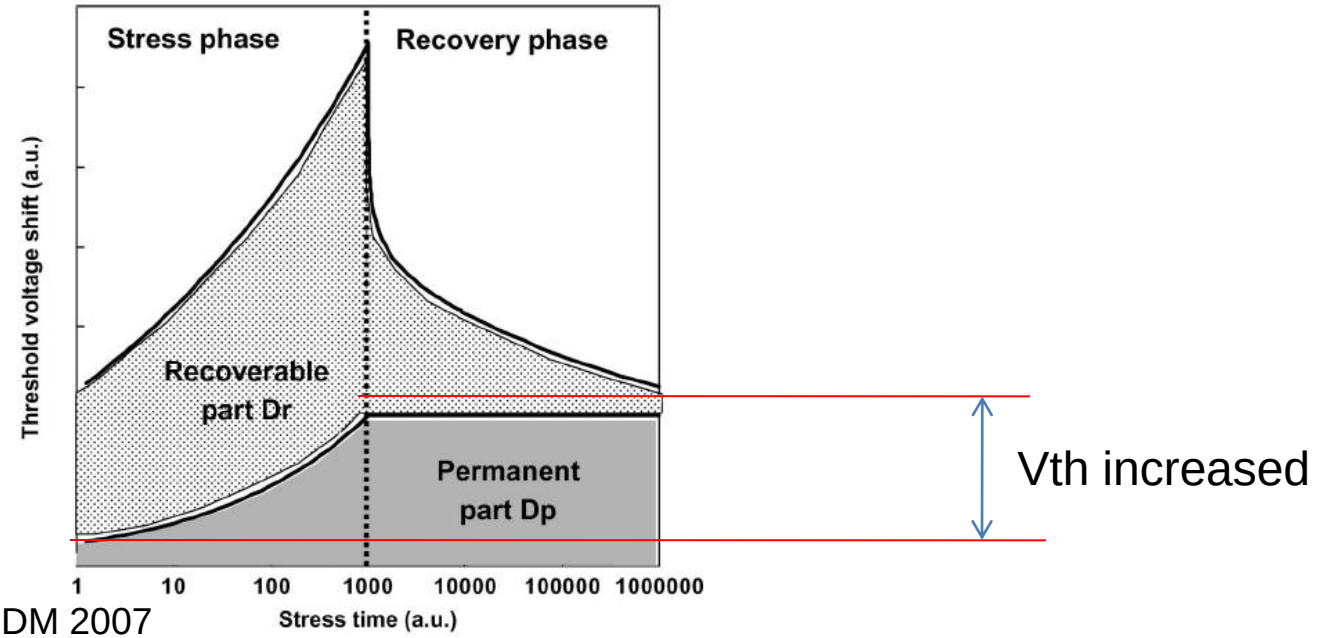
UCLA

Introduction on NBTI

Prepared by : Chan Tuck Boon

What is NBTI ?

- NBTI : Negative Bias Temperature Instability
- Vth varies on PMOS device
  - Vth increase with negative bias, Vgs=-Vdd
  - But recover with zero bias , Vgs=0

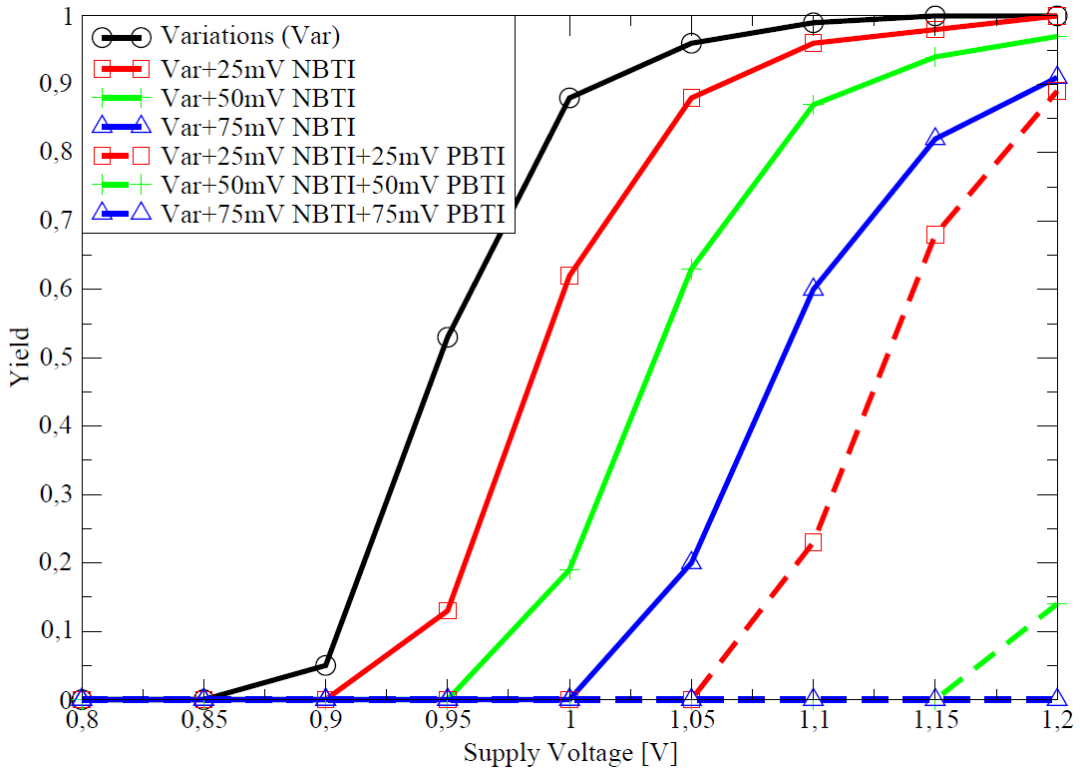


Source : Vincent Huard, IEDM 2007

NBTI impact

- Wang, VLSI 2010
  - 7% to10% frequency degradation on benchmark circuits
- Mangalagiri, ICCAD 2008
  - 5% to 10% delay degradation in FPGA due to NBTI (PTM model)
  - 1% delay degradation for process with hi-Vt and thick oxide.
- Neeraj, IEDM 2005
  - Degradation depends on configuration and application.
  - V_{error} > 7 mV (maximum allowed error=7.8mV) for a 64 bit DAC.
- J.C. Lin, IEDM 2006
  - SRAM read margin decrease as a result of NBTI stress.
  - Limit NBTI impact using a less “read margin” dominant design.

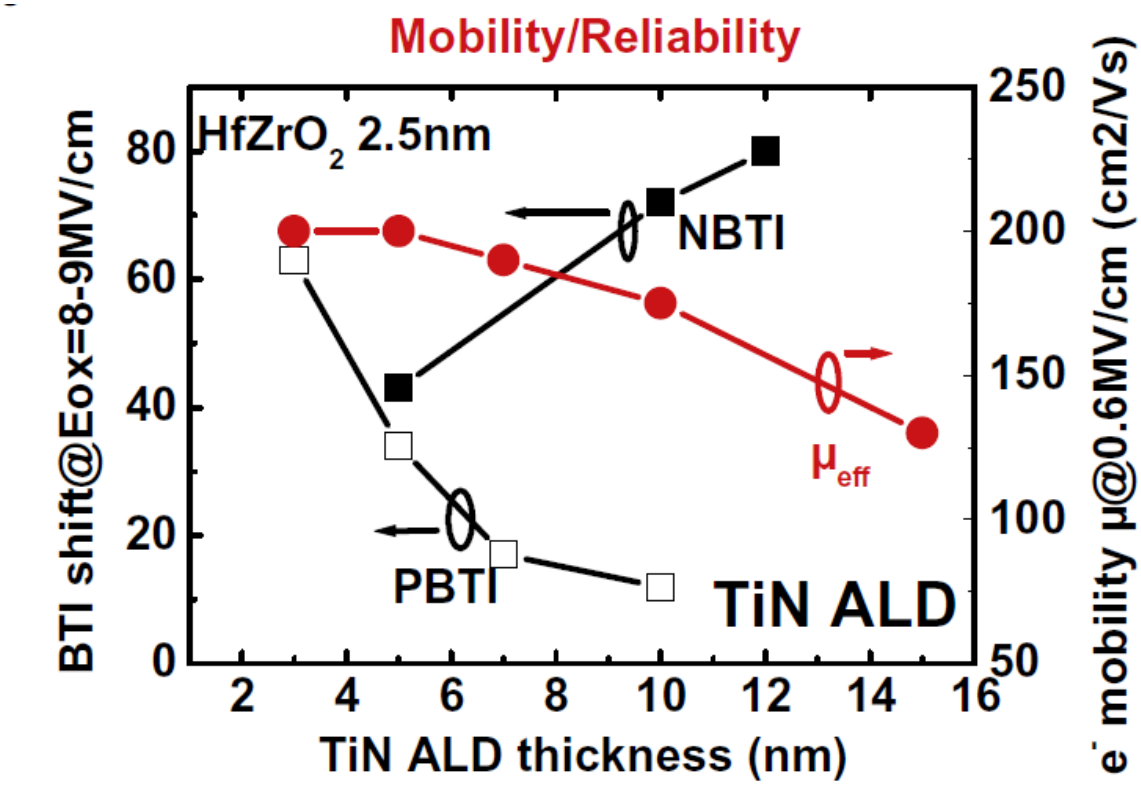
Impact on SRAM



Drapatz ,*Journal Advances in Radio Science, 2009*

- NBTI shows noticeable impact on SRAM yield
- Yield loss is huge considering NBTI + PBTI

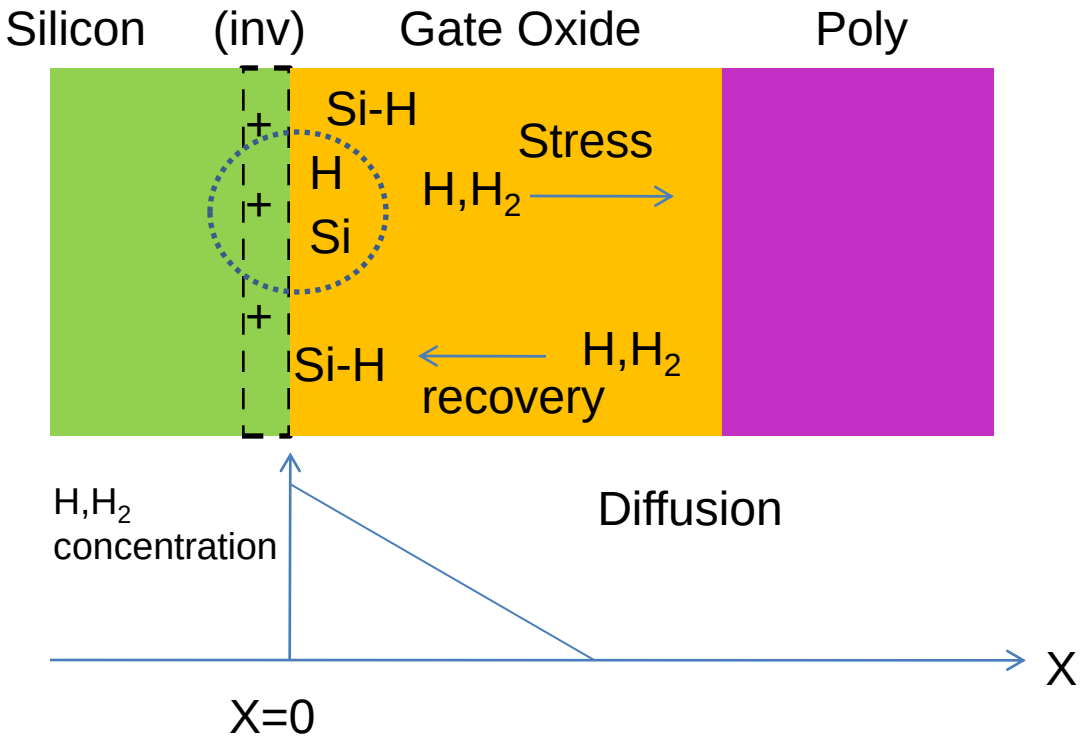
NBTI vs PBTI



- trade-off between NBTI/PBTI and metal gate thickness

Reaction-diffusion model

- Interface traps is generated when device is stressed (negative bias)



Differential Equations for NBTI

$$\frac{dN_{IT}}{dt} = k_F(N_o - N_{IT})P - k_R N_H N_{IT}$$ Reaction

$$\frac{dN_H}{dt} = D_H \frac{d^2 N_H}{dx^2}$$ Diffusion

Analytical model

Kv is proportional to Temperature

Stress

$$\Delta V_{th}(t) = \left(K_v (t - t_0)^{1/2} + \sqrt[2n]{\Delta V_{th}(t_0)}\right)^{2n}$$

2n=1/3 for reaction dominant by H_2

Recovery

$$\Delta V_{th}(t) = \Delta V_{th}(t_1)\left(1 - \frac{2\xi_1 t_e + \sqrt{\xi_2 C(t - t_1)}}{(1+\delta)t_{ox} + \sqrt{Ct}}\right)$$

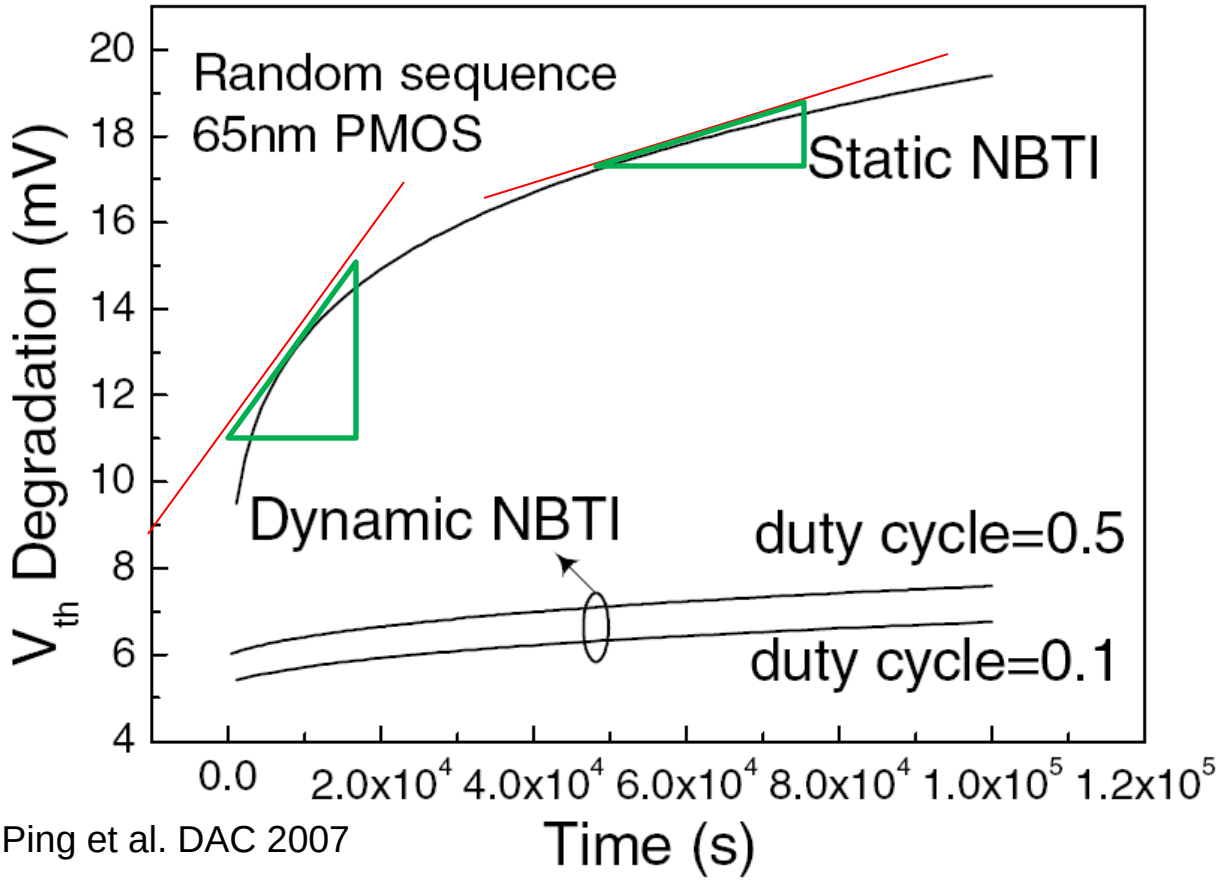
Recovery factor Related to

Source : W. Ping et al. DAC 2007

NBTI Characteristics

- NBTI degradation is front-loaded
- Frequency dependent or independent ?
- V_{gs} dependence
- V_{th} variation reduction due to NBTI

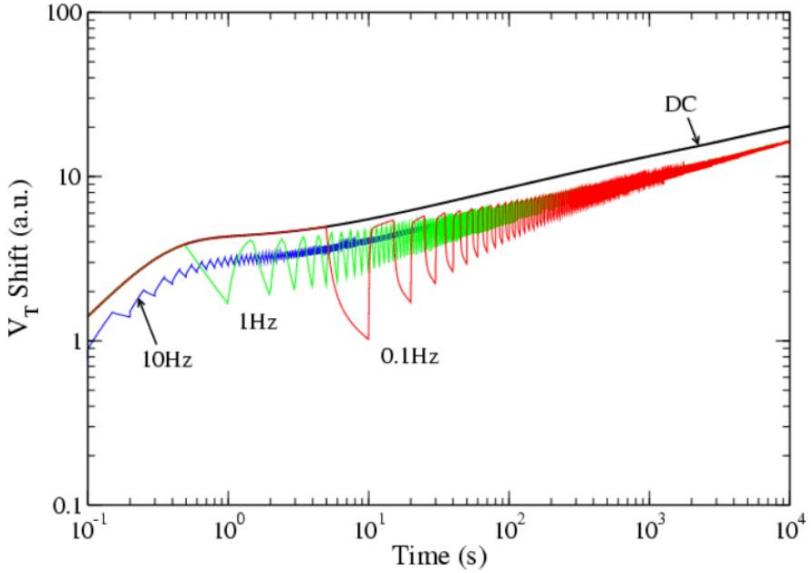
Front Loaded Degradation



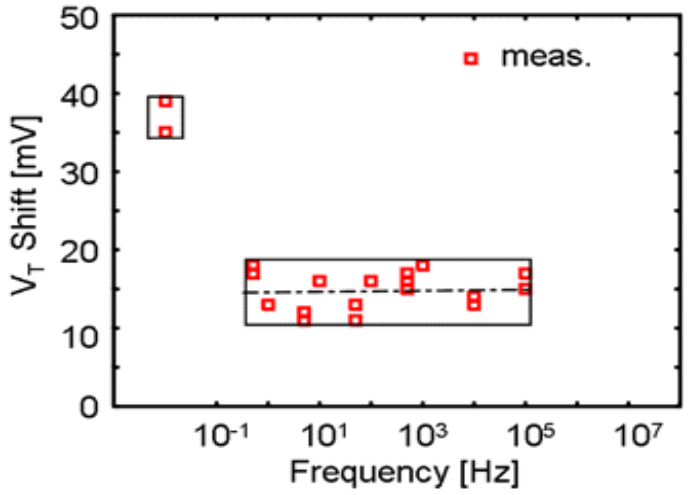
Source : W. Ping et al. DAC 2007

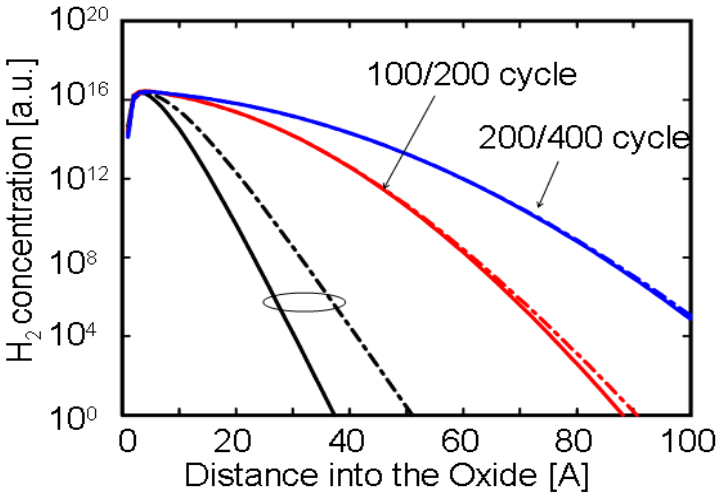
- Degradation rate is steep at the beginning but slows down rapidly

Frequency independence



http://www.iue.tuwien.ac.at/phd/wittmann/node10.html

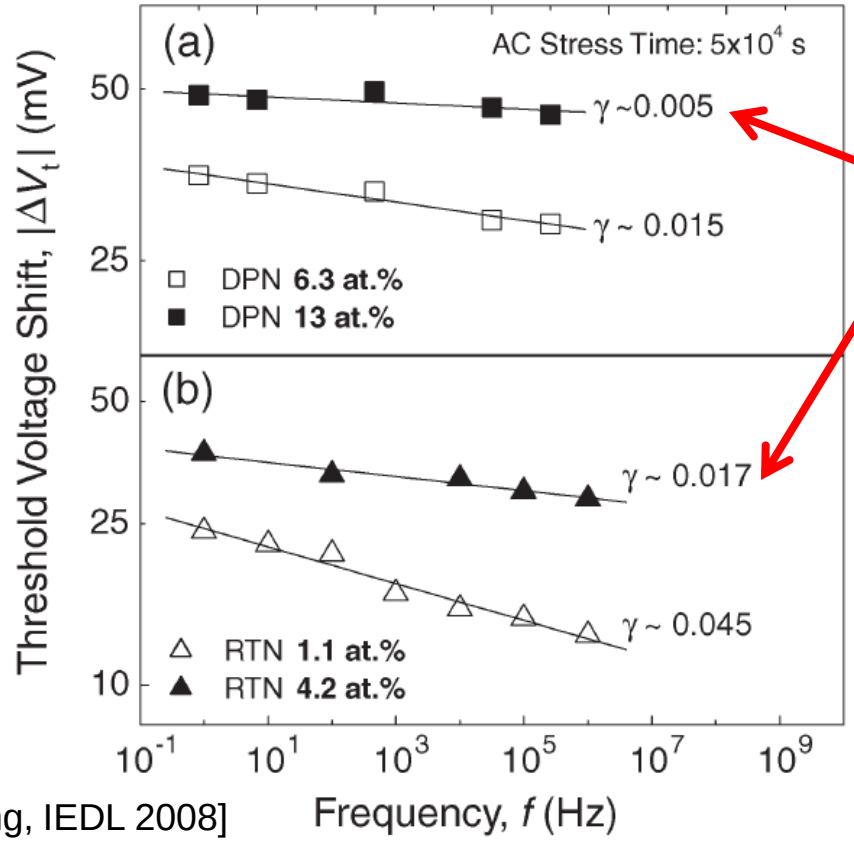




- RD model predicts frequency independence [Alam, IEDM 2003]
- Contradict observations are found in

Frequency Dependence

- DPN : decoupled-plasma-nitrided SiO2
- RTN : rapid-thermal-nitrided SiO2

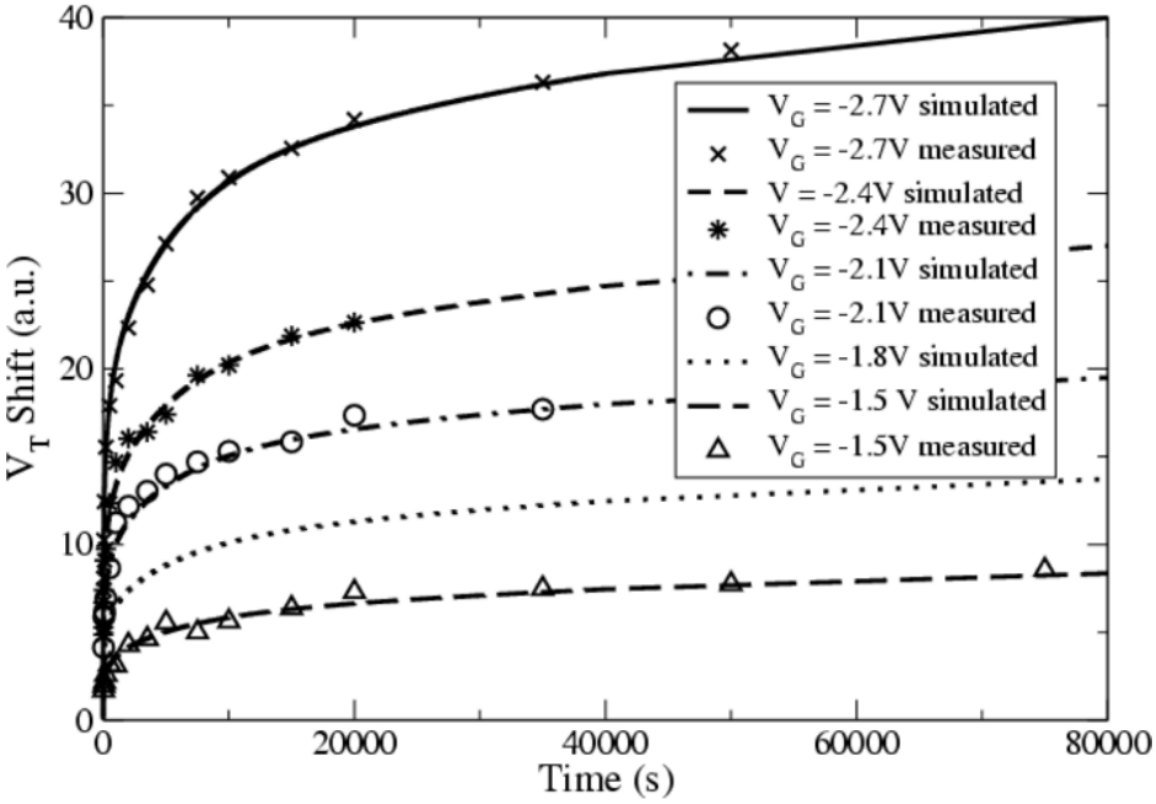


[Wang, IEDL 2008]

increased nitrogen concentration in gate oxide results weaker frequency dependence

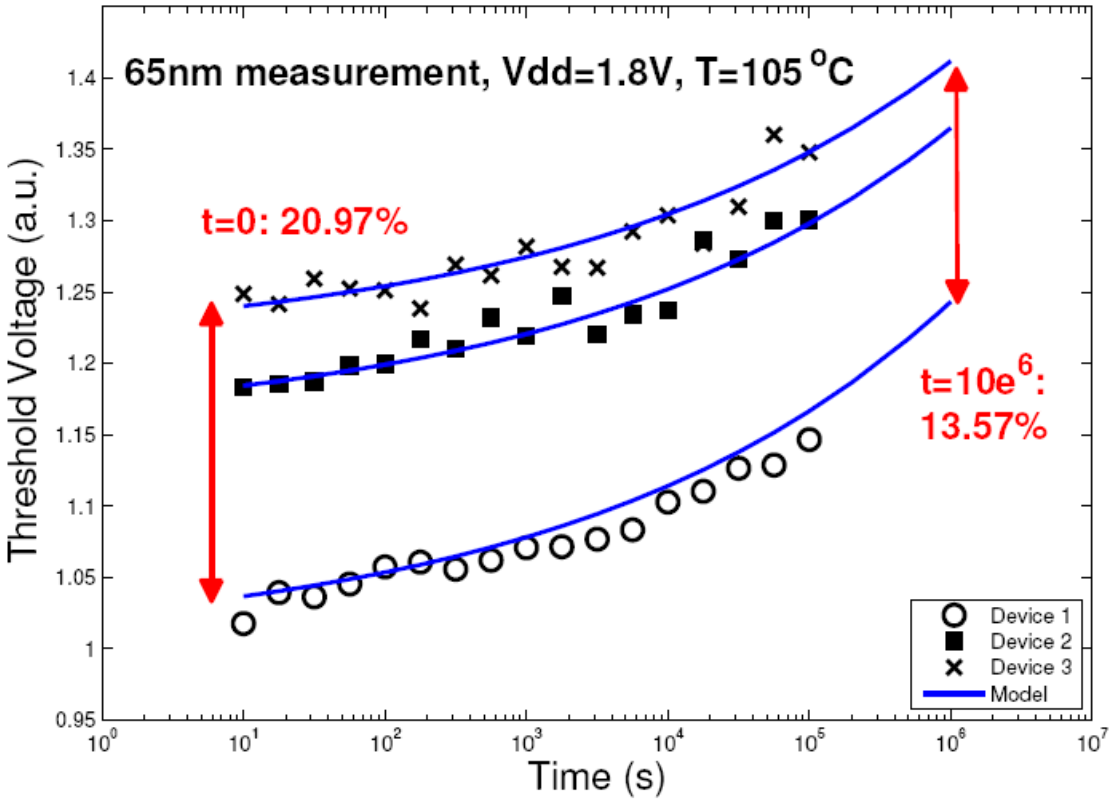
- Frequency dependence is due to deep level holes
  - holes have enough time to generate interface traps during low freq.

NBTI vs Vgs



- ΔV_t increase exponentially with increasing V_{gs}

NBTI and V_{th} Variation



Source : W. Ping et al. DAC 2007

ΔVth process ≡ ΔVth NBTI

ΔVth process + ΔVth NBTI

=> Overall process variation reduced

On-going Studies on NBTI

- Modeling and characterizing NBTI
  - Physical mechanism of NBTI
  - Measuring NBTI
  - Circuit and architectural level NBTI model
- NBTI mitigation techniques
  - Input vector control
    - Flipping bit cell data in SRAM
  - Power-gating schemes for NBTI