IMPACT OF AL_2O_3 POSITION ON PERFORMANCES AND RELIABILITY IN HIGH-K METAL GATED DRAM PERIPHERY TRANSISTORS

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OUTLINE

I. Introduction

II. Samples description

III. Performances

IV. Defects characterization (noise and CP)

V. Reliability (NBTI)

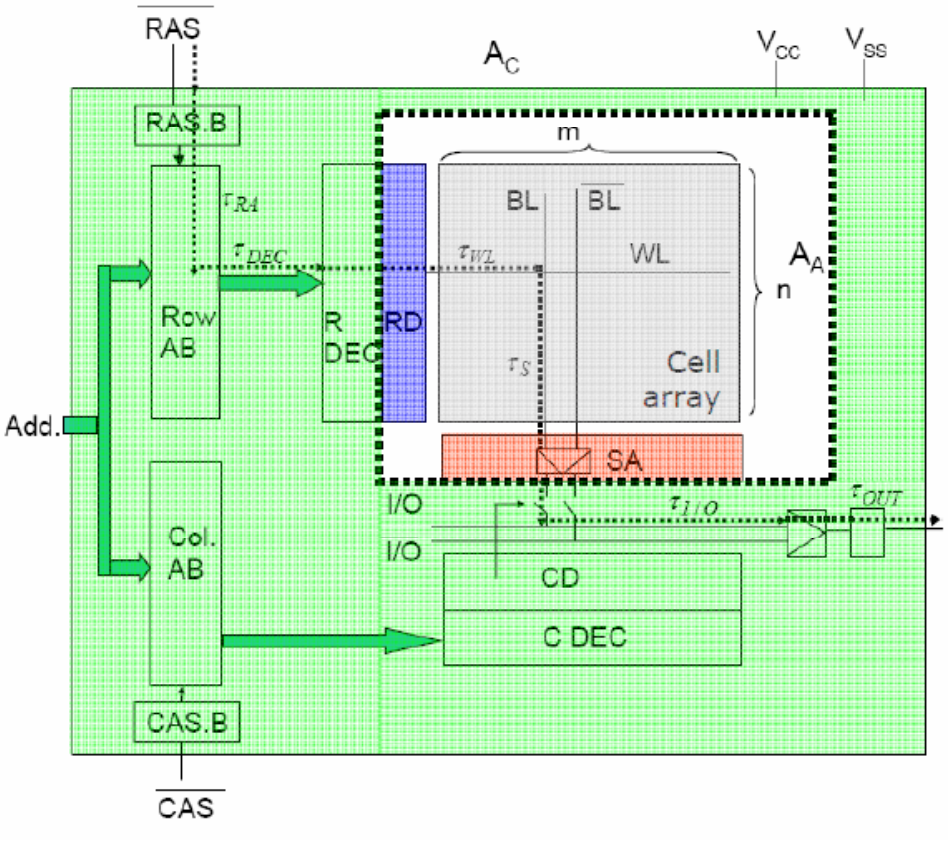
VI. Conclusions

INTRODUCTION

✓ **DRAM "periphery transistors"**: MOSFET used in the DRAM peripheral circuitry e.g.

- **Sense amplifiers**
- **Address decoders**,
- **High voltage applications**

✓ **DRAM "periphery transistors"** are formed before the DRAM cell process.
Therefore they experience the high thermal budget related the DRAM cell process.



source: S.Y. Cha, "DRAM Technology - History & Challenges" @ IEDM 2011 short courses for more details

INTRODUCTION

- Compared to logic applications, DRAM Periphery devices have more relaxed device specifications (L_G, EOT)

- Required **performance similar to that of logic transistors**, but with a number of additional challenges to be tacked: **low power low leakages** (low I_{OFF} and J_G mandatory)

- **HKMG** is needed for future technologies to sustain the performance
  - Stacks surviving the **aggressive anneal** needed in a DRAM process (before silicidation, typically several hours above 600C)

Ref: S.Y. Cha, "DRAM Technology - History & Challenges" @ IEDM 2011 short courses for more details

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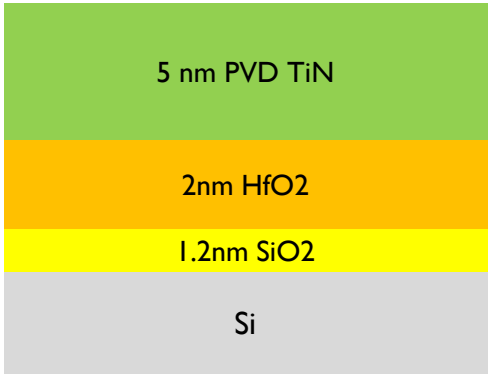
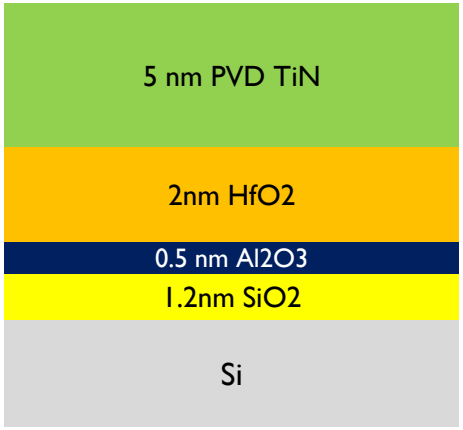
INVESTIGATED SAMPLES

Reference



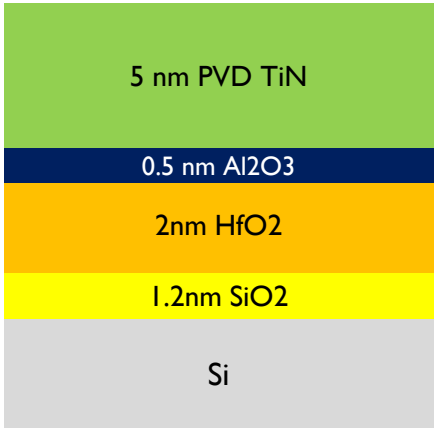
EOT~11.7 A

Al_2O_3 below HfO_2



EOT~12.7A

Al_2O_3 above HfO_2



EOT~ 13.3 A

Al2O3 capping is used in pMOSFETs for Vth adjustment

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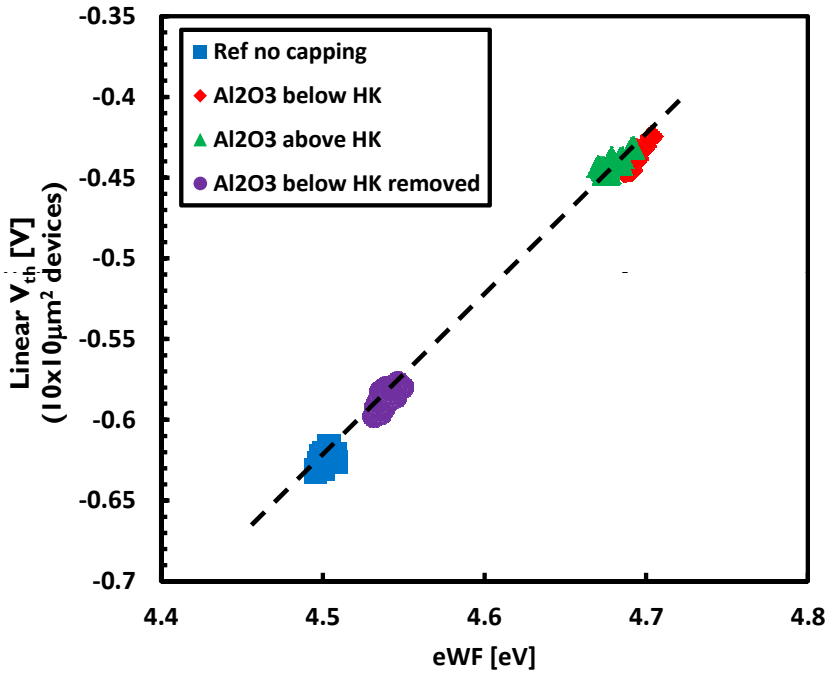
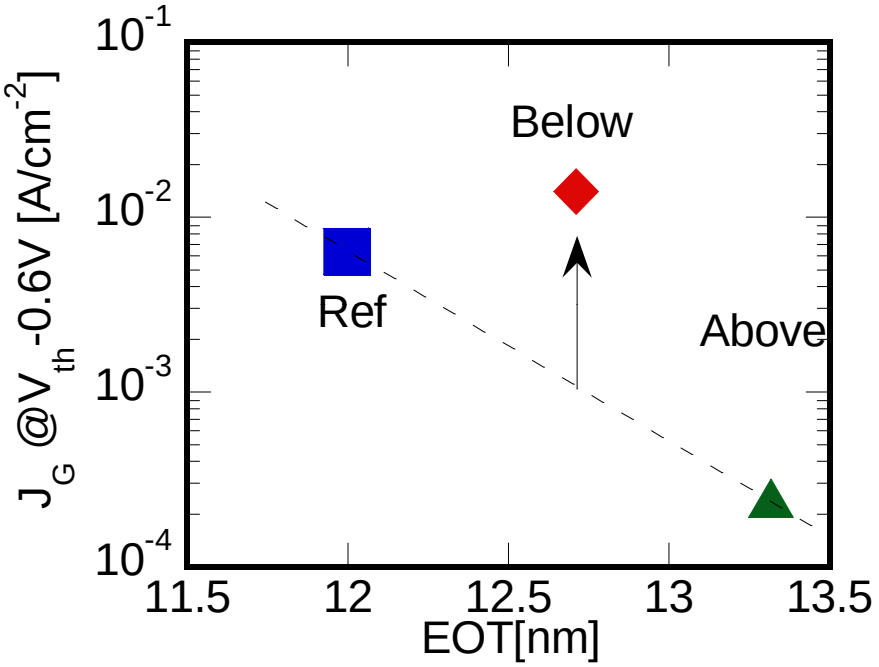
THRESHOLD VOLTAGE SHIFT AND LEAKAGE



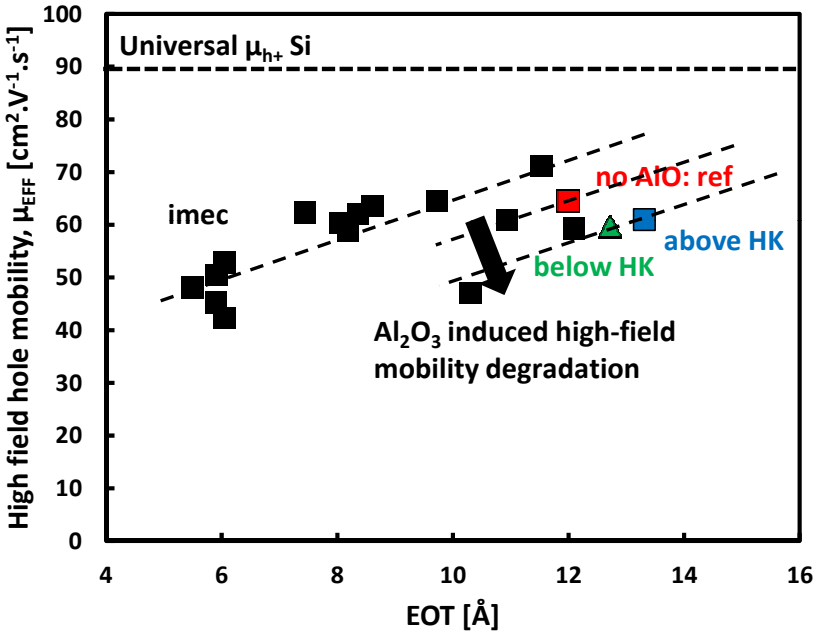


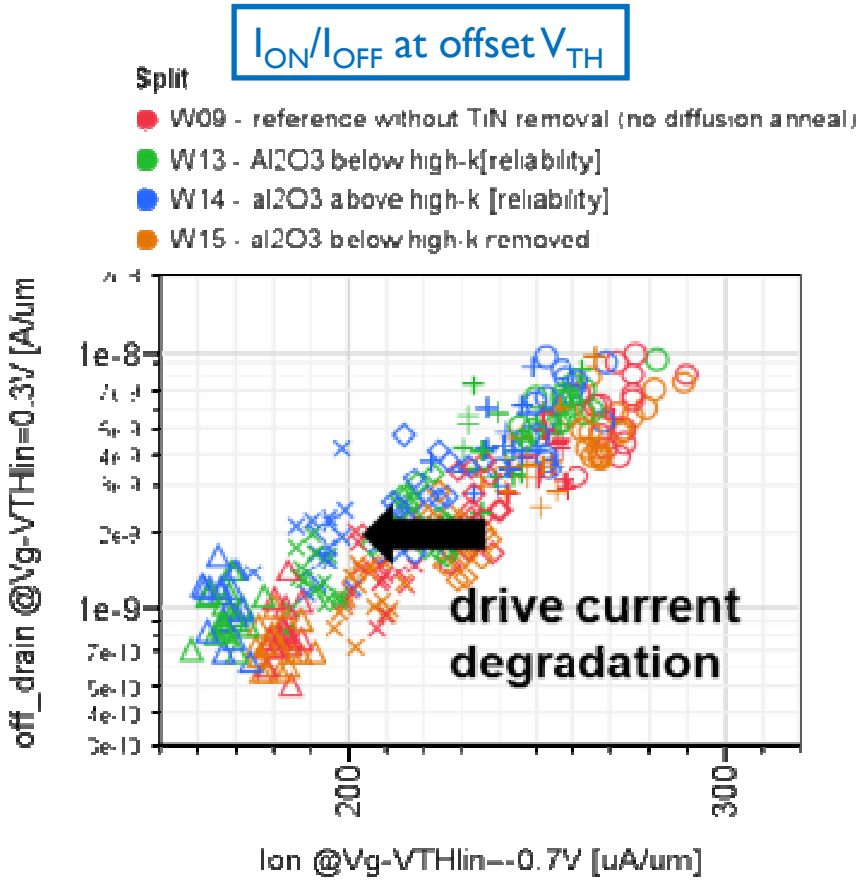
~200mV V_{th} shift using Al_2O_3 independently of the capping location.

Lower EOT and higher I_G for AL_2O_3 below HfO_2.

→ Probably intermixing with the SiO_2 interfacial layer and K value change and Si/SiO_2 energy offset change.

PERFORMANCES





- Higher EOT and lower mobility translate into lower ON current at fixed V_{TH} (trade-off between mobility and V_{TH} shift)
- No difference for capping above or below high-k

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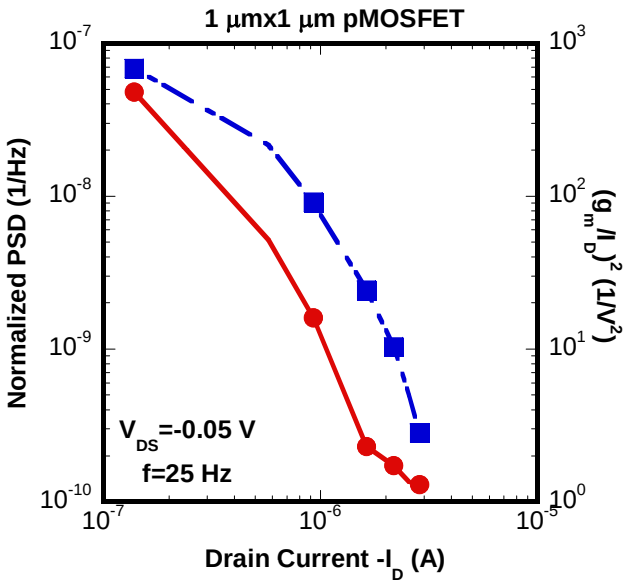
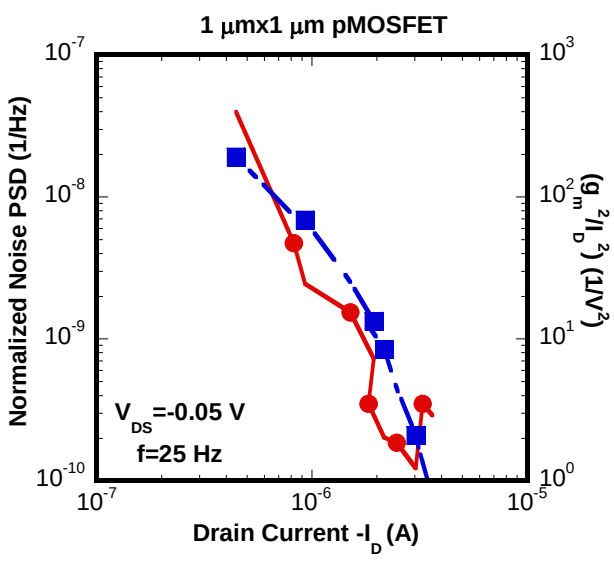
LOW FREQUENCY NOISE

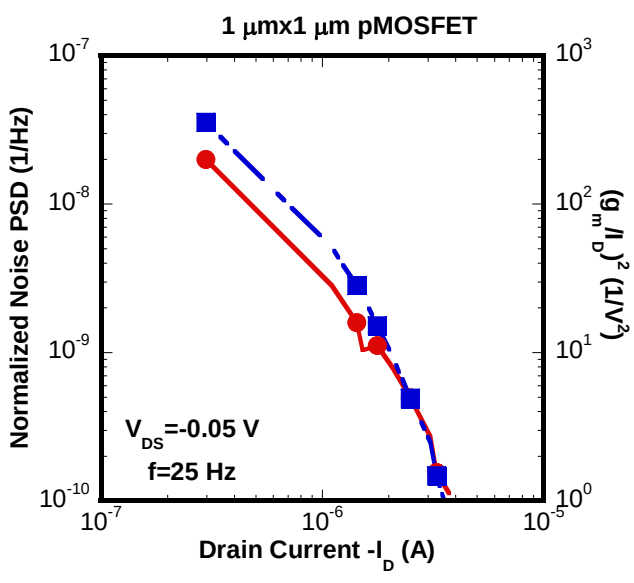
Reference



Al_2O_3 below HfO_2



Al_2O_3 above HfO_2



LF noise is dominated by number fluctuations
– i.e., **trapping in the gate oxide.**

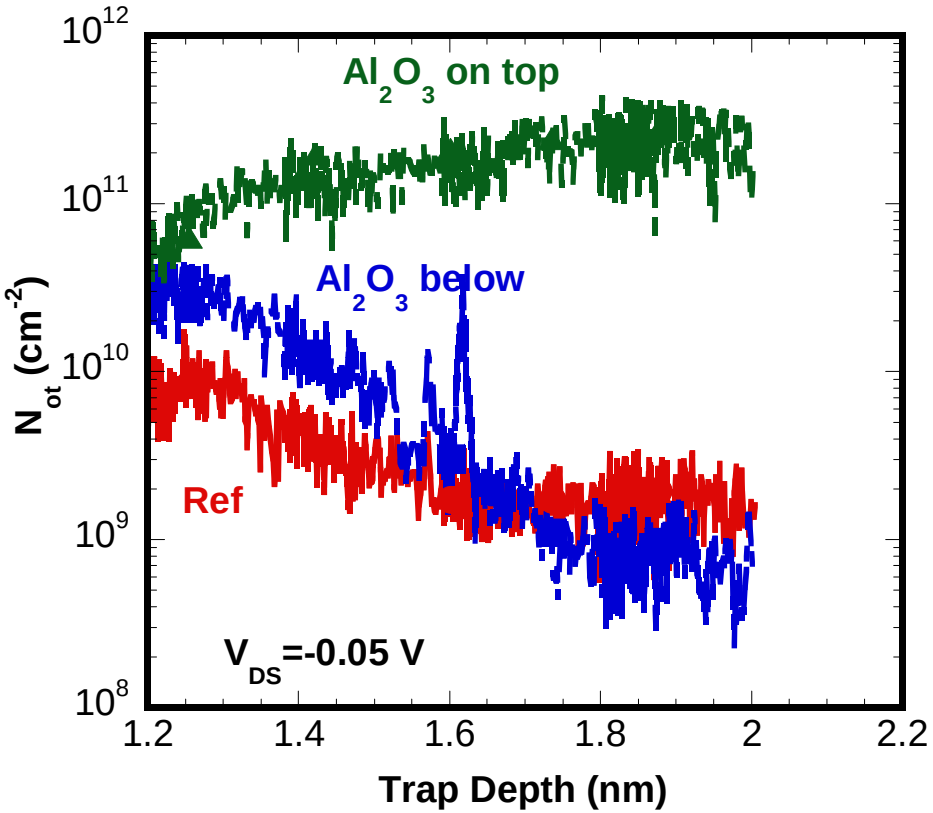
LOW FREQUENCY NOISE

$$S_{VG} = \frac{q^2 kTN_{ot}}{WLC_{EOT}^2 \alpha_t f}$$

$$Not = \frac{S_{VG} WLC_{EOT}^2 \alpha_t f}{q^2 K_B T}$$

$$z = \frac{\hbar}{2\sqrt{2.q.m_{ox}\phi_{it}}} \ln\left(\frac{1}{2\pi f \tau_0}\right)$$

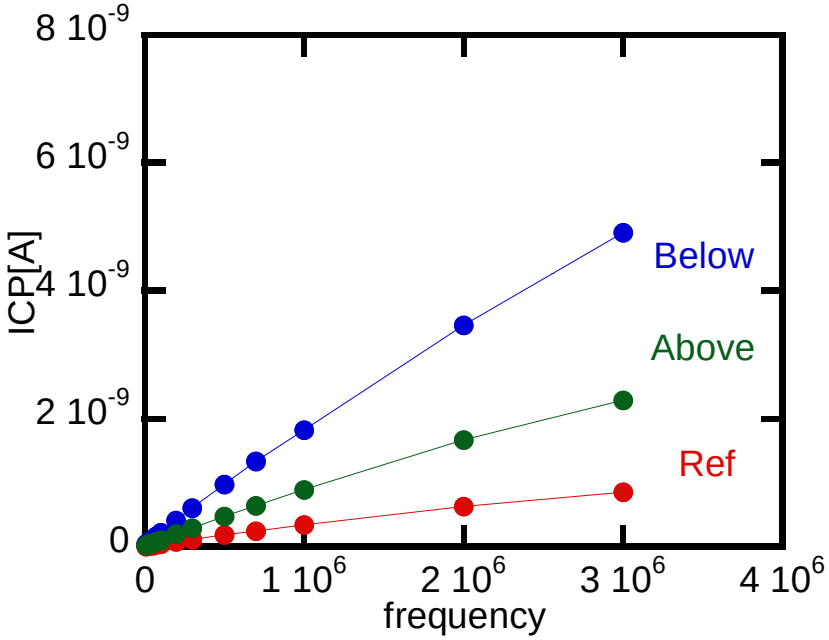
Trap profiles

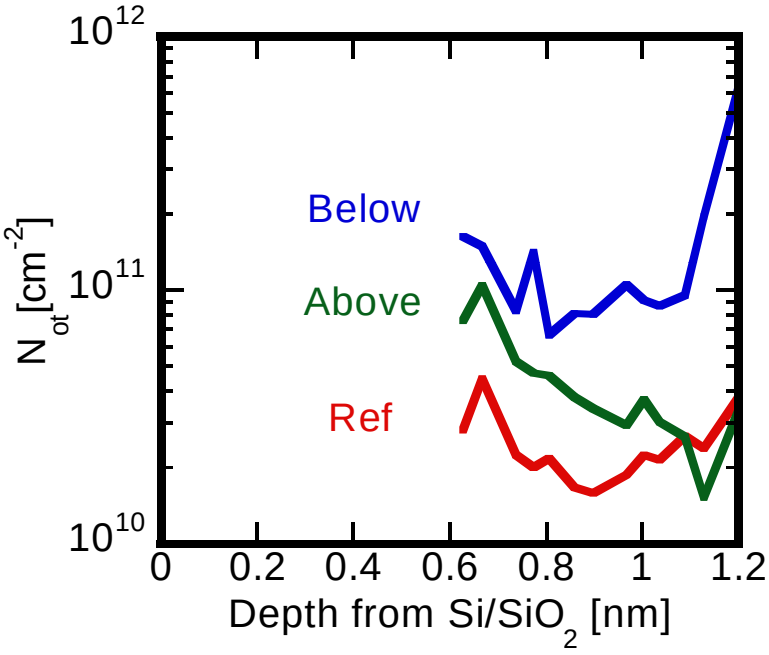


The trap profiles close to the valence band seem to be more sensitive to the additional cap layers.

[1]G. Ghibaudo, et .al. "Improved analysis of low frequency noise in field-effect MOS transistors," *phys. stat. sol. (a)*, vol. 174, pp. 571-581, 1991.
[2]E. Simoen , et al. "On the flicker noise in submicron silicon MOSFETs," *Solid-St. Electron.*, vol. 43, no. 5, pp. 865-882, May 1999.
[3] Z. Çelik and T.Y. Hsiang, "Study of 1/f noise in N-MOSFET's: Linear region," *IEEE Trans. Electron Devices*, vol. 32, no. 12, pp. 2797-2802, Dec. 1985
[27]F.P. Heiman et al. "The effects of oxide traps on the MOS capacitance," *IEEE Trans. Electron Devices*, vol. ED-12, pp. 167-178, Apr. 1965.
[28]I. Lundström et al., "Tunneling to traps in insulators," *J. Appl. Phys.*, vol. 43, no. 12, pp. 5045-5047, Dec. 1972.

VARIABLE FREQUENCY CHARGE PUMPING CURRENT



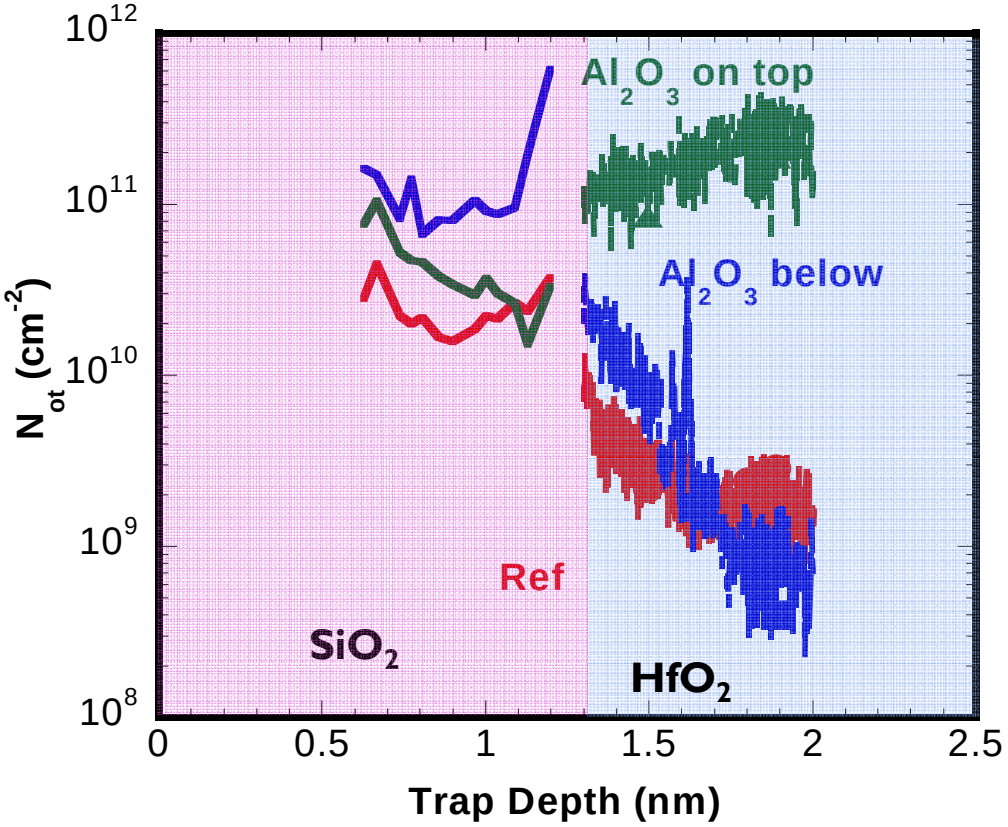


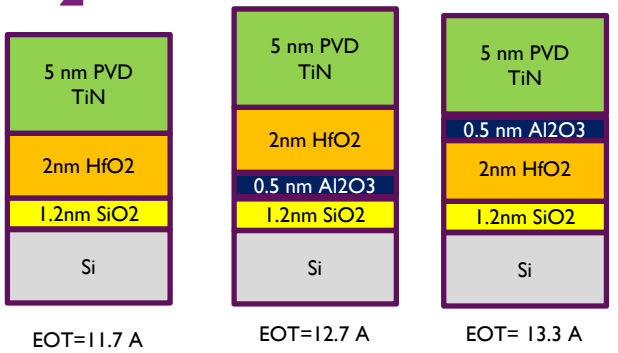
$$Not = \frac{dQ\ cy}{d\ \log(\ f\ )} \qquad \text{and} \qquad z = \frac{\hbar}{2\sqrt{2.q.m_{ox}\phi_{it}}} \ln\left(\frac{1}{2\pi f \tau_0}\right)$$

A slightly higher defects density in the SiO_2 interfacial layer for Al_2O_3 below HfO_2

M.Cho et al."Study of the Reliability Impact of Chlorine Precursor Residues in Thin Atomic-Layer-Deposited HfO2 Layers" IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 54, NO. 4, 2007

IMPACT OF Al_2O_3 LOCATION: BOTTOM OR TOP OF HfO_2





Trap profile follows the expected Al diffusion

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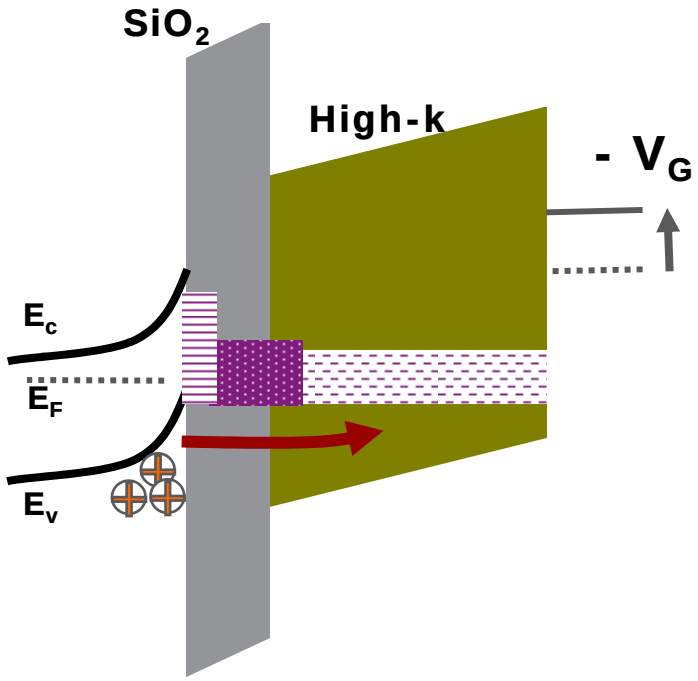
NBTI IN DRAM PERIPHERAL DEVICES



- *Interface defects* and *bulk defects* induce a Vth shift during the stress.
- ΔV_{th} kinetics obeys a power law time dependence on V_G, E_{ox}, EOT (t_{ox})
- Thermally activated
- Bulk defects impact on the ΔV_{th} kinetics.
- Device lifetime is extrapolated for a given ΔVth (design specifications)

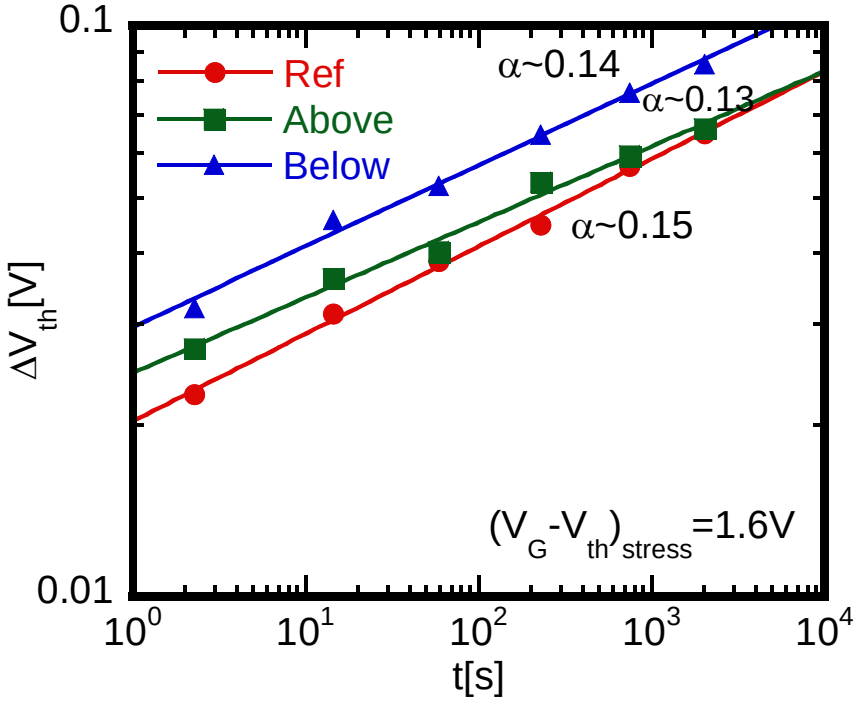
temperature

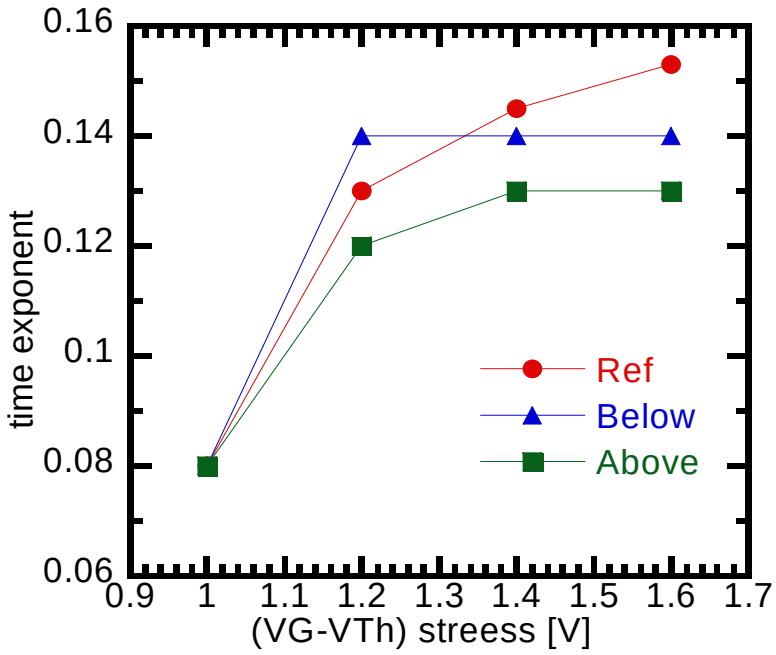
$$\Delta V_{th}(t, V_G, EOT, T) = C.\exp\left(\frac{-Ea}{kT}\right).\left(\frac{V_G - V_{th}}{EOT}\right)^{m}.t^{\alpha}$$

Related to the stack

Field

ΔV_{TH} VERSUS STRESS TIME

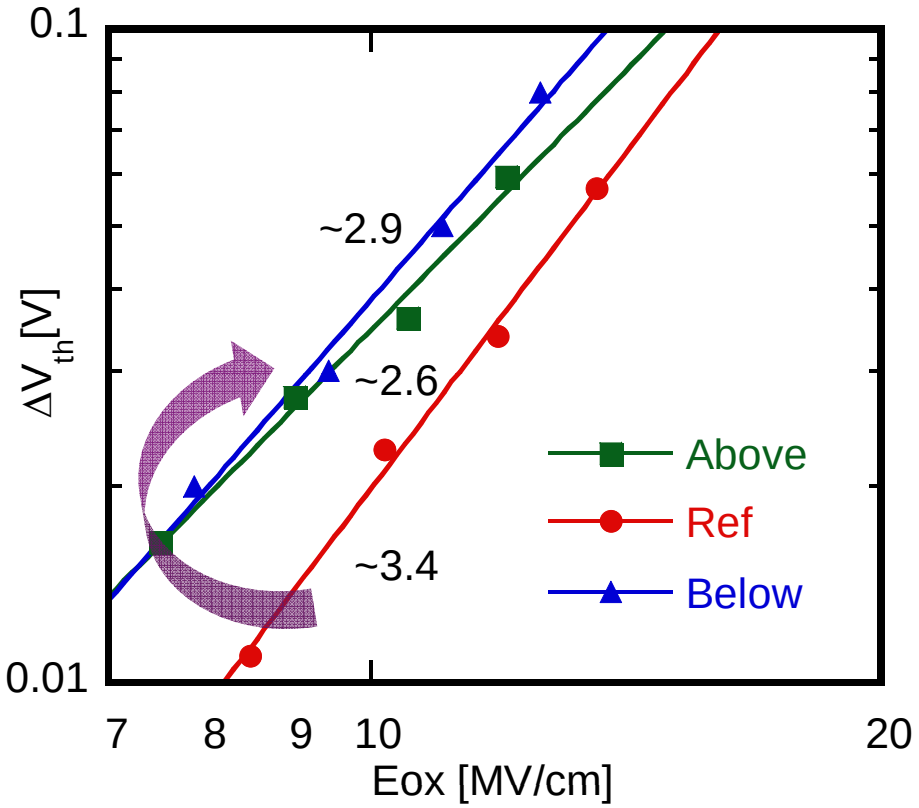




$$\Delta V_{th}(t) = C.\left(\frac{V_G - V_{th}}{EOT}\right)^{m}.t^{\alpha}$$

Higher density of bulk defects lower time exponent

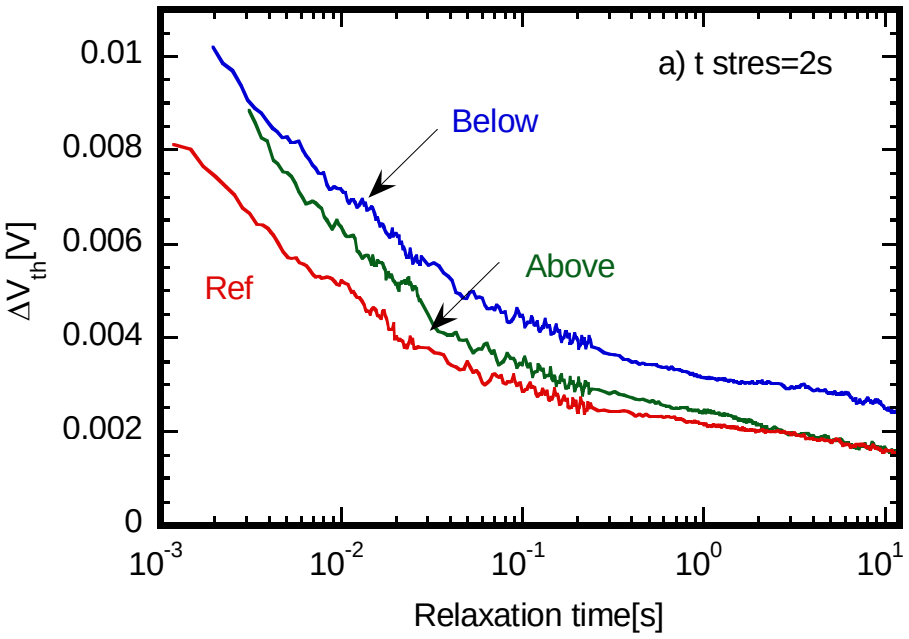
FIELD ACCELERATION

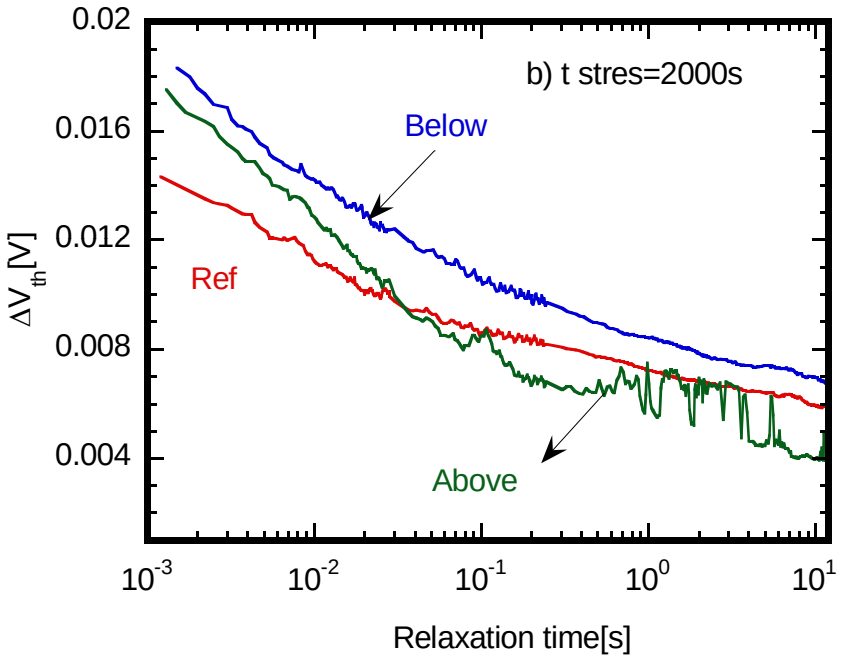


$$\Delta V_{th}(Eox) = C.Eox^{m}.t^{\alpha}$$

More bulk defects higher degradation at lower field and lower field exponent and lower field exponent

DV_{TH} RELAXATION

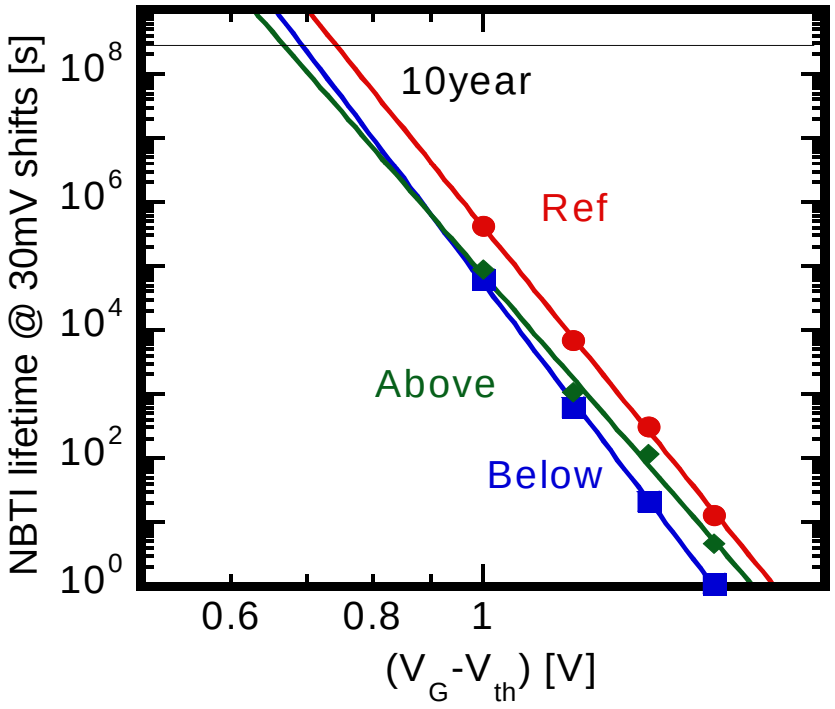




- Faster Vth recovery for Al_2O_3 above HfO_2
- Relaxation for t >1ms is more sensitive to slow traps (farther from the interface)

NBTI LIFETIME EXTRAPOLATION

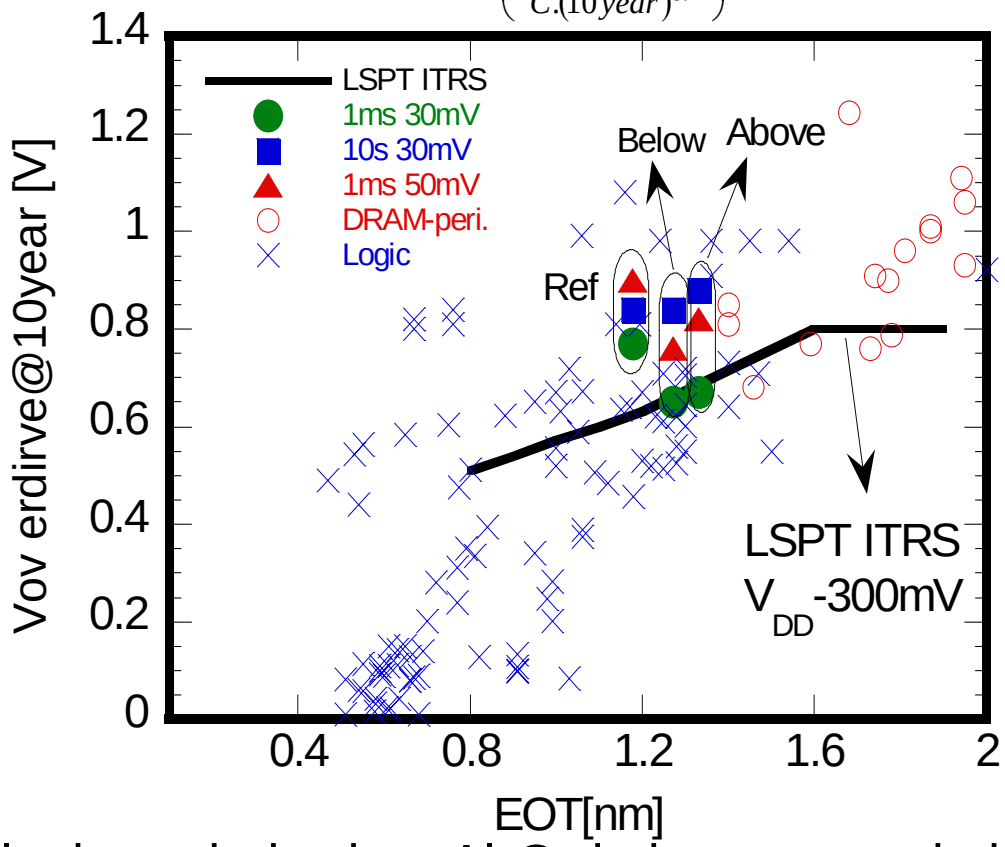
$$Time\ to\ failure = \left(\frac{\Delta V_{th,criterion}}{C} \right)^{\frac{1}{\alpha}} .(EOT)^{\frac{m}{\alpha}} . \left(\frac{1}{V_G - V_{th}} \right)^{\frac{m}{\alpha}}$$



NBTI is slightly degraded when Al_2O_3 in incorporated either below or above HfO_2

NBTI LIFETIME EXTRAPOLATION

$$(V_G - V_{th})_{at10\,year} = \left(\frac{\Delta V_{th,criterion}}{C.(10\,year)^{\alpha}}\right)^{\frac{1}{m}}.EOT$$



NBTI is slightly degraded when Al_2O_3 in incorporated either below or above HfO_2

M. Cho, J-D. Lee, M. Aoulaiche, B. Kaczer, Ph.J. Roussel, T. Kauerauf, R. Degraeve, J. Franco, L.-Å. Ragnarsson, and G. Groeseneken, "Insight Into N/PBTI Mechanisms in Sub-1-nm-EOT Devices", IEEE Trans. On Elect. Dev.,vol. 59, No. 8, pp.2042-2048, 2012.

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CONCLUSIONS

- The defect density profiles from the low frequency noise and charge pumping current are in agreement with what can be expected from traps related to Al diffusion.

→ The higher peak density of traps is at the location where the Al_2O_3 cap is inserted.

- Increased leakage current and reduced LF noise for Al_2O_3 below HfO_2 .
- NBTI is slightly degraded when Al_2O_3 in incorporated either below or on top of HfO_2 compared to the reference.

Thank you

ASPIRE
INVENT
ACHIEVE

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ELPIDA SK hynix TOSHIBA SanDisk SONY FUJITSU QUALCOMM