The Effects of Hydrogen on the Radiation Response of MOS and Bipolar Devices

David Hughart, Ron Schrimpf, Dan Fleetwood, Sokrates Pantelides,
Blair Tuttle, Nicole Rowsey, Mark Law

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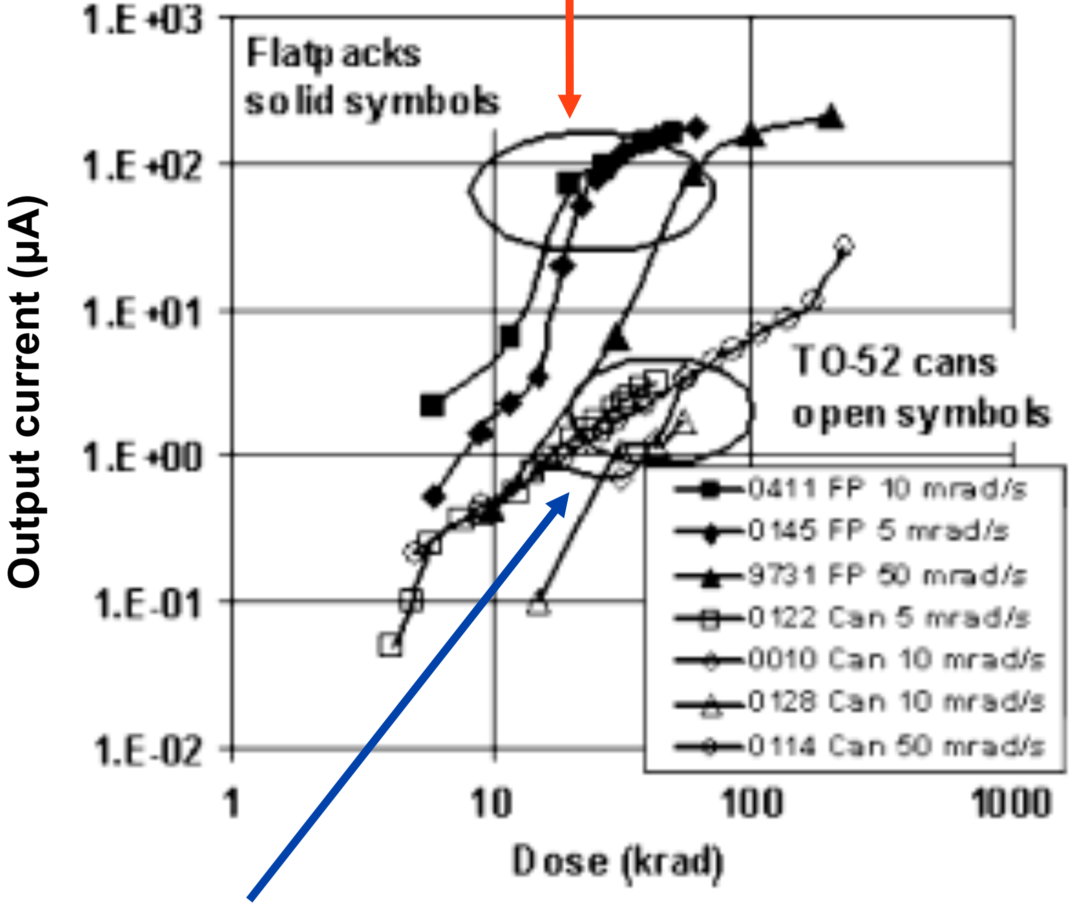
Hydrogen Enhanced Degradation

- AD590 transducers
  - Flat-packs
    - 0.63% H_2
    - High degradation
  - TO-52 cans
    - No detectable H_2
    - Low degradation

Contains H_2



Does not contain H_2

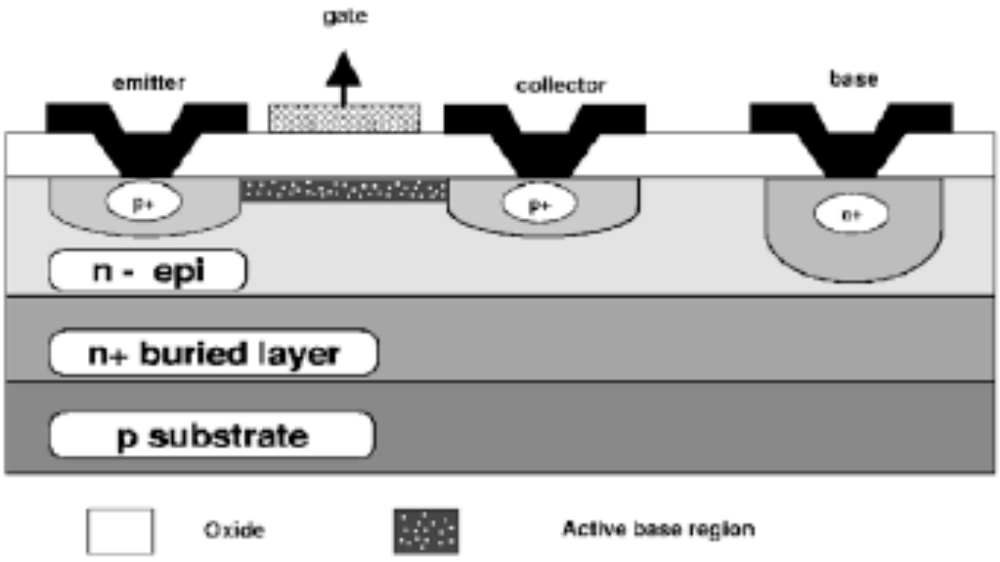
From Pease, et al., IEEE TNS, 54(2007) p.1049

Overview

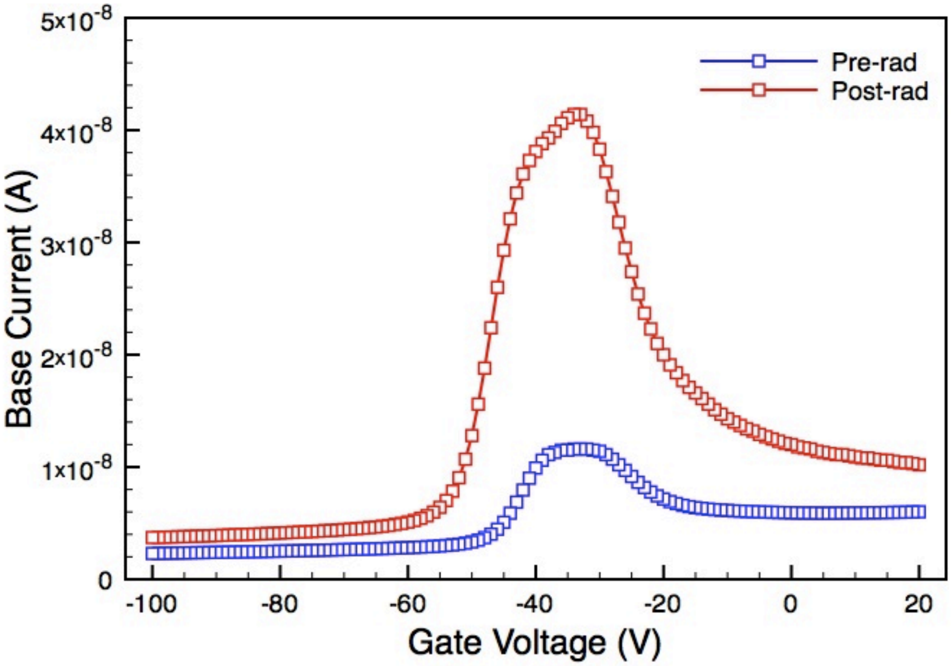
- MURI investigations into hydrogen effects
  - Hydrogen enhanced degradation
  - Dose rate effects
  - Dual role of hydrogen
- What are the mechanisms at work?
  - FLOODS simulations

Investigating the Mechanisms

- Gated lateral PNP transistors provide a convenient way to study the mechanisms



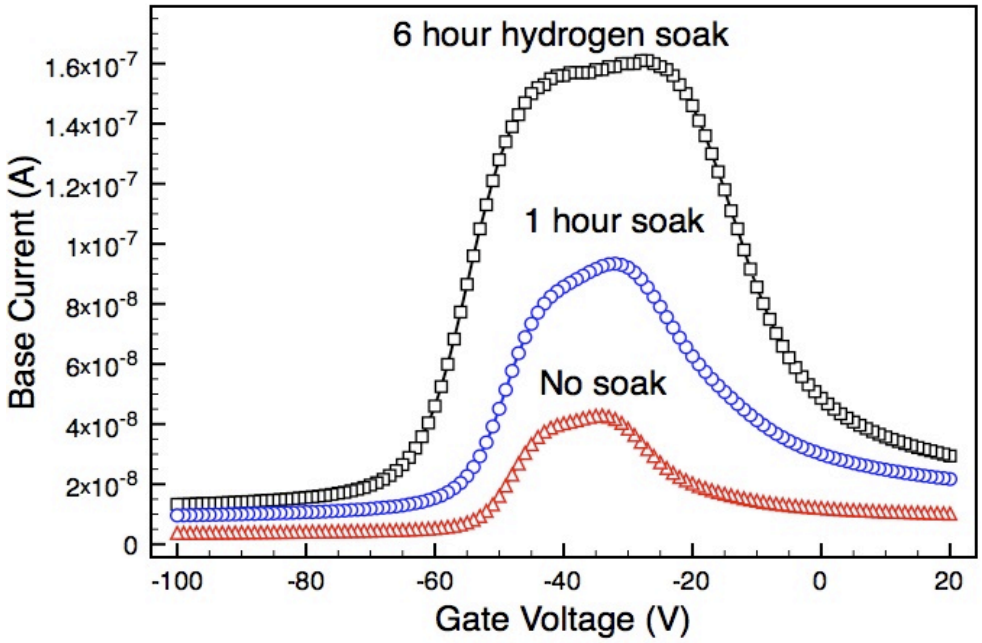
Picture from Ball et al., IEEE TNS, 49(2002) p.3185



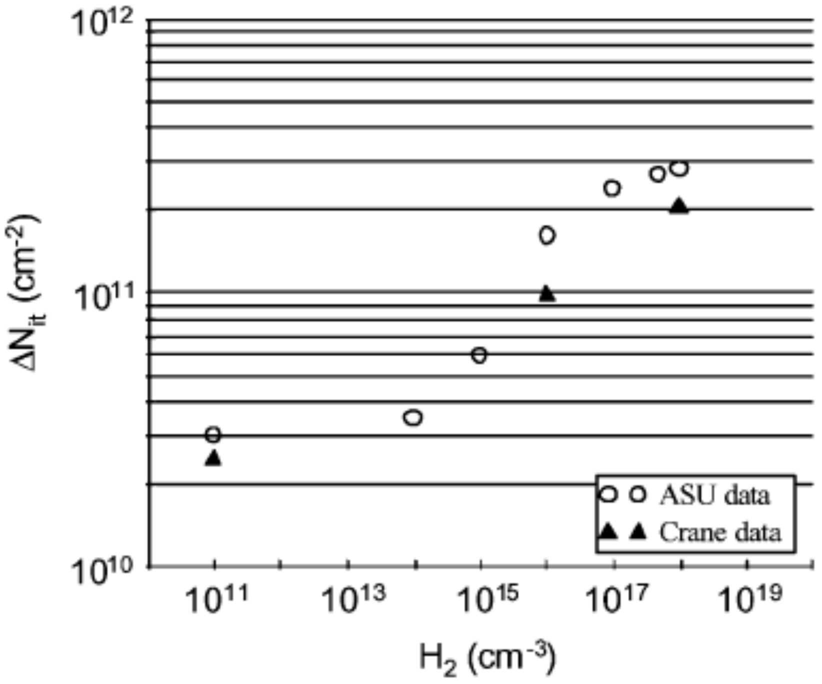
- Changes in peak base current are related to interface trap density

Enhanced Degradation

- Experiments have exposed GLPNP transistors to varying amounts of hydrogen
- Increased hydrogen exposure has increased the buildup of radiation induced interface-traps



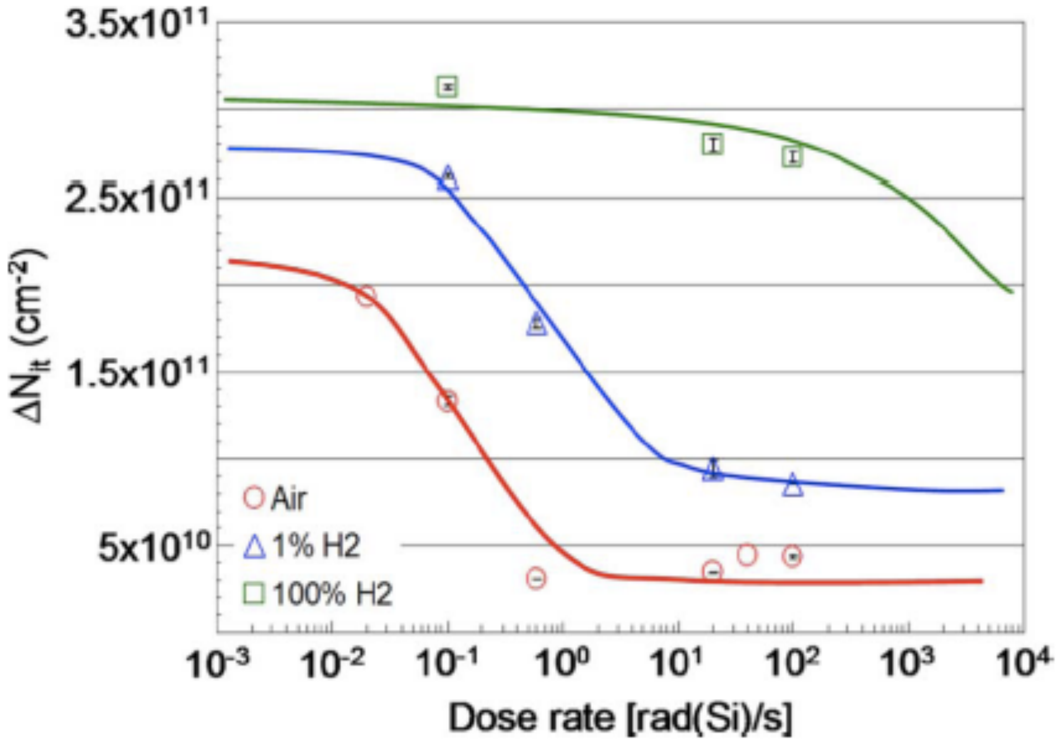
From Hughart, et al., IEEE TNS, 56(2009) p.3361



From Chen, et al., IEEE TNS, 54(2007) p.1913

Dose Rate Effects

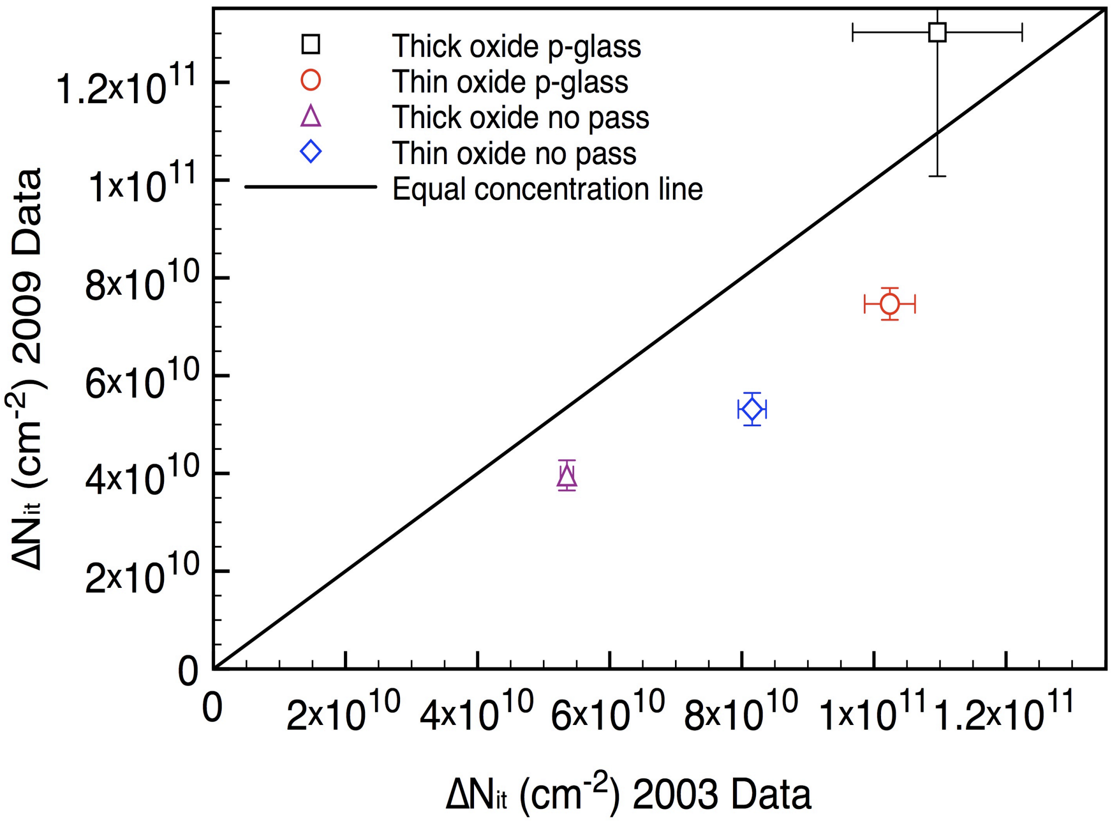
- Hydrogen also affects the dose rate response of bipolar devices
- The transition dose rate is increasing with increasing hydrogen exposure



From Chen, et al., IEEE TNS, 56(2009) p.3196

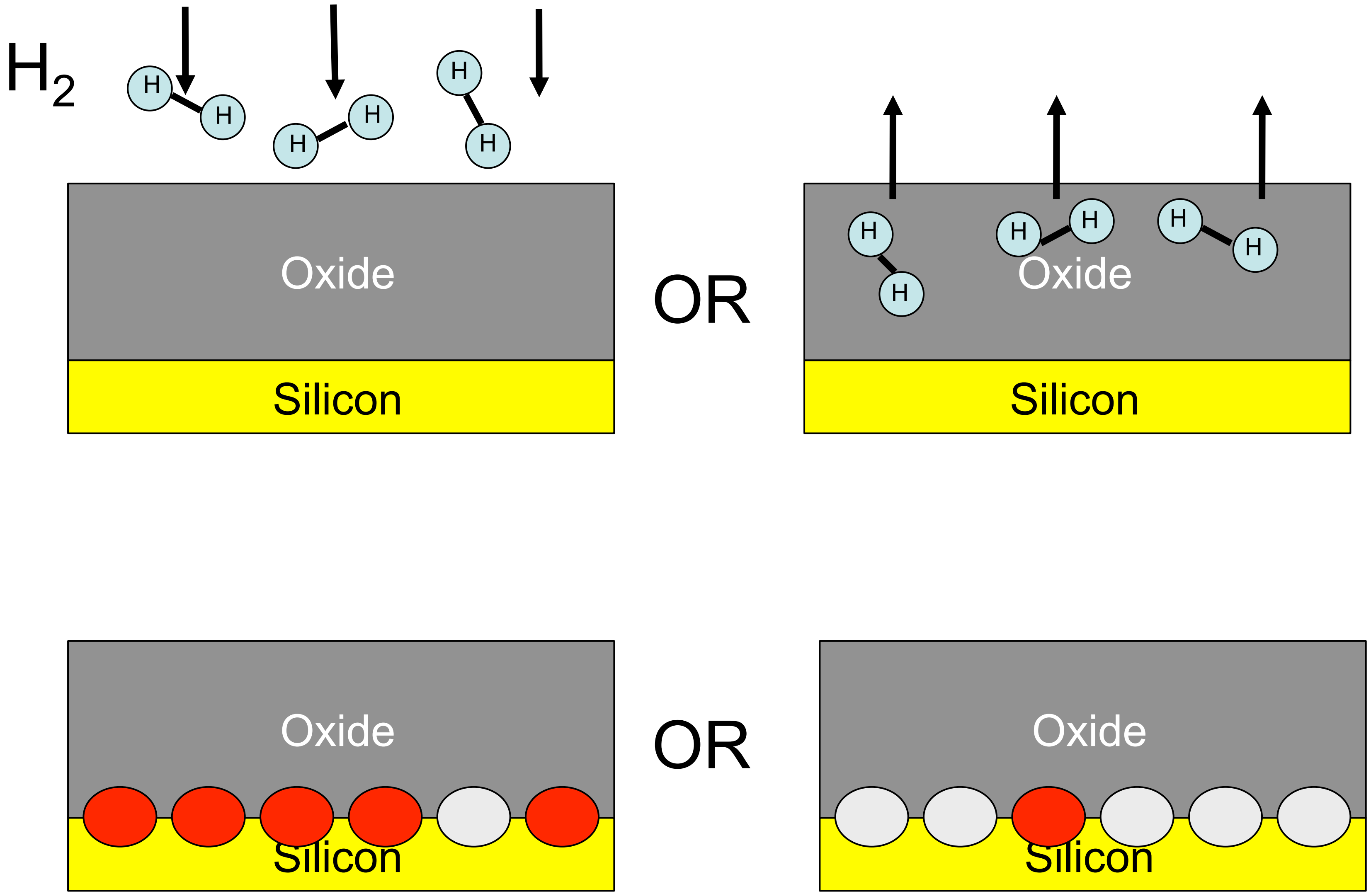
Aging Comparisons

- Transistors in 2009 generally show a reduction in interface traps from identical transistors irradiated in 2003
- Hydrogen likely diffused out of the devices over time



From Hughart, et al., IEEE TNS, 56(2009) p.3361

Dual Role of Hydrogen



🔴 Unpassivated Defect ⚪ Passivated Defect

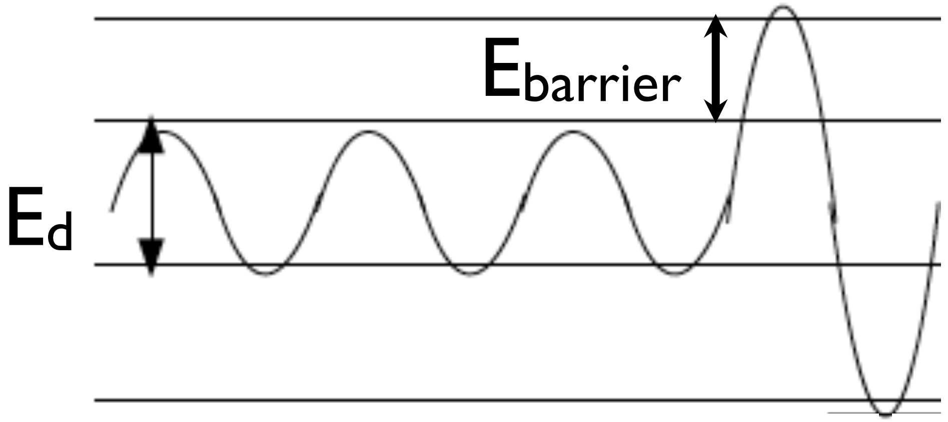
Mechanisms

- What are the mechanisms responsible for proton release?
- New first principles physics calculations
  - Molecular hydrogen interactions with isolated dangling bonds in the oxide may be a significant mechanism

Simulation / Modeling

- FLOODS (FLorida Object Oriented Device Simulator) is used to solve coupled differential equations
  - H_2 soak anneals
  - Co-60 radiation exposure
  - Diffusion + field transport
  - Particle / trap interactions
    - Electron-hole recombination, proton release reactions, and interface-trap buildup

Reaction Rates



- Energy barriers calculated using DFT (density functional theory)
- Reaction rates $\propto \exp(-E/kt)$

Reactions

- $h^+ + Vo \rightarrow Vo^+$
- $e^- + Vo^+ \rightarrow Vo$
- $H_2 + Vo^+ \rightarrow VoH + H^+$
- $VoH + h^+ \rightarrow Vo + H^+$
- $Si\text{-}H + h^+ \rightarrow Si\text{-} + H^+$
- $Si\text{-} + h^+ \rightarrow Si\text{-}^+$
- $Si\text{-}^+ + H_2 \rightarrow Si\text{-}H + H^+$

- h^+ = Hole
- e^- = Electron
- Vo = Oxygen vacancy
- VoH = Hydrogenated vacancy
- Si- = Isolated dangling bond

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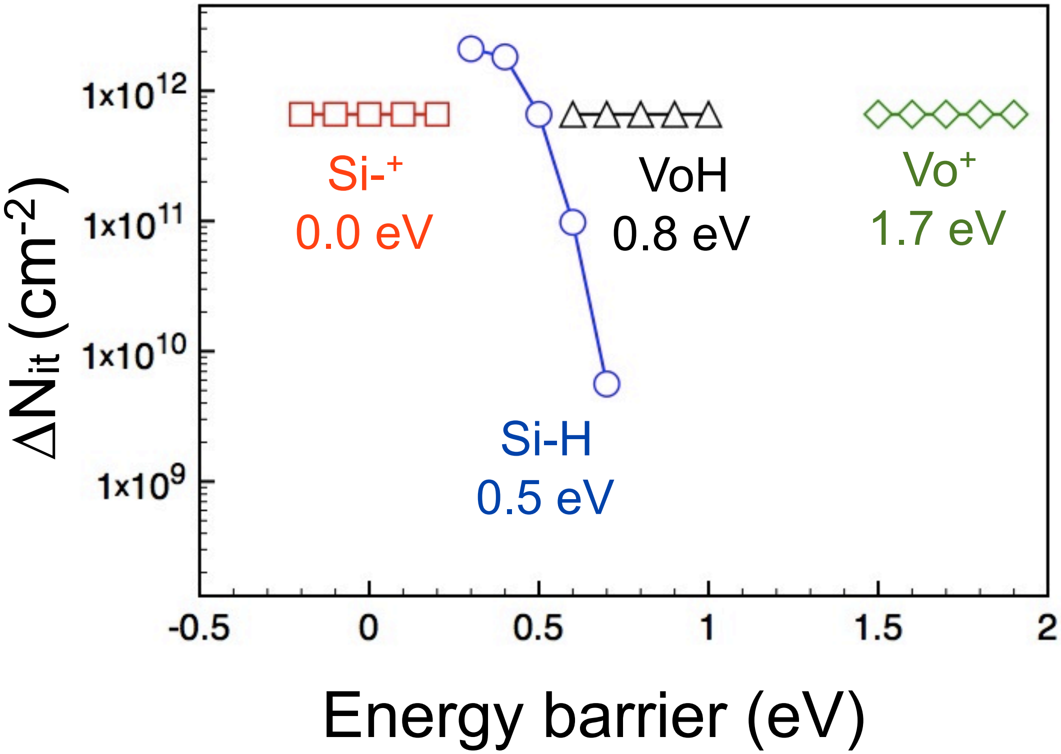
Proposed Mechanisms

- Si-H bonds are created during processing
- During irradiation holes can release protons
  - $\text{Si-H} + h^+ \rightarrow \text{Si-} + H^+$
- Dangling bonds capture a hole, then react with molecular hydrogen to produce more protons
  - $\text{Si-} + h^+ \rightarrow \text{Si-}^+$
  - $\text{Si-}^+ + H_2 \rightarrow \text{Si-H} + H^+$

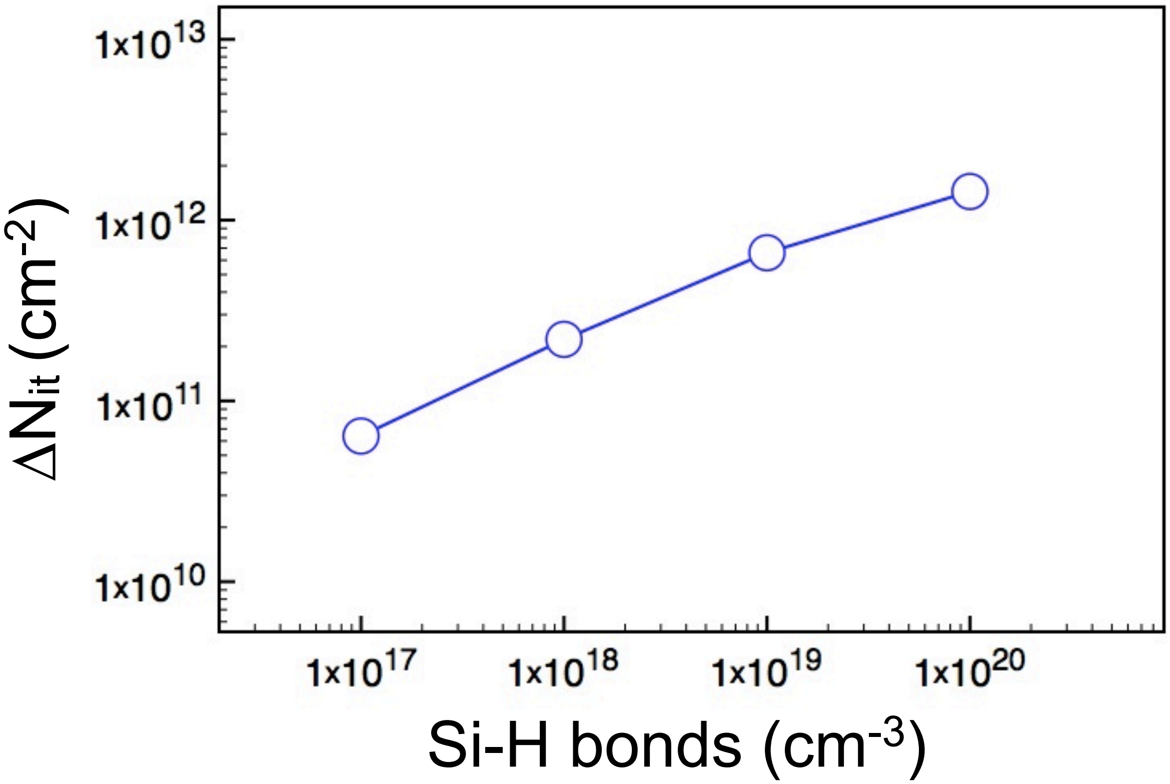
Proton Release

- Interface trap buildup is sensitive to changes in the energy barrier of the Si-H bond reaction
  - $Si\text{-}^{+} + H_2 \rightarrow Si\text{-}H + H^{+}$
  - $Si\text{-}H + h^{+} \rightarrow Si\text{-} + H^{+}$
  - $VoH + h^{+} \rightarrow Vo + H^{+}$
  - $H_2 + Vo^{+} \rightarrow VoH + H^{+}$



Si-H Bonds

- Initial Si-H bond concentration strongly affects interface trap buildup
- Interface trap density is related to defect density of oxide

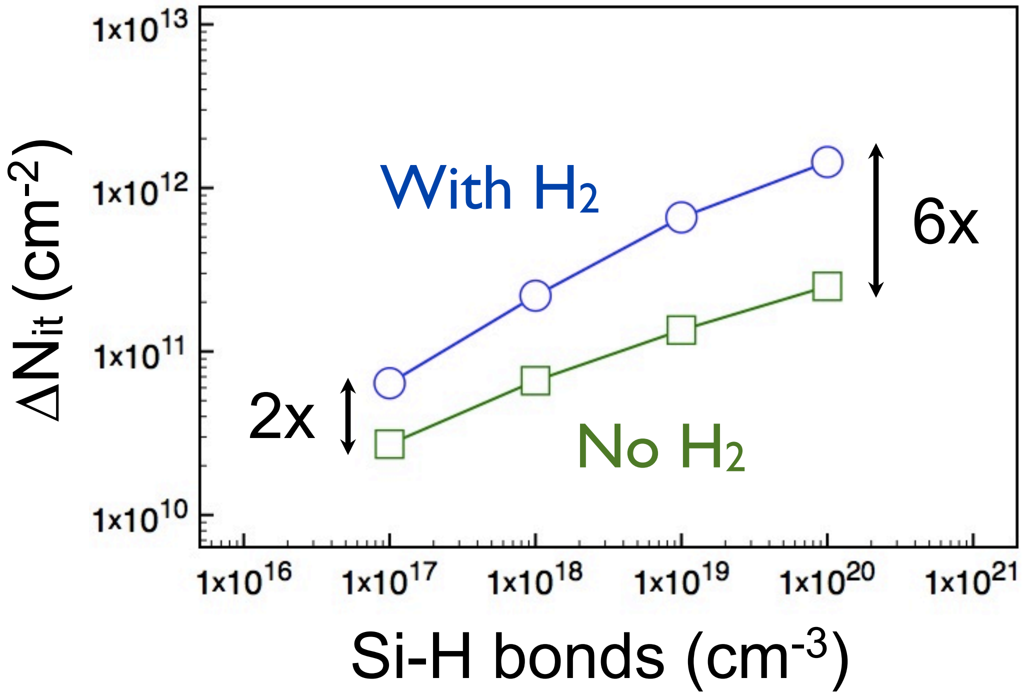


H_2 Mechanisms

- Two proton release mechanisms depend directly on molecular hydrogen
  - $Si\text{-}^{+} + H_2 \rightarrow Si\text{-}H + H^{+}$
    - Energy barrier = 0.0 eV
  - $H_2 + Vo^{+} \rightarrow VoH + H^{+}$
    - Energy barrier = 1.7 eV

Si-H Bond Sensitivity

- H_2 enhanced degradation is also sensitive to the Si-H bond concentration
  - $Si\text{-}^{+} + H_2 \rightarrow Si\text{-}H + H^{+}$



Summary and Conclusions

- The effects of hydrogen
  - Enhanced degradation and dose rate effects
  - Dual role of hydrogen
- Isolated dangling bond mechanisms may contribute to radiation induced interface trap buildup
- Interface trap buildup is dependent on:
  - H_2 concentration present during irradiation
  - Si-H bonds created during processing