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ECE606: Solid State Devices
Lecture 39: Reliability of MOSFET

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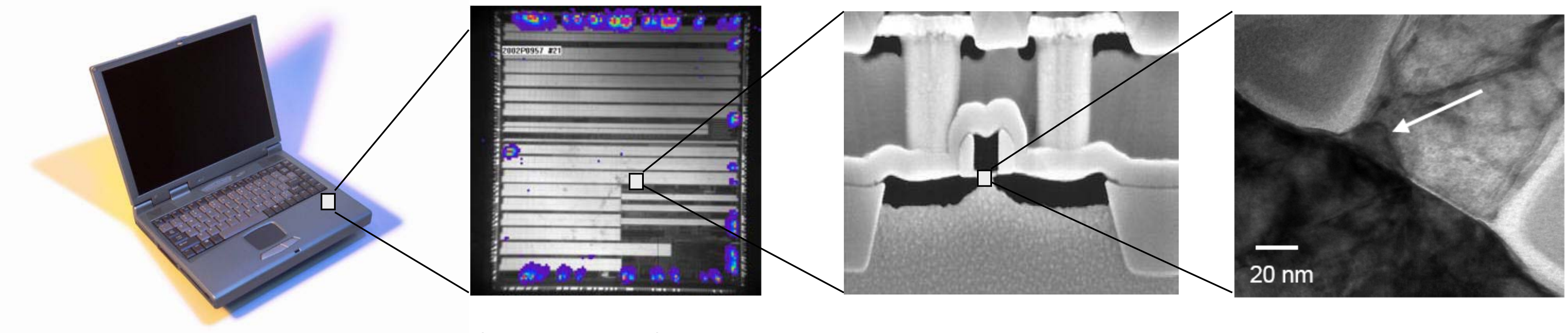
Outline

1. **Introduction**
2. Negative Bias Temp. Instability
3. Gate Dielectric Breakdown
4. Radiation Induced Damage
5. Conclusion

Warranty, product recall and other facts of life

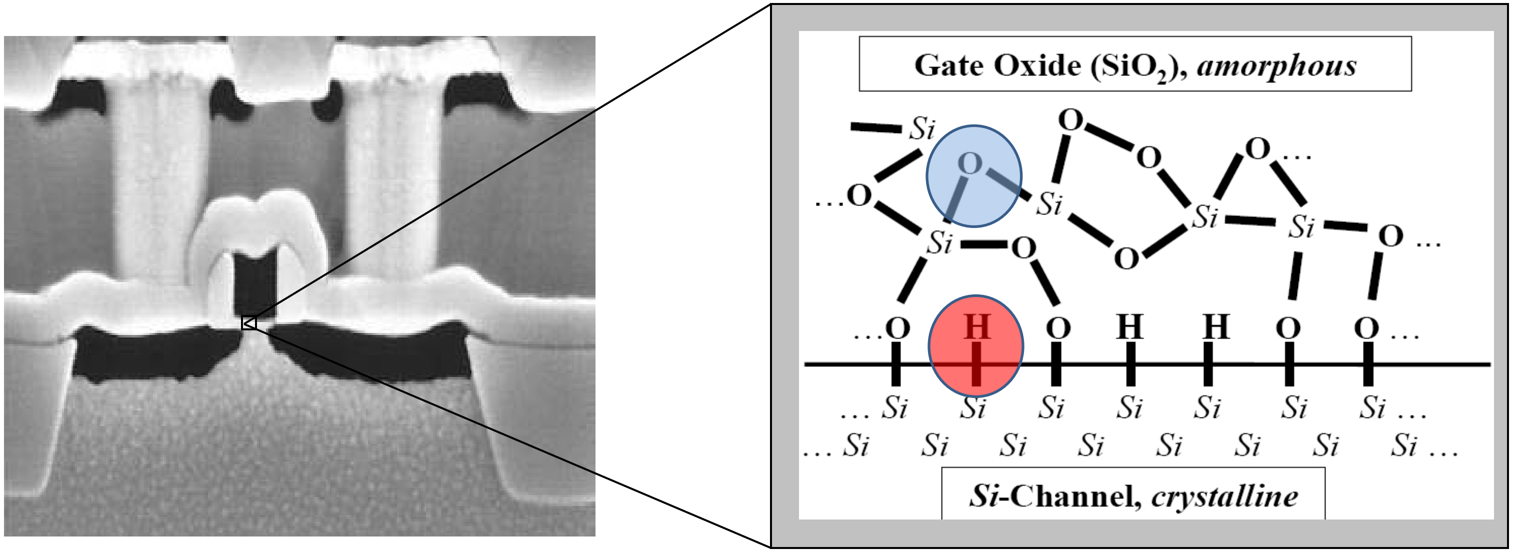


In this course, you are learning to analyze/design MOSFETs that go in an IC …

… because the ICs operate in incredibly harsh conditions, turning on and off trillions of time during its lifetime ….

… therefore the properties of the MOSFET keep changing. Eventually, S/D can be shorted, the gate oxide can break, etc ….

SiO and SiH Bonds



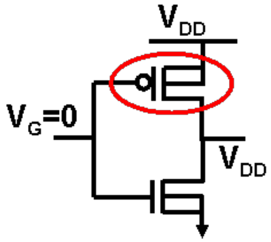
Broken Si-H bonds

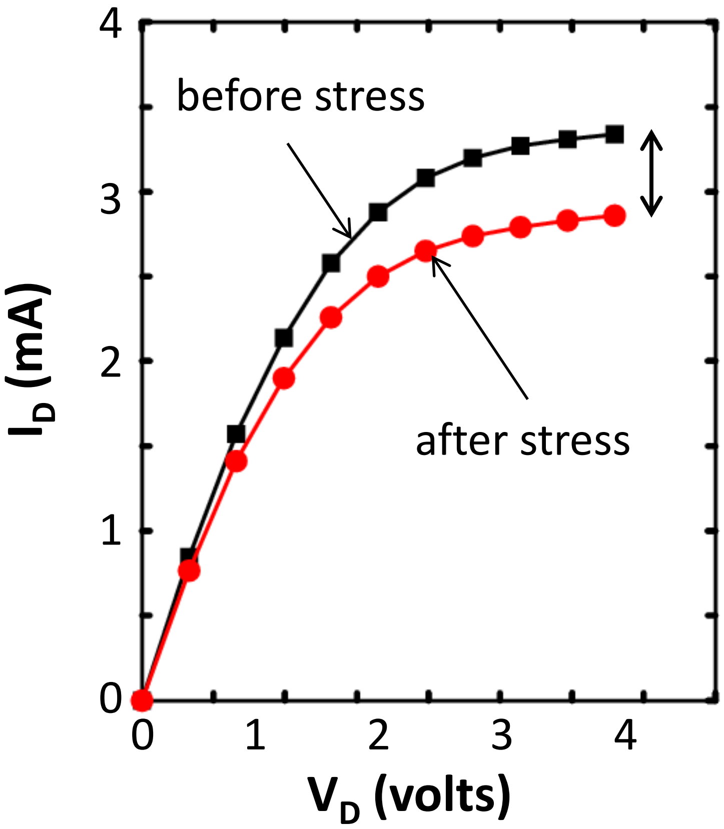
Negative Bias Temperature Instability (NBTI)
Hot carrier degradation (HCI)

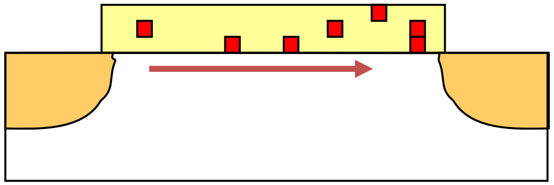
Broken Si-O bonds

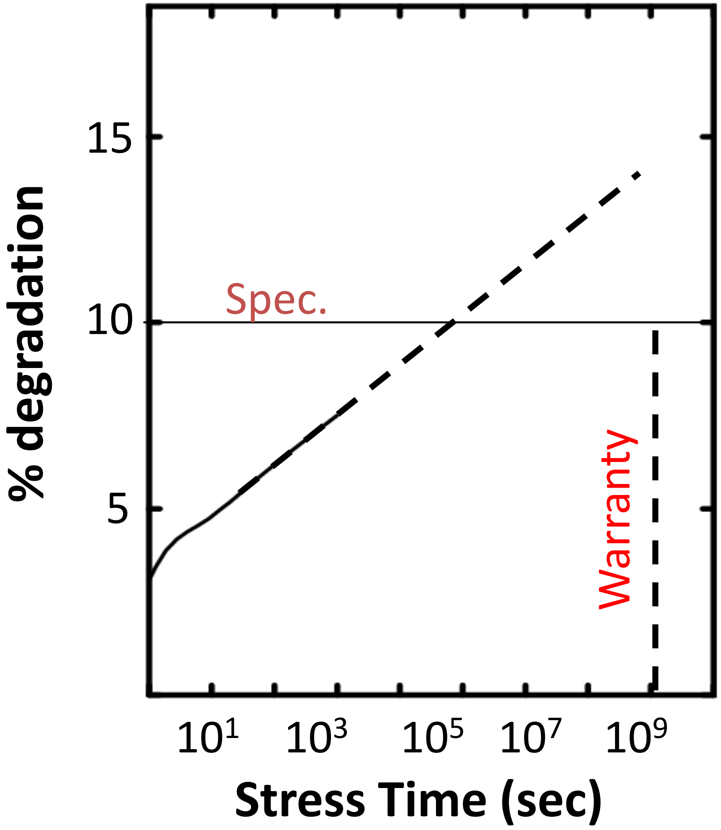
Gate dielectric Breakdown (TDDB)
Electrostatic Discharge (ESD)
Radiation induced Gate Rupture (RBD)

Negative Bias Temperature Instability Defined



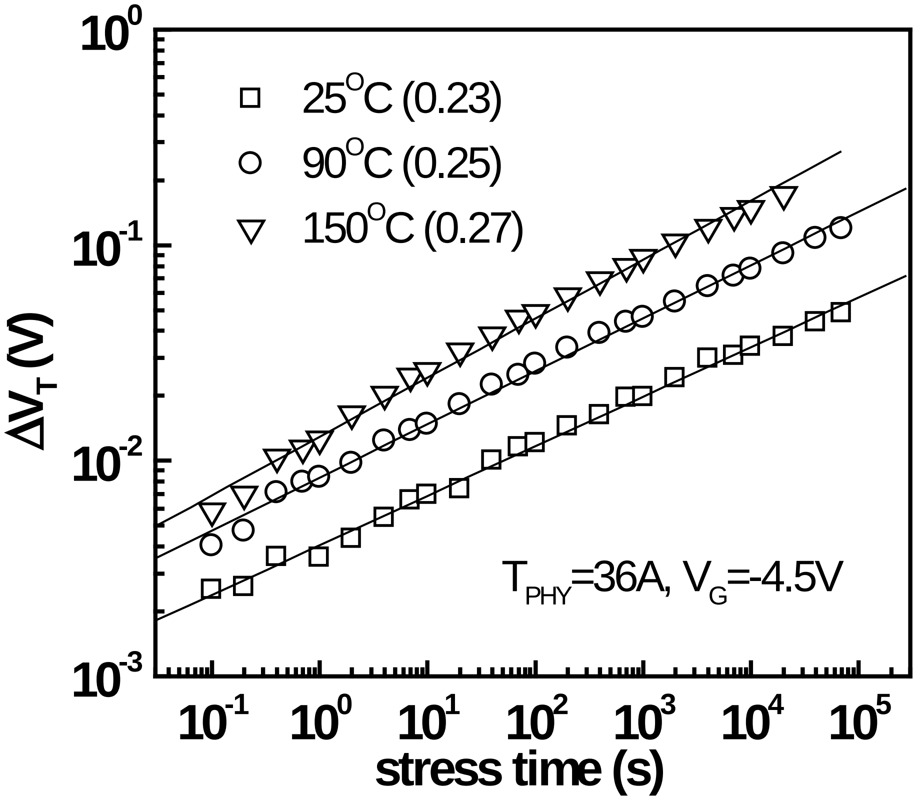






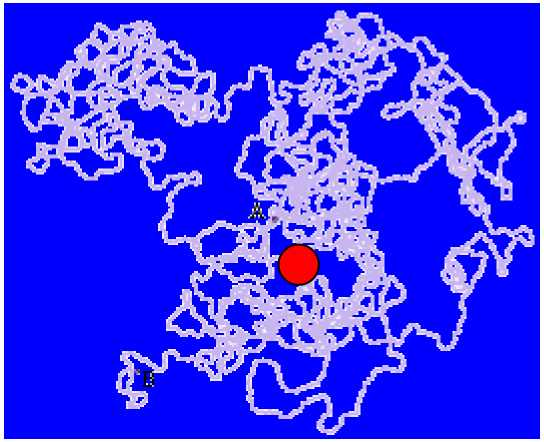
NBTI defined …

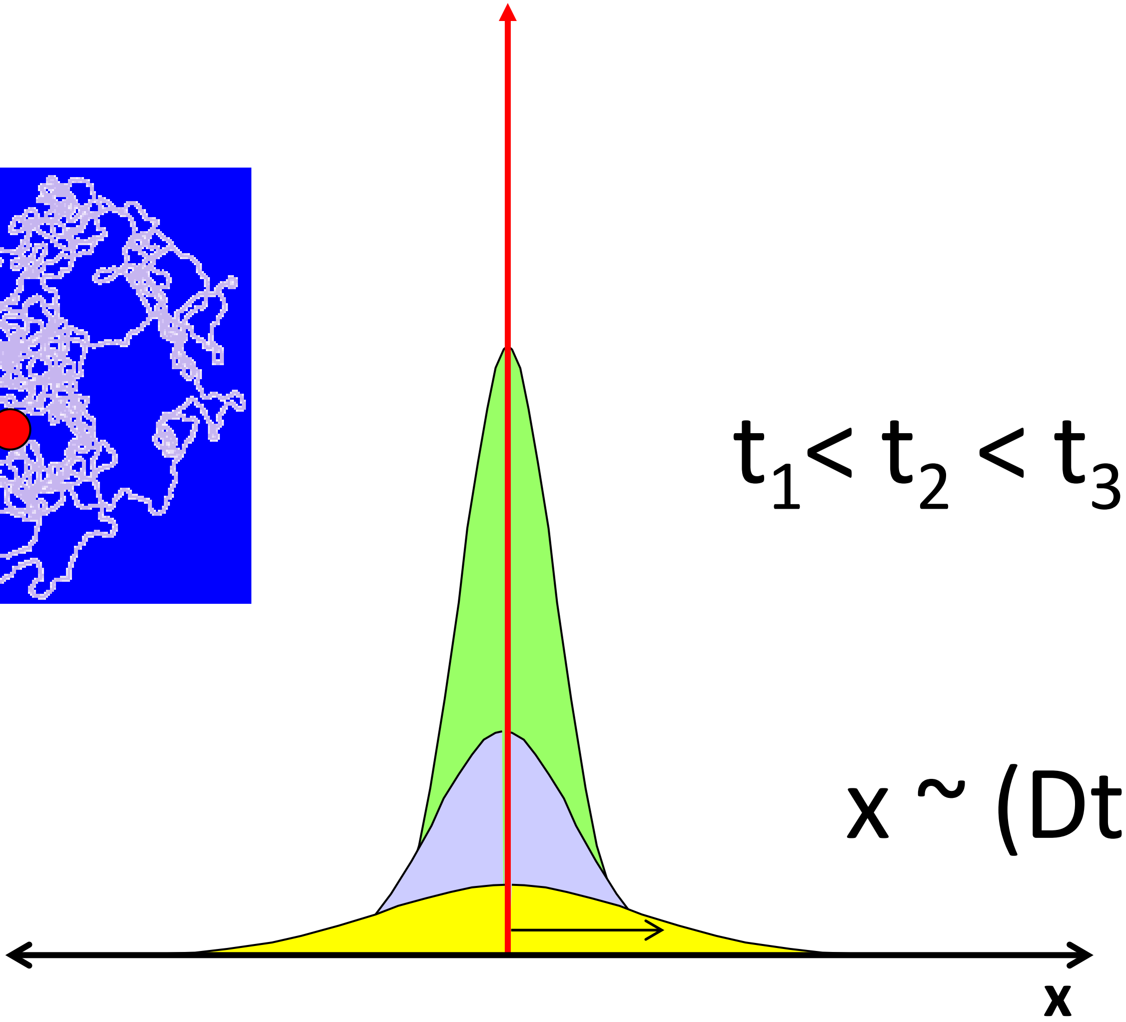
$$\Delta V_T = Ae^{-Ea/k_BT}t^n$$



- *n ~ 0.25*
- *Ea ~ 0.5 eV*
- *A depends on Eox*

Diffusion Distance

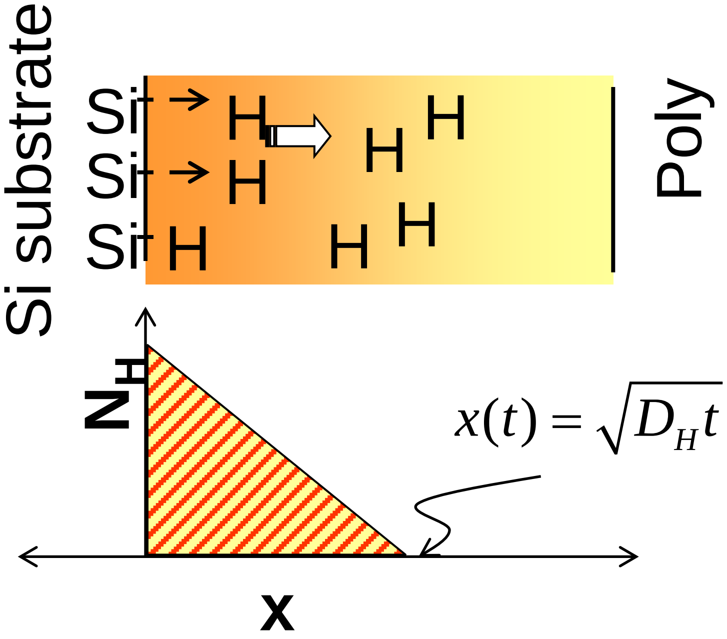




$t_1 < t_2 < t_3$

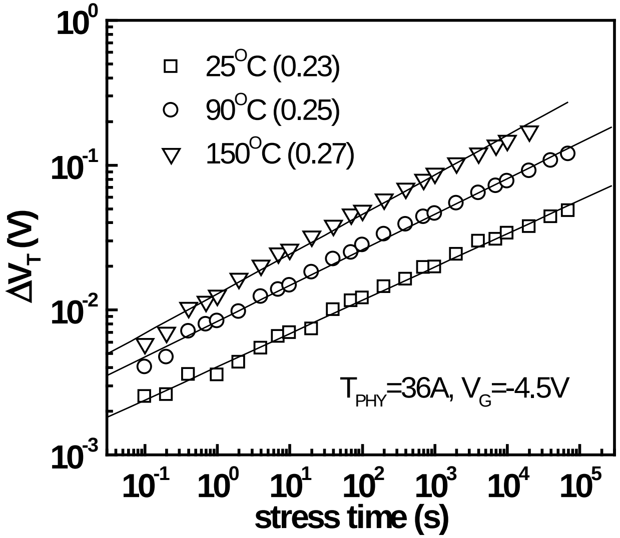
$x \sim (Dt)^{0.5}$

NIT with H diffusion



$$\frac{dN_{IT}}{dt}=k_F\left(N_0-N_{IT}\right)-k_R N_H(0)N_{IT}$$

$$\left(\frac{k_F N_0}{k_R}\right)\approx N_H(0)N_{IT}$$

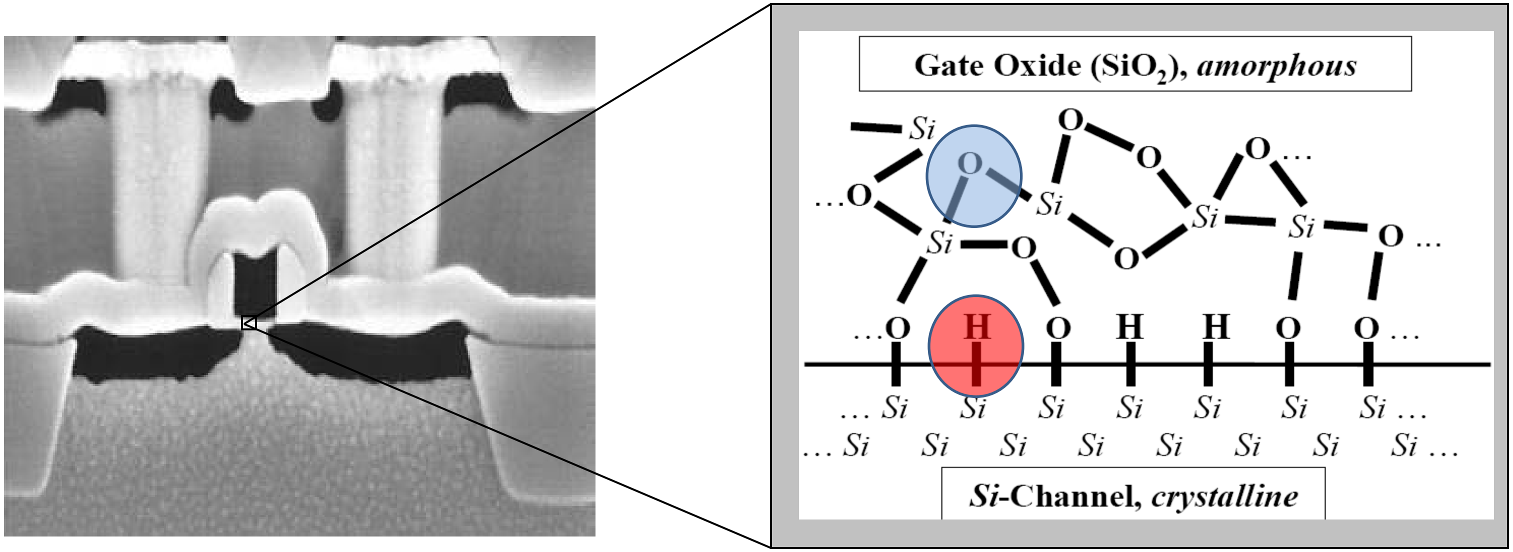


$$N_{IT}(t)=\frac{1}{2}N_H(0)\sqrt{D_H t}$$

Combining these two, we get

$$N_{IT}(t)=\sqrt{\frac{k_F N_0}{2k_R}}\left(D_H t\right)^{1/4}$$

SiO Bonds



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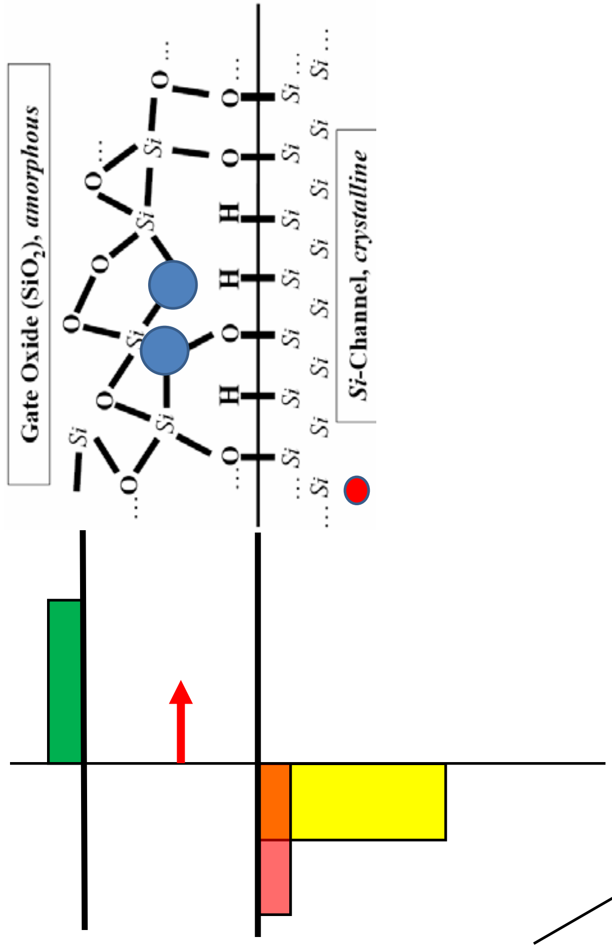
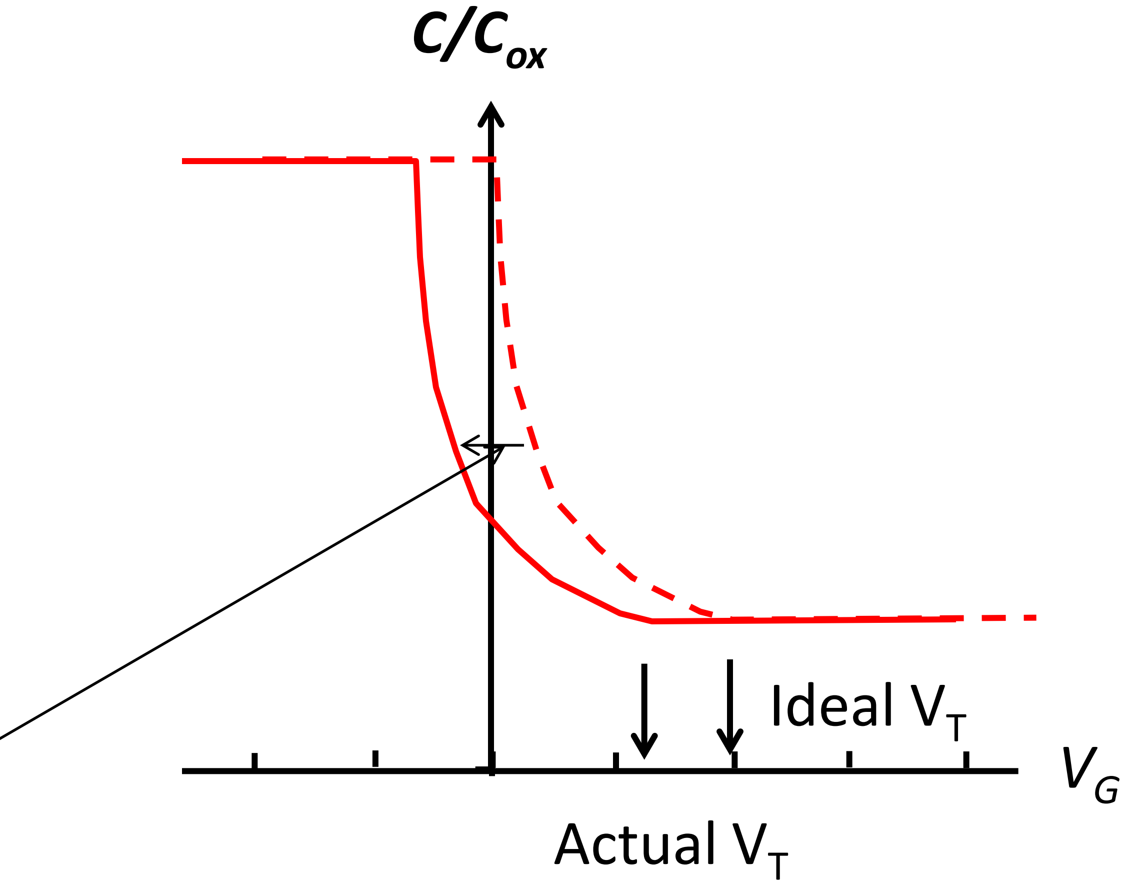
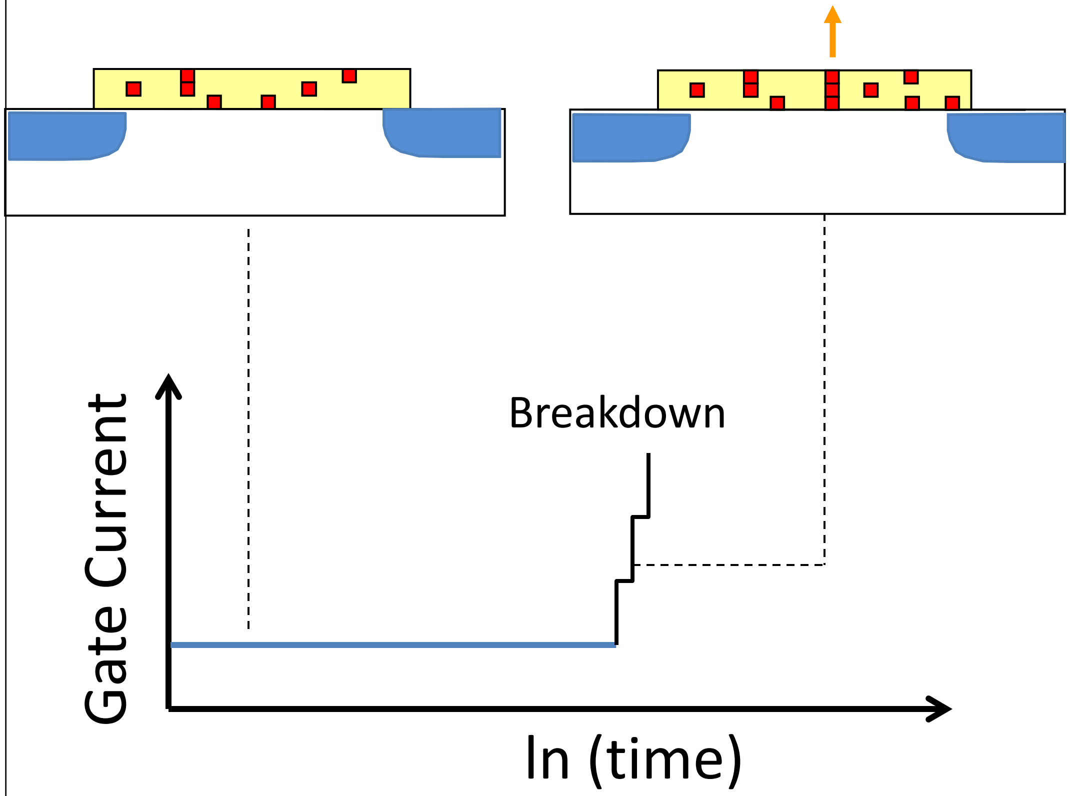
Time-dependent Bulk Trap

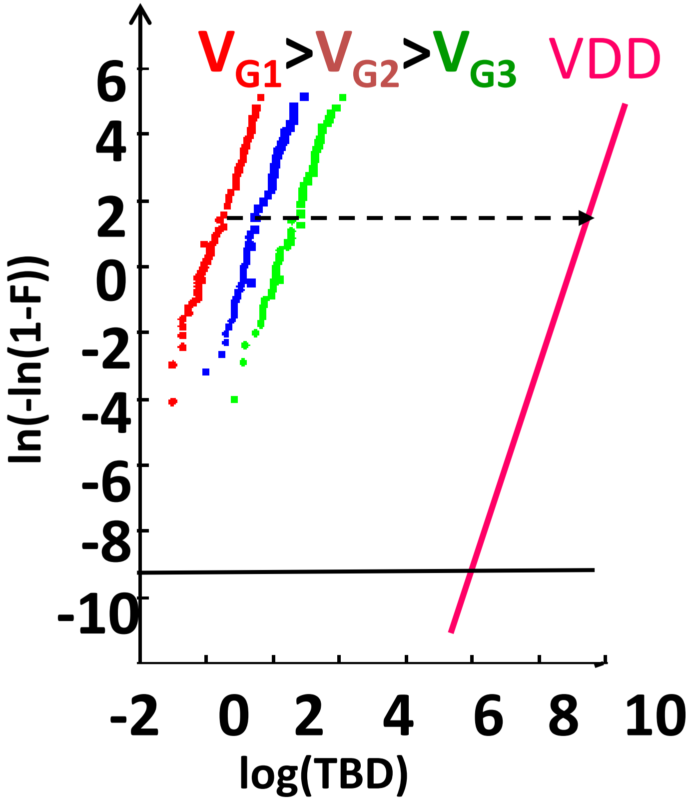


$$V_{th} = V_{th}^{*} - \frac{x_1}{x_0}\frac{Q_{ox}(x_1, t)}{C_{ox}}$$



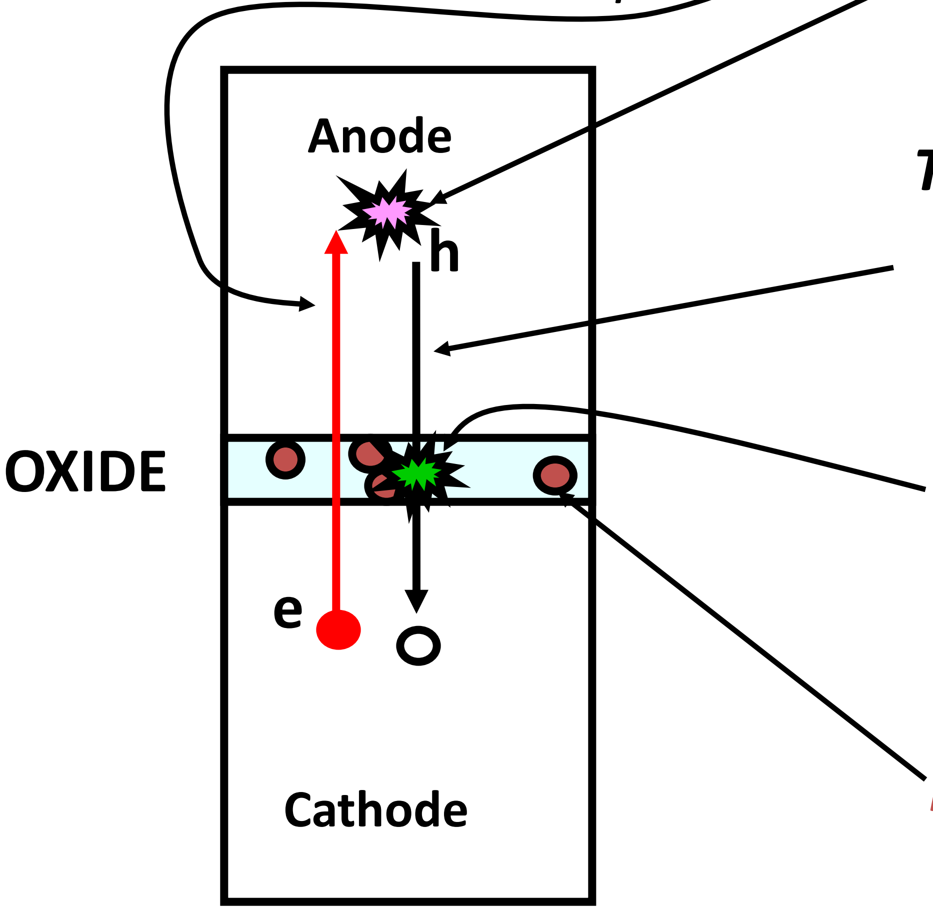
Dielectric Breakdown





Anode Hole Injection for Dielectric Breakdown

$$T_B \propto \left(\frac{N_{BD}}{k}\right)^n \times \frac{1}{J_e a T_p}$$



J_e - Electron current density

a - Impact Ionization Rate

(probability that a hole will be created by an incoming electron)

T_p - Transmission Rate

(probability that the hole will travel through the oxide layer)

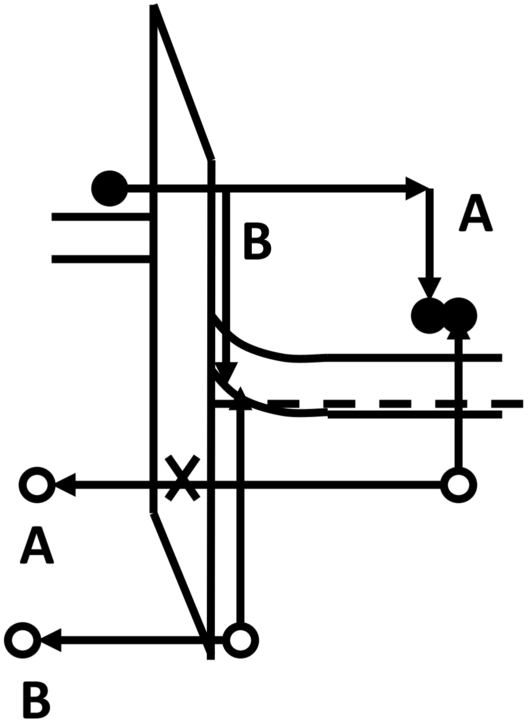
k - Trap Generation Efficiency

(probability that the hole will create a percolation defect)

N_{BD} - Density of percolation defects at breakdown

Anode Hole Injection Theory of TDDB

$J_h = J_e \alpha T_p$



V~high

$J_e = A \exp(-B/E)$

$\alpha = 1\text{-}2$

$T_p \sim \text{const}$

$\ln(T_{BD}) \sim 1/R \sim 1/E$

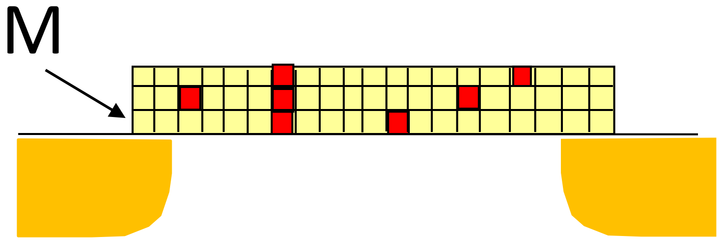
V~low

$J_e \sim f(E)$

$\langle \alpha T_p \rangle \sim M \exp(DV)$

$\ln(T_{BD}) \sim 1/R \sim V$

Percolation Model for Dielectric Breakdown



Prob. of a filled column: $p = q^M$

Prob. of filled cell: $q=(at^a/NM)$

Prob. of exactly 1 BD

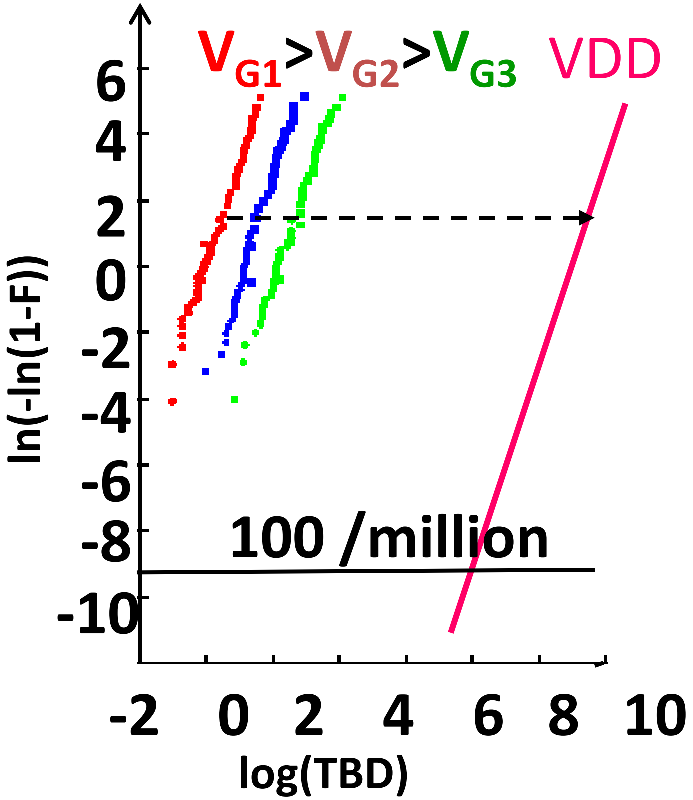
$$P_1 = {}^N C_1 \, [p^{1}] \, [(1-p)^{(N-1)}]$$

$$P_1 = (\chi)\exp(-\chi)$$

with $\chi=(t/\eta)^\beta$ and $\beta=M\alpha$

$$F_1(\chi) = 1 - P_o(\chi)$$

$$\boldsymbol{\ln[-\ln(1-F_1)] \sim \beta \ln t}$$



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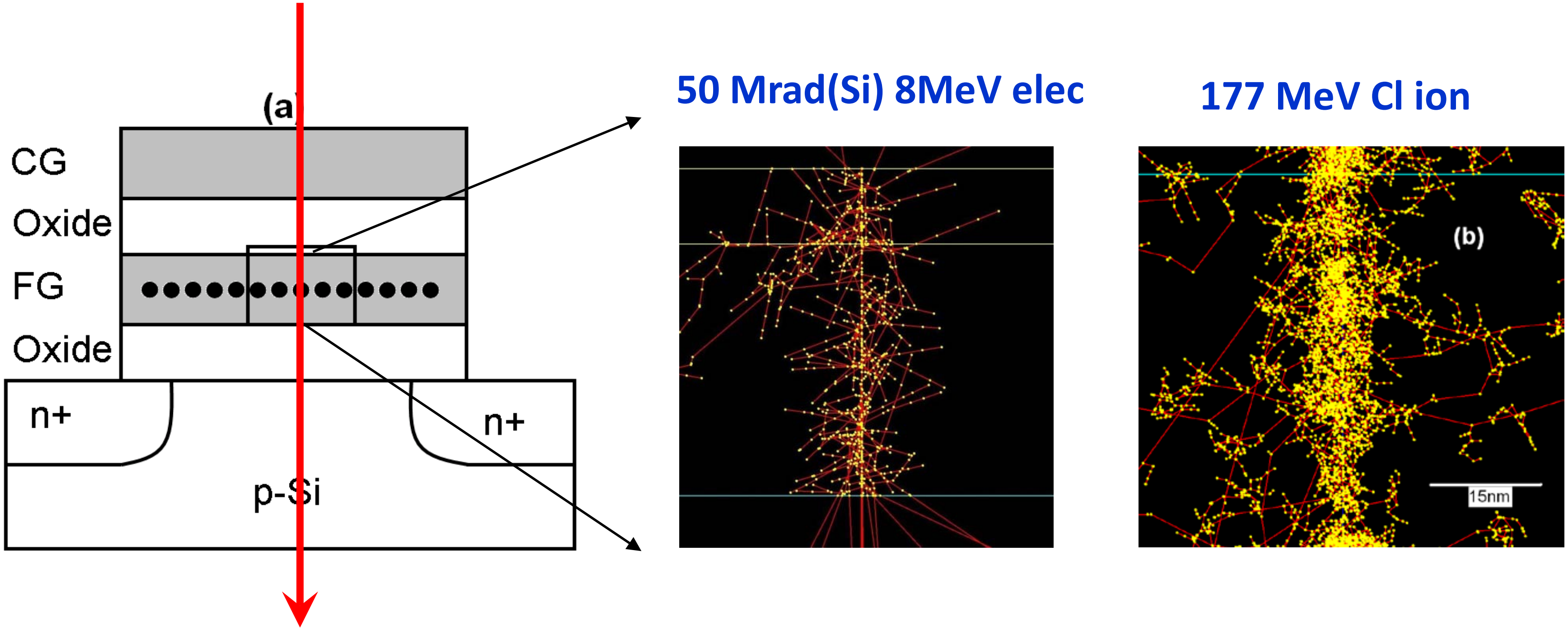
Radiation Induced Damage

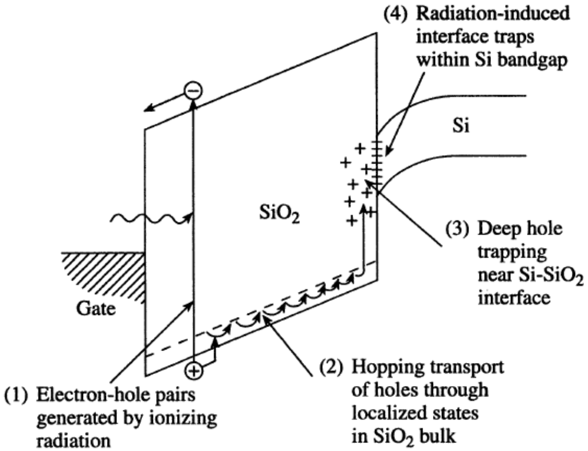

50 Mrad(Si) 8MeV elec

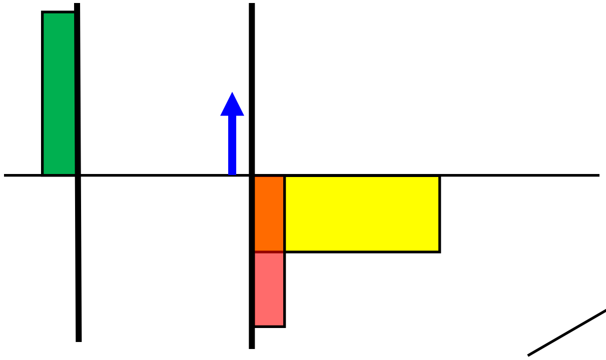
177 MeV Cl ion

Geant4 – high energy particle physics based toolkit

Used for the ionization and energy relaxation (~10eV – keVs)

Radiation Induced Charge Buildup





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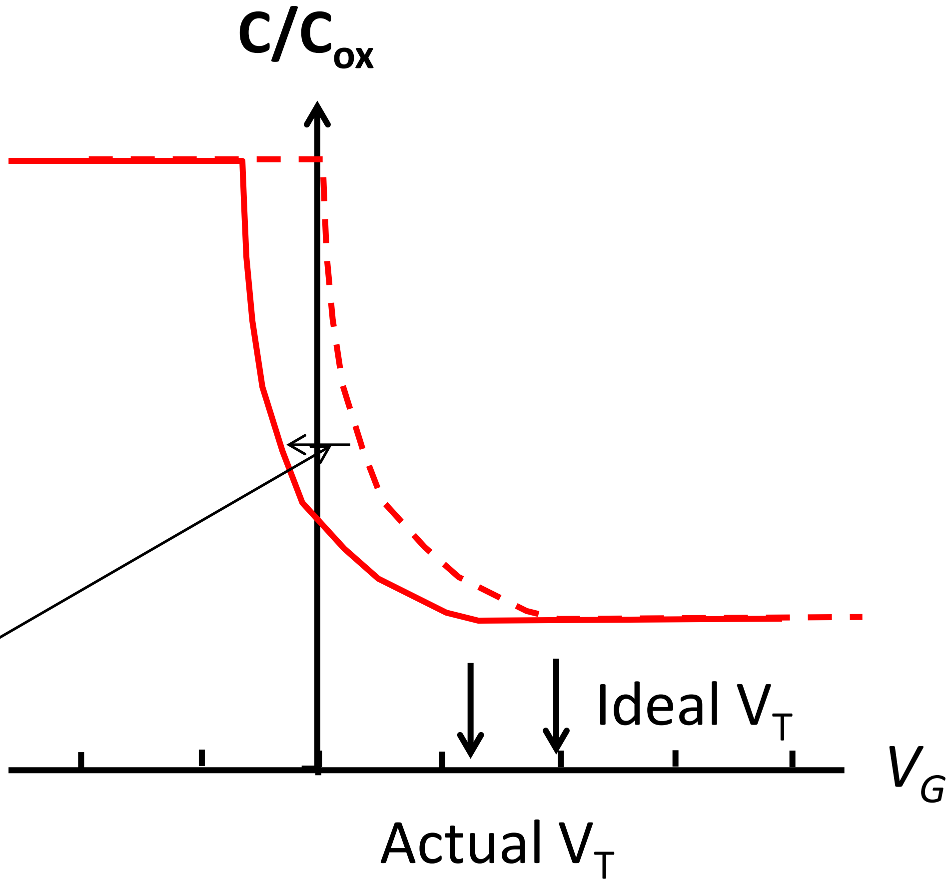

Summary

1) Reliability is a serious concern for scaling of MOSFETs.
2) There are many different types of degradation mechanisms that needs careful modeling to predict the lifetime of a MOSFETs.
3) At present, NBTI in PMOS transistors is the most difficult reliability problem, followed by HCI, TDDB, and Radiation effects.