Characterization and Modeling of Low-frequency Noise in IGZO Source-Gated Transistors

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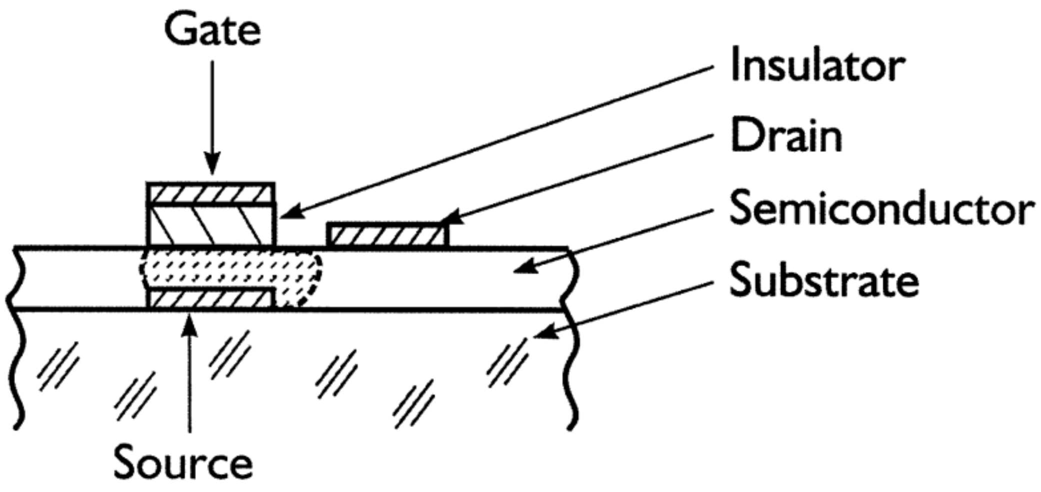
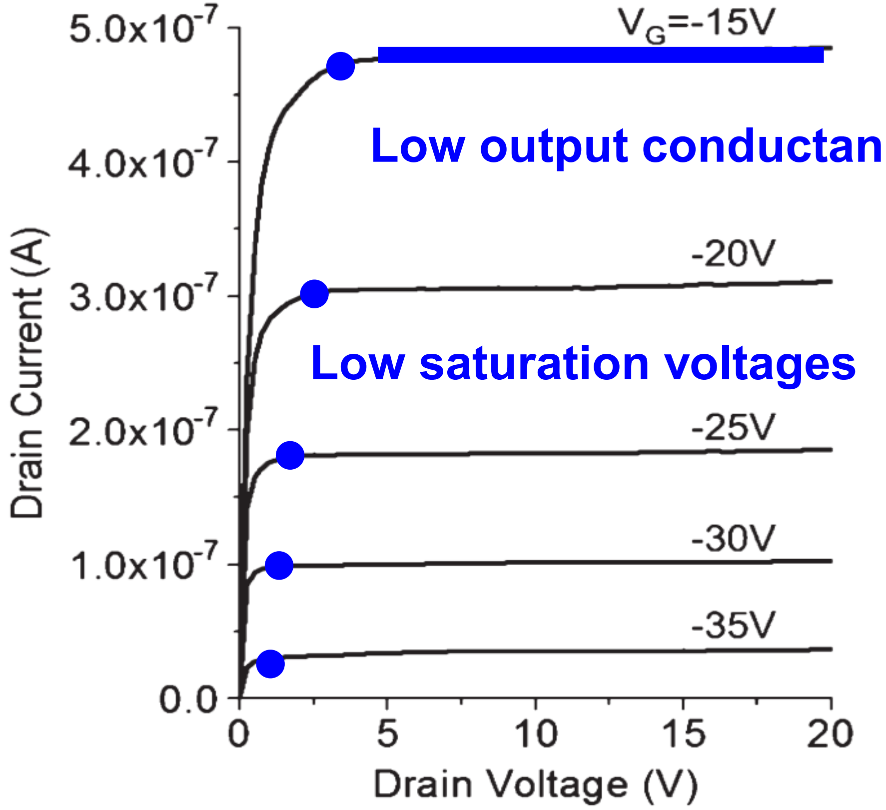
Source-gated transistor (SGT)



J. M. Shannon *et al*., IEEE Electron Device Lett., 2003.



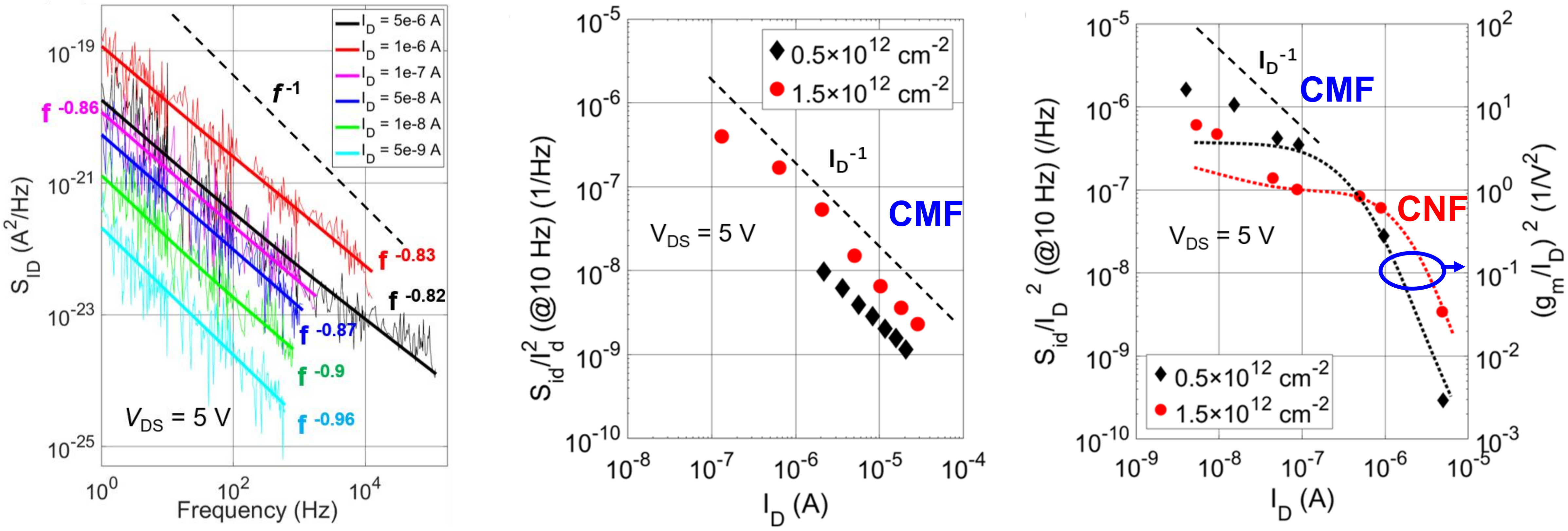
Low output conductance: $g_d = \left.\frac{\partial I_D}{\partial V_{DS}}\right|_{V_{GS}}$

Low saturation voltages

Radu A. Sporea et al., IEEE Trans. Electron Devices, 2010

- **High intrinsic gain:** $A_v = \frac{g_m}{g_d}$

Low-frequency noise (LFN) in polysilicon transistors



Q. Chen *et al.*, Solid State Electronics, 2024.

- Bulk carrier mobility fluctuation (CMF) model：

$$\frac{S_{I_D}}{I_D^2} \propto I_D^{-1}$$

- Carrier number fluctuation (CNF) model：

$$\frac{S_{I_D}}{I_D^2} \propto \left(\frac{g_m}{I_D}\right)^2$$

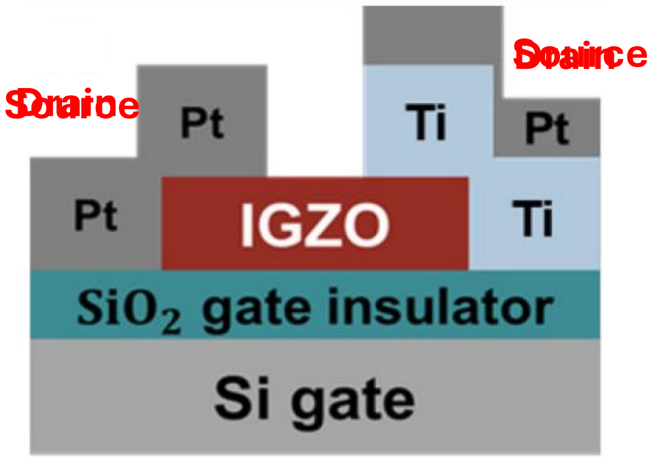
Outline

1. Characterization of LFN in IGZO TFTs and SGTs
2. LFN Models for IGZO TFTs and SGTs
3. Conclusions and Perspectives

1.1. IGZO device structure and IV measurements

➢ **Schematic of IGZO device**

SGT / TFT
Configuration



➢ **Device parameters :**

Source-channel overlap length: 210 µm

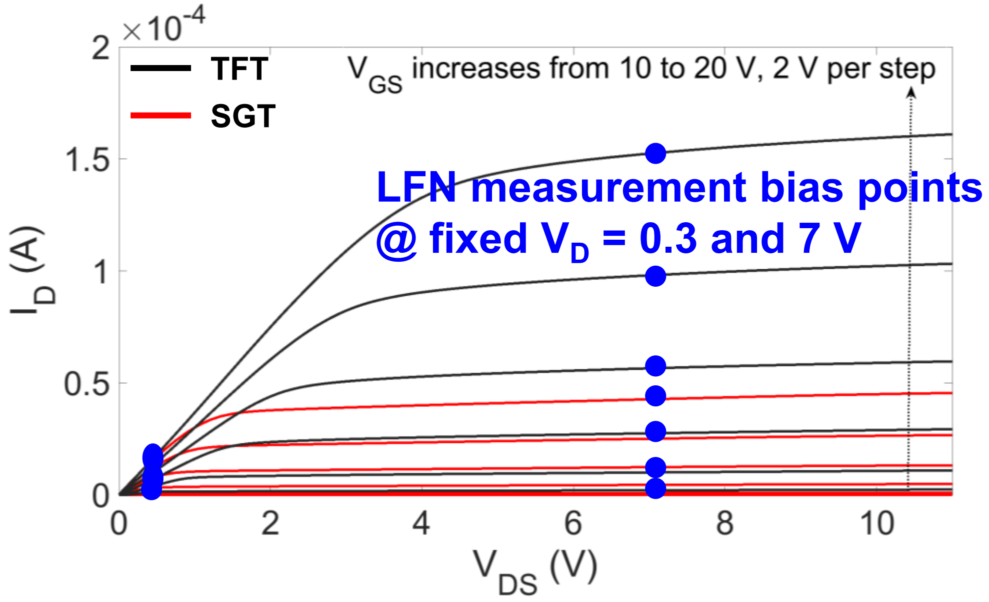
Source-drain gap *d*: 5 µm, 10 µm

Channel Width: 90 µm

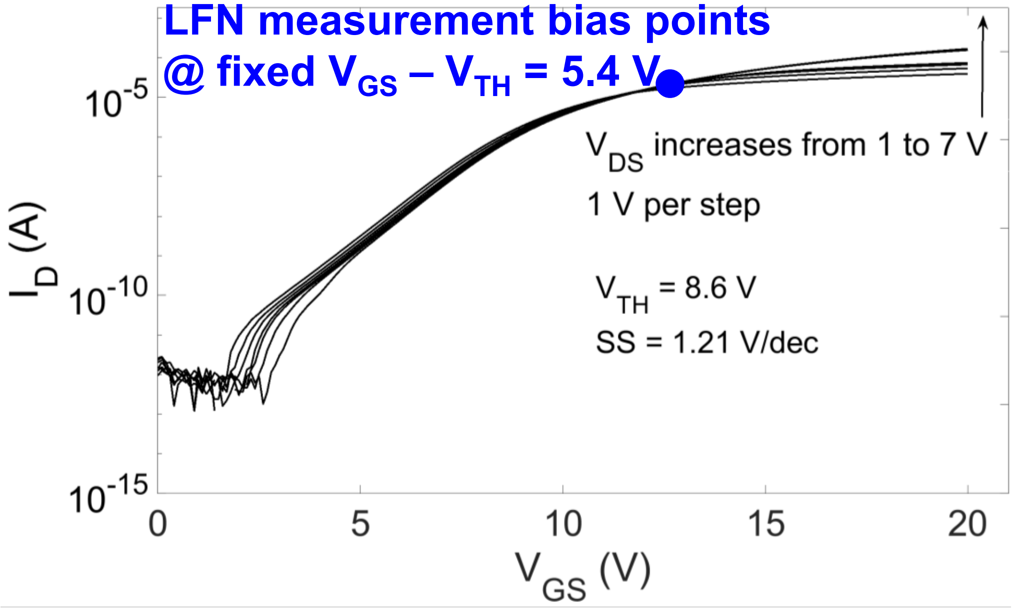
IGZO thickness: 20 nm

SiO_2 gate insulator thickness: 85 nm

➢ **Output curves for TFT and SGT**

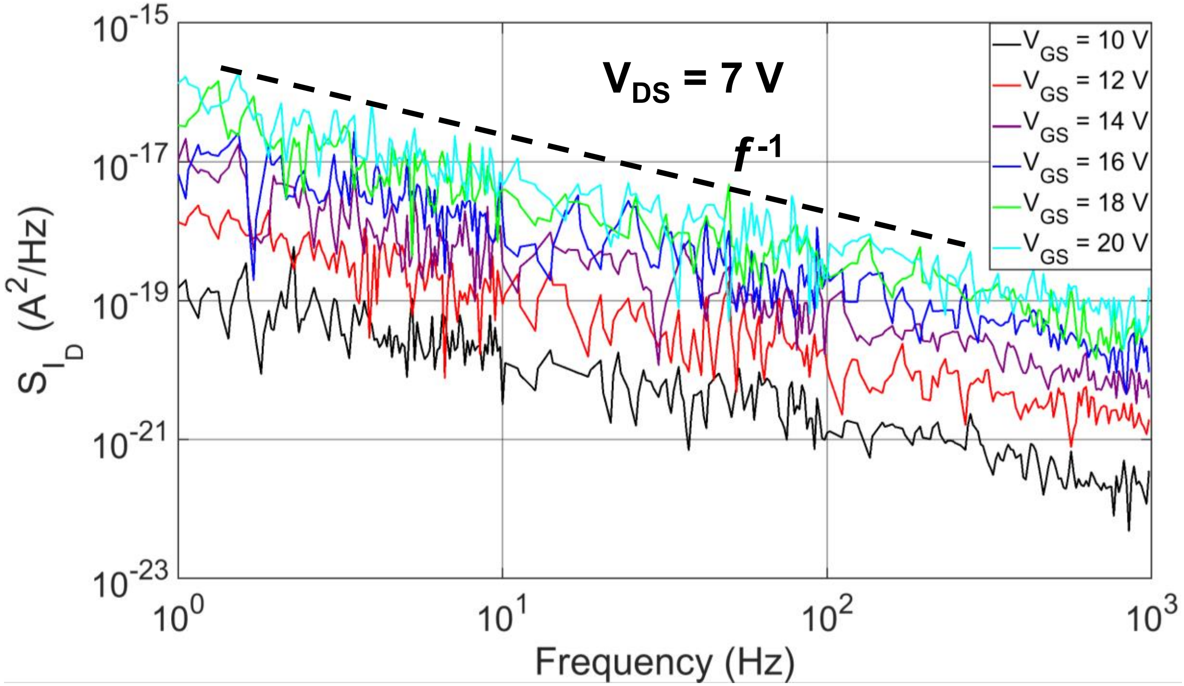


➢ **SGT transfer curves**

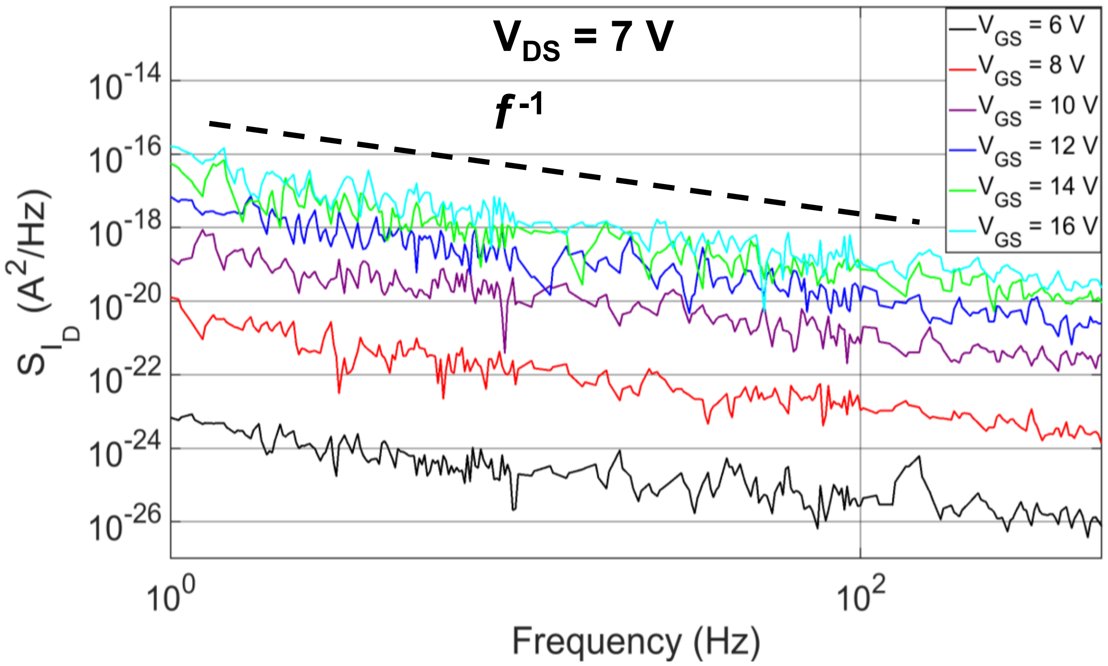


1.2. LFN measurement results of IGZO transistors

- **LFN of TFT configuration in saturation @ fixed V_{DS}**



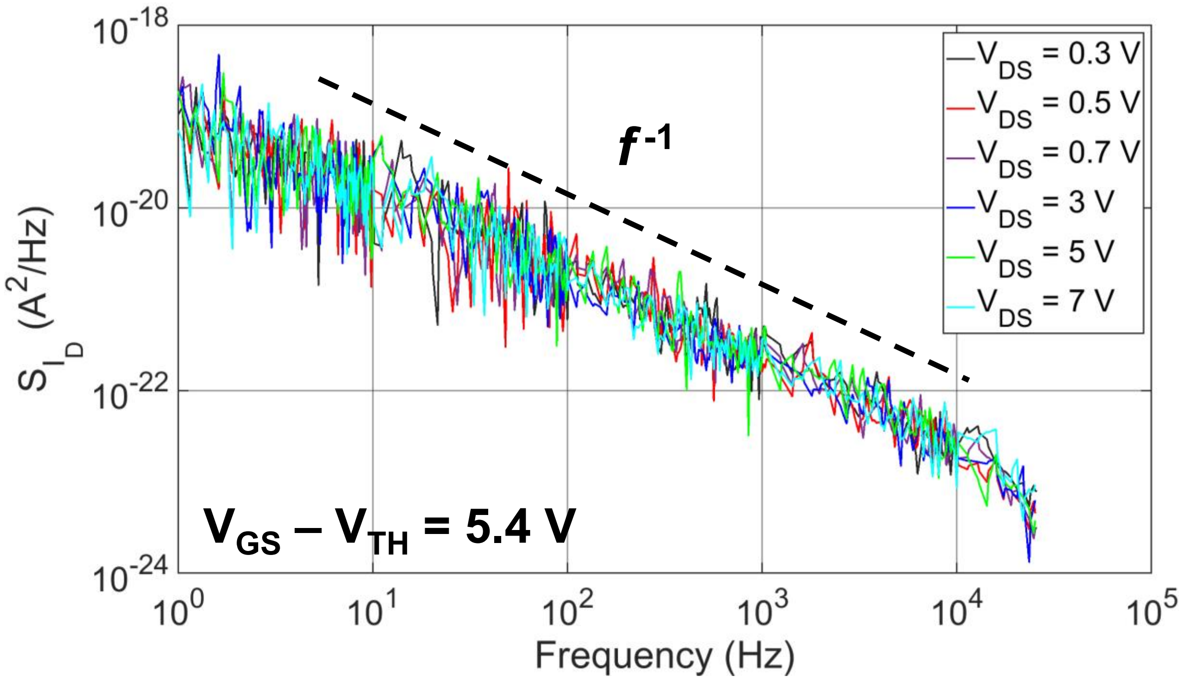
- **LFN of SGT configuration in saturation @ fixed V_{DS}**



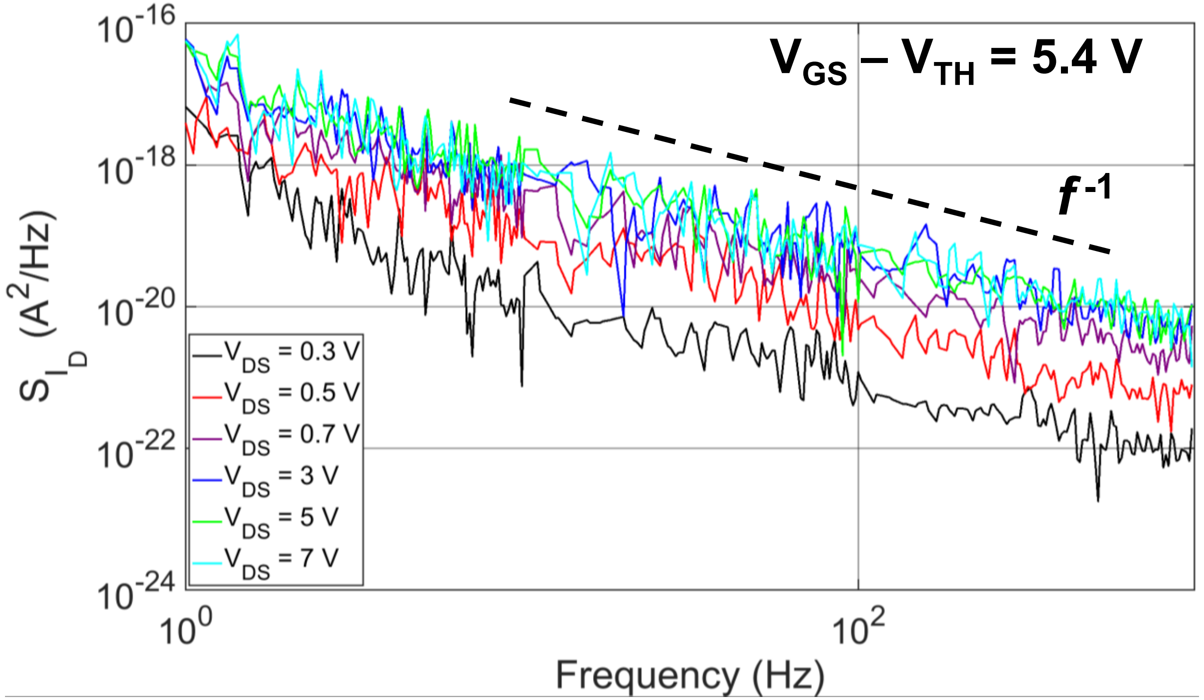
LFN in both IGZO TFTs and SGTs shows gate voltage dependencies

1.2. LFN measurement results of IGZO transistors

➢ **TFT configuration @ fixed V_{GS}**



➢ **SGT configuration @ fixed V_{GS}**



IGZO SGTs show a stronger LFN dependence on drain voltage than TFTs

2.1. Conventional FET LFN models

➢ **Comparison of CNF and CMF models in different operation regimes**

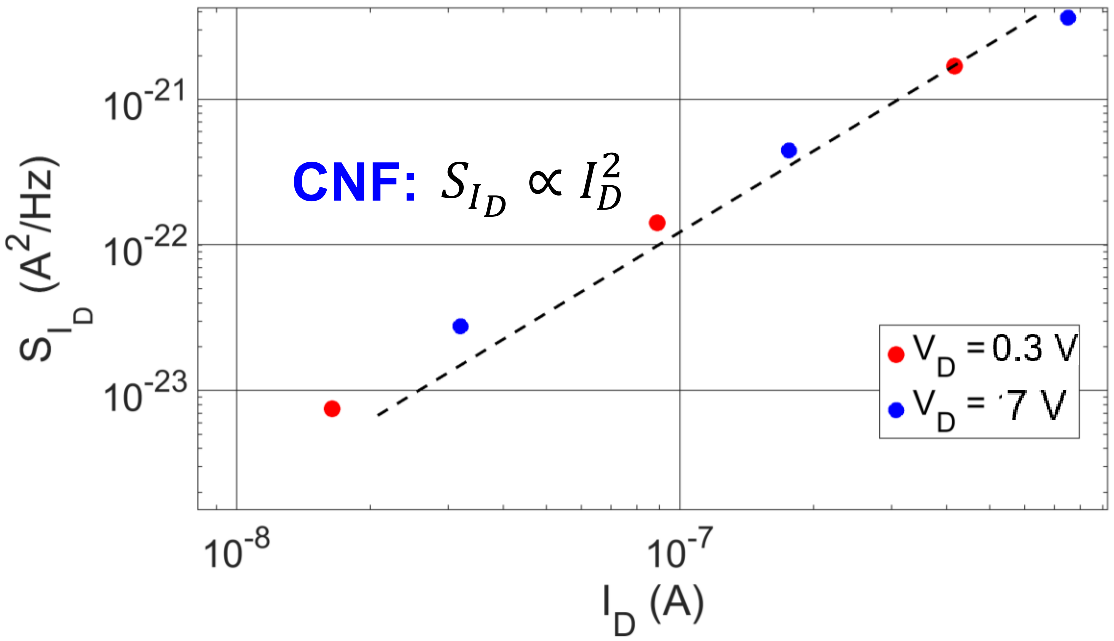
	Subthreshold	**Above threshold**	
		Linear	**Saturation**
CMF Model	$\frac{S_{I_\mathrm{D}}}{I_\mathrm{D}^2} \propto I_\mathrm{D}^{-1}$	$\frac{S_{I_\mathrm{D}}}{I_\mathrm{D}^2} \propto I_\mathrm{D}^{-1}$ $\frac{S_{I_\mathrm{D}}}{I_\mathrm{D}^2} \propto (V_\mathrm{GS} - V_\mathrm{TH})^{-1}$	$\frac{S_{I_\mathrm{D}}}{I_\mathrm{D}^2} \propto I_\mathrm{D}^{-0.5}$ $\frac{S_{I_\mathrm{D}}}{I_\mathrm{D}^2} \propto (V_\mathrm{GS} - V_\mathrm{TH})^{-1}$
CNF Model	$\frac{S_{I_\mathrm{D}}}{I_\mathrm{D}^2} \propto \left(\frac{g_m}{I_\mathrm{D}}\right)^2$ $S_{I_\mathrm{D}} \propto I_\mathrm{D}^2$	$\frac{S_{I_\mathrm{D}}}{I_\mathrm{D}^2} \propto \left(\frac{g_m}{I_\mathrm{D}}\right)^2$ $\frac{S_{I_\mathrm{D}}}{I_\mathrm{D}^2} \propto (V_\mathrm{GS} - V_\mathrm{TH})^{-2}$	

D. Rigaud *et al.*, *IEE Proc.-Circuits Devices Sysi.*, 149, 1 (2002)

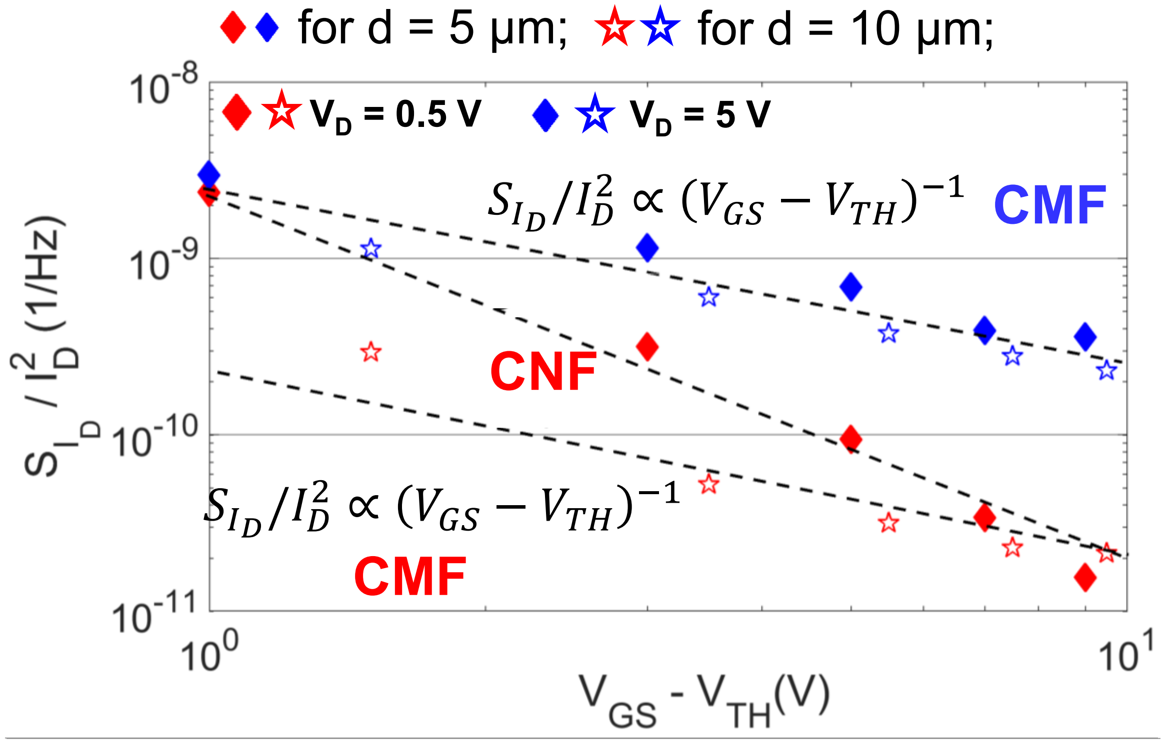
Tze-Ching F. *et al., Journal of Applied Physics* 108, 074518 (2010)

2.2. LFN models of IGZO TFTs

- **LFN in subthreshold**



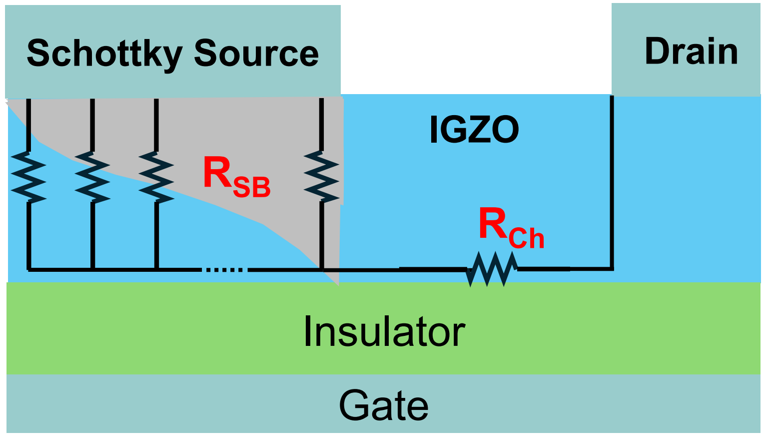
- **Normalized LFN in linear and saturation**

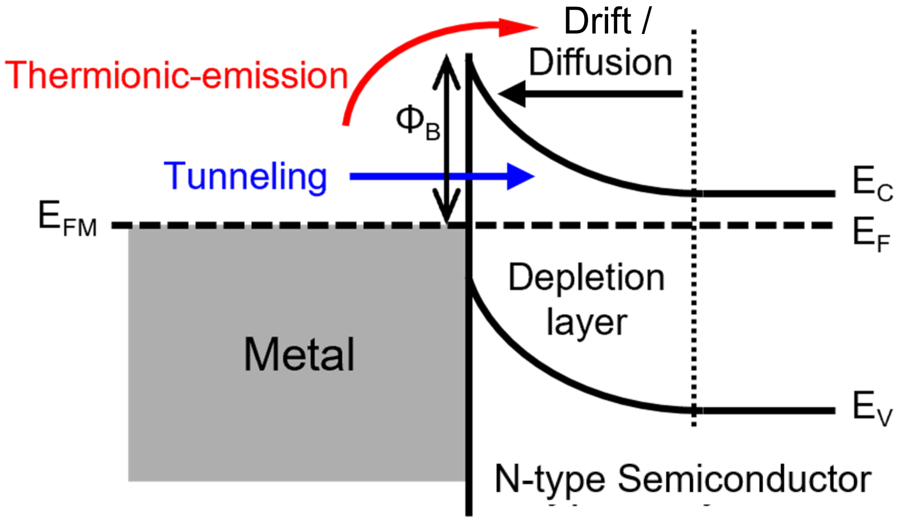


2.3. Comparison with literatures regarding the IGZO TFT LFN models

	Above threshold		Subthreshold
	Linear	**Saturation**	
Our results	**CMF @ large channel length** **CNF @ small channel length**	**CMF**	**CNF**
Sanghun J. *et al.*	CNF	/	/
Tze-Ching F. *et al.*	CMF	CMF	/
Jae C. P. *et al.*	**CMF @ large channel length** **CNF @ small channel length**	CMF	CNF

2.4. IGZO SGT LFN modeling





- The fundamental physical model:

$$\frac{S_{I_D}}{I_D^2} = \frac{S_{R_T}}{R_T^2} = \frac{S_{R_{SB}} + S_{R_{ch}}}{(R_{SB} + R_{ch})^2} = \eta^2 \frac{S_{I_{SB}}}{I_{SB}^2} + (1-\eta)^2 \frac{S_{I_{ch}}}{I_{ch}^2} \quad \text{with} \quad \eta = \frac{R_{SB}}{R_{SB} + R_{ch}}$$

- In subthreshold region, R_{ch} >> R_{SB}, η ~ 0 ➡ **The channel LFN is dominant**

- In above threshold region, R_{SB} >> R_{ch}, η ~1 ➡ **The Schottky barrier LFN is dominant**

2.4. SGT LFN modeling

- **V_D dependence of normalized LFN**

Tunneling : $$\frac{S_{I_{SB}}}{I_D^2} \propto \left(1-\exp\left(-q\frac{\eta V_D}{kT}\right)\right)^{-2}$$ → **Trend Ⅰ:** The noise decreases with V_D

Nicolas Clément et al., IEEE Trans. Electron Devices, 2012

Thermionic-emission:

$$\left(\frac{S_{I_{SB}}}{I_D^2}\right)_{lin} \propto \boxed{\sqrt{\frac{2\varepsilon_S(\Phi_B+\eta V_D)}{qN_D}}}$$ Depletion Width → **Trend Ⅱ:** The noise increases with V_D in linear region

$$\left(\frac{S_{I_{SB}}}{I_D^2}\right)_{sat} \propto t_S$$ → **Trend Ⅲ:** The noise is constant with V_D in saturation region

- **V_{GS} dependence of normalized LFN**

$$\left(\frac{S_{I_{SB}}}{I_D^2}\right)_{lin} \propto \sqrt{\frac{N_C(\Phi_B+\eta V_D)}{2\varepsilon_S N_D t_S C_i \boxed{(V_G-V_{TH})} \exp\left(-q\frac{\Phi_B}{kT}\right)}}$$

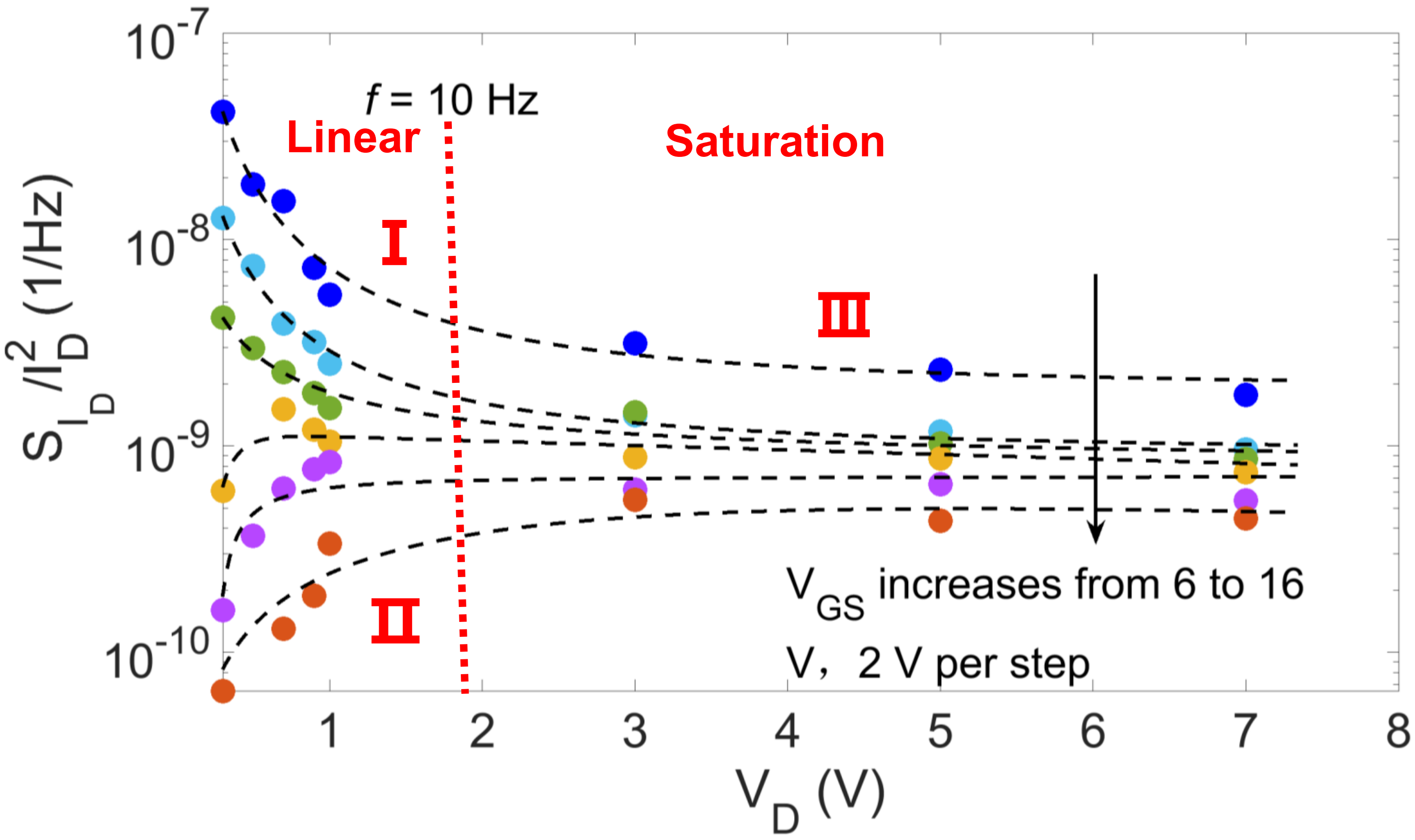
$$\left(\frac{S_{I_{SB}}}{I_D^2}\right)_{sat} \propto \sqrt{\frac{q t_S N_C}{C_i \boxed{(V_G-V_{TH})} \exp\left(-q\frac{\Phi_B}{kT}\right)}}$$

→ **Trend Ⅳ:** The normalized LFN varies as $(V_{GS} - V_{TH})^{-1/2}$ in both linear and saturation regions

Q. Chen *et al.*, IEEE Trans. Electron Devices, 2025 (under second review).

2.5. LFN models for the IGZO SGT

➢ V_D dependence of normalized LFN



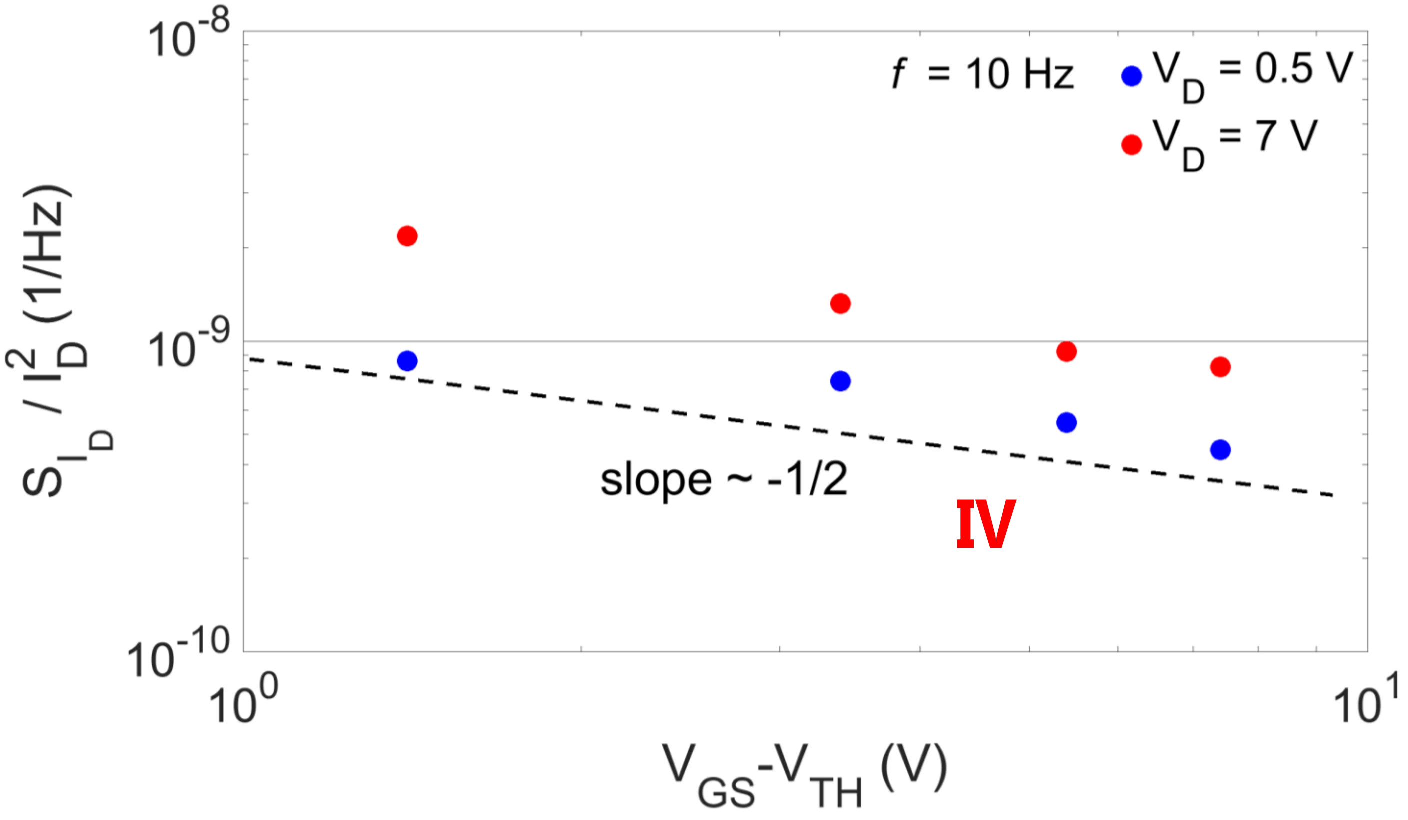
Trend I: $\frac{S_{I_{SB}}}{I_D^2} \propto \left(1-\exp\left(-q\frac{\eta V_D}{kT}\right)\right)^{-2}$

Trend II: $\left(\frac{S_{I_{SB}}}{I_D^2}\right)_{lin} \propto \sqrt{\frac{2\varepsilon_s(\Phi_B+\eta V_D)}{qN_D}}$

Trend III: $\left(\frac{S_{I_{SB}}}{I_D^2}\right)_{sat} \propto \text{Constant}$

2.5. LFN models for the IGZO SGT

➢ **V_{GS} dependence of normalized LFN**



Trend IV: $\left(\frac{S_{I_{SB}}}{I_D^2}\right)_{lin} \propto \sqrt{\frac{N_C(\Phi_B+\eta V_D)}{2\varepsilon_s N_D t_s C_i (V_G - V_{TH}) \exp\left(-q\frac{\Phi_B}{kT}\right)}}$ and $\left(\frac{S_{I_{SB}}}{I_D^2}\right)_{sat} \propto \sqrt{\frac{q t_s N_C}{C_i (V_G - V_{TH}) \exp\left(-q\frac{\Phi_B}{kT}\right)}}$

3. Conclusions and perspectives

Operation regime	LFN models	
	Polysilicon SGT	IGZO SGT
Subthreshold	CMF (Low I_D region) CNF (High I_D region)	CNF
Linear	Tunneling: $S_{I_D}/I_D^2 \propto \left(1 - exp\left(-q\frac{\eta V_D}{kT}\right)\right)^{-2}$	
	Thermionic-emission: $\frac{S_{I_D}}{I_D^2} \propto \sqrt{\frac{2\varepsilon_s(\Phi_B + \eta V_D)}{qN_D}}$ or $S_{I_D}/I_D^2 \propto (V_{GS} - V_{TH})^{-1/2}$	
Saturation	$S_{I_D}/I_D^2 \propto (V_{GS} - V_{TH})^{-1/2}$	

- Parameter fitting of LFN models with measurements
- Device analog performance regarding LFN
- ……

Thank you !