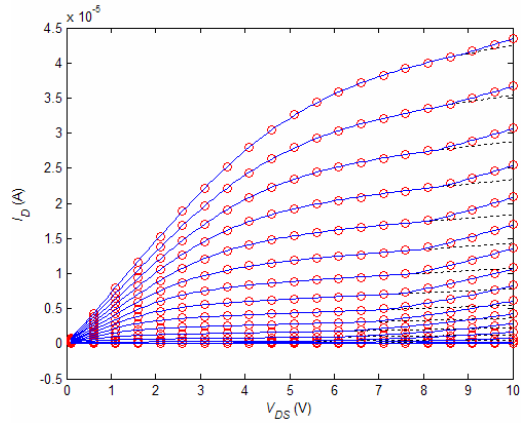

Figure 4. I_{DS}-V_{DS} characteristics with V_{GS}-steps: 0.5V. (circles: measurement, solid line: calculation with kink effect, dotted lines: calculation without kink effect.)

Conclusion

In conclusion, we proposed a new kink effect model which expresses the multiplication factor as exponential functions of V_{DS}. Using the model, we obtained excellent agreements between the measured and calculated characteristics.

Acknowledgements

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