Physically-Based Compact Modeling for Amorphous Oxide Thin Film Transistors

Sungsik Lee and Arokia Nathan

The Hetero-Genesys Laboratory, Department of Engineering, University of Cambridge

(E-mails: sl684@cam.ac.uk, an299@cam.ac.uk)

Introduction

- Both TLC, associated with tails states, and Percolation, due to compositional disorder, considered.
- Above-threshold and Sub-threshold models separately derived and combined in a harmonic average.

Results and Discussions

- Mobility and I-V relation for above-threshold regime:

$$\mu_0^* = \mu_0 \exp\left(\frac{-q\phi_{B0}}{kT} + \frac{(q\sigma_{B0})^2}{2(kT)^2}\right)$$

$$\mu_n = \mu_0 \exp\left(\frac{-q\phi_{B0}}{kT} + \frac{(q\sigma_{B0})^2}{2(kT)^2}\right)\exp\left(\frac{\gamma_B}{kT}(E_F - E_m)\right)$$

$$\mu_{FE}(V_{GS}, V_{ch}) \approx \mu_0^*\left(\frac{N_C}{N_C + 0.5N_{tc}kT_t}\right)\left(\frac{C_{ox}}{Q_{ref}}\right)^{\alpha_p}(V_{GS} - V_{ch} - V_T)^{\alpha_p}$$

$$I_{DS} \approx \mu_{FE}\left(\frac{N_C}{N_C + 0.5N_{tc}kT_t}\right)WC_{ox}(V_{GS} - V_{ch} - V_T)\frac{dV_{ch}}{dx}$$

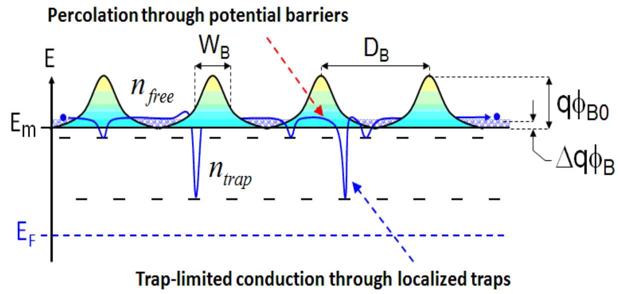
$$\int_0^L I_{DS}dx \approx \mu_0^*\left(\frac{N_C}{N_C + 0.5N_{tc}kT_t}\right)W\frac{C_{ox}^{\alpha_p+1}}{Q_{ref}^{\alpha_p}}\int_0^{V_{DS}}(V_{GS} - V_{ch} - V_T)^{\alpha_p+1}dV_{ch}$$

$$I_{DS} = \mu_0^*\left(\frac{N_C}{N_C + 0.5N_{tc}kT_t}\right)\frac{W}{L'}\frac{C_{ox}^{\alpha_p+1}}{Q_{ref}^{\alpha_p}(\alpha_p+2)}\left[(V_{GS} - V_T)^{(\alpha_p+2)} - (V_{GS} - V_T - V'_{DS})^{(\alpha_p+2)}\right]$$

$$(V_{GS} - V_T)^{(\alpha_p+2)} - (V_{GS} - V_T - V'_{DS})^{(\alpha_p+2)} \approx (\alpha_p + 2)(V_{GS} - V_T)^{(\alpha_p+1)}V'_{DS}$$

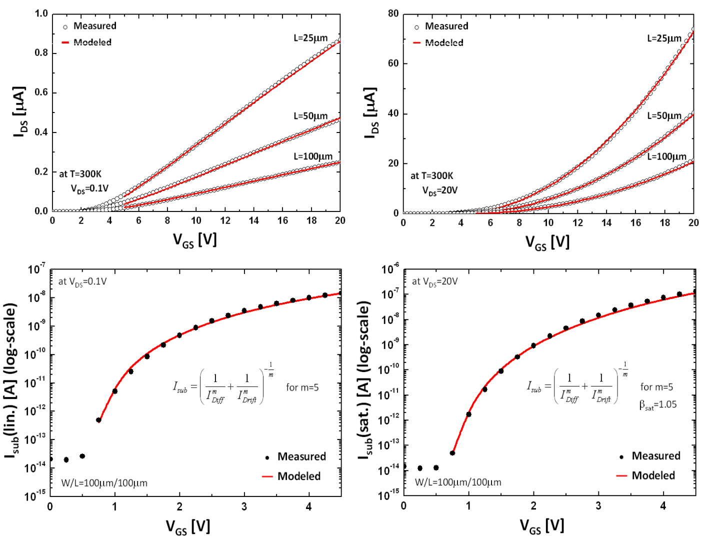
$$I_{sat} = \mu_0^*\left(\frac{N_C}{N_C + 0.5N_{tc}kT_t}\right)\frac{W}{L'}\frac{C_{ox}^{\alpha_p+1}}{Q_{ref}^{\alpha_p}}(V_{GS} - V_T)^{(\alpha_p+2)}\alpha_{sat}$$

- Illustration of carrier transports:



Modes	$kT_t > kT$	$kT_t < kT$
Free Carrier (Boltzmann Approx.)	$n_{free}(E_F) = N_C \exp\left(\frac{E_F - E_m}{kT}\right)$	$n_{free}(E_F) = N_C \exp\left(\frac{E_F - E_m}{kT}\right)$
Trapped Carrier (Tail states)	$n_{tail}(E_F) \approx N_{tc}kT_t \exp\left(\frac{E_F - E_m}{kT_t}\right)$	$n_{tail}(E_F) \approx N_{tc}kT_t \exp\left(\frac{E_F - E_m}{kT}\right)$
$\gamma_{TLC} = \frac{n_{free}}{n_{free} + n_{tail}}$	$\approx \frac{N_C}{N_{tc}kT_t}\exp\left((E_F - E_m)\left(\frac{1}{kT} - \frac{1}{kT_t}\right)\right)$	$= \frac{N_C}{N_C + N_{tc}kT_t}$

- Modeled results on I-V:



- Sub-threshold equations based on drift and diffusion:

$$I_{Diff} \approx \mu_0 \frac{kT}{q}\frac{W}{L'}Q_{fi}\exp\left(\frac{q}{kT}\left(\frac{V_{GS} - V_{FB}}{1 + q^2D_{it}/C_{ox}}\right)\right)\left(1 - \exp\left(-\frac{qV'_{DS}}{kT}\right)\right)$$

$$I_{Drift} \approx \mu_0 \frac{W}{L'}\frac{C_{ox}^{\alpha_d+1}}{Q_d^{\alpha_d}}(V_{GS} - V_{FB})^{(\alpha_d+2)}\beta_{sat} \qquad I_{sub} \equiv (I_{Diff}^{-m} + I_{Drift}^{-m})^{-1/m}$$

Conclusion

- Fully physical model developed for oxide TFTs, considering TLC and percolation mechanisms for above-threshold regime while considering both diffusion & drift transports for sub-threshold regime.

Related Publications:

- Sungsik Lee *et al.*, ***IEEE Journal of Display Technology*** 9(11), 883 (2013).
- Sungsik Lee *et al.*, ***SID Symposium Digest*** 44(1), 22 (2013).