A Simple Model for the Kink Effect for the Intrinsic p-channel Polysilicon thin film transistors

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Abstract— **In order to improve the modeling of Polysilicon thin film transistors (Poly-Si-TFTs) a precise evaluation of the excess current due to impact ionization is needed. In this paper, we have proposed a simple model for the excess current resulting from the impact ionization occurring at high drain biases. Model is based on the estimation of the electric field in the saturated part of the channel. The electric field in the saturated region is obtained by the solution of the two-dimensional Poisson's equation. The model is semi-analytical and uses only one fitting parameter which is desirable for circuit simulation. The simulation results with the developed impact ionization current model are in excellent agreement with the available experimental output characteristics of the intrinsic p-channel Poly-Si-TFTs.**

***Index Terms*—Kink Effect, Polysilicon, Thin Film Transistors, semi-analytical model.**

I. Introduction

RECENTLY the intrinsic polysilicon Thin Film Transistors (Poly-Si TFTs) have received considerable attention for large area electronics applications, in particular, active matrix liquid crystal display (AMLCD) applications like high definition television (HDTV), projection displays and portable devices. As a result of growing interest of Poly-Si TFTs in large area integrated electronics, there is need for accurate, analytical models for circuit design and simulations. It is desirable to have physical models employing minimum number of parameters which can be extracted easily.

The kink effect has been investigated by several researchers [1,2,3,4] with the aid of two dimensional numerical simulation, the nature of kink effect has been identified to be due to the impact ionization mechanism in the high field regime near the drain.

In this paper, we have proposed a simple model to estimate the excess current resulting from the impact ionization at high drain biases. The excess current due to kink effect is added to the drain current obtained by the surface potential based charge sheet model for the Poly-Si TFT presented in [5].

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II. Model for the Kink Effect

The Poly-Si TFT goes into the saturation when $V_{DS} > V_{DSAT}$ as shown in Figure 1(a), where V_{DSAT} is the drain to source voltage (V_{DS}) at which Poly-Si TFT enters into saturation and it is given by

$$V_{DAST} = V_{GS} - V_T \qquad (1)$$

Where V_T is the threshold voltage. The kink effect occurs for large drain to source voltage, when TFT is biased in saturation. It is modeled as impact ionization in the pinch-off region of length ΔL as shown in Figure 1(b). For $V_{DS} > V_{DSAT}$, impact ionization leads to avalanche multiplication and subsequent increase in drain current can be written as $\Delta I_{kink} = M.I_{DSAT}$. Where M is the multiplication factor and is function of V_{DS}. The total drain current is given by

$$I_D = I_{DSAT} + \Delta I_{Kink} = I_{DSAT}(1 + M) \qquad (2)$$

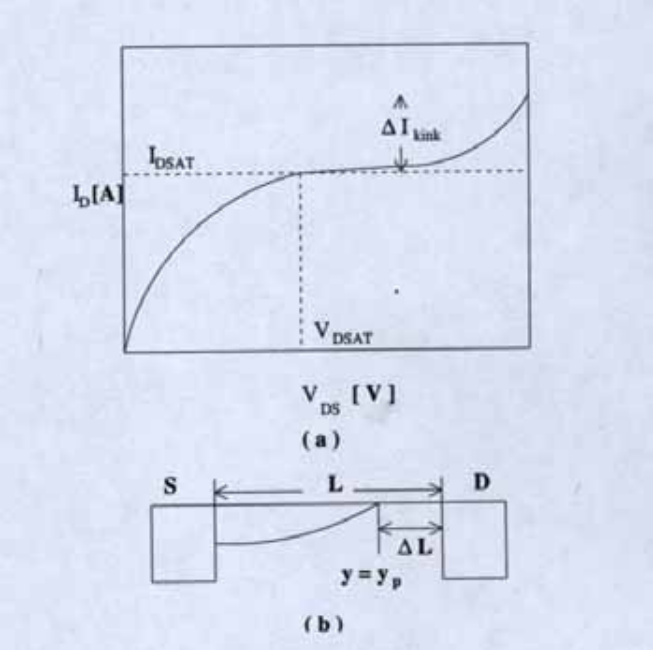

Fig. 1. (a) Definition of I_{DSAT}, V_{DSAT} and ΔI_{kink}. (b) Pinch-off region ΔL

The multiplication factor M can be given by the integral of impact ionization generation rate α_n

$$M = \int_{y=y_p}^{y=L} \alpha_n dy \qquad (3)$$

α_n is a strong function of channel electric field E. The exact dependence of α_n on the electric field is complicated, however most commonly used expression [6]

$$\alpha_n = A_i \exp(\frac{B_i}{E}) \qquad (4)$$

Where A_i and B_i are called ionization constants [6]. For the evaluation of channel electric field E, we have to consider the saturation region. The saturation region can be described by two dimensional Poisson's equation of the form

$$\frac{\partial E_y}{\partial y} + \frac{\partial E_x}{\partial x} = \frac{\rho(x,y)}{\varepsilon_s} \qquad (5)$$

Where E_x and E_y are the transverse and longitudinal components of the electric field respectively. $\rho(x,y)$ is the charge density in the semiconductor consisting of mobile charge density, n_m and trapped charge density, n_t. Integrating equation (5) with respect to x from the semiconductor –insulator interface through the effective channel thickness δd, we obtain

$$\left\langle \frac{\partial E_y}{\partial y} \right\rangle \delta d + E_x(\delta d) - E_x(0) = -\frac{q}{\varepsilon_s}(n_m + n_t)\delta d \qquad (6)$$

Where $\left\langle \frac{\partial E_y}{\partial y} \right\rangle$ is the average of $\frac{\partial E_y}{\partial y}$ over the channel thickness. In the strong inversion region the $n_m >> n_t$, the electric field at will be small compared to the vertical electric field at the interface, in which case $E_x(\delta d)$ can be neglected. Making substitution $\left\langle \frac{\partial E_y}{\partial y} \right\rangle = \frac{\partial^2 V}{\partial y^2}$, where V is the average channel potential over the cross-section of the channel. Therefore, above equation can be written as

$$\frac{\partial^2 V}{\partial y^2} + \frac{E_x(0)}{\delta d} = \frac{q}{\varepsilon_s}(n_m + n_t) \qquad (7)$$

The electric field at the interface is obtained by equating the electric displacement of the two side of the semiconductor-insulator interface

$$\varepsilon_i E_i = \varepsilon_s E_s \qquad (8)$$

At the interface $E_x(0) = E_s = \frac{\varepsilon_i E_i}{\varepsilon_s} = \frac{\varepsilon_i V_{ox}}{\varepsilon_s t_{ox}}$ and $C_{ox} = \frac{\varepsilon_i}{t_{ox}}, V_{ox} = V_{GS} - V_{FB} - \Psi_s - V$. Where Ψ_s is the surface potential at source end. From the condition of velocity saturation and current continuity, we know that the electron concentration is constant in the saturation region. Its value can be determined at the boundary point, $y = y_p$, where the gradual channel approximation is still valid. Thus we can write the charge density Q_s at boundary point as

$$Q_s = q(n_s + n_t\delta d) = \varepsilon_s E_s \qquad (9)$$

Where n_s is the electron sheet density in the channel and hence

$$n_s = \varepsilon_s \frac{C_{ox}}{q\varepsilon_s}(V_{GS} - V_{FB} - \Psi_s - V_p) - n_t\delta d \qquad (10)$$

The combination of above equations leads to the following second order differential equation for the channel potential in the saturation region:

$$\frac{\partial^2 (V - V_p)}{\partial y^2} - \frac{(V - V_p)}{\gamma^2} = 0 \qquad (11)$$

Where $\gamma = \sqrt{\frac{\varepsilon_s \delta d}{C_{ox}}}$ and known as characteristics length.

The above second order differential equation can be solved by putting appropriate boundary conditions which will give us the expression of channel electric field in the saturated part of the channel as:

$$E(y) = E_{SAT} \cosh(\frac{y}{\gamma}) \qquad (12)$$

Top

It can be put in equation (3) to get the multiplication factor M as:

$$M = \frac{V_{DS} - V_{DSAT}}{V_K} e^{\left(-\frac{\lambda_K}{V_{DS} - V_{DSAT}}\right)} \qquad (13)$$

where V_K and λ_K are the fitting parameters.

III. Result

The kink model along with the charge sheet model described in [5] has been verified on p-channel Poly-Si TFTs. The p-channel Poly-Si TFTs were fabricated using Low Pressure Chemical Vapor Deposition technique. The parameters associated with charge sheet model for p-channel Poly-Si TFTs are given [6]. The parameters used for the kink model for p-channel Poly-Si TFTs are given in Table-1. It is observed that the parameter λ_K is same for both p-channel Poly-Si TFTs, only the parameter is changing.That is our model uses only one fitting parameter which is desirable for circuit simulation. The curves show the drain current obtained from the proposed model and symbols show the experimental data obtained from [7]. A reasonable good match is observed in the linear, saturation and kink regimes.

IV. Conclusion

The kink model proposed in this paper has been verified on intrinsic p-channel Poly-Si TFTs and has a reasonable good match with experimental data. This physics based kink model uses only one fitting parameter which is desirable for circuit simulation.

Table 1 : The Kink parameters for p-channel Poly-Si TFTs.

Parameter	TFT-1	TFT2
V_K	52	06
λ_K	0.91	0.91

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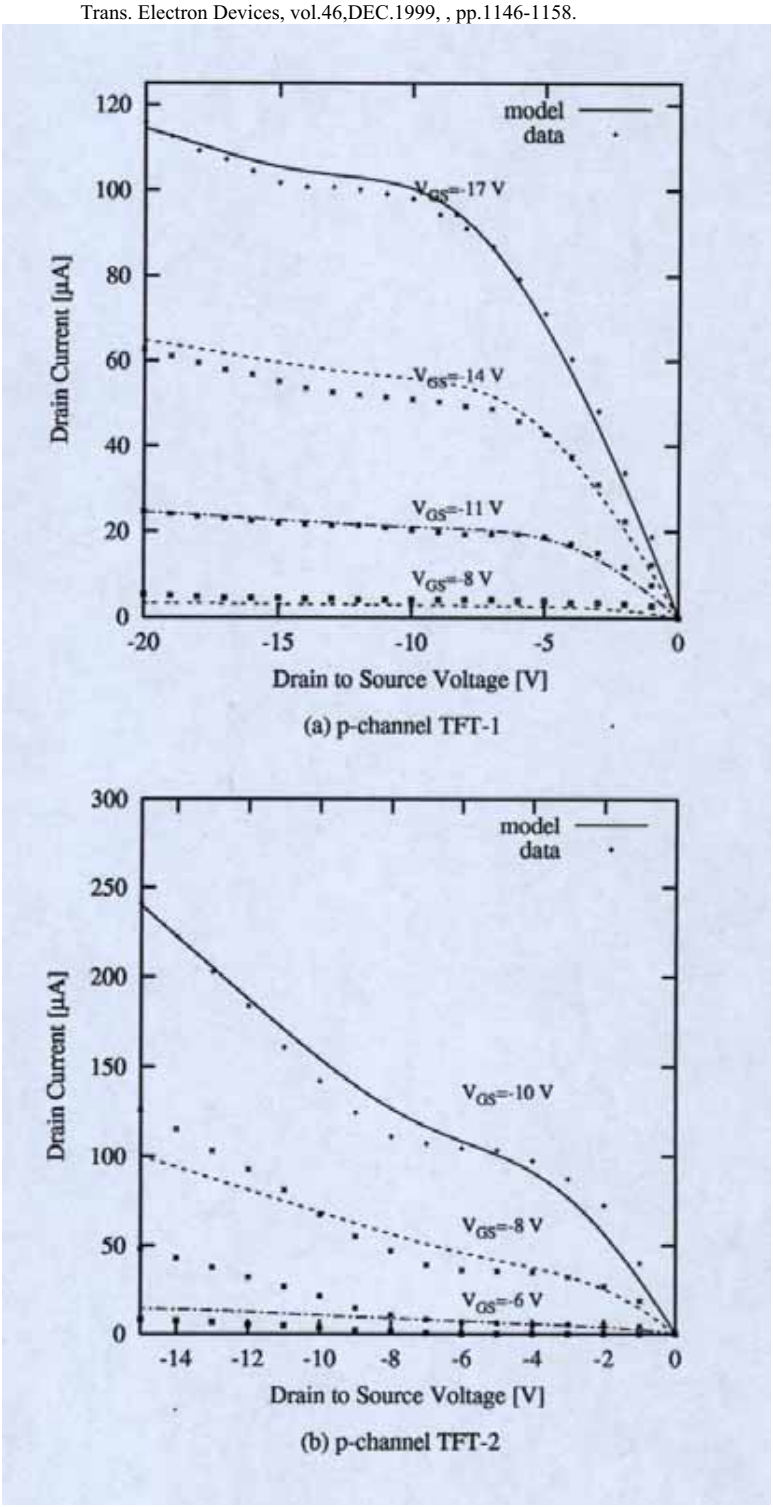

Fig. 2. Output characteristics of p-channel Poly-Si TFTs. Curve indicate model results and symbols indicate experimental data.

Top