A Surface-Potential-Based MOSFET Substrate Current Model

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Outline

- Introduction
- V_{dsat}-based approach
- Surface-potential-based approach
- Computing ϕ accurately
- Model verification
- Conclusions

Introduction

- Impact ionization $\Rightarrow$ substrate current
- Most of existing compact models are based on the same approach – V_{dsat}
- Within the context of the threshold-voltage-based models, smoothing function has to be used to achieve the transition from subthreshold to velocity saturation
- Using surface-potential-based approach and replacing V_{dsat} with the surface potential difference (ϕ) between the two ends of the gradual channel, the asymptotic transition is automatic
- The accuracy of the developed model was verified using experimental data

V_{dsat}-based approach

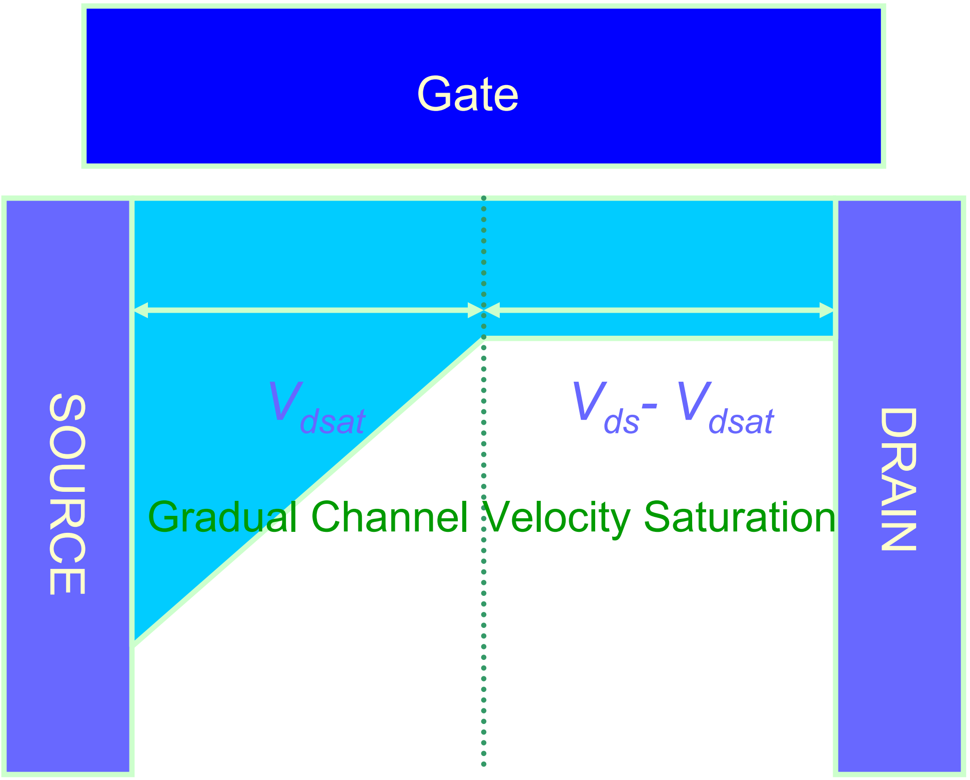
- The original expression based on the pseudo-2D analysis

$$I_b = a_1 I_d \exp\left(\frac{a_2}{V_{ds} - a_3 V_{dsat}}\right)$$

$$V_{ds} > a_3 V_{dsat}$$

- V_{ds}-a_3V_{dsat} represents the potential drop across the velocity saturation region and a_2 models the characteristic length

P. KO *et al.* TED 1985



V_{dsat}-based approach

- In subthreshold region, similar analysis shows

$$I_b = a_1 I_d \exp\left(\frac{a_2}{V_{ds}}\right) \quad \text{in subthreshold}$$

B. INIGUEZ *et al.* SSE 1997

- Conventional models have to rely on the smoothing functions to achieve the transition between the two regions

$$I_b = a_1 I_d \exp\left(\frac{a_2}{V_{ds} - a_3 V_{dse}}\right)$$

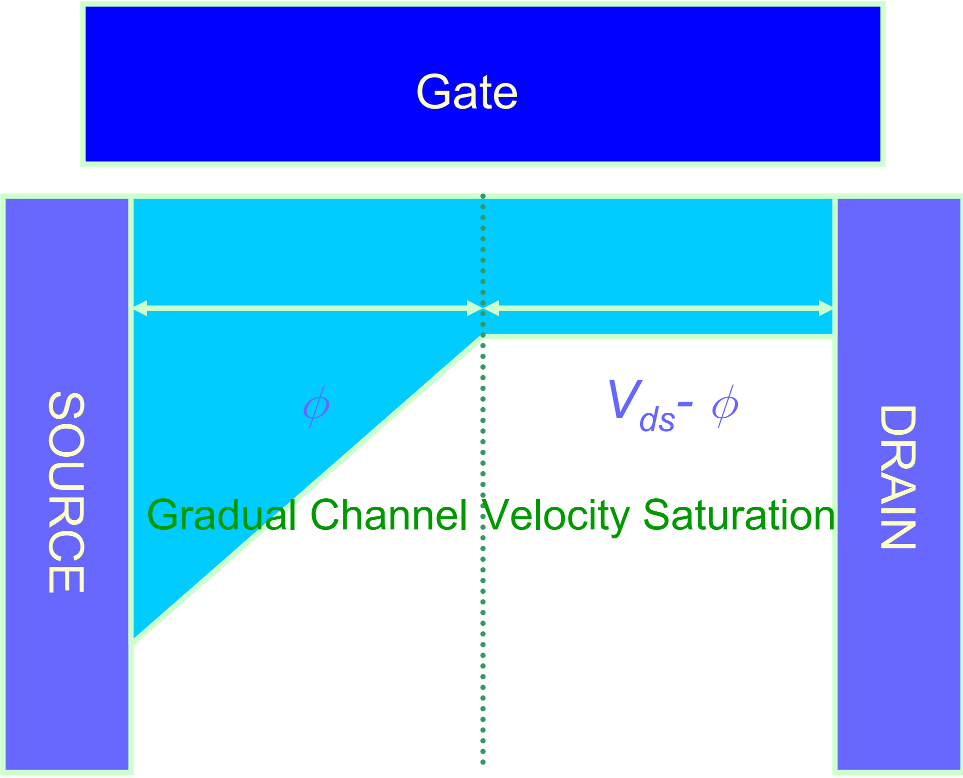
$$V_{dse} : \quad \text{transition from 0 to } V_{dsat}$$

Surface-Potential-Based Approach

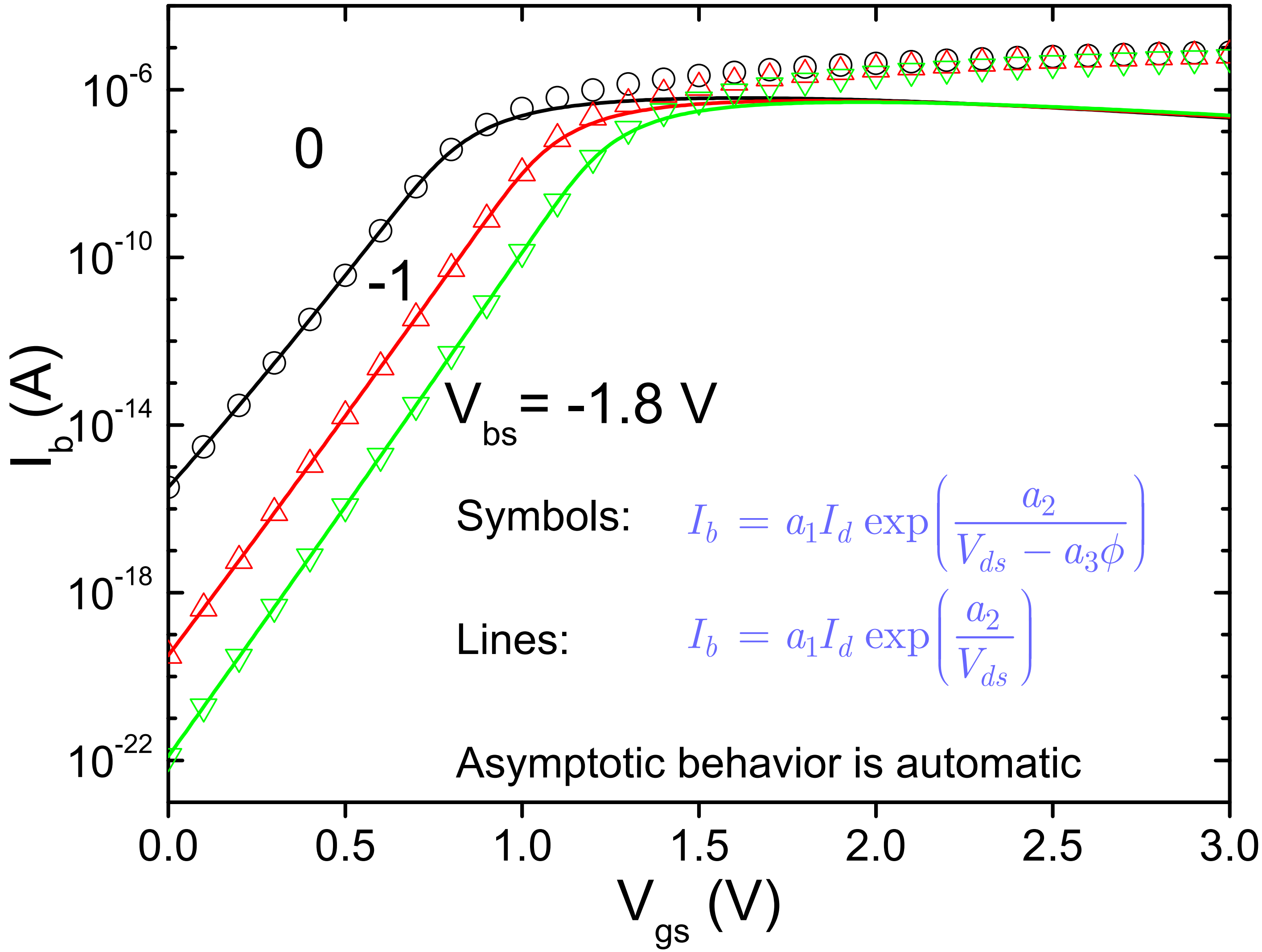
- Within the context of the surface-potential-based models, the potential drop across the velocity saturation region is given by V_{ds}-ϕ

$$I_b = a_1 I_d \exp\left(\frac{a_2}{V_{ds} - a_3\phi}\right)$$

- ϕ: the difference between the surface potentials at the two ends of the gradual channel region
- In the subthreshold region, $\phi \rightarrow 0$, the asymptotic behavior is achieved automatically



Surface-Potential-Based Approach

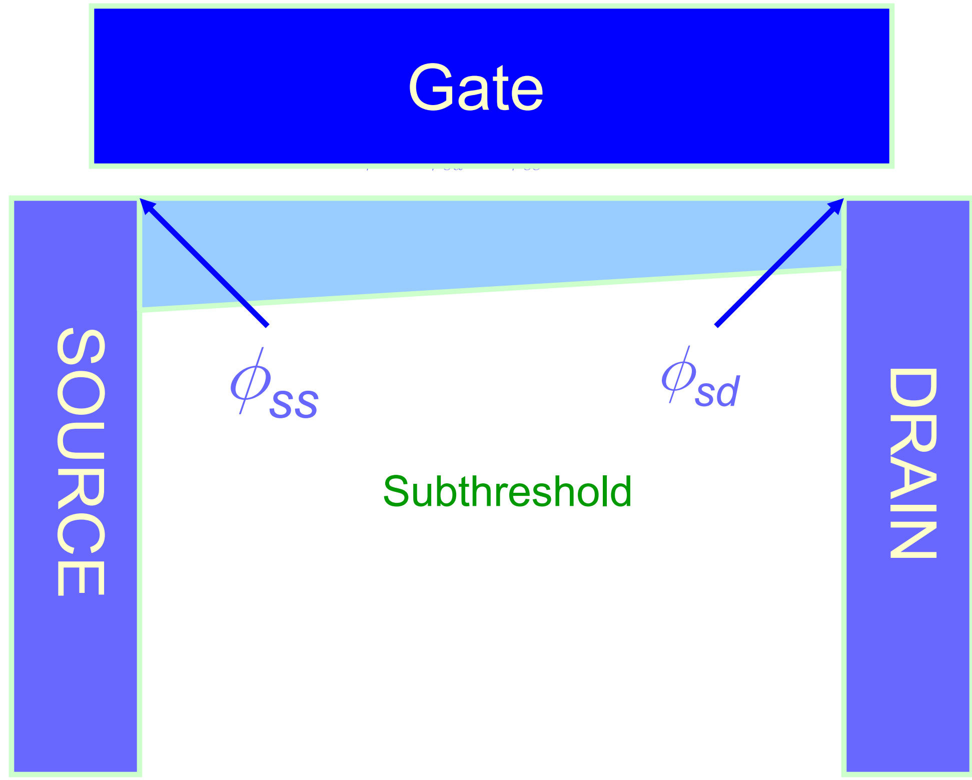


Computing ϕ Accurately

- In the strong inversion region

$$\phi = \phi_{sd} - \phi_{ss}$$

- In the subthreshold region, ϕ_{ss} is very close to ϕ_{sd}, hence ϕ is exponentially small
- ϕ will be buried by numerical noise if continue computing ϕ by subtracting
- Instead, ϕ is computed directly by manipulating the surface potential equations at the two ends of the channel



Computing ϕ Accurately (I)

- At the source end of the channel:

$$\left[\left(V_{gb}-V_{fb}-\phi_{ss}\right)/\gamma\right]^2=\phi_{ss}-\phi_t+\phi_t\Delta_s;\;\;\Delta_s=\exp\left[\left(\phi_{ss}-2\phi_f+V_{bs}\right)/\phi_t\right]$$

- At the drain end of the channel:

$$\left[\left(V_{gb}-V_{fb}-\phi_{sd}\right)/\gamma\right]^2=\phi_{sd}-\phi_t+\phi_t\Delta_d;\;\Delta_d=\exp\left[\left(\phi_{sd}-2\phi_f+V_{bs}-V_{ds}\right)/\phi_t\right]$$

- Subtracting the two equations yields:

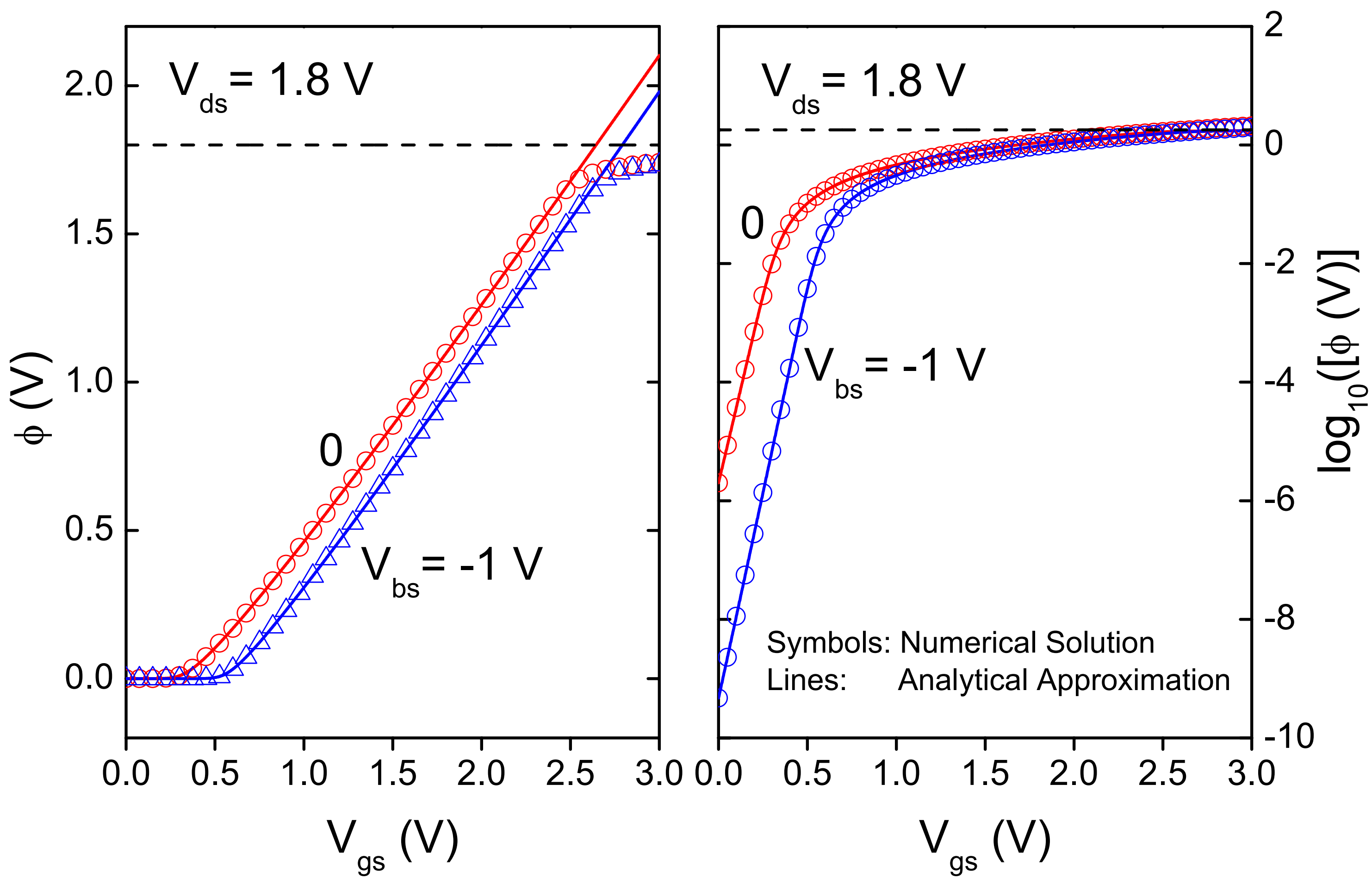
$$\phi^2-2a\phi+\gamma^2\phi_t\Delta_s\left[1-\exp\left(\frac{\phi-V_{ds}}{\phi_t}\right)\right]=0$$

$$a=V_{gb}-V_{fb}-\phi_{ss}+\left(\gamma^2/2\right)$$

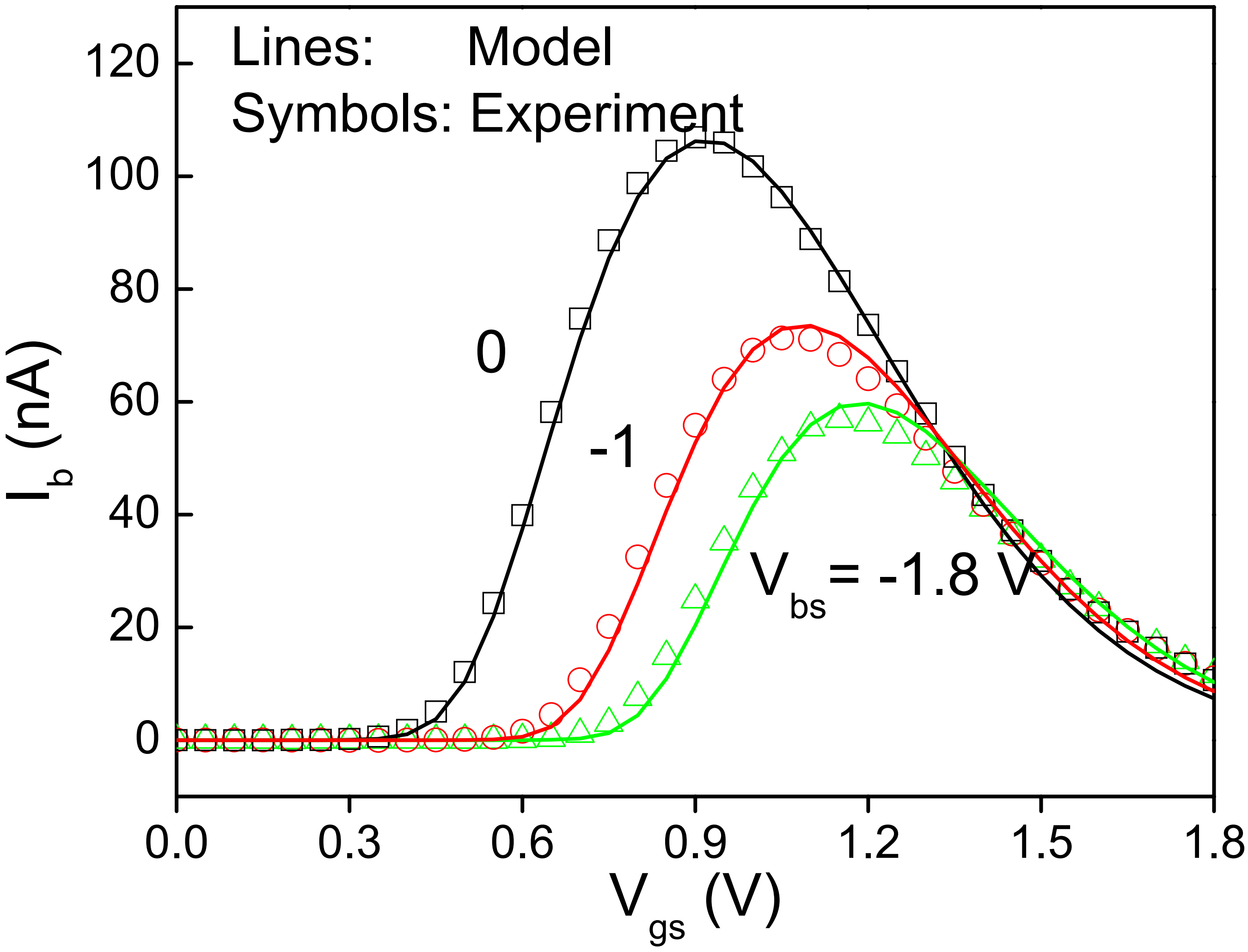
- Analytical solutions:

$$\phi=b\left(a+\sqrt{a^2+b}\right)^{-1};\qquad b=\gamma^2\phi_t\Delta_s\left[1-\exp\left(-V_{ds}/\phi_t\right)\right]$$

Computing ϕ Accurately (II)



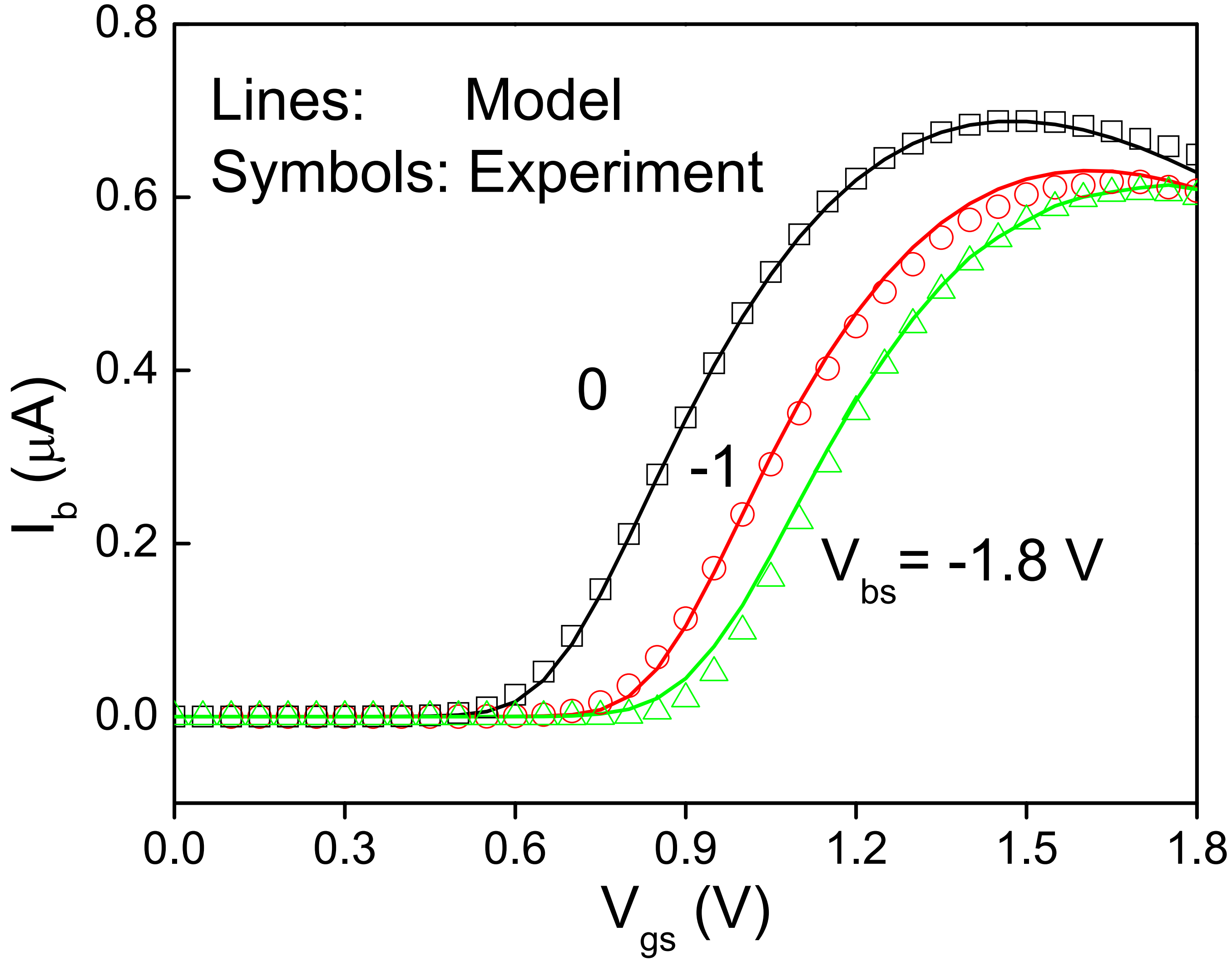
Model Verification



W/L=10μm/0.5μm

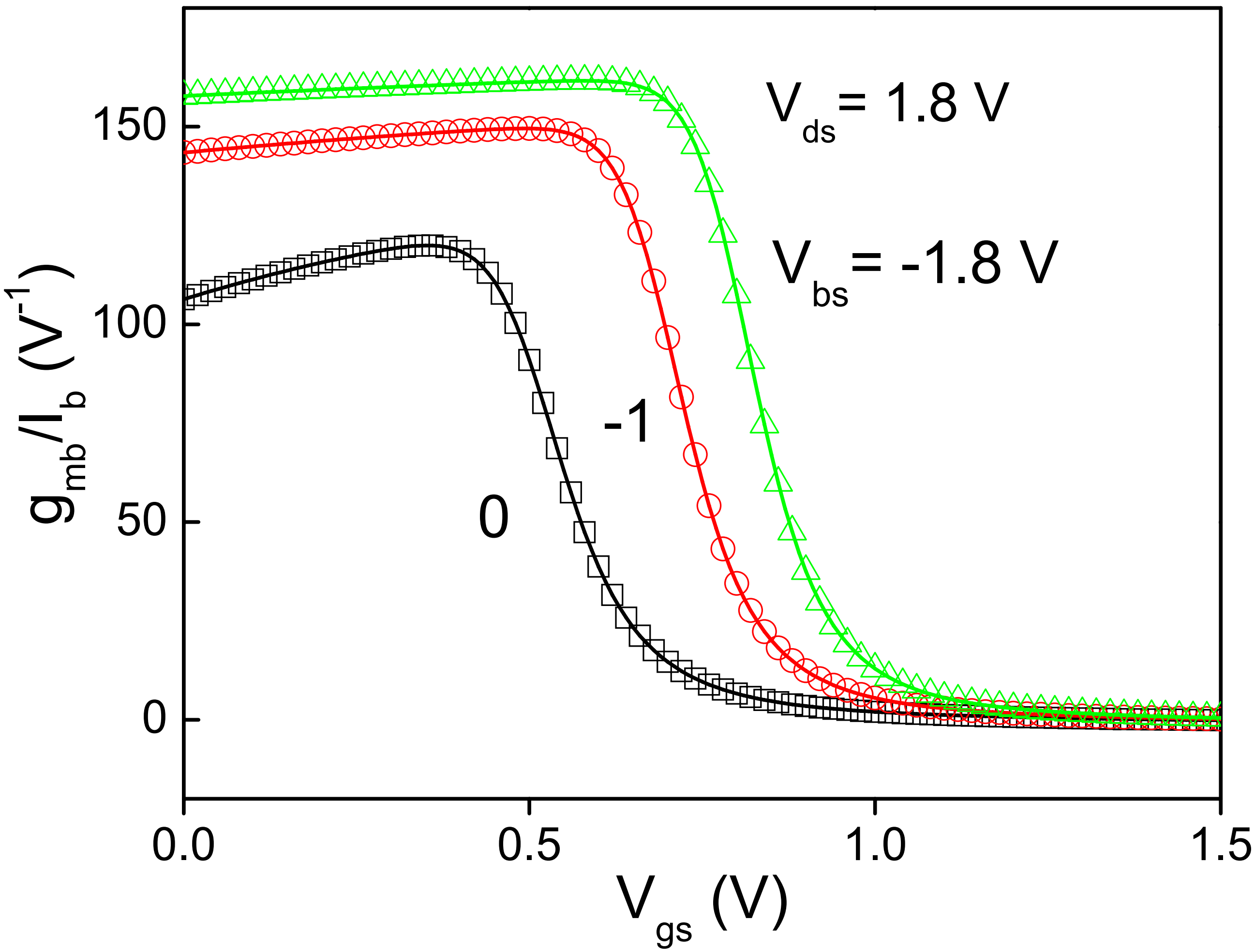
a_2 is made a function of V_{bs} to model the back-bias dependence of characteristic length

Model Verification



W/L=10μm/0.2μm

Asymptotic Transition



$$g_{mb} = \partial I_b / \partial V_{gs}$$

Conclusions – SP Substrate Current Model

- Using surface-potential-based approach to achieve the correct asymptotic behavior automatically, not by using smoothing functions
- Surface potential difference is evaluated accurately by manipulating surface potential equations at the two ends of the channel
- Excellent reproduction of experimental data
- SP model is complete now, being transferred to industry

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