

LCDE of FET Drain Current and Application in Parameter Extraction

Jin He, Xuemei Xi, Mansun Chan, Ali M.
Niknejad, and Chenming Hu

Department of EECS, University of California, Berkeley, CA
94720, USA

jinhe@eecs.berkeley.edu



OUTLINE

- ◆ **NEED** for accurate parameter extraction in MOSFET modeling
- ◆ **PINCIPLE** of **Linear Cofactor Difference Extreme** for analytical extraction
- ◆ **LCDE** application and verification
- ◆ **CONCLUSIONS**

INTRODCUTION

- ◆ **Important parameters:** V_{th} and mobility
- ◆ **Previous methods:** simplicity and accuracy
- ◆ **LCDE method:** non-linear conduction principle of FET and a mathematical test
- ◆ **Principle introduction** and applications

PRINCIPLE OF LCDE

- ◆ Non-linear conduction principle of FET: If FET current is non-linear, the difference of FET current and any linear function always shows the extreme peak in this non-linear region

$$G'(x_p) = \left. \frac{\partial G}{\partial x} \right|_{x=x_p} = 0$$

$$G(x) = \Delta f(x) = b + Kx - f(x)$$

- ◆ $G(x_1) = b + Kx_1 - f(x_1) = 0$ LCDE makes use of this principle to extract FET parameters.
- ◆ $G(x_0) = b + Kx_0 - f(x_0) = 0$ FET drain current always shows the extreme peak either in gate voltage axis or drain voltage axis.

FORMULATION OF LCDE

MOSFET drain current equation including series resistance and mobility degradation effect

$$\frac{V_{ds}}{I_{ds}} = R_s + R_d + \frac{1}{\beta \mu_{eff} (V_{gs} - V_{th})}$$

$$R_t = R_s + R_d \quad \theta = \theta_0 + R_t \beta$$

$$I_{ds} = \frac{\beta (V_{gs} - V_{th}) V_{ds}}{1 + \theta (V_{gs} - V_{th})}$$

EXTRACTION EQUATIONS

- ◆ Extraction function

$$\Delta I_{ds}(V_{gs}) = \frac{\beta(V_{gs} - V_{th})V_{ds}}{1 + \theta(V_{gs} - V_{th})} - (KV_{gs} + b)$$

- ◆ LCDE Principle

$$\left. \frac{\partial \Delta I_{ds}(V_{gs})}{\partial V_{gs}} \right|_{V_{gs}=V_{GP}} = 0$$

- ◆ Extraction equation (1)

$$I_{ds}(V_{GP}) = \sqrt{Kv_{ds}} \beta (V_{GP} - V_{th})$$

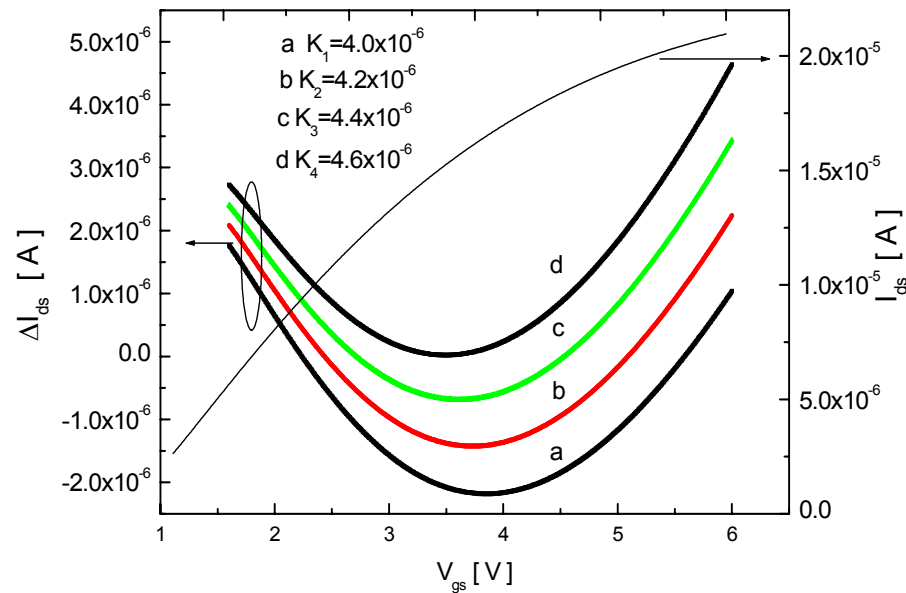
- ◆ Extraction equation (2)

$$\beta = \frac{1}{V_{ds}} \left[\frac{\frac{I_{ds}(V_{GP1})}{\sqrt{K_1}} - \frac{I_{ds}(V_{GP2})}{\sqrt{K_2}}}{V_{GP1} - V_{GP2}} \right]^2$$

- ◆ Extraction equation (3)

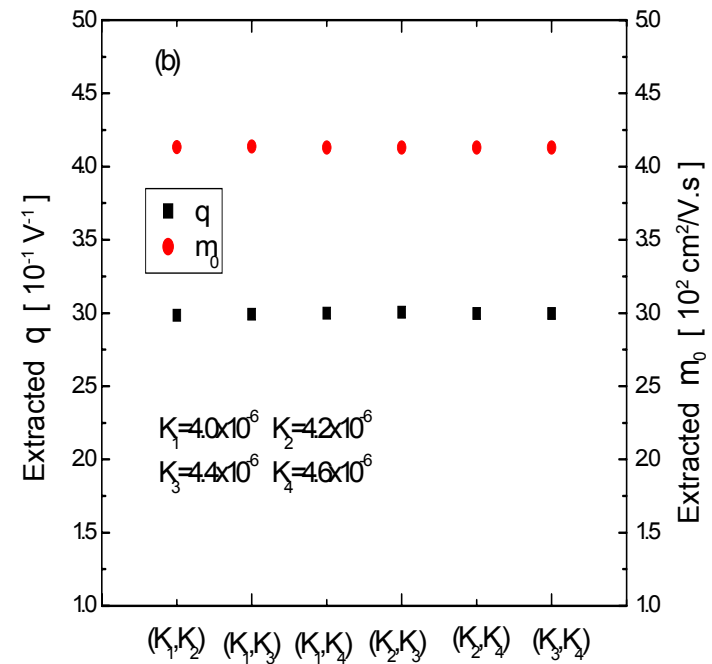
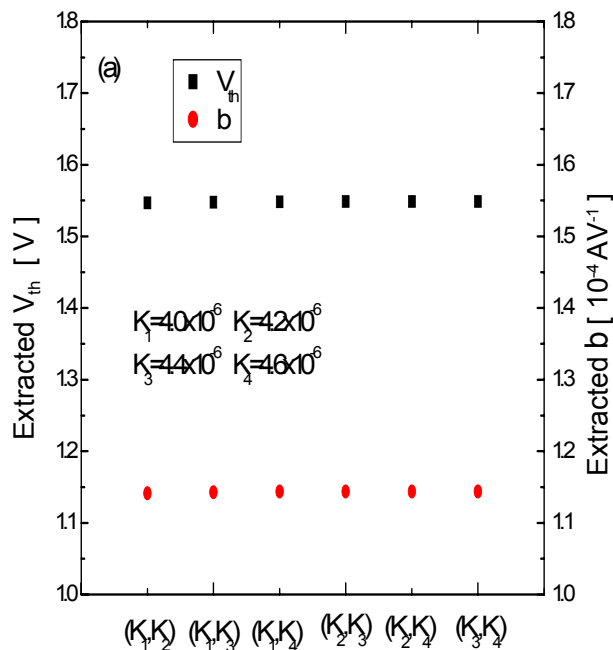
$$\theta = \frac{\sqrt{\beta V_{ds}} - \sqrt{K}}{\sqrt{K} [V_{GP} - V_{th}]}$$

LCDE DEMONSTRATION



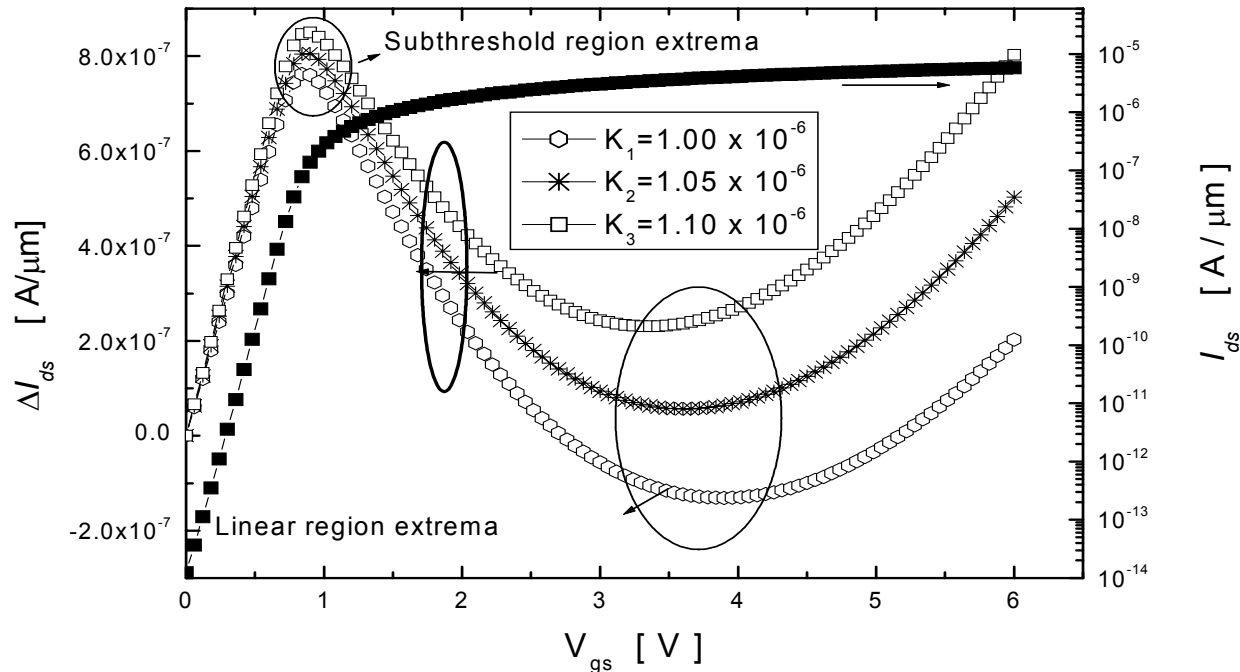
The drain current linear cofactor difference versus gate voltage for different value of K . The LCDO method is applied to the linear region I-V characteristics of a fabricated n-channel MOSFET.

SENSISTIVE OF PARAMETERS



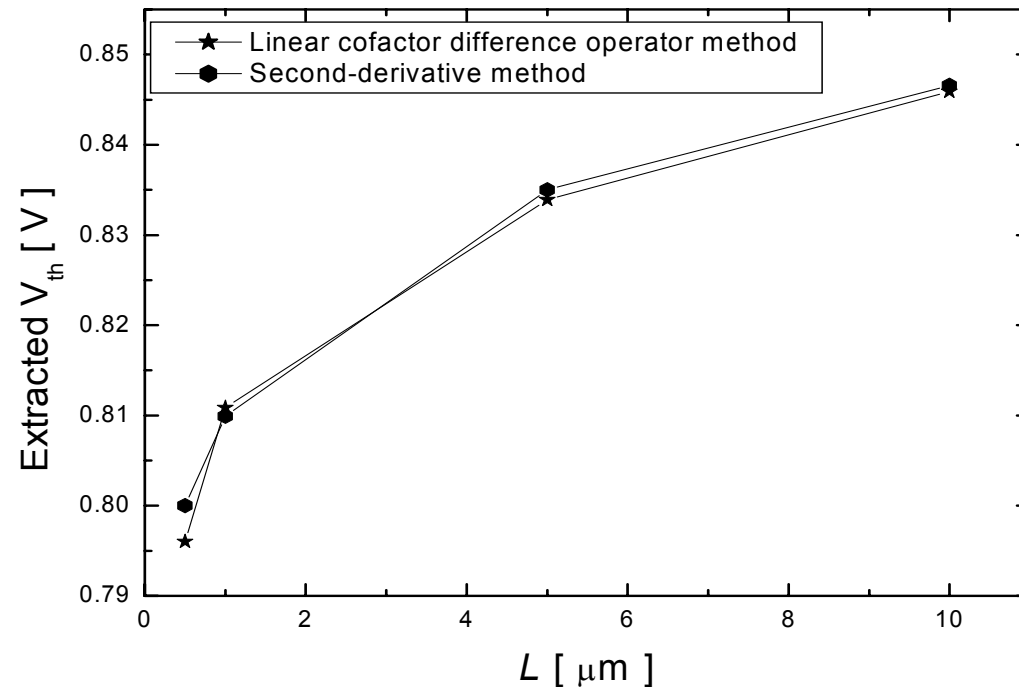
Dependence of the extracted parameters on K_i and K_j : (a) Threshold voltage and transistor gain factor extracted (b) Low field mobility and its degradation factor for the different K_i .

LCDE DEMONSTRATION



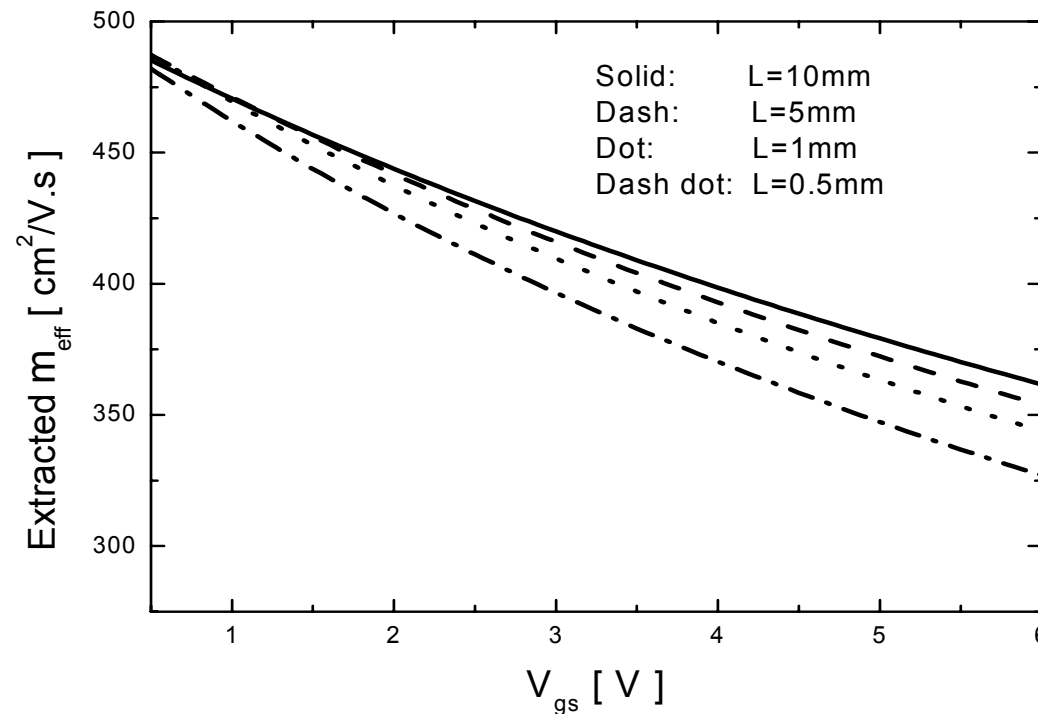
The drain current linear cofactor difference versus gate voltage for different values of K in the sub- and linear region of a simulated n -FETs.

V_{th} EXTRACTION COMPARISON



Comparison of threshold voltage variation obtained by LCDO the standard second-derivative methods.

MOBILITY DEGRADATION



Mobility degradation characteristics of the simulated MOSFETs with the different channel length obtained by the linear cofactor difference operator method.

SUMMARY

- ◆ New method LCDE for FET parameter extraction developed
- ◆ LCDE spectrums of MOSFET drain current demonstrated
- ◆ Parameter extraction of MOSFET realized and verification
- ◆ LCDE can be used in more MOSFET modeling characterization.