P087 Reliability Modeling on 90 nm n-channel MOSFETs with BSIM4 Dedicated to HCI Mechanisms

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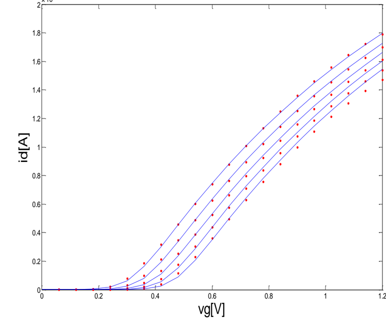
Introduction

Research Goal

Developed MOSFET model

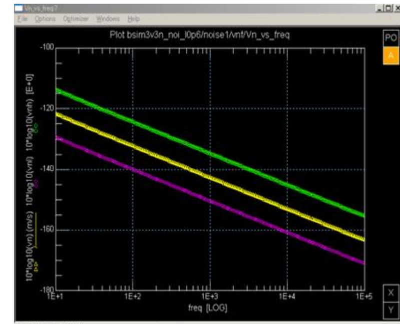
- HCI induced DC degradation model

Show degradation DC characteristics

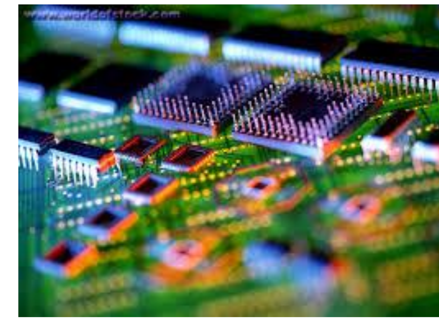


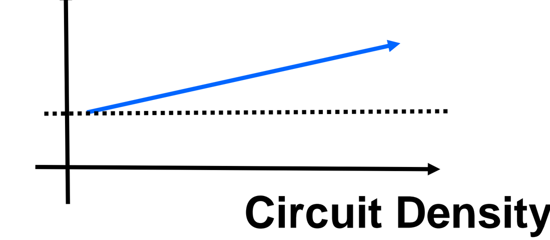
- 1/f noise model

Show deterioration 1/f noise at DC



Background





Performance

Circuit Density

Circuit Size

Large ⇒ Small

- Manufacturing Variations
- Degradations of Circuit Performance Due to Time and Temperature

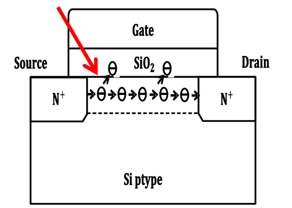
Generation Principle of 1/f noise

1/f noise: Occurred in all active elements

Dominant in the low frequency

Electrons are trapped in the channel

$$S_{id}(f) = \frac{KF \cdot I_{ds}^{AF}}{C_{OX} L_{eff}^{2} f^{EF}}$$



Hot Carrier Injection (HCI)

Reaction-Diffusion model (RD model)

- Modeled hot carrier effect
- Represented hydrogen diffusion of particles

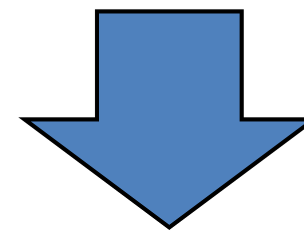
Degradation Equations

RD Model Equations

- $N_{H(0)} N_{it} \approx \frac{k_F}{k_R} N_0$ (1)
- $N_{H_x} = k_H N_H^{\,n_x}$ (2)
- $N_{it} = \frac{\pi W}{2A_{tot}} n_x \int_0^{\sqrt{D_{H_x}t}} \left(N_{H_x(0)} \left[r - \frac{r^2}{\sqrt{D_{H_x}t}} \right] \right) dr = N_{H_x(0)} \frac{\pi n_x}{12L} D_{H_x}t$ (3)
- $N_{it} = \left(\frac{k_F N_0}{k_R}\right)^{\frac{n_x}{1+n_x}} \left(\frac{n_x \pi k_H}{12L} D_H\right)^{\frac{1}{1+n_x}} * t^{\frac{1}{1+n_x}}$ (4)
- $\Delta V_{th_{DEGRADATION}} = C_{HCI} \left(\frac{k_F N_0}{k_R}\right)^{\frac{n_x}{1+n_x}} \left(\frac{n_x \pi k_H}{12L} D_H\right)^{\frac{1}{1+n_x}} * t^{\frac{1}{1+n_x}}$ (5)

Proposed Model

Threshold voltage shift due to HCI Implemented to mobility model equation



Modeling of mobility degradation phenomenon

Mobility Model

$$\mu_{eff} = \frac{U0}{1 + (UA + UC * V_{bseff}) \left[\frac{V_{gsteff} + C_0 (VTH0 - VFB - \phi_s)}{TOXE} \right]^{EU}} \quad (6)$$

$$V_{th} = VTH0 + \Delta V_{th,\ body_effect} - \Delta V_{th,\ carge_{sharing}} - \Delta V_{th,\ DIBL} + \Delta V_{th,\ reverse_short_cannel} + \Delta V_{th,\ narrow_{width}} + \Delta V_{th,\ small_size} - \Delta V_{th,\ pocket_implant} + \Delta V_{th_DEGRADATION} \quad (7)$$

Simulation

Conditions for Our Experiments

90 nm process n-channel MOSFET

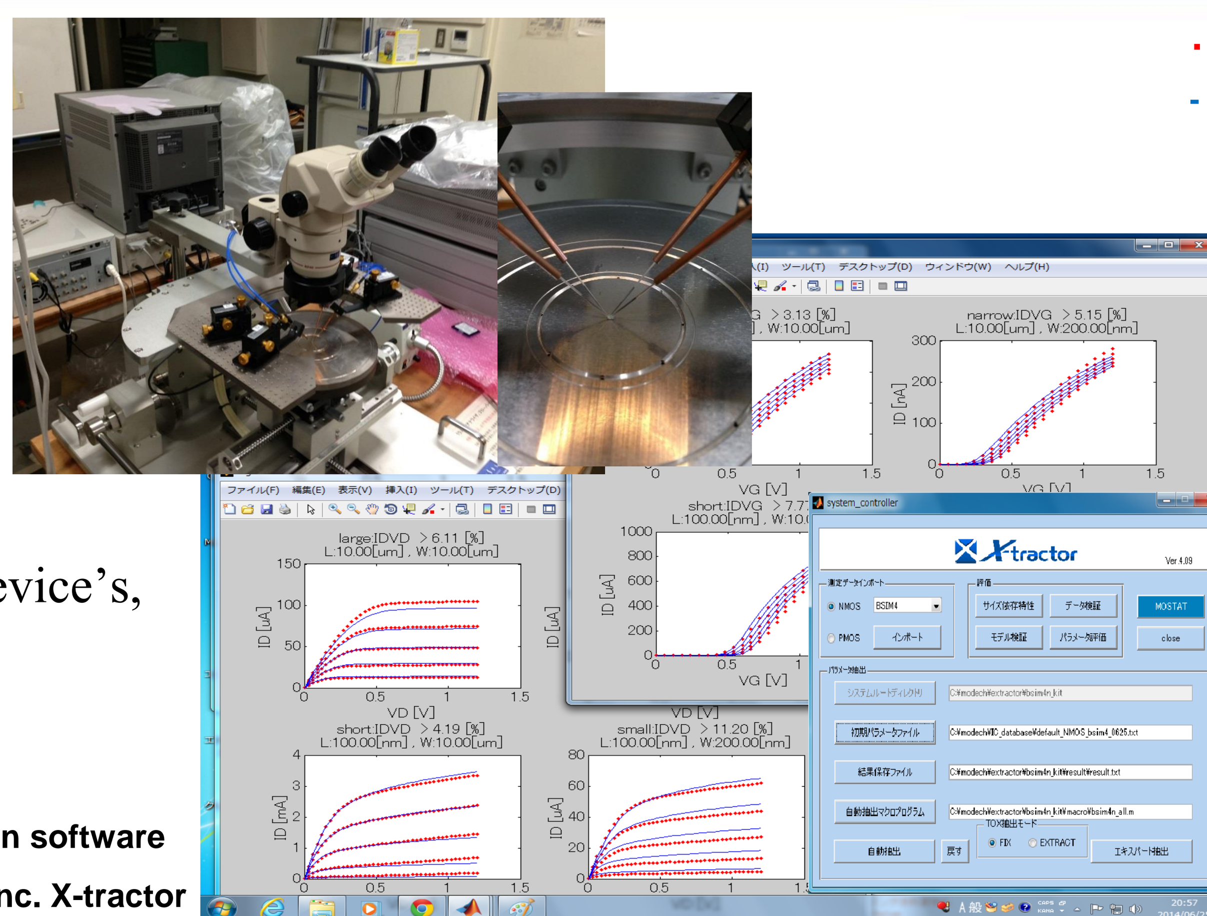
Large	Channel Width	10.0µm
	Channel Length	10.0µm
Short	Channel Width	10.0µm
	Channel Length	0.1µm

Stress condition

Degradation parameter is based on 65nm process device's, whereas our device is fabricated with 90nm process

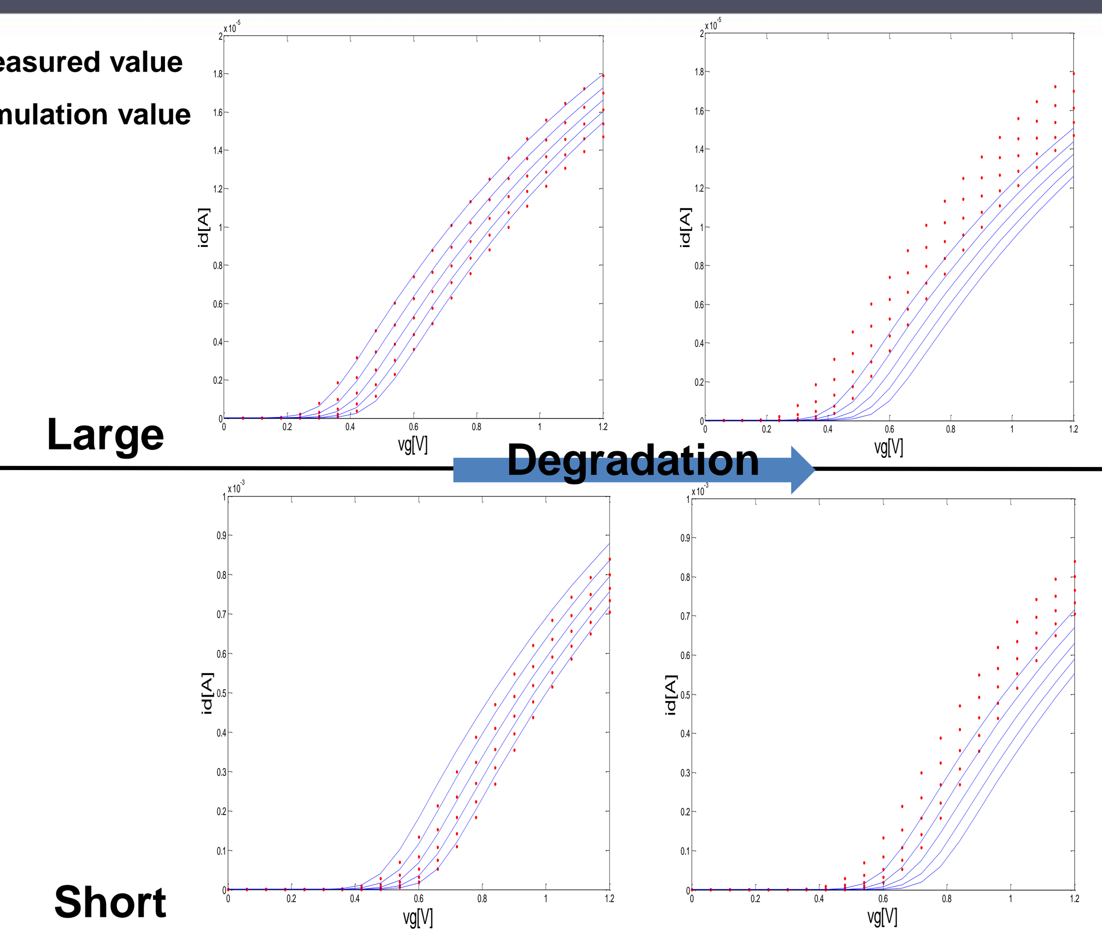
- Temperature 300.15 [K]
- Time 1,000 [hours]

Measurement and Simulation Environment

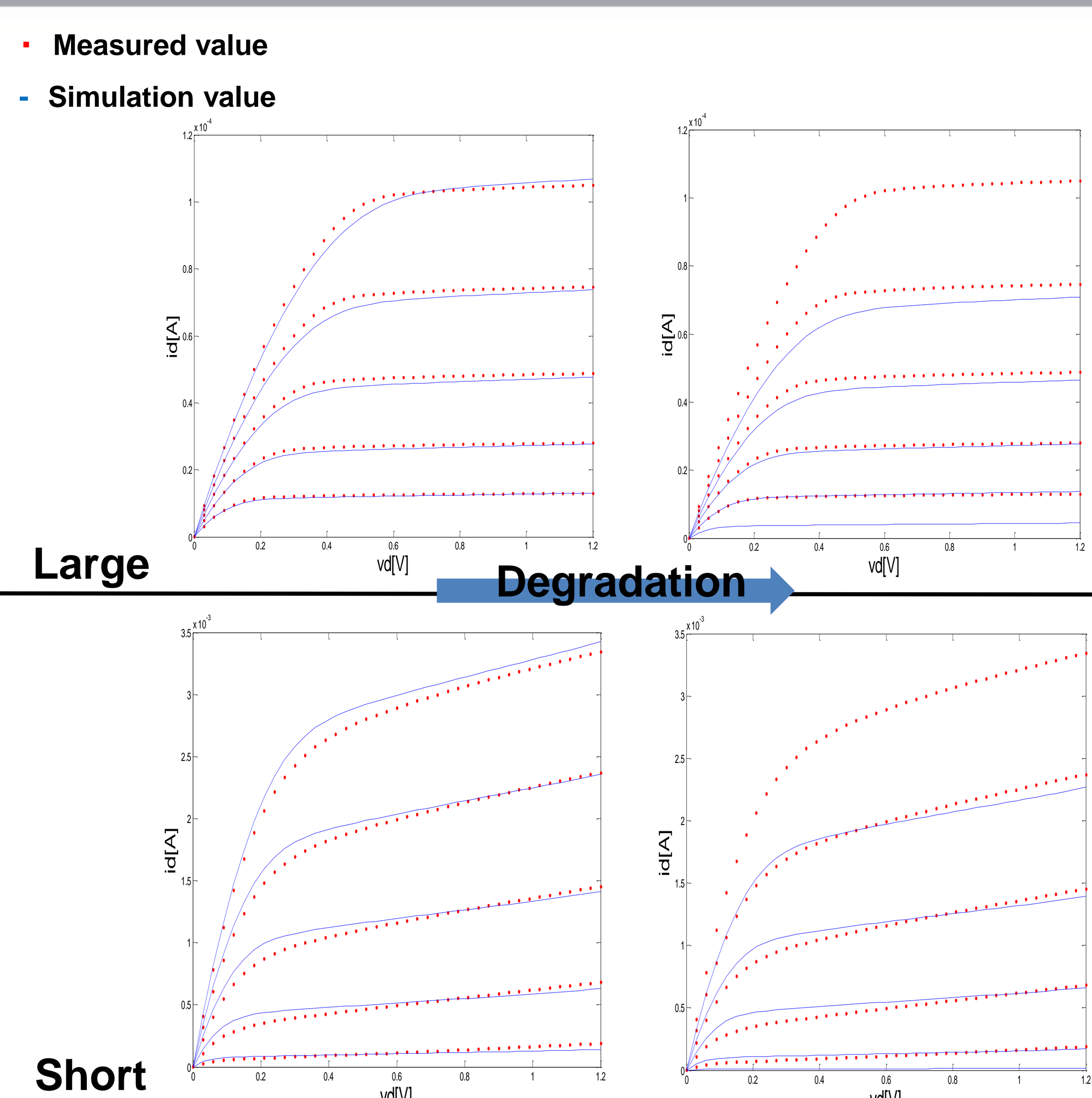


Extraction software MoDeCH Inc. X-tractor

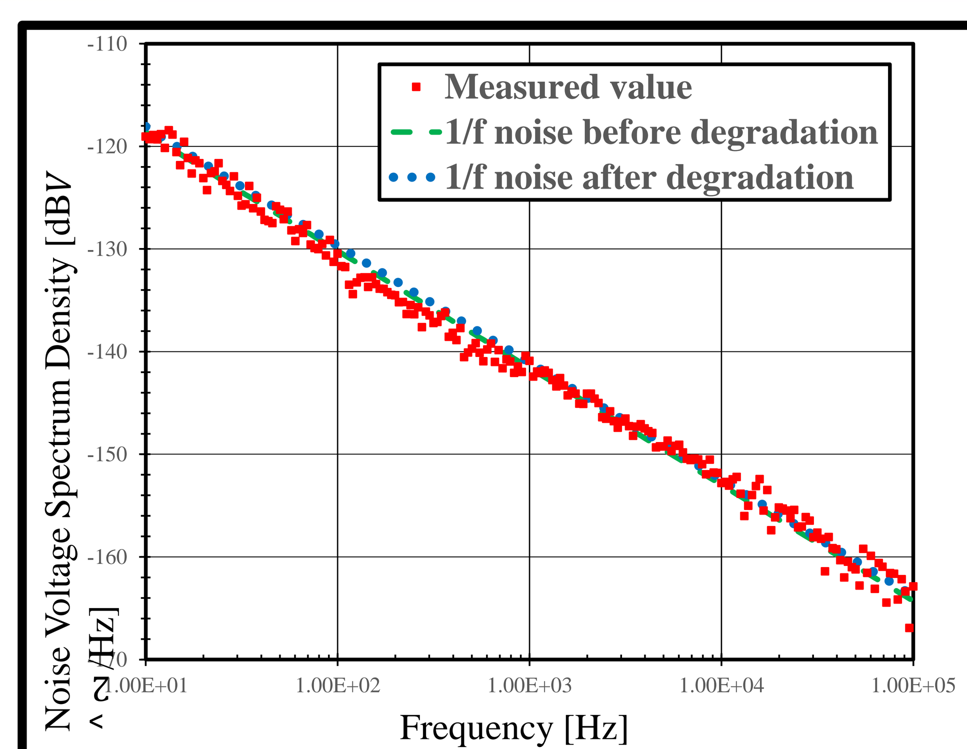
Id-Vg Characterizations



Id-Vd Characterizations



Measurement and Simulation of Drain Output 1/f Noise Density



$$S_{I_D} = \frac{C_{OX} * \mu_{eff} * 2 * k * T * \alpha_{H_{nominal}} * D * e^{-(V_{gs} - V_{th})} * I_{ds}^{AF}}{C_{OX} L_{eff}^{2} f^{EF}}$$

Vth↑ ⇒ Ids↓ ⇒ Sid↓

αHnormal↑ ⇒ Sid↑

Summary

- HCI degradation model was studied and implemented in BSIM4 of our MDW-SPICE simulator
- BSIM4 and degradation model parameters were extracted with measurements of 90nm n-channel MOSFETs
- Simulation verifications of DC drain currents were performed with and without bias stresses
- 1/f noise model parameters were extracted with measurements
- Simulation verifications of drain output 1/f noise density were performed with and without bias stresses

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