Unified I–V Model and Parameter Extraction of Submicron nMOSFET for Circuit Simulation and Statistical Process Characterization

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Abstract

A new unified charge control model (UCCM) for short channel nMOSFET is proposed to describe subthreshold, near and above threshold regions simultaneously using an analytical formula as follows,

$$V_{GS} - (V_{th,o} - \sigma V_{DS}) - \alpha V = \eta V_T \ln(n_{inv}/n_0) + a(n_{inv} - n_0). \qquad (1)$$

Fig.1 shows the comparison of the n_{inv} vs. V_{GS} characteristics between the measurement and calculated results using eq.(1) for long channel nMOSFET.

We propose the universal mobility model at room temperature. It was found that $\mu_\perp$ is universally dependent on effective transverse electric field, F_{eff}. From the fact that F_{eff} is approximately proportional to $(V_{GS}+V_{th})$ for nMOSFET using n^+ doped poly gate, we found $\mu_\perp$ is linearly and universally dependent on $(V_{GS}+V_{th})$ as shown in Fig.2.

Based on UCCM and universal $\mu_\perp$ model, we develop a new unified I-V model, which is continuous and can cover all operation region of MOSFET for submicron nMOSFET.

$$I_{DS} = qv_{sat}W \frac{[n_S - (\alpha/2\delta)V_{DS}]\cdot V_{DS}}{\sqrt{V_L{}^2+V_{DS}{}^2}} \qquad (V_{DS} \le V_{DSAT}), \quad (2)$$

$$I_{DS} = I_{DSAT}\left[1 + \frac{2V_L V_\lambda}{V_L{}^2+V_{DSAT}{}^2}\cdot\left(\ln\left(\frac{x+\sqrt{x^2+c^2}}{c}\right) + \frac{x}{x+\sqrt{x^2+c^2}}\right)\right] \quad (V_{DS} > V_{DSAT}), \quad (3)$$

where $x=V_{DS}-V_{DSAT}$, and c is a parameter determined from the condition that $\partial I_{DS}/\partial V_{DS}$ is continuous at saturation point.

Our parameter extraction starts from the experimental determination of (V_{dsat}, I_{dsat}) from the $I_{DS}\cdot(\partial V_{DS}/\partial I_{DS})$ plot as shown in Fig.3 in a systematic and unambiguous way , which is based on the finite drain conductance due to the channel length modulation in saturation. The parameter α and the saturation velocity are found from linear regression as shown in Fig.4. Our calculation of I–V characteristics using extracted parameters show excellent agreement with experimental results as shown in Fig.5 and Fig.6 for the entire V_{ds}, V_{gs} and V_{BS} (V_{BS} dependence is not shown here).

The extracted parameters also agree well with independent measurement results and thus are very physical. Our unified model and parameter extraction are very suitable for circuit simulation, process characterization using computer controlled measurement system and statistical yield analysis due to parameter variation.

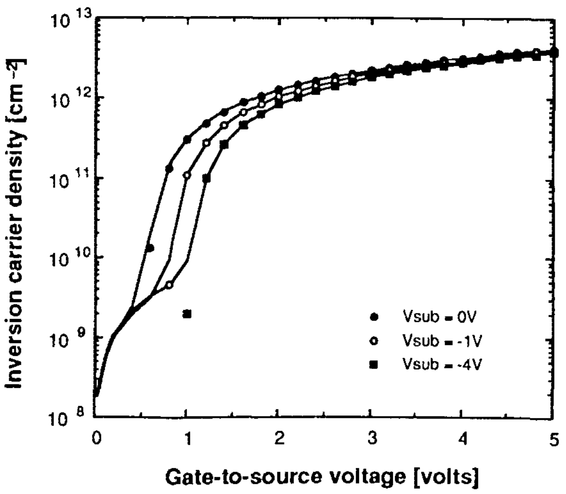

Fig.1 Comparison of n_{inv} vs. V_{GS} characteristics between experimental measurement (lines) and UCCM (dots)

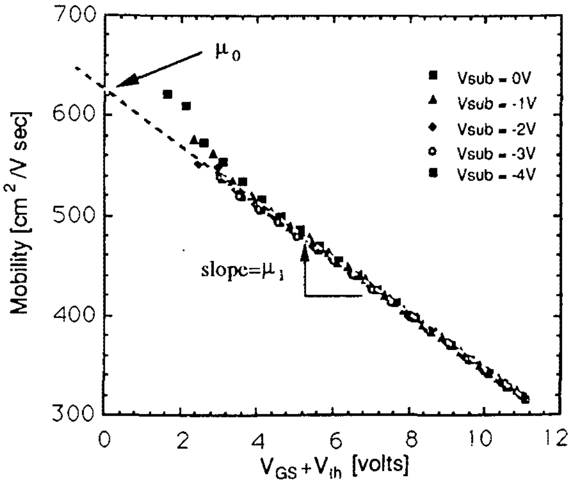

Fig.2 Measured mobility vs. (V_{GS}+V_{th}) plot for different substrate bias, showing universal and linear dependence of mobility on (V_{GS}+V_{th}).

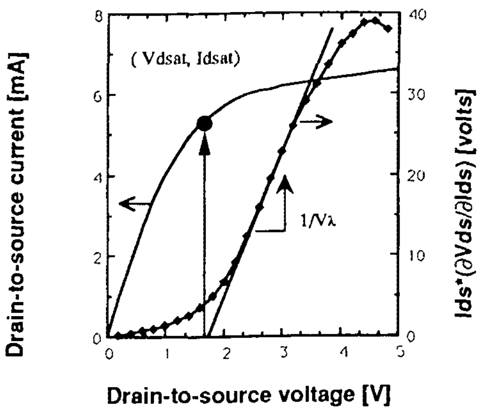

Fig.3 Determination of sturation point and V_λ from I_{ds}*R_{ds} plot.

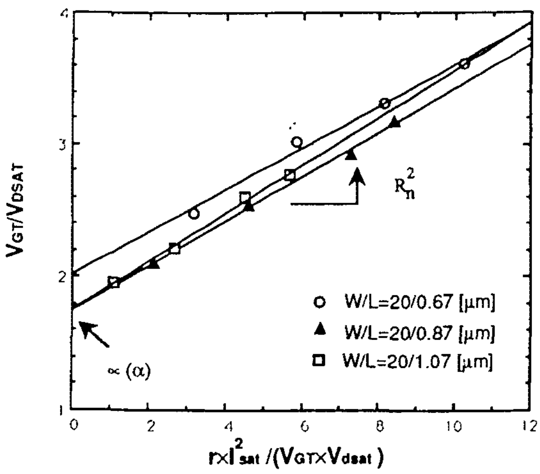

Fig.4 Extraction of α and v_{sat}, R_n = $1/WC_{ox}v_{sat}$.

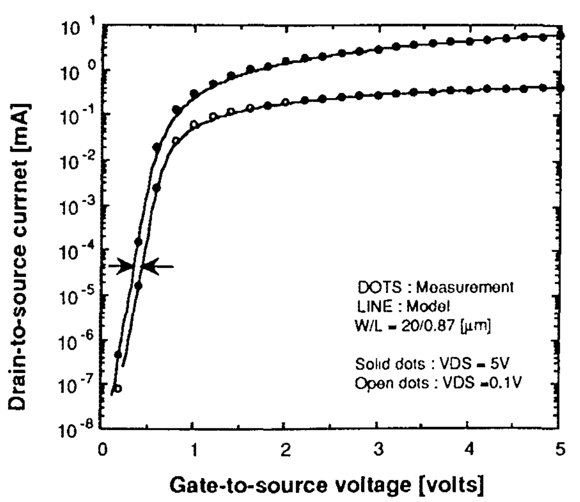

Fig.5 Comparison of I_D vs. V_{GS} characteristics for V_{DS} = 0.1V and 5V between measurement (dots) and unified I-V model (lines), showing the DIBL effect.

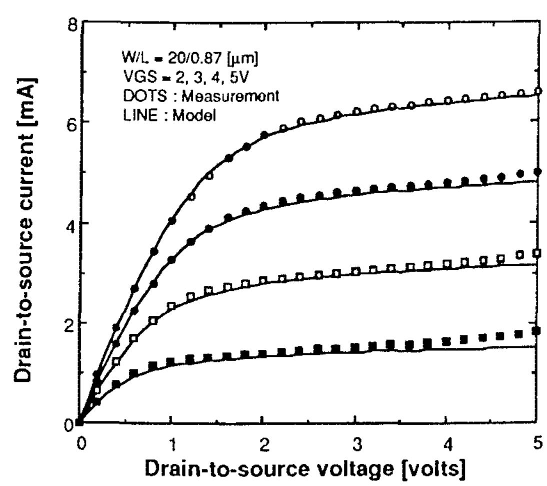

Fig.6 Comparison of I_D vs. V_{DS} characteristics for V_{GS} = 2, 3, 4, 5V between measurement (dots) and unified I-V model (lines) for W/L=20/0.87 [μm] nMOSFET. V_{th} = 0.65V.