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Unified Length-/Width-Dependent Threshold Voltage Model with Reverse Short-Channel and Inverse Narrow-Width Effects

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Introduction

- **Measurement data show**
  i) for W_{max}, threshold voltage roll-up and roll-off at decreasing channel length
  --- Short-channel effect (SCE)
  --- Reverse-short-channel effect (RSCE)
  ii) for L_{max}, threshold voltage roll-off at decreasing channel width.
  --- Inverse narrow-width effect (INWE)
  iii) for L_{min}, threshold voltage roll-up and roll-off at decreasing channel length
  --- Narrow-width effect (NWE)
  --- INWE

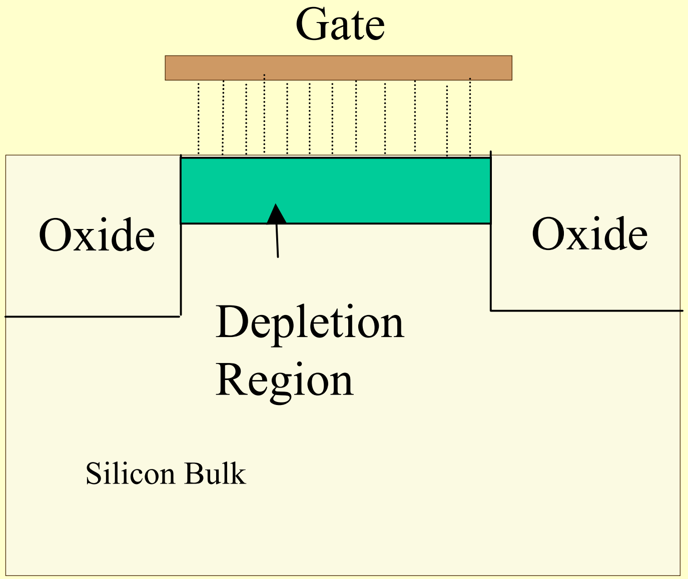
Modeling Approach for $V_t(L,W)$

- Both INWE and NWE are included into our previous $V_t(L)$, which allows unified V_t model to be extended to $V_t(L,W)$

nMOSFET’s with Long-/Narrow-Channel

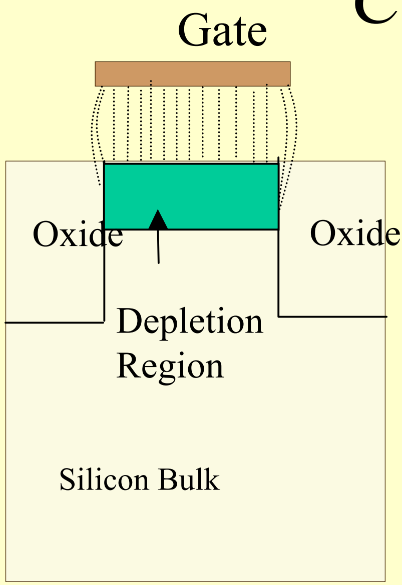
(INWE, V_t roll-off, STI edge fringing capacitance)

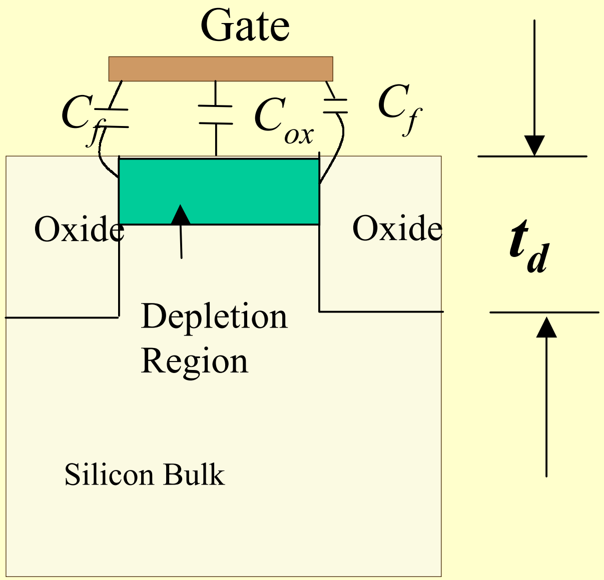
$$V_t = V_{fb} + \phi_s + \frac{Q_{B,L}}{C_g}$$



$$C_g = C_{ox}$$

fitting: τ

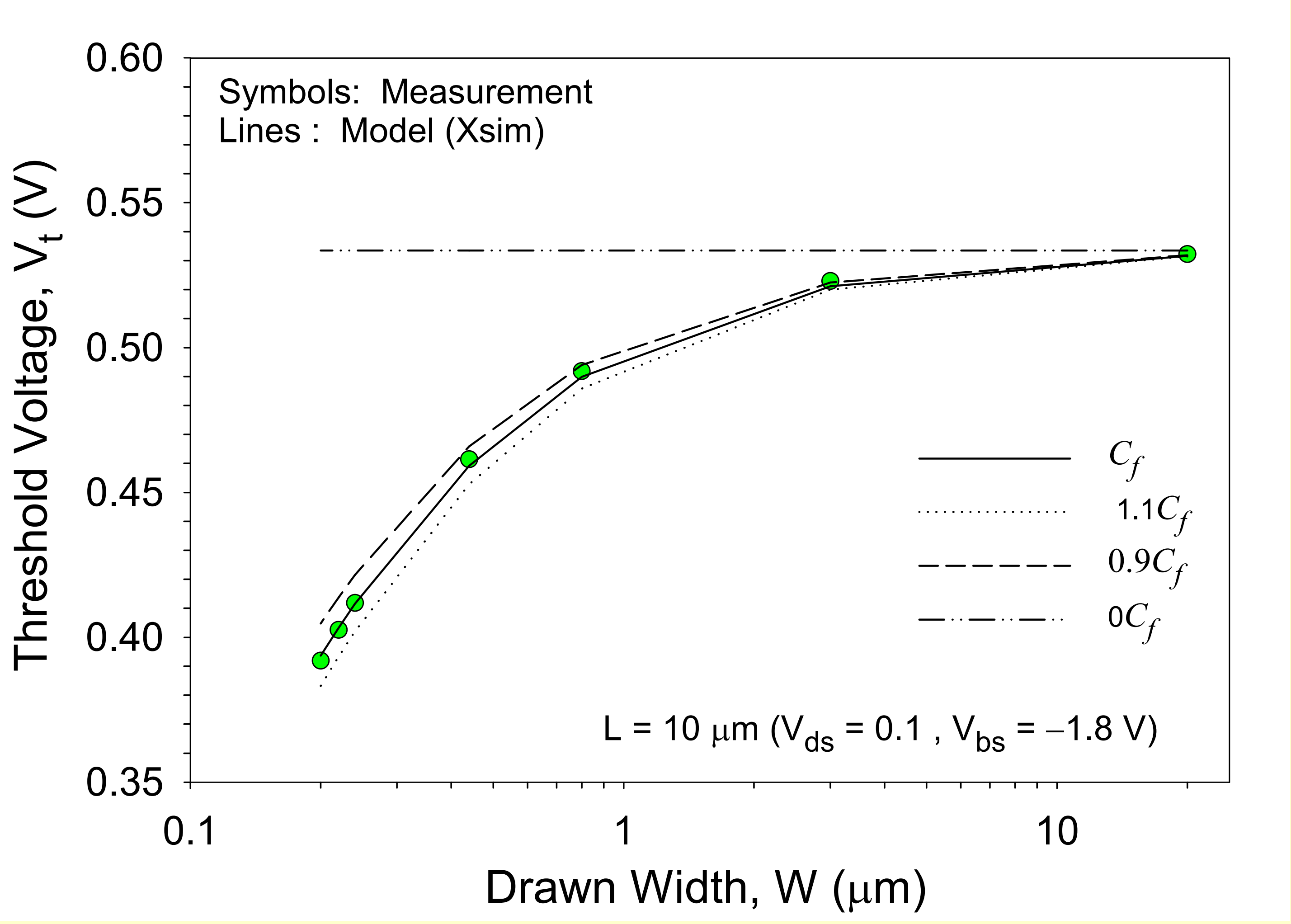




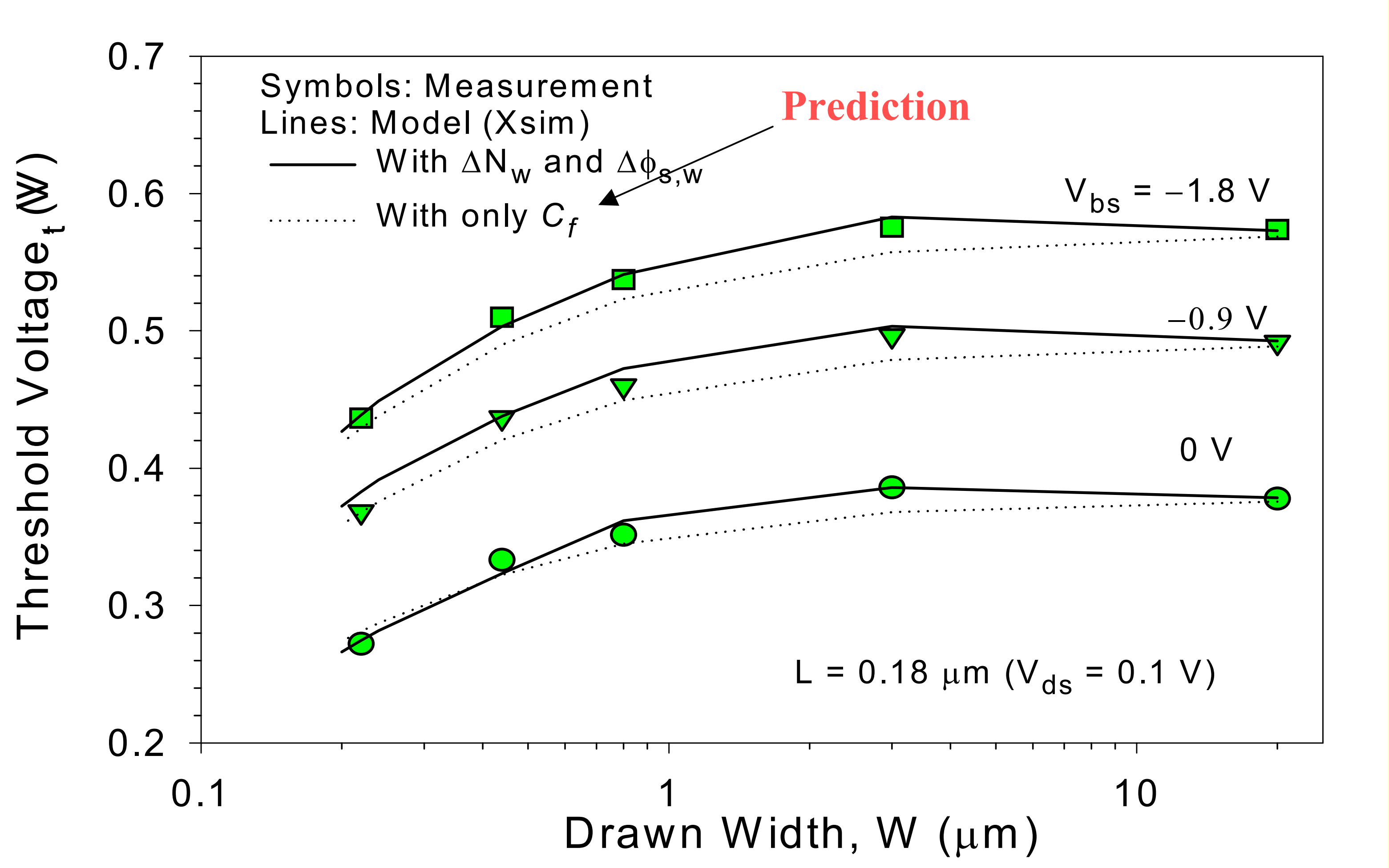
$$C_g = C_{ox} + 2C_f$$

$$C_f = \left(\frac{2\varepsilon_{ox}}{W_{eff}\pi}\right)\ln\left(\frac{2\tau t_d}{t_{ox}}\right)$$

INWE on Threshold Voltage behaviors

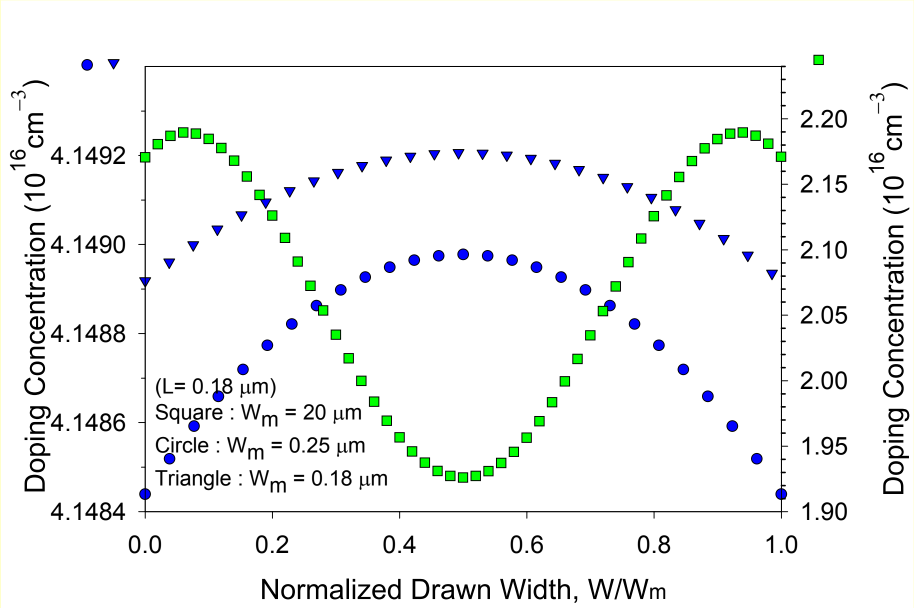


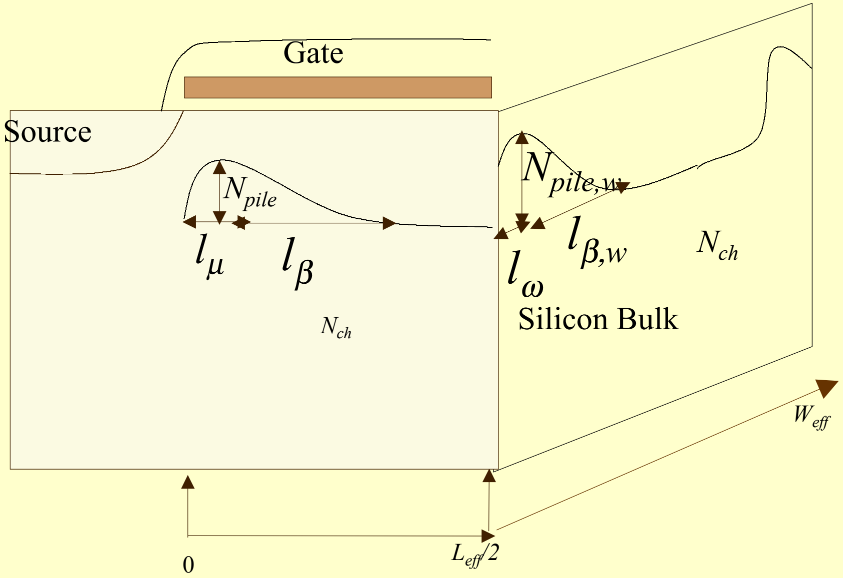
NWE and INWE on Threshold Voltage behaviors



nMOSFET's with Short-/Narrow-Channel

(NWE, V_t roll-up, Gaussian pile-up profile at two edges of STI)





$$N_{eff} = \frac{\sqrt{\pi}\,N_{pile}}{L_{eff}/l_\beta}\left[\mathrm{erf}\left(\frac{L_{eff}-l_\mu}{l_\beta}\right)+\mathrm{erf}\left(\frac{l_\mu}{l_\beta}\right)\right] + \Delta N_w + N_{ch}$$

$$\Delta N_w = \frac{\sqrt{\pi}\,N_{pile,w}}{W_{eff}/l_{\beta,w}}\left[\mathrm{erf}\left(\frac{W_{eff}-l_\omega}{l_{\beta,w}}\right)+\mathrm{erf}\left(\frac{l_\omega}{l_{\beta,w}}\right)\right]$$

$$N_{pile,W} = \kappa_w\left(L_{\min}/L\right)^{\omega_2} N_{ch}, \qquad N_{pile} = \kappa N_{ch}$$

$$l_{\beta,w} = \beta_w\left(\phi_{s0} - V_{bs}\right)^{0.25}$$

- **Pile-up charge at two isolation edges : $N_{pile,w}$**
- **Lateral spread: $l_{\beta,w}$**
- **Pile-up centroid: l_ω**

fitting: $\kappa_w, \beta_w, \omega_2$

nMOSFET's with Short-/Narrow-Channel
(NWE, V_t roll-off)
surface potential shift at two STI edges

$$\phi_{eff} = \phi_s = \phi_{so} - \Delta_1 V_{ds} \quad \text{for long channel}$$

$$\phi_{eff} = \phi_s - \Delta\phi_s \quad \text{for SCE}$$

$$\phi_{eff} = \phi_s - \Delta\phi_s - \Delta\phi_{s,w} \quad \text{for INWE}$$

$$\Delta\phi_s = \frac{\left(V_{bi} - 2\phi_F + \frac{V_{ds}}{2}\right)}{\cosh\left(\frac{L_{eff}}{2l_\alpha}\right)}$$

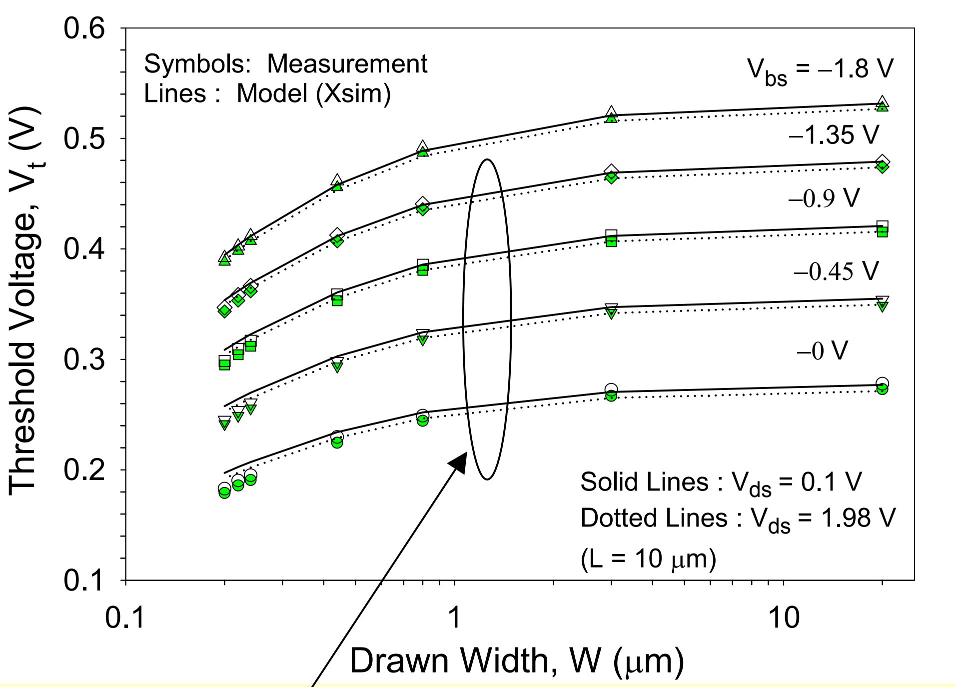
$$\Delta\phi_{s,w} = \frac{V_{bi} - \phi_{s0}}{\cosh\left(W_{eff}/2l_{\alpha,w}\right)}$$

$$l_{\alpha,w} = \alpha_{w,eff}\left(\phi_{s0} - V_{bs}\right)^{0.25}$$

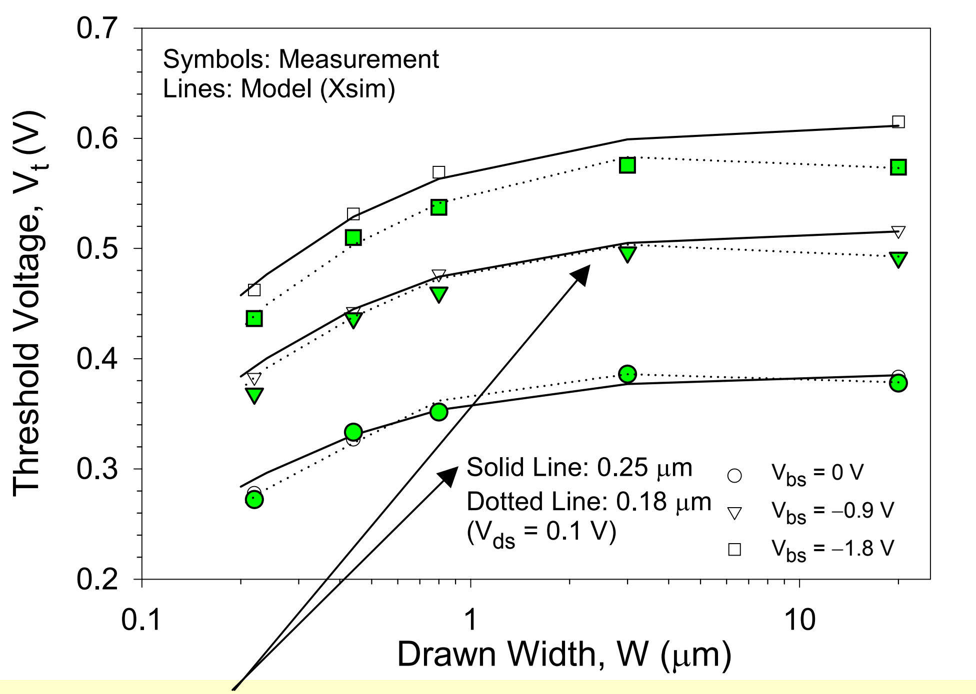
$$\alpha_{w,eff} = \alpha_w\left(L_{\min}/L\right)^{\omega_1}$$

fitting: α_w, ω

Model Verification and Prediction

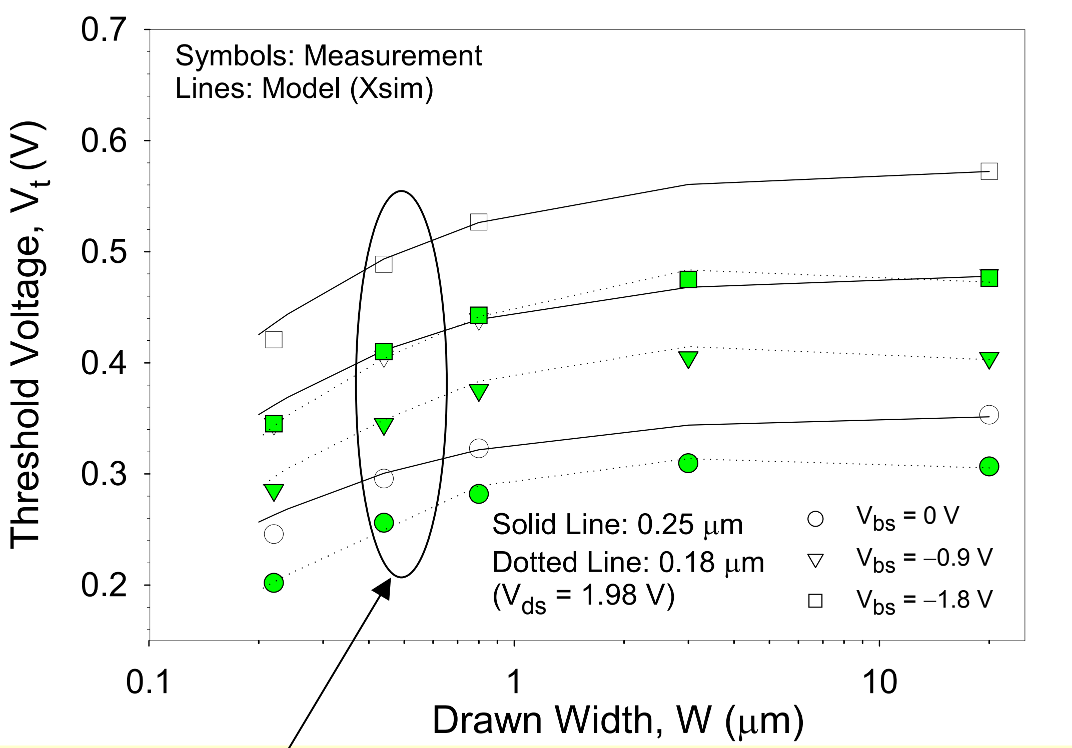


Prediction

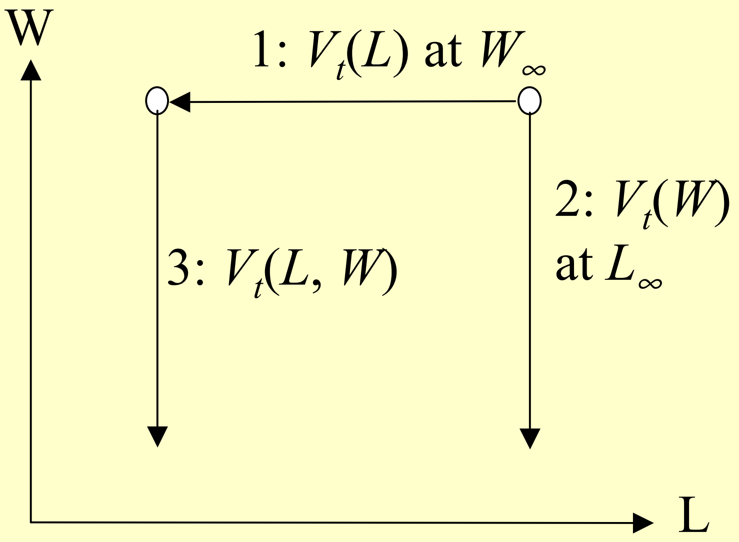


Prediction

Model Prediction and Calibration Sequence



Prediction



W

L

1: $V_t(L)$ at W_∞

2: $V_t(W)$ at L_∞

3: $V_t(L, W)$

Conclusion

- Our previous length-dependent threshold voltage is extended to both length and width dimensions at various bias conditions.
- NWEs and INWEs are modeled through fringing capacitance, surface-potential barrier lowering and pile-up charge with an effective doping.
- Accurate width-dependent threshold voltage modeling allows less effort to model width dependence in the drain current model.