Displacement Damage Effects in Single-Event Gate Rupture

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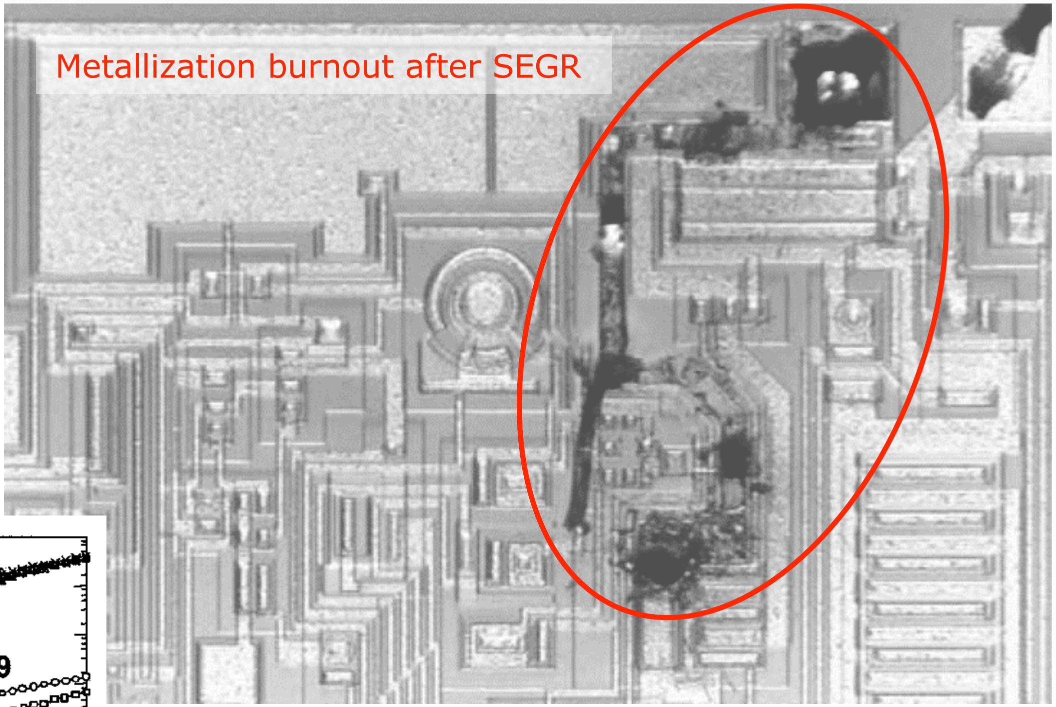
Background: Single-Event Gate Rupture

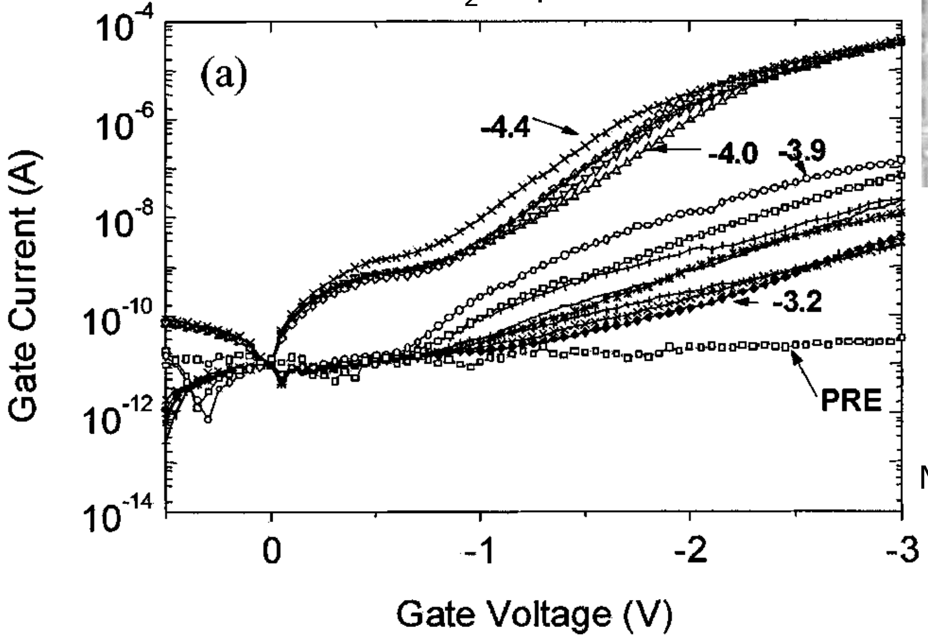
Single-ion induced dielectric failure

MOSFETs, Capacitors, FG Devices



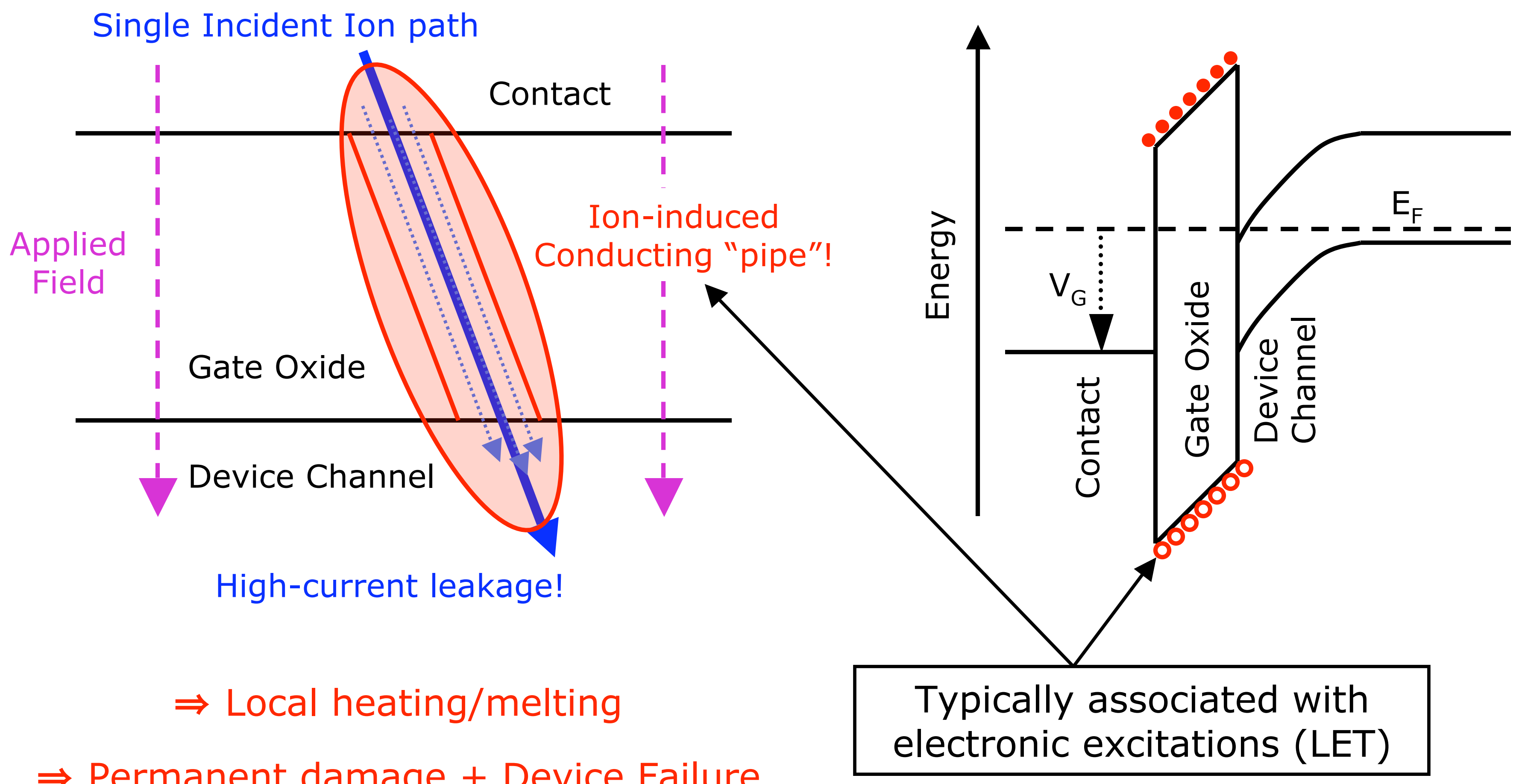
Lum, et al., IEEE TNS 51 3263 (2004)

I-V following biased irradiation of 3.3 nm SiO_2 capacitors



Massengill, et al., IEEE TNS 48 1904 (2001)

Background: Single-Event Gate Rupture



Typically associated with electronic excitations (LET)

⇒ Local heating/melting

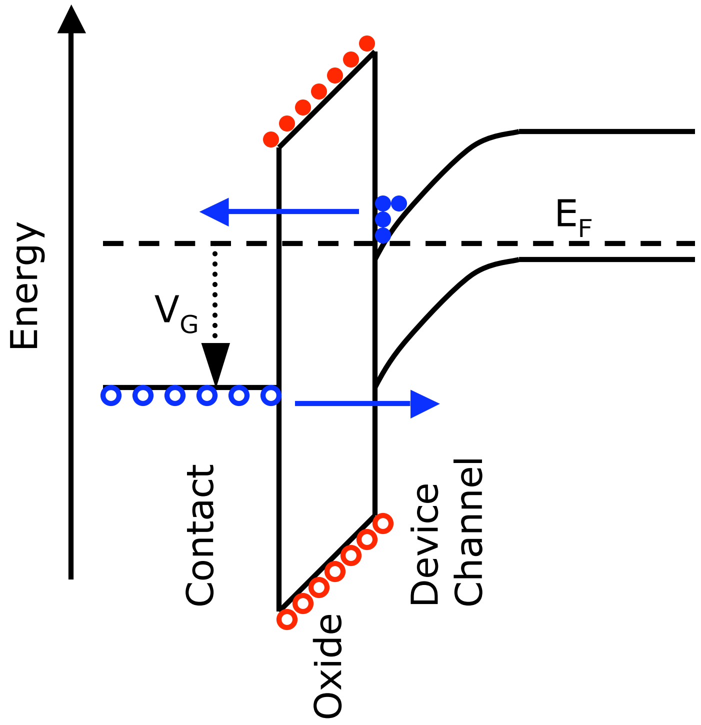
⇒ Permanent damage + Device Failure

Background: Leakage-induced Melting

Local heating is due to motion of ion-excited carriers…

$$\frac{1}{E_{CR}} = \frac{q\mu_1 n(V)}{J_{CR}} + \frac{q\mu_2 n(L)}{J_{CR}}$$

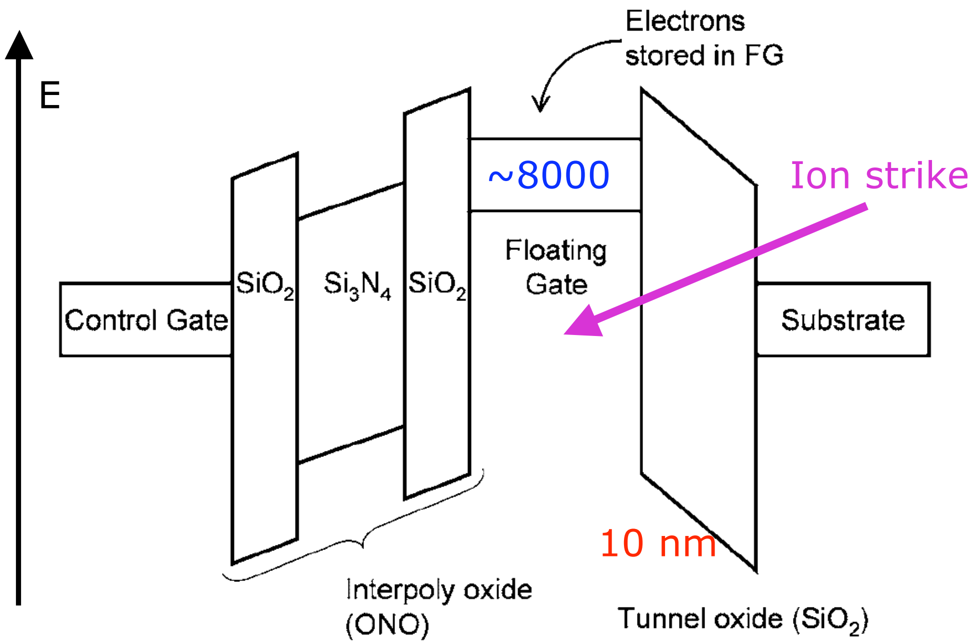
…AND carriers injected by the applied field!



How does the ion strike induce carrier injection?

Sexton, et al., IEEE TNS 45 2509 (1998)

Background: Ion-induced FG Discharge



Ion-excited e-h pairs surviving recombination: **~80**

Effective Discharge: **~4000 e-**

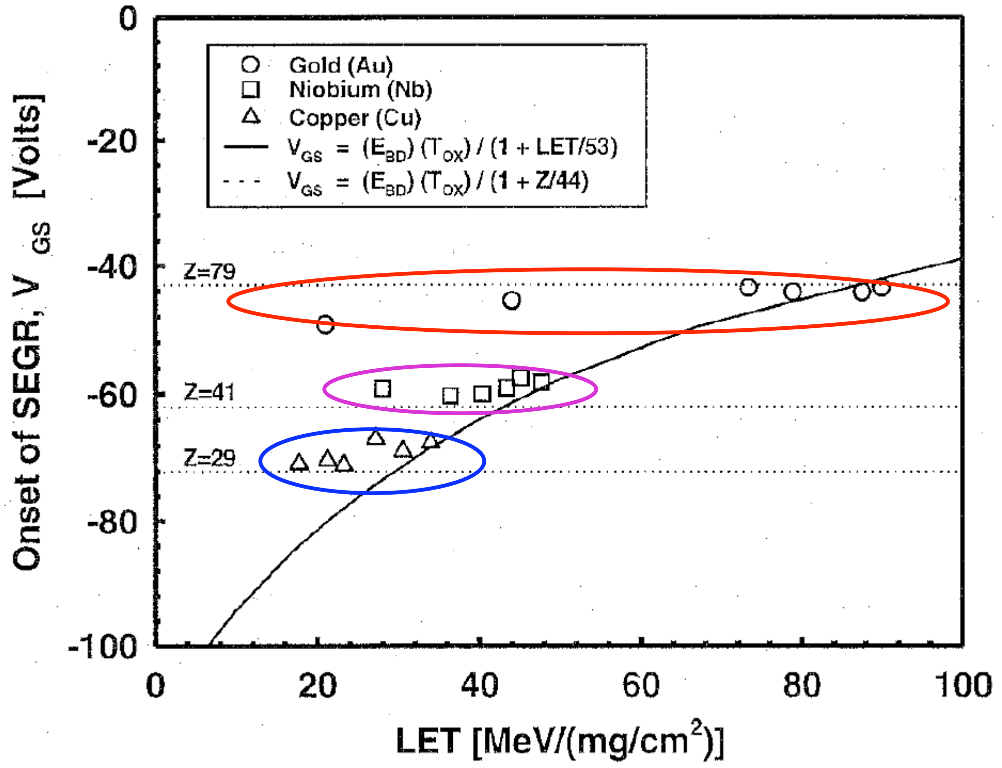
Time for discharge: **~100 fs**

Time for carrier induced melting: **>1000 fs**

Conclusion: Ion strike directly induces a transient "conducting path" in the oxide

Cellere, et al., JAP 99 074101 (2006)

Background: Dependence on Z



Displacement damage effects??

Titus, et al., IEEE TNS 45 2492 (1998)

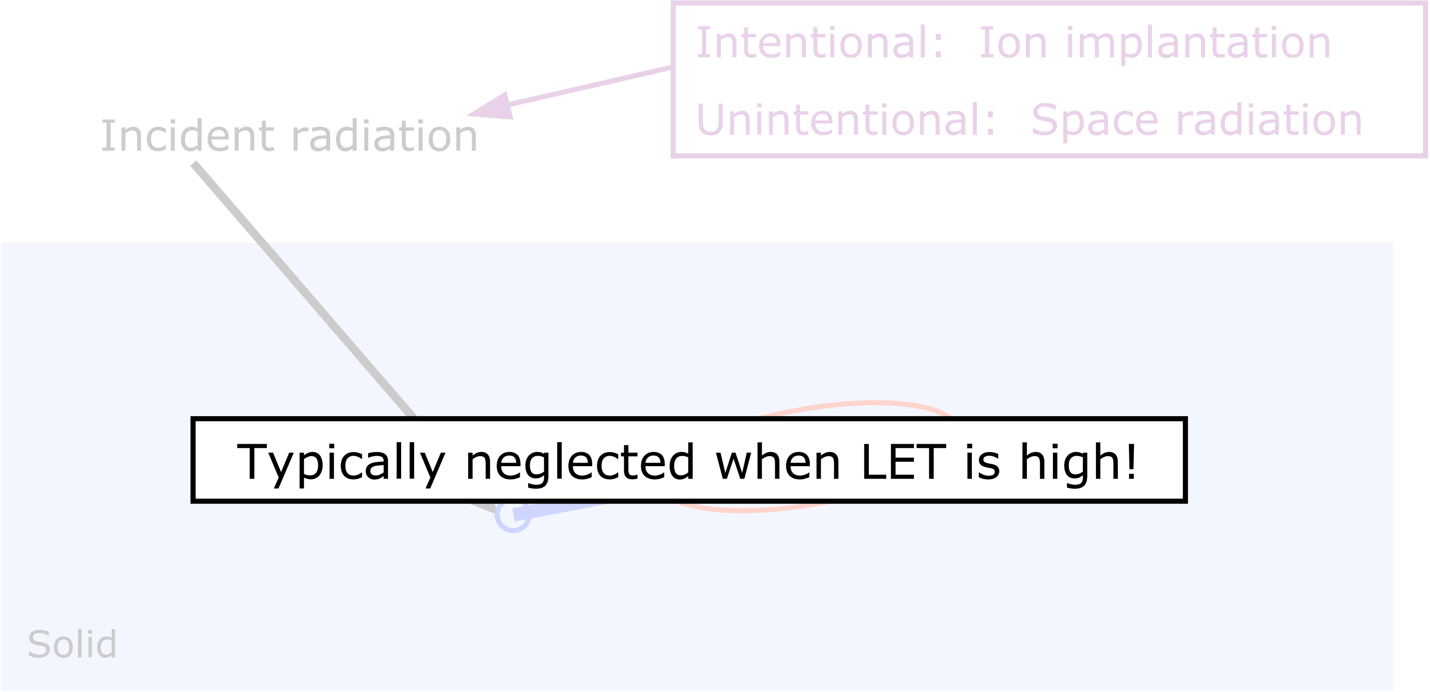
Background: Displacement Damage

Incident Radiation

⇒ Atomic recoils/displacements

⇒ Defect/Damage formation

⇒ Altered materials properties!

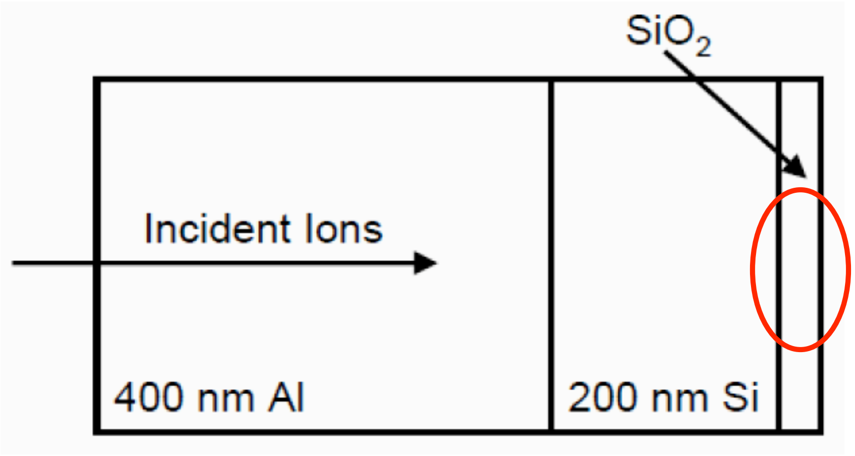


Intentional: Ion implantation

Unintentional: Space radiation

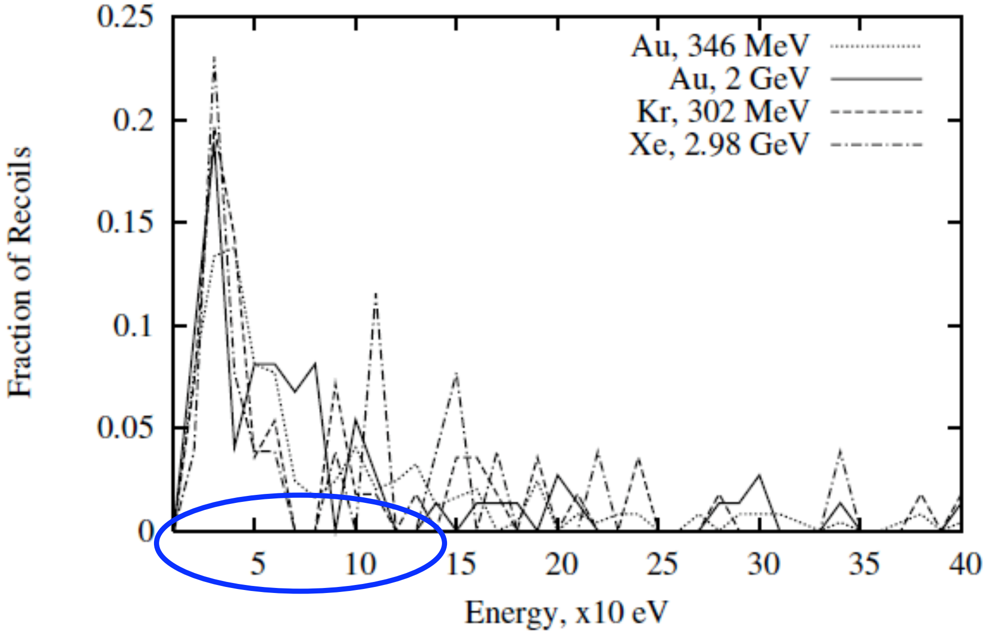
Typically neglected when LET is high!

Results: Recoils at High LET



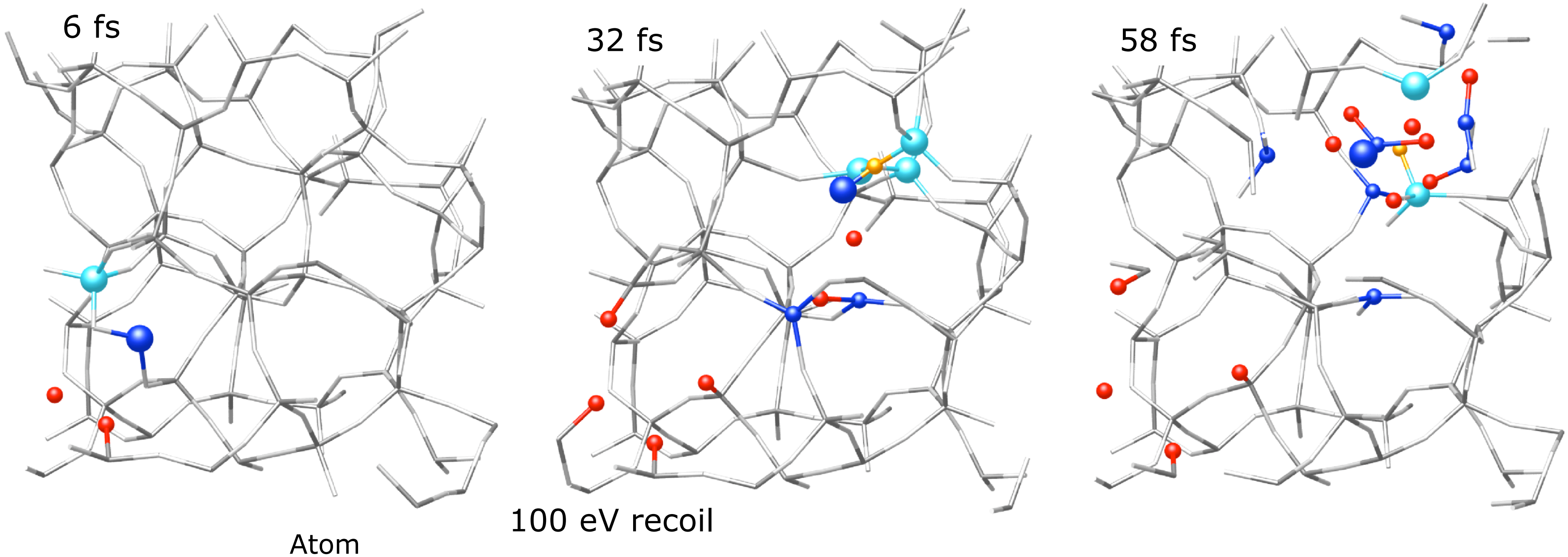
Recoils in oxide layer…

…are principally low-energy recoils!



SRIM: 1-10% of all ions produce a recoil in a 3.3 nm SiO$_2$ layer!

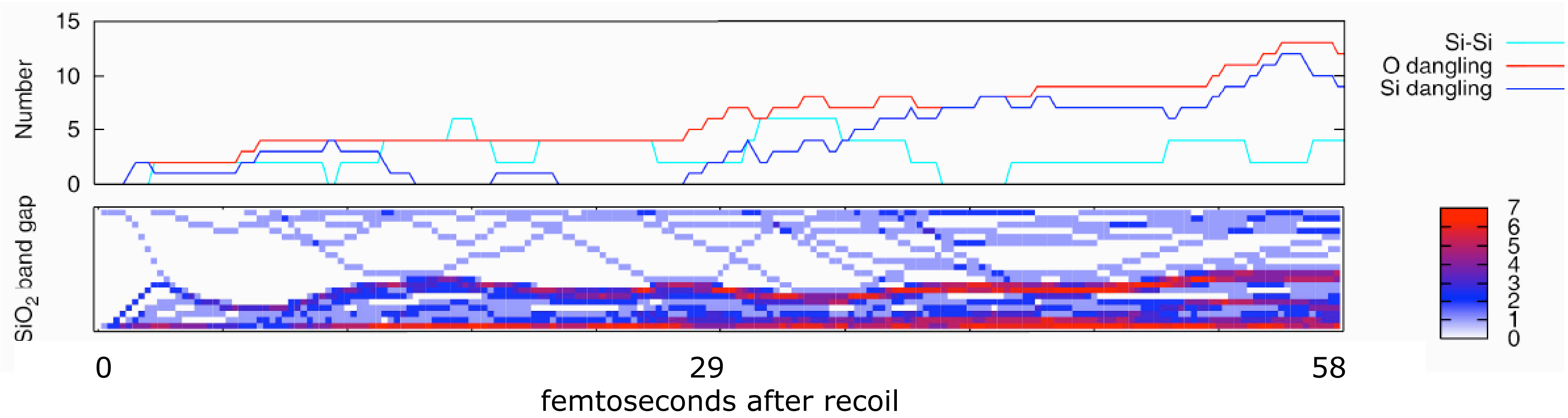
Results: Low-E Recoil Dynamics in SiO_2



	Atom	
Defect	Silicon	Oxygen
Dangling Bond	●	●
Extra Bond	●	●
"Self Bond"	Big Ball	

Damage in amorphous material:
Network defects

Results: Defect States in SiO_2

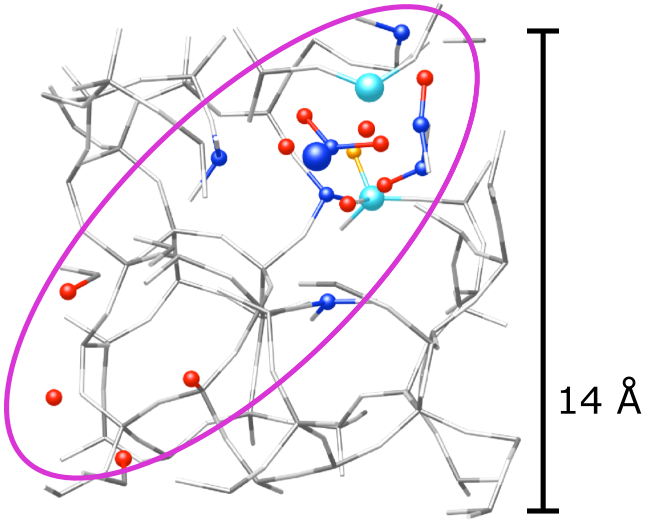


Increasing numbers of defects…

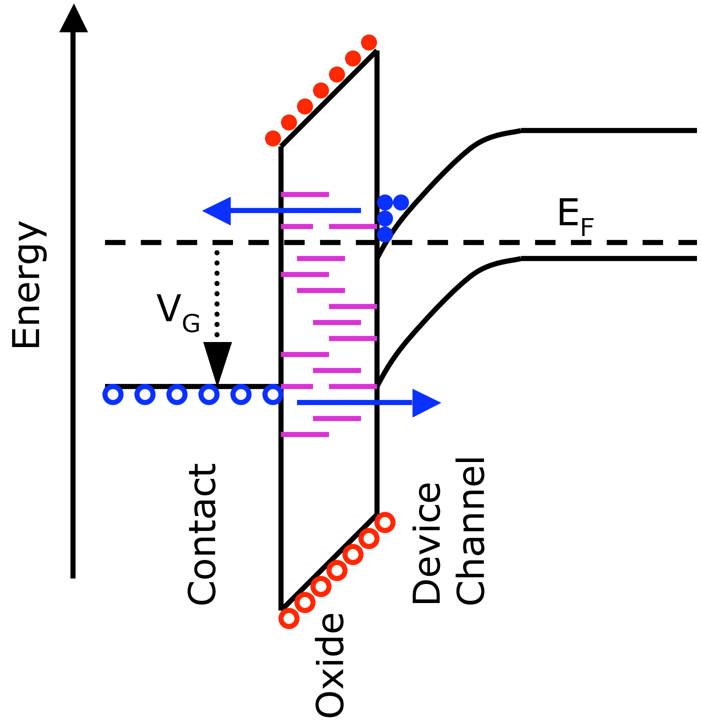
…increasing number of defect states within the bandgap!

Defect states separated by ~2-5 Å!

Conducting path!



Analysis: Defect-mediated Leakage



Displacement damage induced defect states
facilitate field-injected leakage

Analysis: Reliability Degradation

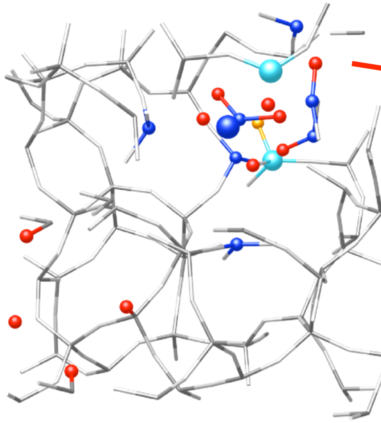
Long-term reliability is degraded by high-LET irradiation…

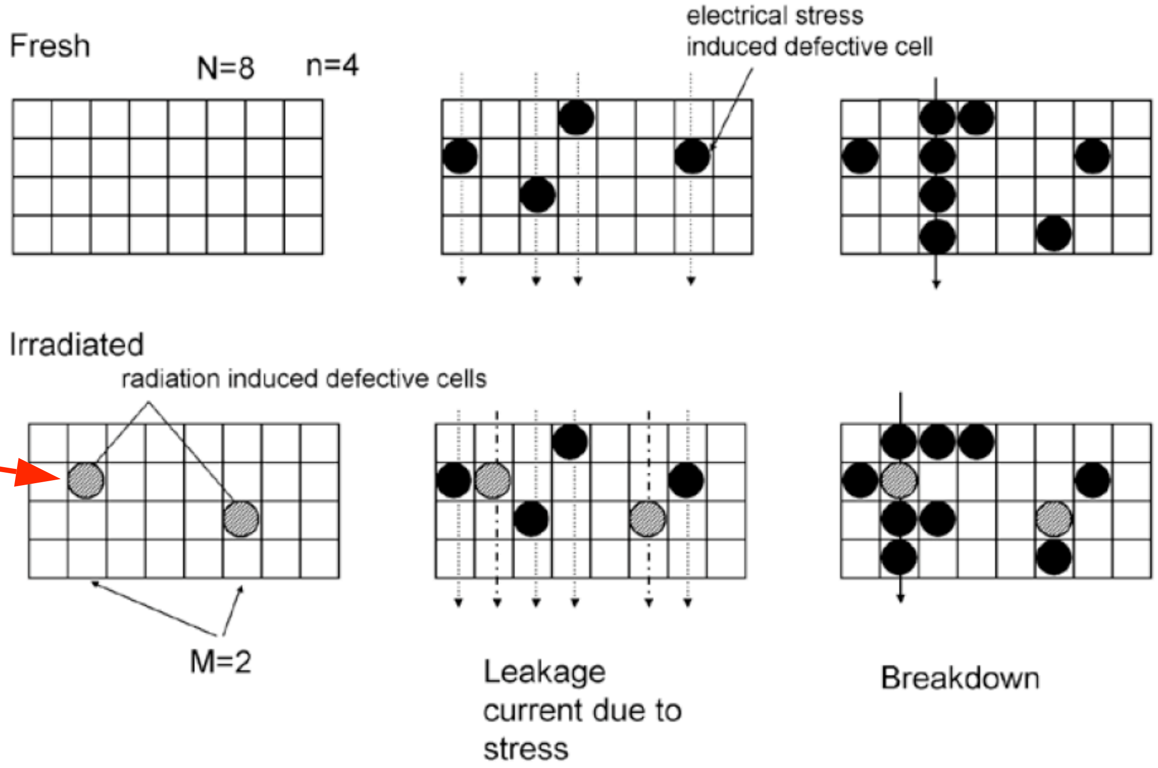
… but *electronic excitation* is transient!

“Percolation Model”

Gate Oxide

Network defects!





Choi, et al., IEEE TNS v. 39 p. 3045 (2002)

Summary

- High-LET irradiations of SiO_2 produce low-energy (<1 keV) atomic recoils

- Low-energy recoils produce network defects in SiO_2
- …associated with spatially correlated defect states in the SiO_2 band gap

- These defects represent a low-resitivity conducting path
- …and provide an atomistic explanation for the “percolation model” of high-LET reliability degradation