1/*f* Noise Model for Double-Gate FinFETs Biased in Weak Inversion

Chengqing Wei [1,2], **Yong-Zhong Xiong** [2] **and Xing Zhou** [1]

[1] Nanyang Technological University, Singapore

[2] Institute of Microelectronics (IME), Singapore

Outline

- **Introduction**
- **Model Development**
- **Model Verification**
- **Conclusion**

Introduction

- **1/*f* noise model**
  - **- Number fluctuation model (McWhorter theory)**
  - **- Mobility fluctuation model (Hooge theory)**
  - **- Unified number-mobility fluctuation model**
- **1/*f* noise model of double-gate FinFETs in weak inversion by McWhorther theory**

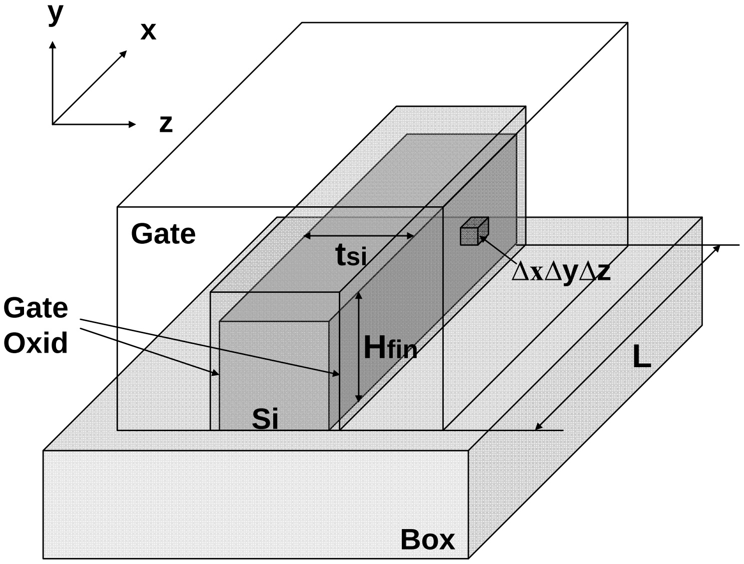
$$S_{I_D}(f) = q^4 \frac{N_t(E_F)}{kT\gamma}\frac{1}{f}\frac{1}{WL}\frac{1}{(C_{ox}+C_d+C_{it})^2} I_D^2$$ where $W=2H_{fin}$

- S_{Id} shows quadratic variations vs. I_d

- **Apply Hooge theory to 1/*f* noise of double-gate FinFETs in weak inversion**

$$S_{i_D}(f) = \frac{\alpha_H}{fN} I_D^2$$

Double-Gate FinFET

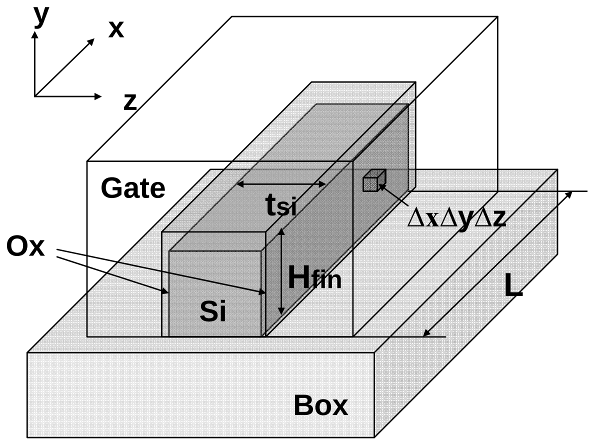


Subthreshold Current: $$I_d = \mu \frac{W}{L} kT n_i t_{si} e^{\frac{q(V_{gs}-\Delta\phi)}{kT}}\left(1-e^{-\frac{qV_{ds}}{kT}}\right)$$ **[1]**

I_d is proportional to t_{si}, volume inversion occurs.

[1] Y. Taur, *et al*., *IEEE Electron Device Lett.*, vol. 25, pp. 107-109, 2004.

Model Development



- **Hooge Mobility Fluctuation Theory:**

$$\frac{S_{Id}(f)}{I_d^2} = \frac{\alpha_H}{fN}$$

Key: total number of carriers under gate

- ***Q_i(x), the carrier charge density per unit area in the channel at x is [1]:***

$$Q_i(x) = 8\frac{\varepsilon_{Si}}{t_{si}}\frac{kT}{q}\beta\tan\beta \xrightarrow[\text{in weak inversion}]{\beta \ll 1} Q_i(x) \approx 8\frac{\varepsilon_{si}}{t_{si}}\frac{kT}{q}\beta^2$$

$$f_r(\beta) = \frac{q}{2kT}\left(V_{gs} - V_o - V(x)\right)$$

with $V_o = \Delta\phi + \frac{2kT}{q}\ln\left(\frac{2}{t_{si}}\sqrt{\frac{2\varepsilon_{si}kT}{q^2 n_i}}\right)$

$f_r(\beta) \sim \ln(\beta)$ in weak inversion

$$\beta = e^{\frac{q}{2kT}\left(V_{gs} - V_o - V(x)\right)}$$

[1] Y. Taur, *et al.*, *IEEE Electron Device Lett.*, vol. 25, pp. 107-109, 2004.

Model Development (Cont.)

$$Q_i(x) \approx 8\frac{\varepsilon_{si}}{t_{si}}\frac{kT}{q}\beta^2$$

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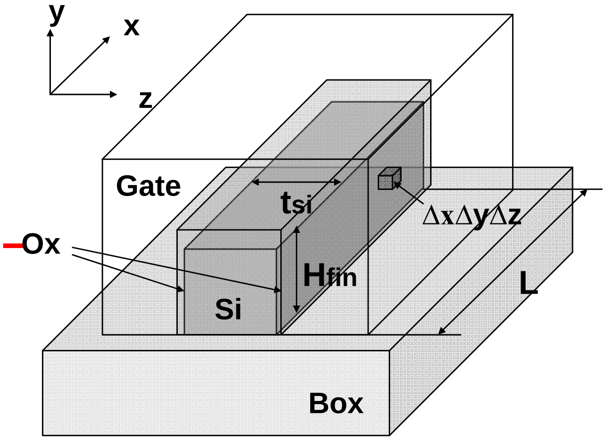
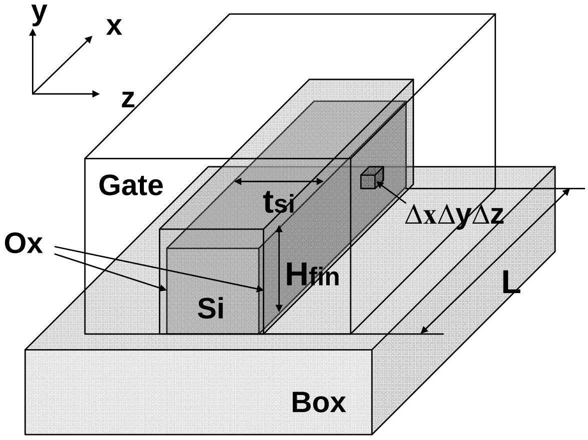


$$Q_i(x) = qn_i t_{si} e^{\frac{q}{kT}\left(V_{gs} - \Delta\phi - V(x)\right)}$$

***Q_i(x)* is proportional to *t_{si}* and volume inversion occurs.**

[1] Y. Taur, *et al.*, *IEEE Electron Device Lett.*, vol. 25, pp. 107-109, 2004.

Model Development (Cont.)



$$I_d = W\mu Q_i(x)\frac{dV(x)}{dx}$$

$$dx = W\mu Q_i(x)\frac{dV(x)}{I_d}$$

$$N = \frac{W}{q}\int_0^L Q_i(x)dx$$

$$Q_i(x) = qn_i t_{si} e^{\frac{q}{kT}\left(V_{gs}-\Delta\phi-V(x)\right)}$$

$$N = \frac{L^2}{2\mu kT}\,\frac{1+e^{\frac{-qV_{ds}}{kT}}}{1-e^{\frac{-qV_{ds}}{kT}}}\,I_d$$

$$\frac{S_{Id}(f)}{I_d^2} = \frac{\alpha_H}{fN} = \frac{\alpha_H}{f}\,\frac{2\mu kT}{L^2}\,\frac{1-e^{\frac{-qV_{ds}}{kT}}}{1+e^{\frac{-qV_{ds}}{kT}}}\,\frac{1}{I_d}$$

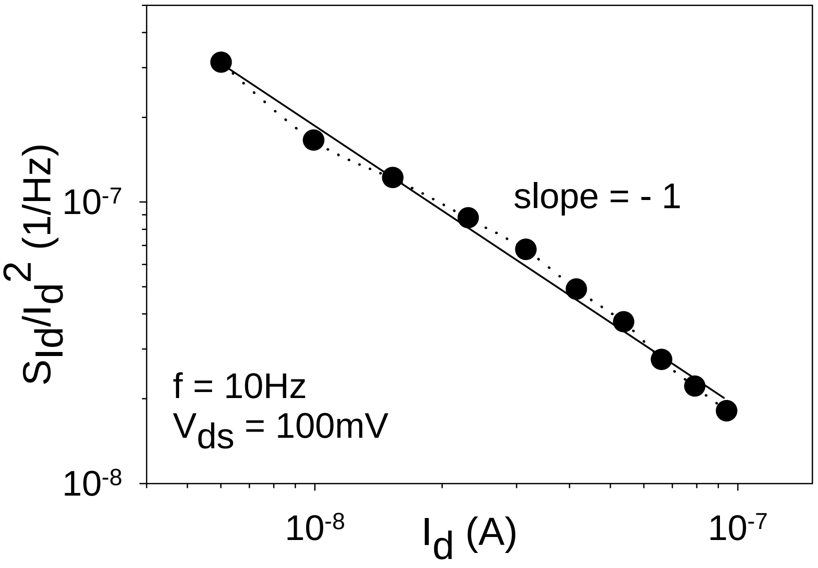
Final 1/*f* noise expression in weak inversion

Conduction Parameters

t_{si} = 0.14 μ m, H_{fin} = 0.12 μ m, L = 5 μ m, V_{ds} = 100 mV

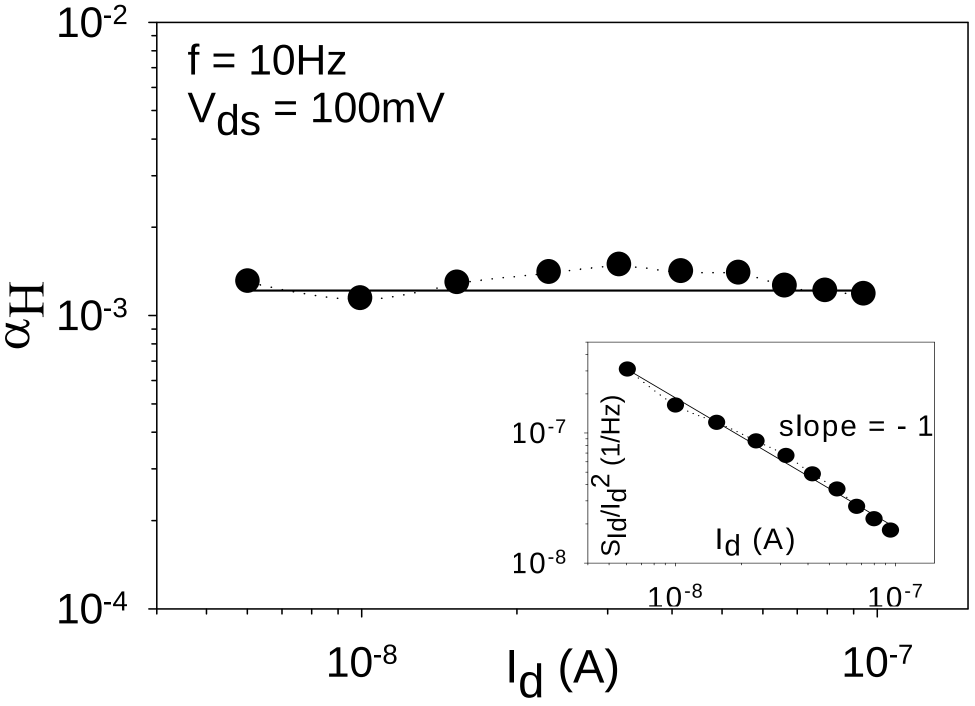
C_{ox} F/cm^2	V_T V	μ cm^2/Vs	ΔL μm
3.83×10^{-7}	0.13	228	0.15
θ V^{-1}	R_S kΩ	S mV/dec	m
0.13	1.346	71.2	1.186

Model Verification



$$\boxed{\frac{S_{Id}(f)}{I_d^2}} = \frac{\alpha_H}{fN} = \frac{\alpha_H}{f}\frac{2\mu kT}{L^2}\frac{1-e^{\frac{-qV_{ds}}{kT}}}{1+e^{\frac{-qV_{ds}}{kT}}}\boxed{\frac{1}{I_d}}$$

Model Verification (cont.)



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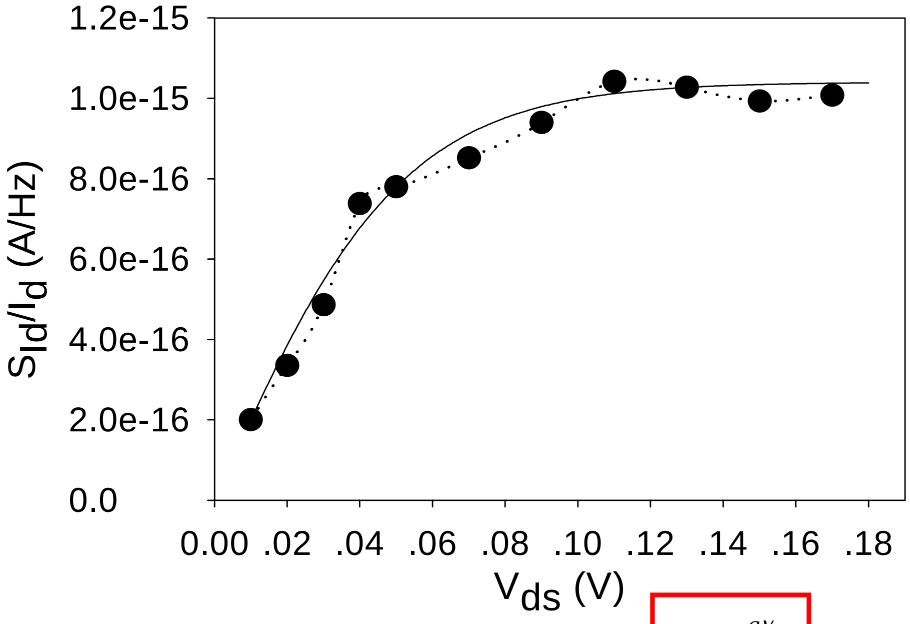
Model Verification (Cont.)



$$\frac{S_{Id}(f)}{I_d^2}=\frac{\alpha_H}{fN}=\frac{\alpha_H}{f}\frac{2\mu kT}{L^2}\boxed{\frac{1-e^{\frac{-qv_{ds}}{kT}}}{1+e^{\frac{-qV_{ds}}{kT}}}}\frac{1}{I_d}$$

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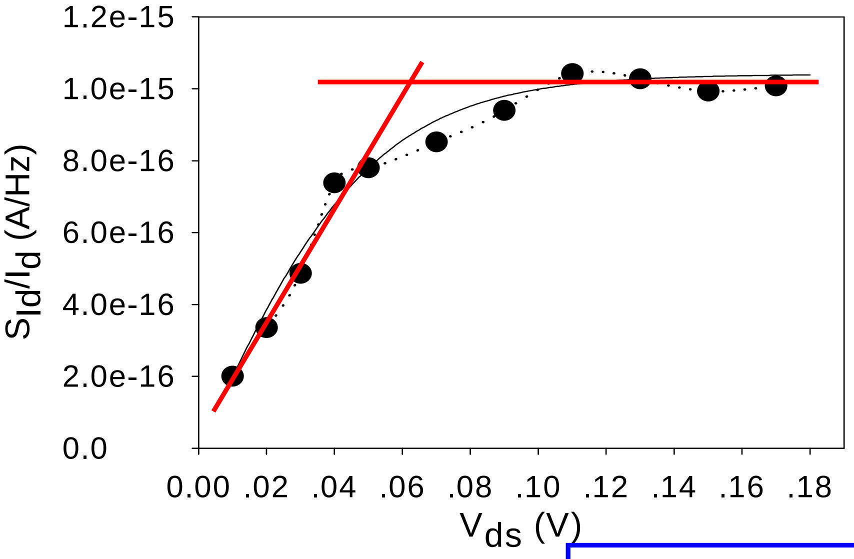
Model Verification (Cont.)



$$\boxed{\frac{S_{Id}(f)}{I_d^2}=\frac{\alpha_H}{fN}=\frac{\alpha_H}{f}\frac{2\mu kT}{L^2}\frac{1-e^{\frac{-qV_{ds}}{kT}}}{1+e^{\frac{-qV_{ds}}{kT}}}\frac{1}{I_d}}$$

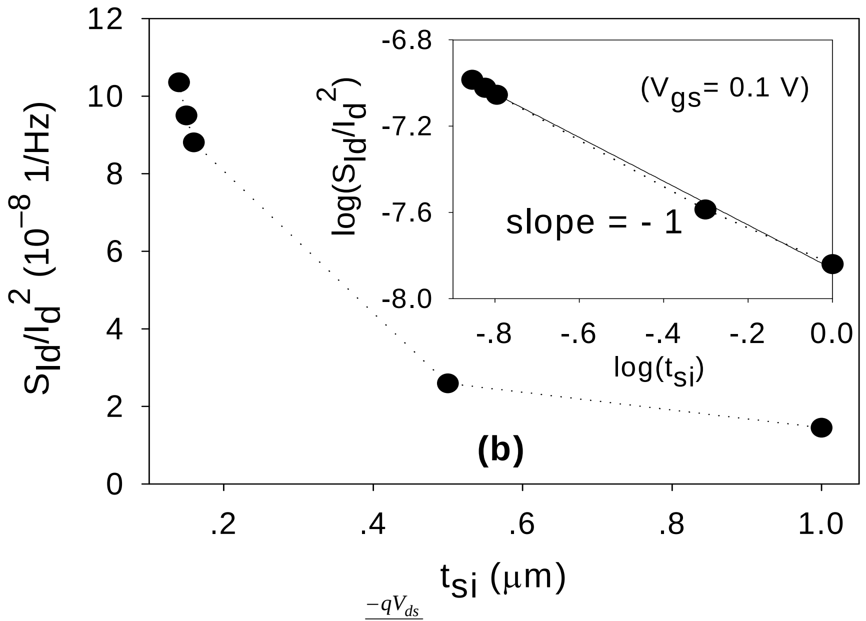
Low V_{ds}

$$\boxed{\frac{S_{Id}(f)}{I_d^2}=\frac{\alpha_H}{fN}=\frac{\alpha_H}{f}\frac{q\mu}{L^2}\boxed{V_{ds}}\frac{1}{I_d}}$$

High V_{ds}

$$\boxed{\frac{S_{Id}(f)}{I_d^2}=\frac{\alpha_H}{fN}=\frac{\alpha_H}{f}\frac{2\mu kT}{L^2}\frac{1}{I_d}}$$

Model Verification (Cont.)



$$\frac{S_{Id}(f)}{I_d^2}=\frac{\alpha_H}{fN}=\frac{\alpha_H}{f}\frac{2\mu kT}{L^2}\frac{1-e^{\frac{-qV_{ds}}{kT}}}{1+e^{\frac{-qV_{ds}}{kT}}}\frac{1}{\bigcirc\!\!\!\!I_d} \longleftarrow I_d=\mu\frac{W}{L}kTn_i\boxed{t_{si}}e^{\frac{q(V_{gs}-\Delta\phi)}{kT}}\left(1-e^{-\frac{qV_{ds}}{kT}}\right)$$

***S_{Id}/I_d^2* is inversely proportional to *t_{si}* .**

Conclusion

- **Silicon channel of FinFETS is volume-inverted in weak inversion, considered as “bulk conduction”. The large separation of most carriers from the interface and the oxide traps makes the generation of the exact 1/*f* noise through the carrier trapping and de-trapping process become less probable and the 1/*f* noise data following mobility-fluctuation behavior is observed.**
- **1/f noise model based on Hooge mobility fluctuation theory is developed and verified for the ultra-low-doping long-channel symmetrical double-gate FinFETs.**
- **The extracted Hooge parameter is within the range reported for conventional silicon CMOS bulk devices (SiO_2/polysilicon gate stack).**

Question & Answer