Introduction on NBTI

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What is NBTI?

- NBTI: Negative Bias Temperature Instability
- \( V_{th} \) varies on PMOS device
  - \( V_{th} \) increases with negative bias, \( V_{gs} = -V_{dd} \)
  - But recover with zero bias, \( V_{gs} = 0 \)

Source: Vincent Huard, IEDM 2007
NBTI impact

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

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

Drapatz, *Journal Advances in Radio Science, 2009*
**NBTI vs PBTI**

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

![Graph showing the trade-off between NBTI/PBTI and metal gate thickness](image-url)
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

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

Recovery
\[ \Delta V_{th}(t) = \Delta V_{th}(t_1) \left(1 - \frac{2\xi_1 t_c + \sqrt{\xi_2 C(t-t_1)}}{(1 + \delta) t_{ox} + \sqrt{C t}}\right) \]

Kv is proportional to Temperature

2n=1/3 for reaction dominant by H₂

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

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

Source: W. Ping et al. DAC 2007
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

Increased nitrogen concentration in gate oxide results in weaker frequency dependence.

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

[Wang, IEDL 2008]
NBTI vs Vgs

- $\Delta V_t$ increase exponentially with increasing $V_{gs}$
NBTI and $V_{th}$ Variation

$\Delta V_{th}$ process $\approx \Delta V_{th}$ NBTI

$\Delta V_{th}$ process + $\Delta V_{th}$ NBTI

$\Rightarrow$ Overall process variation reduced

Source: W. Ping et al. DAC 2007
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