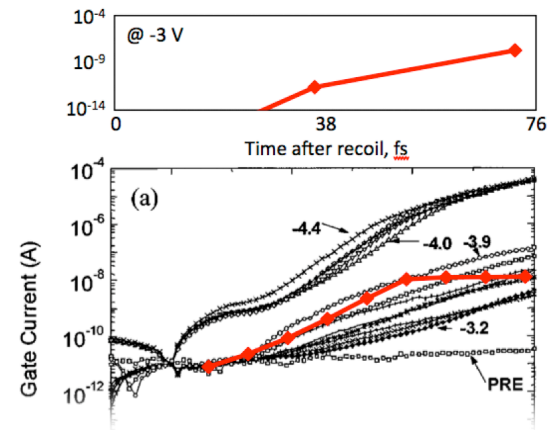
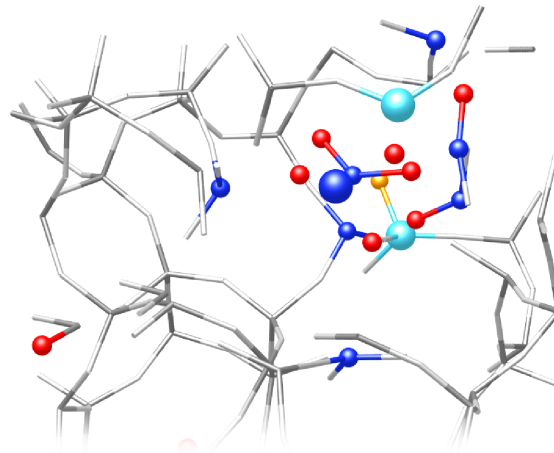


Ion-Induced Leakage Currents

I. Defect Formation



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¹Dept. of Physics & Astronomy, Vanderbilt University, Nashville, TN 37235

²Dept. of Electrical Engineering & Computer Science,
Vanderbilt University, Nashville, TN 37235

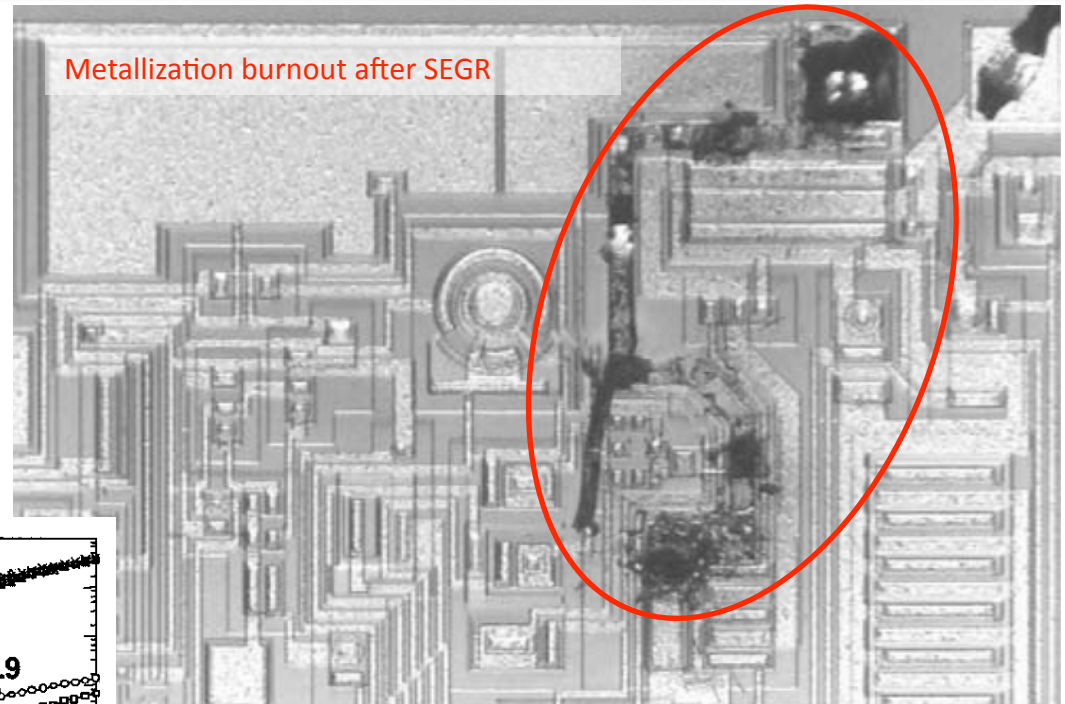
³Oak Ridge National Laboratory, Oak Ridge, TN

2009 MURI Review

Background: Ion Induced Leakage Currents



Heavy-Ion strikes degrade or destroy dielectric layers

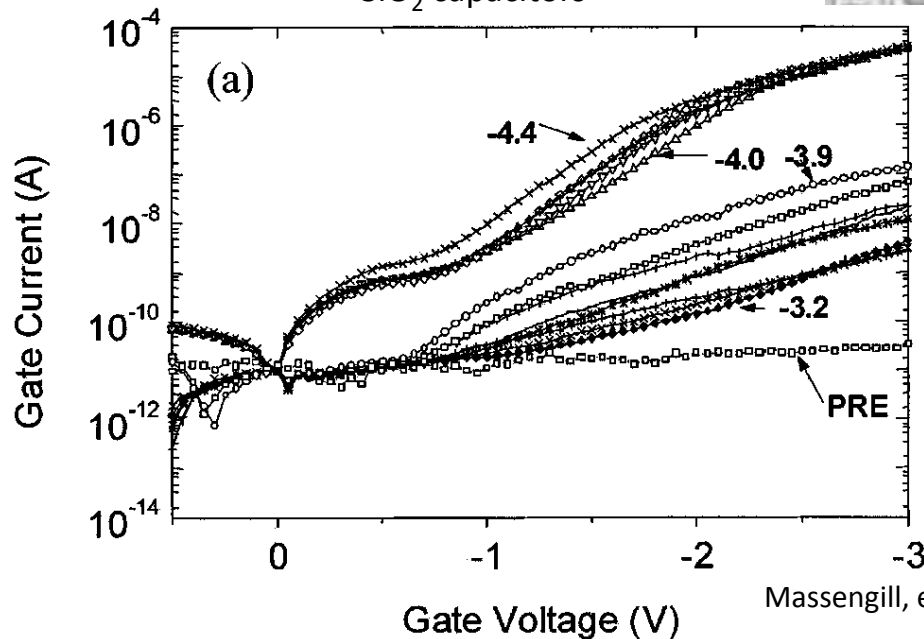


Metallization burnout after SEGR

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

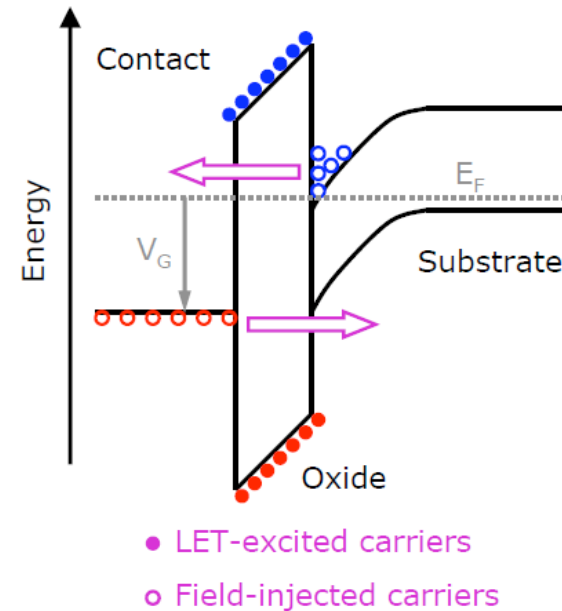
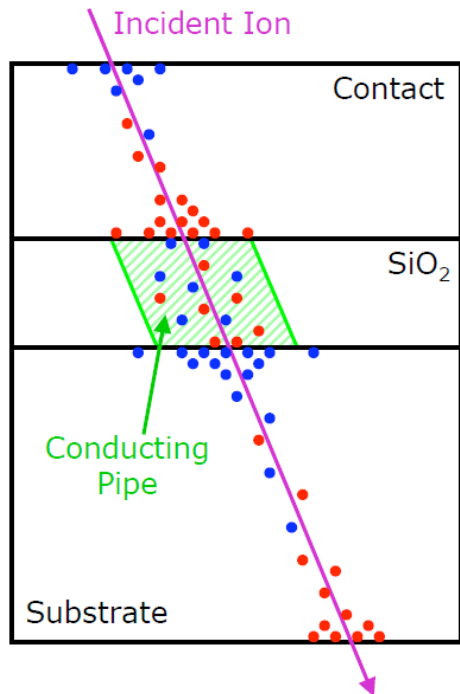
Distinct Electrical degradation modes:
Rupture (Hard breakdown), Soft breakdown,
Long-term reliability degradation

I-V following biased irradiation of 3.3 nm SiO₂ capacitors



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

Background: Ion Induced Rupture Mechanism



LET-generated carriers ->
 local field enhancements ->
 dielectric rupture ->
 local heating ->
 permanent damage!

Local heating requires LET-generated carriers...

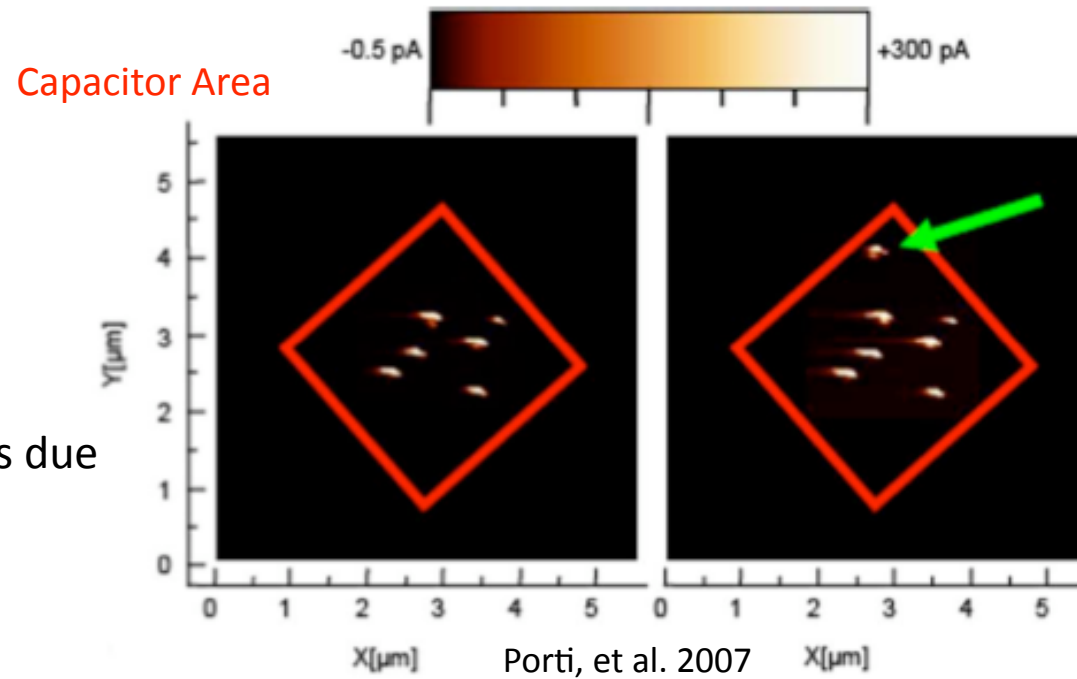
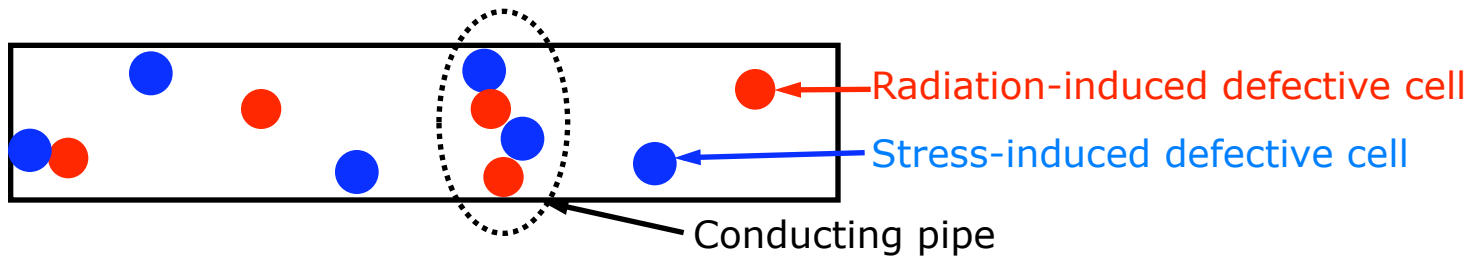
$$\frac{1}{E_{CR}} = \frac{q\mu_1 n(V)}{J_{CR}} + \frac{q\mu_2 n(L)}{J_{CR}}$$

...AND field-injected carriers!

Background: RISB/LTRD Mechanism

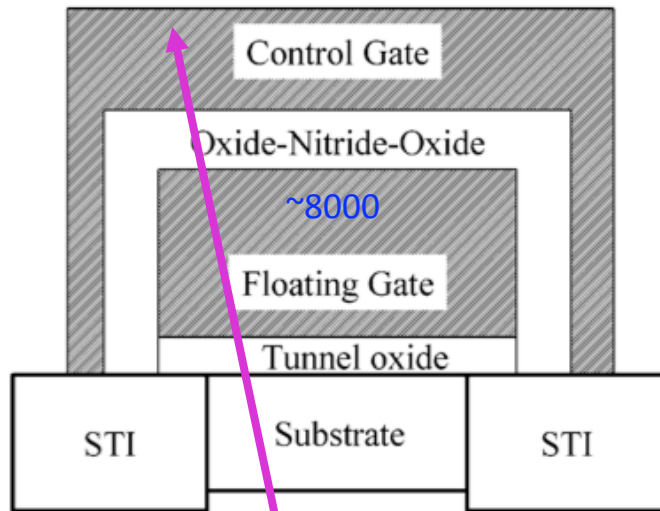


Radiation-induced soft breakdown, and Long-term reliability degradation:

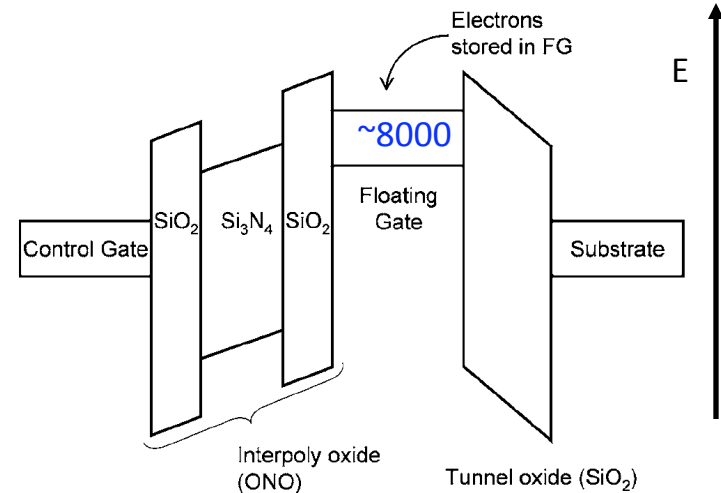


Individual leakage paths due to latent defects!

Background: Ion-induced FG Discharge



Ion strike



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

Effective Discharge: **~4000 e-**

Time for discharge: **~100 fs**

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

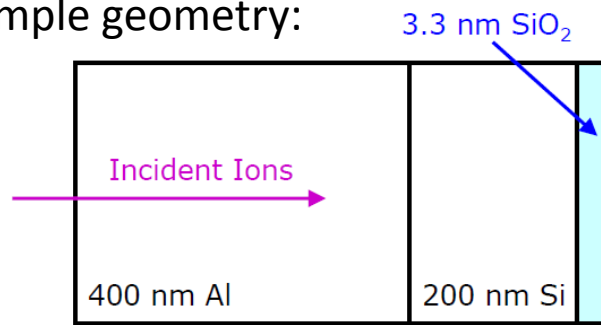
Conclusion: Ion strike directly induces a transient “conducting path” in the oxide

Results: Low-Energy Recoils



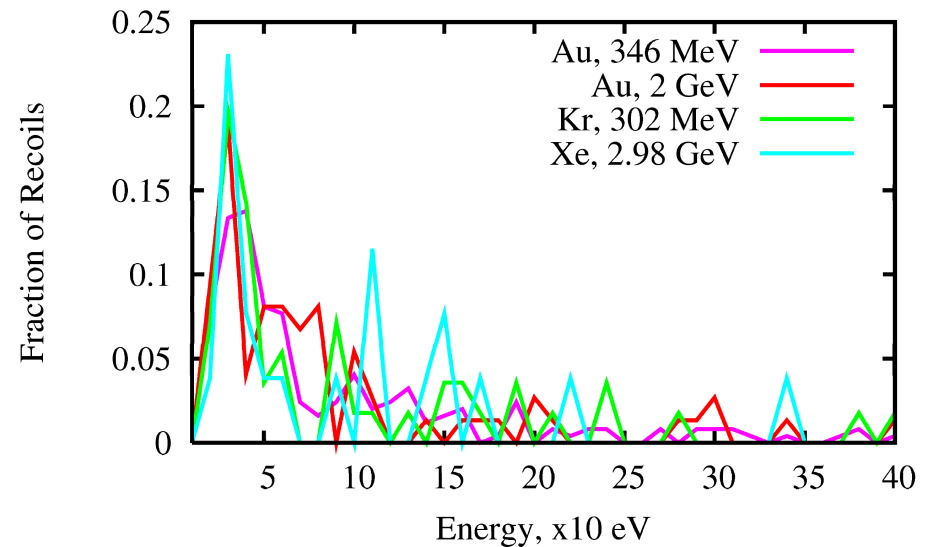
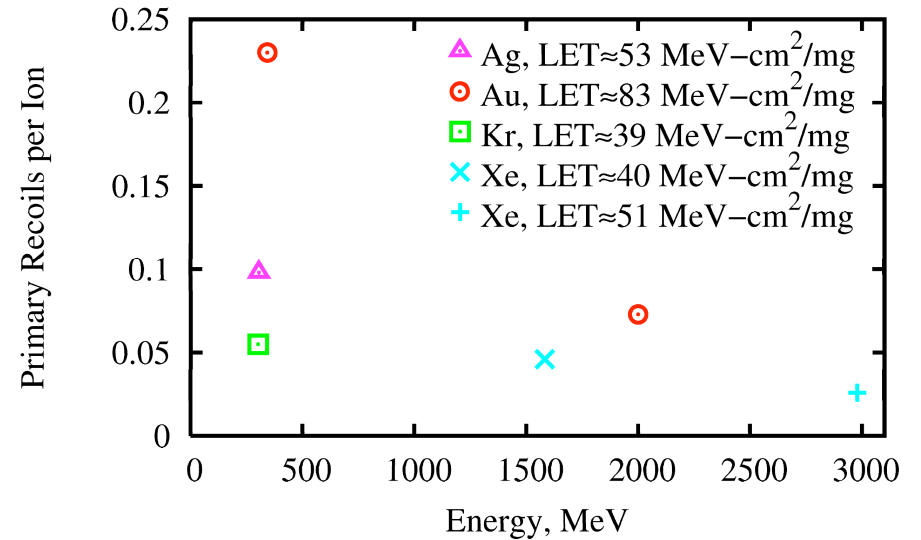
TRIM Calculations:

Sample geometry:

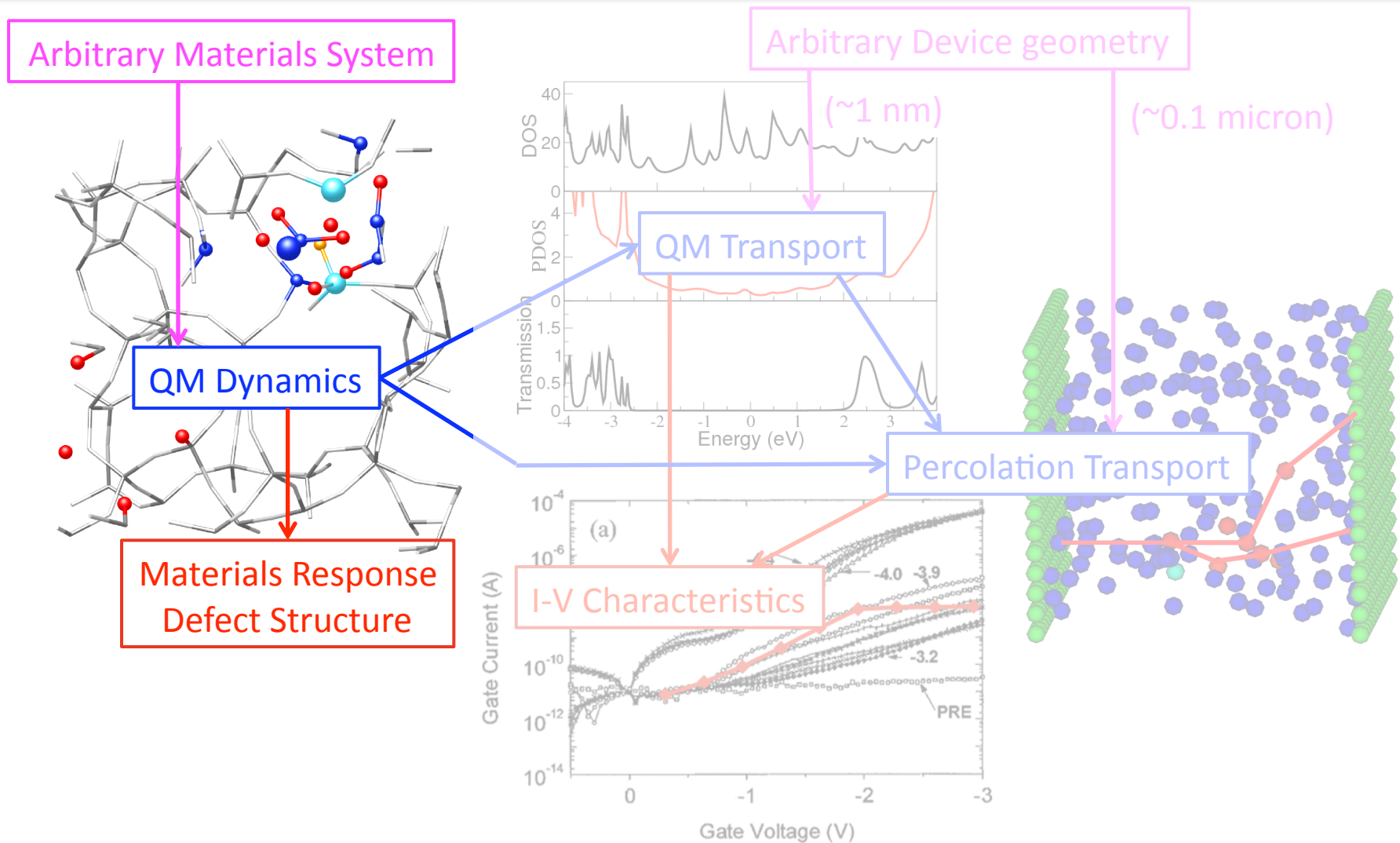


Only atomic recoils occurring IN the SiO₂ layer!

High-LET ions generate O(100) eV recoils in thin oxide layers!



Current Result: Multi-scale Model



Ab Initio calculation of experimentally measurable device properties!

Method: First-principles Dynamics

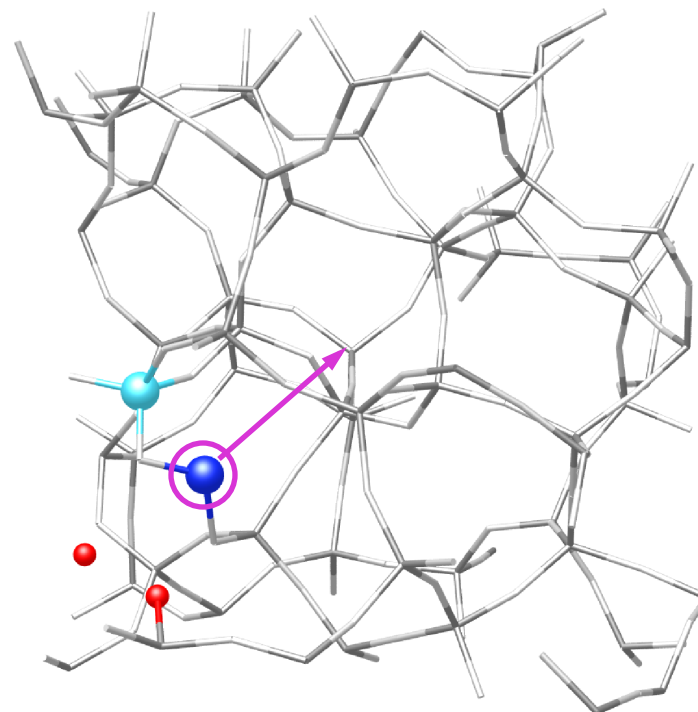


- DFT-LDA for energy and forces
- Classical mechanics for ions
- Cell sizes: 200-1000 atoms
- Calculation times: 0-1000 fs

Highest fidelity for bond-breaking/forming during low-energy events

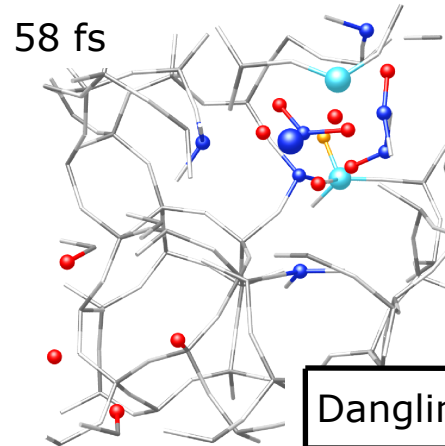
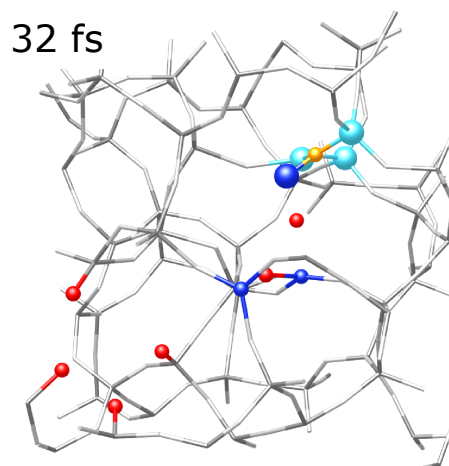
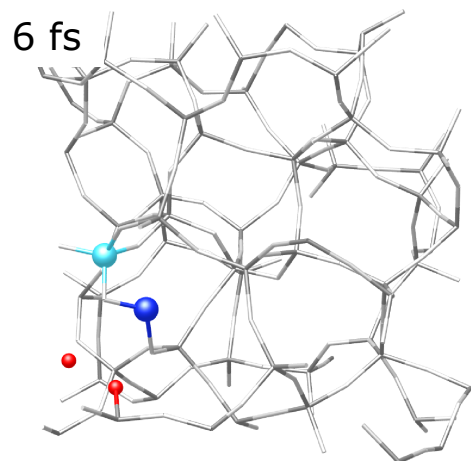
Atomic AND electronic structure!

Apply KE to primary atom...
...evolve system!



Ion Induced Leakage Currents: I. Defect Formation

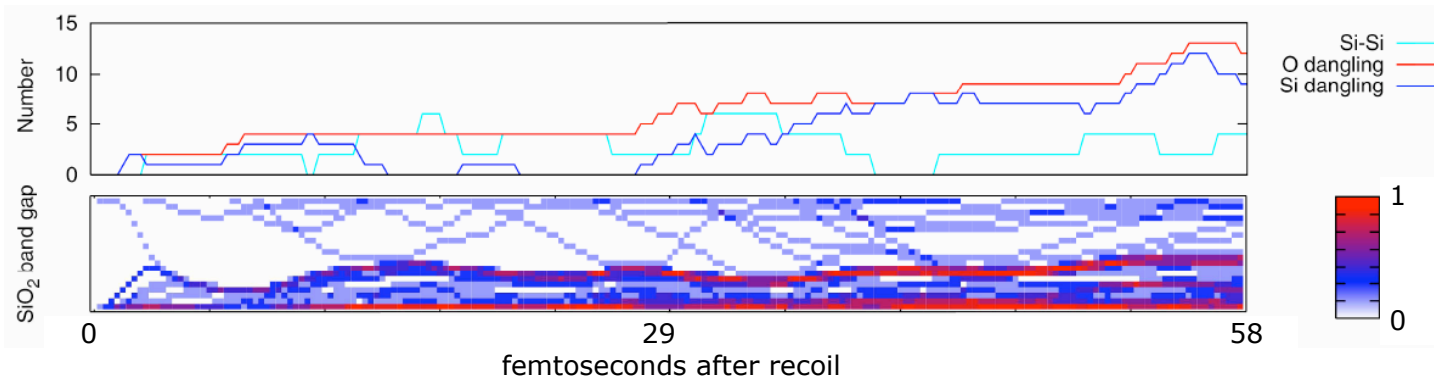
Results: Low-energy Recoils



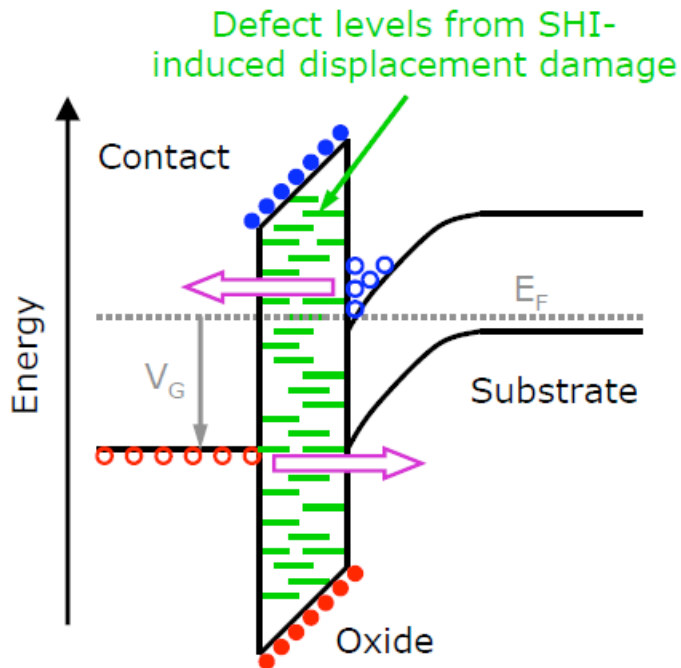
Defect formation with time after recoil...

Dangling Bond	●	●
Extra Bond	●	●
"Self Bond"	Big Ball	
	$\bar{\text{Si}}$	O

...Correlates with formation of electronic defect states in band gap!



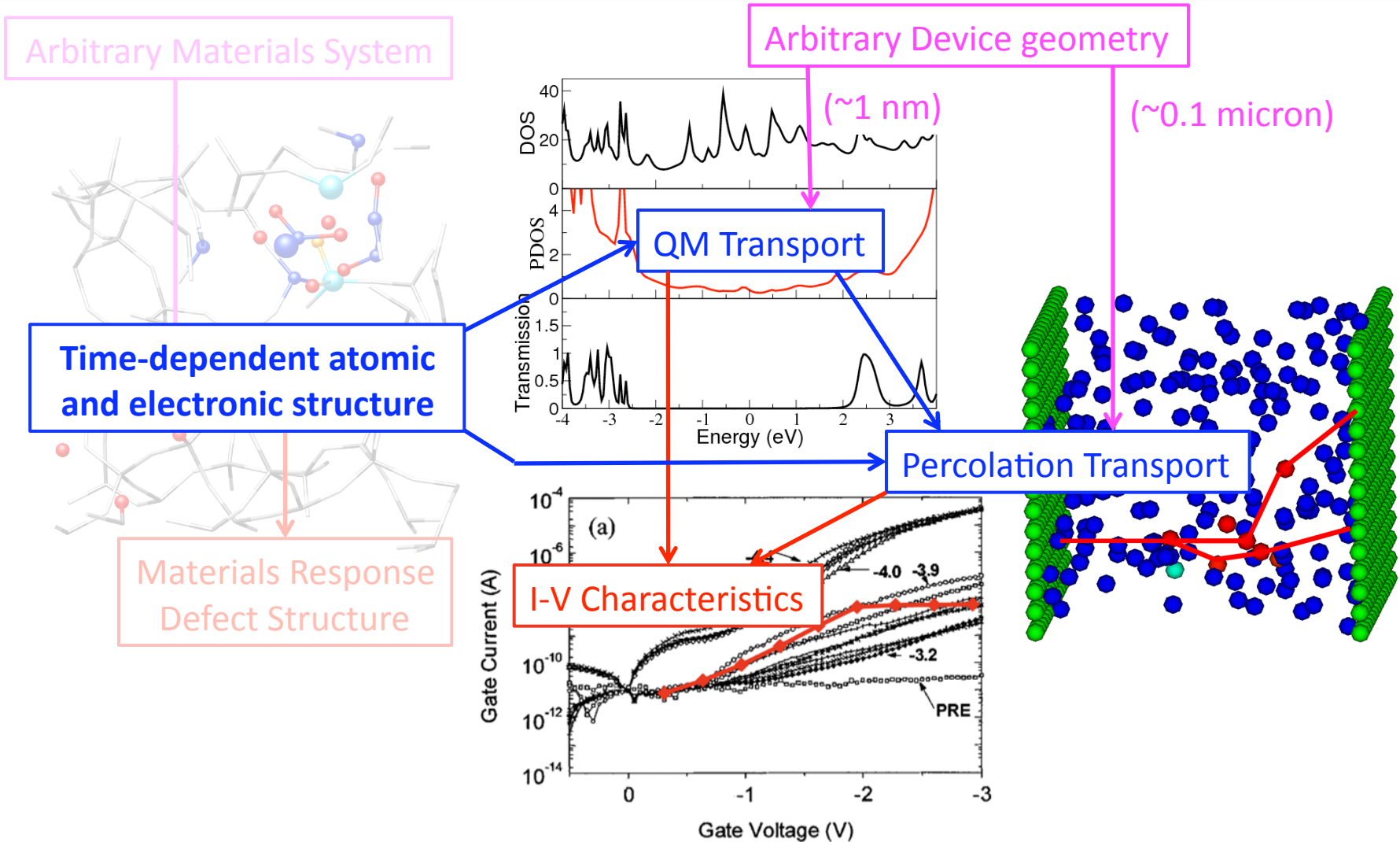
Summary: Defect Formation



- Defects are generated by high-LET ions!
- Form low-resistivity conducting path
- Complex time evolution of atomic/electronic structure

But what about actual currents?!

Current Result: Multi-scale Model



Ab Initio calculation of experimentally measurable device properties!