Changes in Reliability Physics with Hyper-Thin SiO_2

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SiO_2 TDDB Data @ Eox = 8MV/cm and 125ºC

Median TF (sec)

1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01

0 40 80 120 160 200 240

tox (Å)

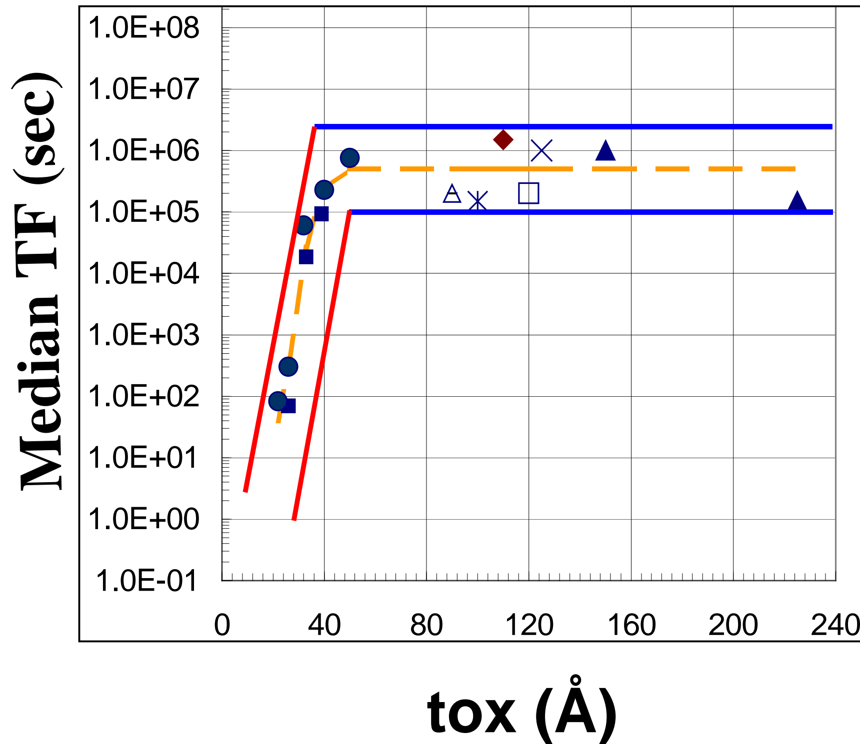
4V 10V 19V

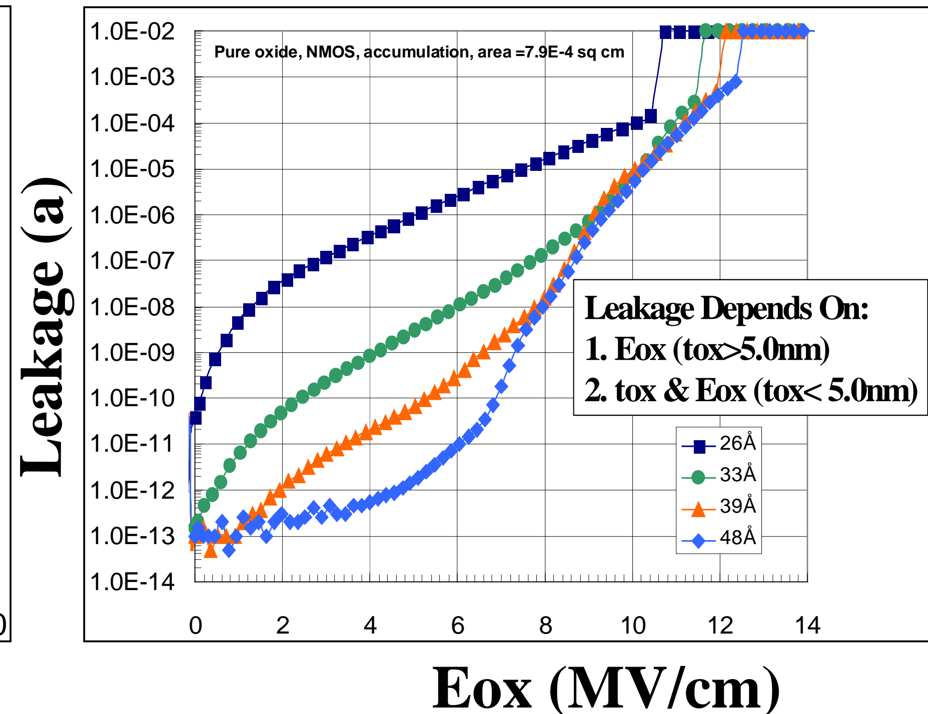
TF Depends On:
1. tox
2. Vox ?

TF Depends On:
1. Eox
2. Not Vox
3. Not tox

This work
TI
Mitsubishi
NTT
NIST
IBM
Phillips
Analog Devs.
Model 8MV/cm

TDDB Degradation Correlates with Enhanced Leakage

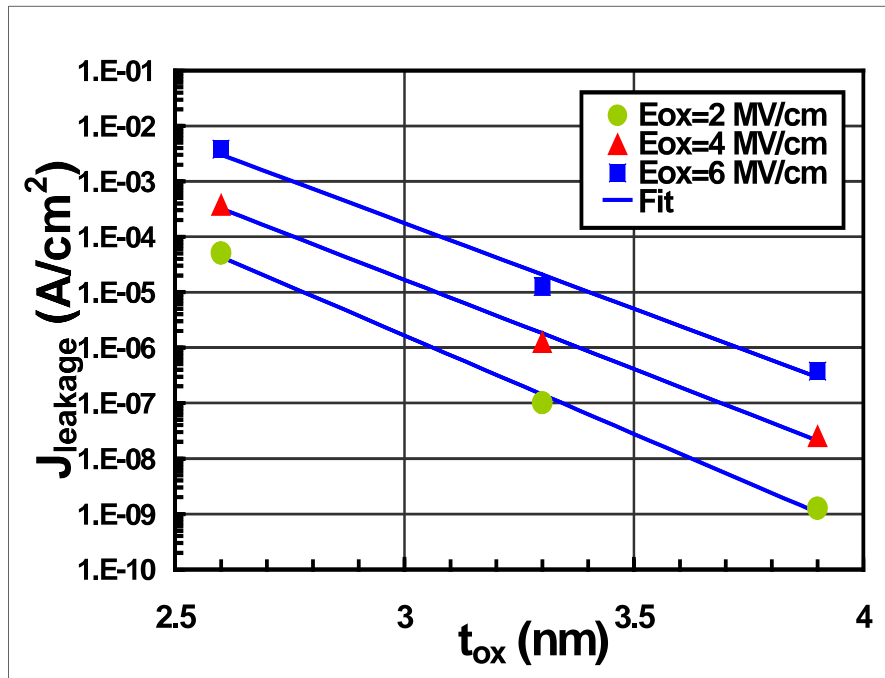


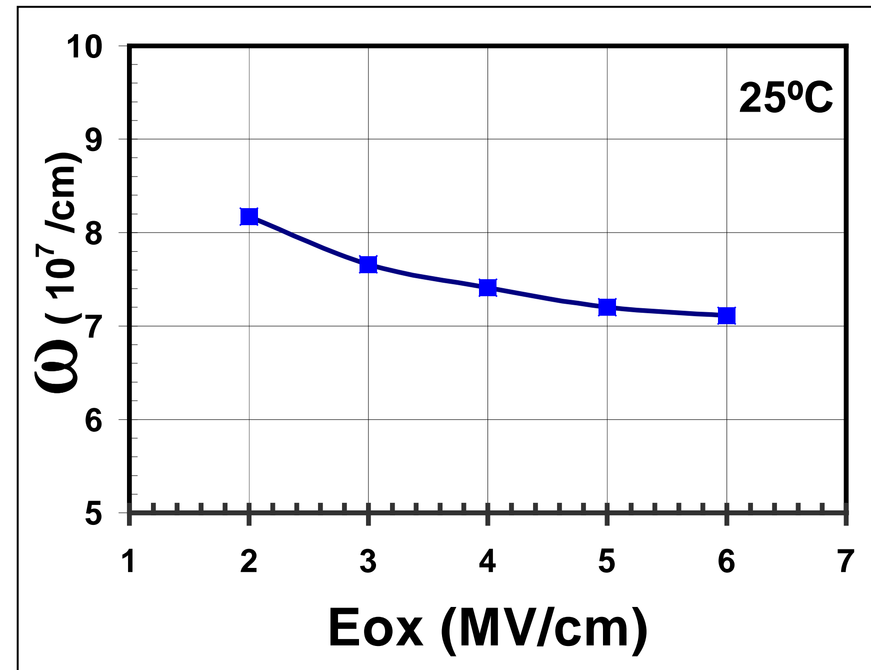


Empirical Relationship:

$$\left(\frac{\partial \ln(TF)}{\partial t_{ox}}\right)_{Eox\,,\,T} \propto -\left(\frac{\partial \ln(J_{leakage})}{\partial t_{ox}}\right)_{Eox\,,\,T}$$

Empirical Time-To-Failure Eq. for Hyper-Thin SiO2





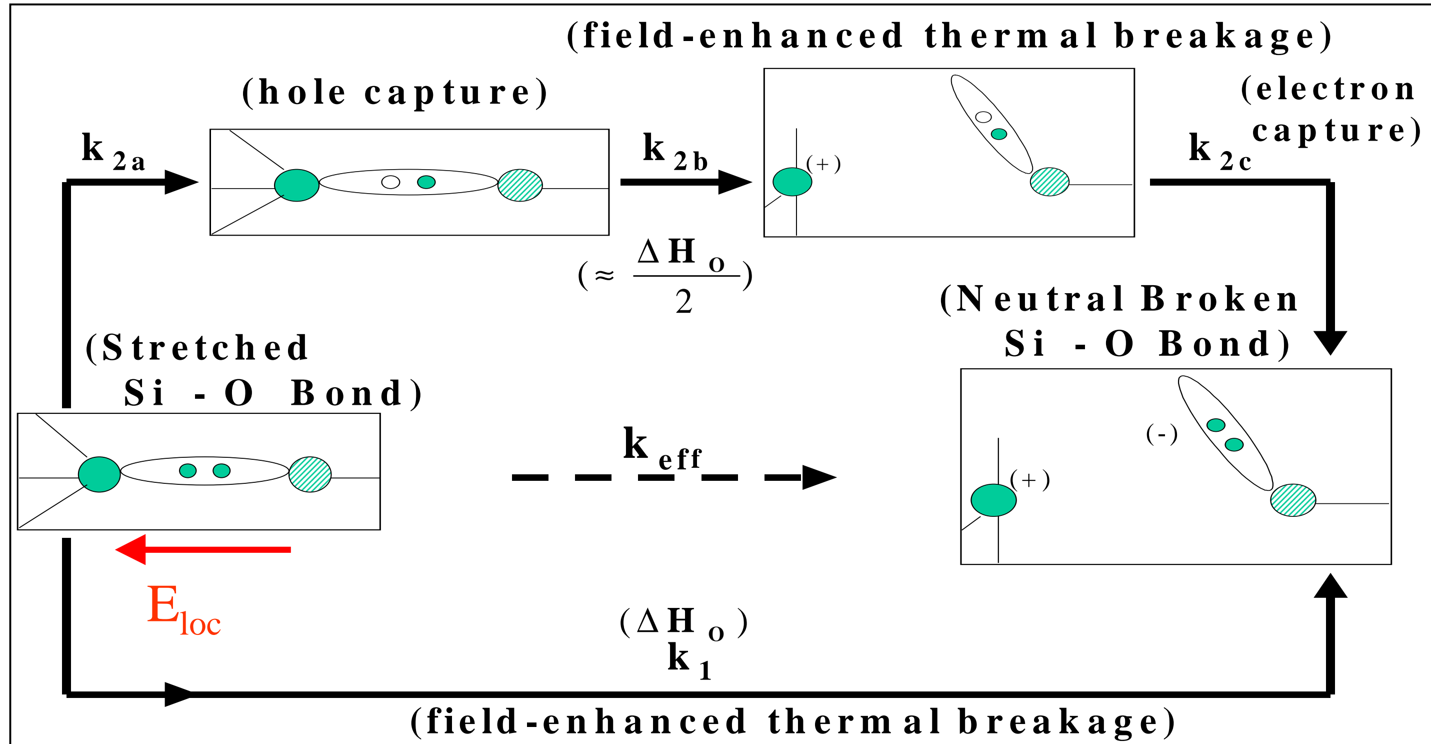
Empirical Leakage: $J_{Leakage} \propto \exp[-\omega_{(E_{ox},T)} \bullet t_{ox}]$

Expansion: $\omega_{(E_{ox},T)} \cong \omega_0 - mE_{ox}$

Leakage Equation: $J_{Leakage} = J_o(t_{ox})\exp(mE_{ox}t_{ox}) = J_o(t_{ox})\exp(mV_{ox})$

Time-to-Failure Equation: $TF \propto (J_{Leakage})^{-1} \propto \exp(-m'V_{ox})$

Molecular Description for Dielectric Degradation



Effective bond-breakage rate: k_{eff}

$$k_{eff} = k_1 + \frac{k_{2a} k_{2b} [\exp(-k_{2a} t) - \exp(-k_{2b} t)]}{k_{2b} \exp(-k_{2a} t) - k_{2a} \exp(-k_{2b} t)}$$

If $k_{2a} >> k_1$ but $k_{2a} << k_{2b}$, then

$$TF = \frac{\ln(1/f_{crit})}{k_{eff}} \cong \frac{\ln(1/f_{crit})}{k_{2a}} \propto \frac{\ln(1/f_{crit})}{J_{Leakage}} \propto \exp(-m' V_{ox})$$

Conclusions

- **TDDB for hyper-thin SiO_2 is dominated by enhanced DT leakage current.**
- **TF for the hyper-thin SiO_2 depends on voltage, not field.**
- **Reliability scaling limit will be dominated by leakage and by its reliability impact.**