Mechanisms of Hydrogen Effects in Bipolar Radiation Response

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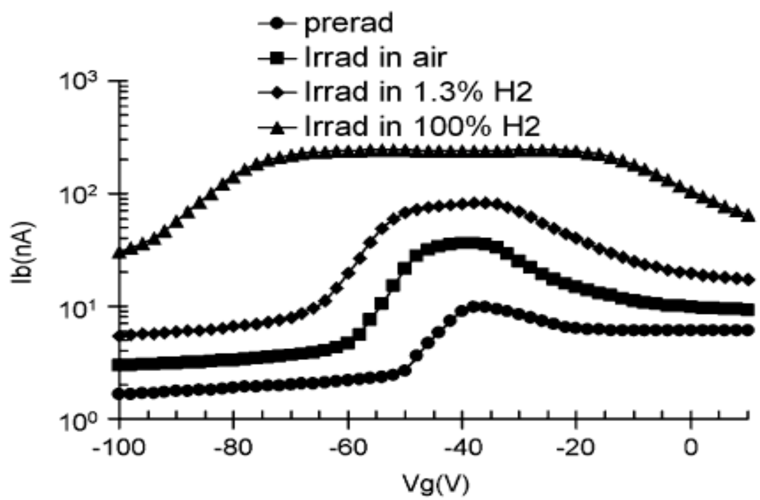
Motivation

- Hydrogen has strong effect on radiation response and long term aging
- Identify the fundamental physical mechanisms

Hydrogen effects on radiation response of field oxides

- Packaging with hydrogen negatively impacts radiation response
  - R.L. Pease, et. al. 2007
- Enhanced degradation of bipolar transistors exposed to hydrogen
  - X.J. Chen, et. al. 2007



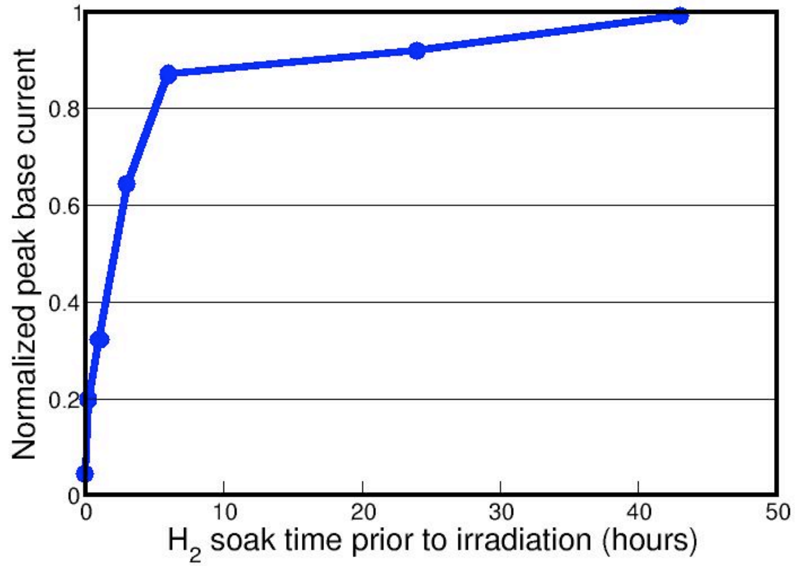
- What physical mechanisms are responsible for these effects?
  - Answered through experiments, first-principles calculations, and simulation

Outline

- Experimental results on H_2 diffusion from NAVSEA Crane
  - Strong effect of H_2 exposure on BJT rad response
- Modeling
  - Hydrogen molecule diffusion, FLOODS
  - First principles calculations
    - Interactions of H_2 with defects
    - Generation of protons
    - Interaction of H^+ with defects/trapping of the charge

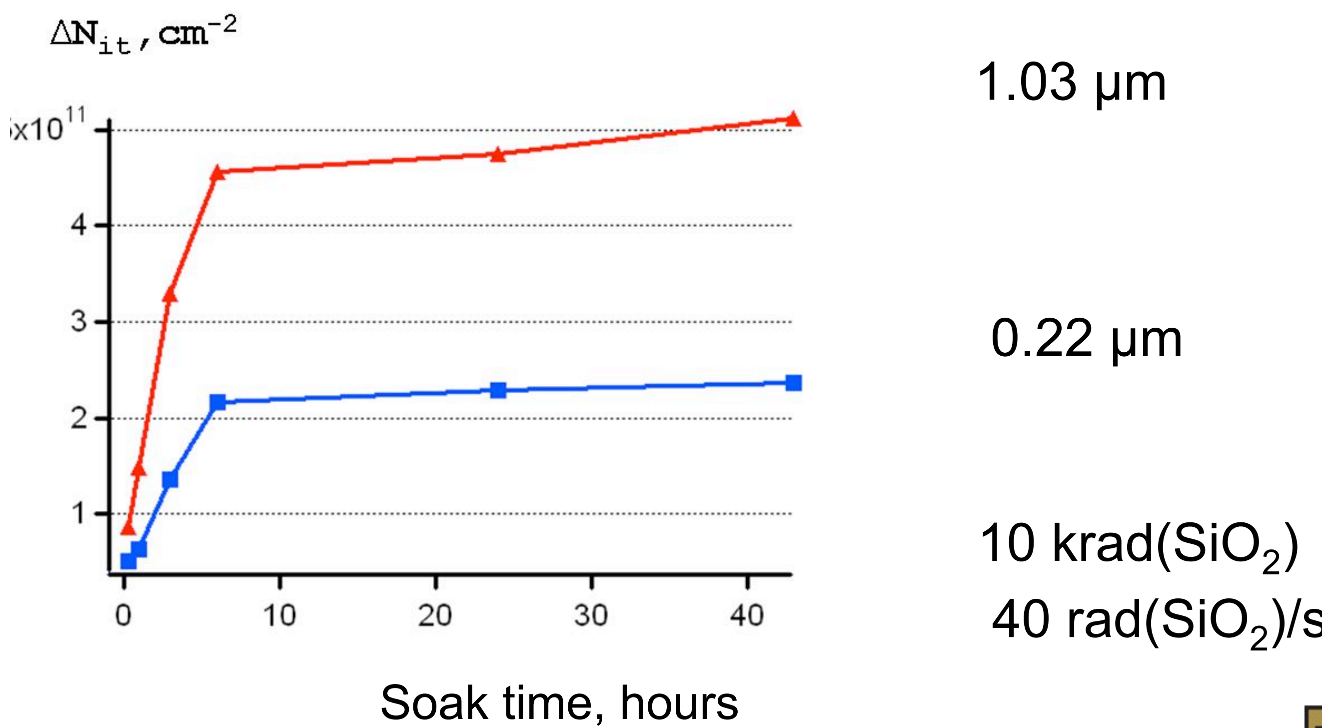
Hydrogen exposure experiments at NAVSEA Crane

- Experimental conditions
  - 100% H_2 atmosphere for various times at room temperature
  - 10 krad(SiO_2) at 40 rad(SiO_2)/s
- Results
  - Increased degradation correlated with increased pre-irradiation soaking time in hydrogen



Interface trap density in thin and thick oxides

- Interface trap density extracted from gated lateral pnp transistors
  - Used method developed by Ball, Schrimpf, and Barnaby (2002)



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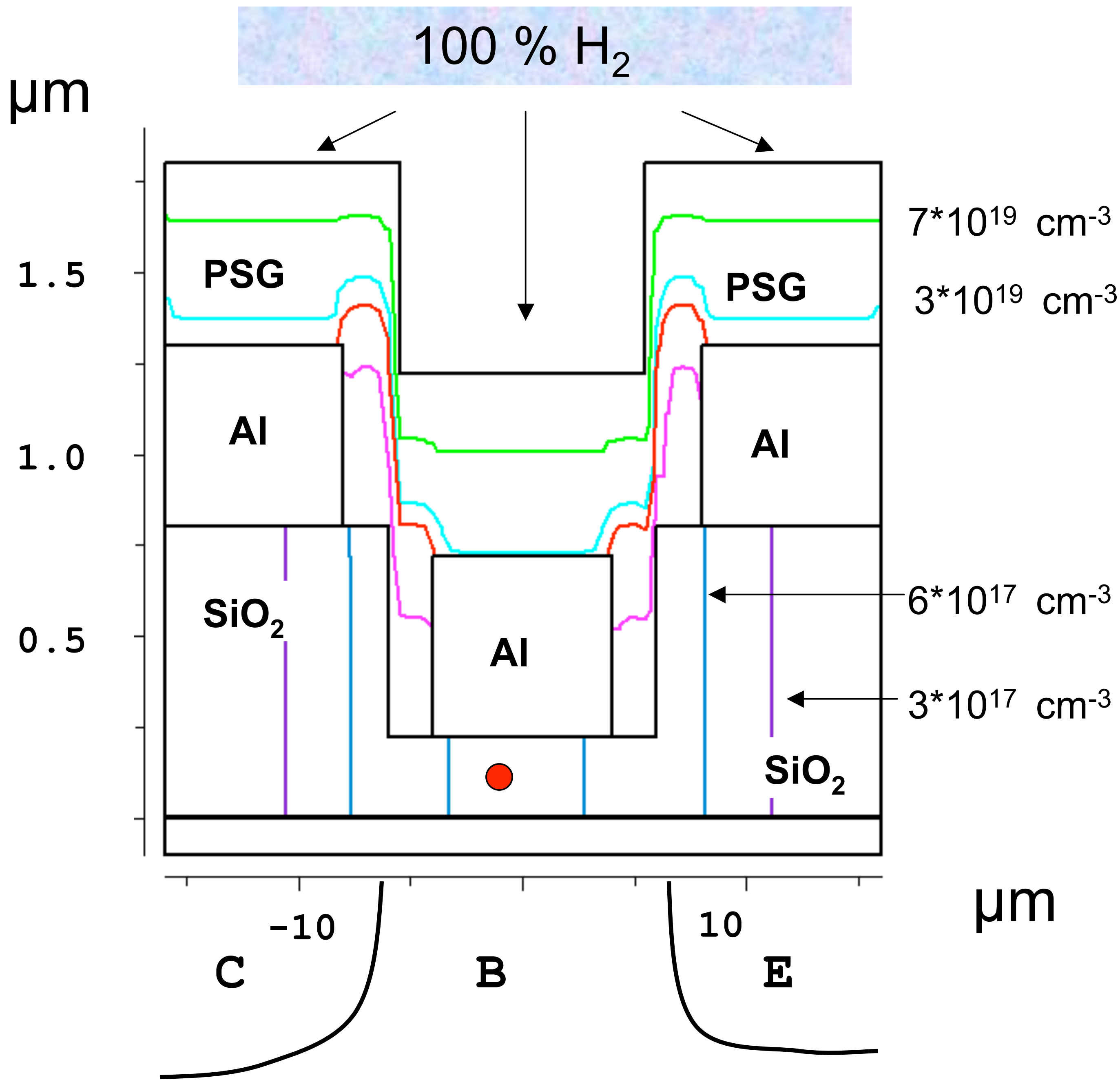
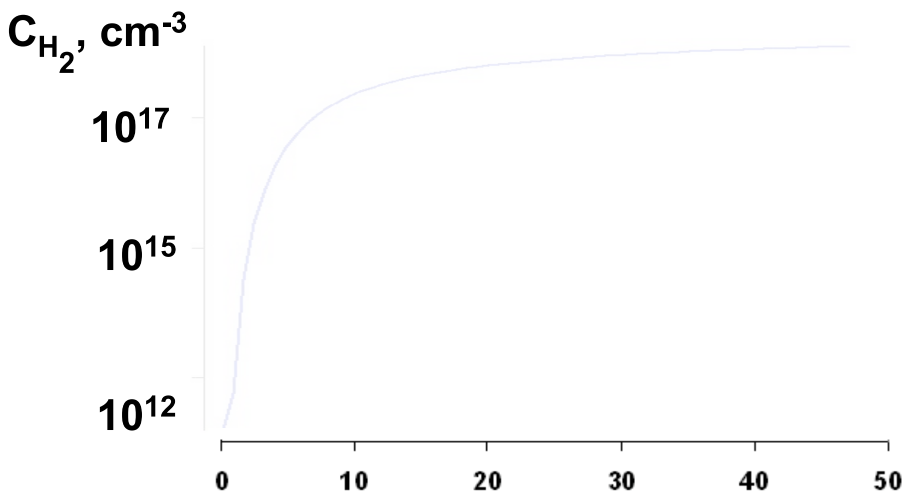
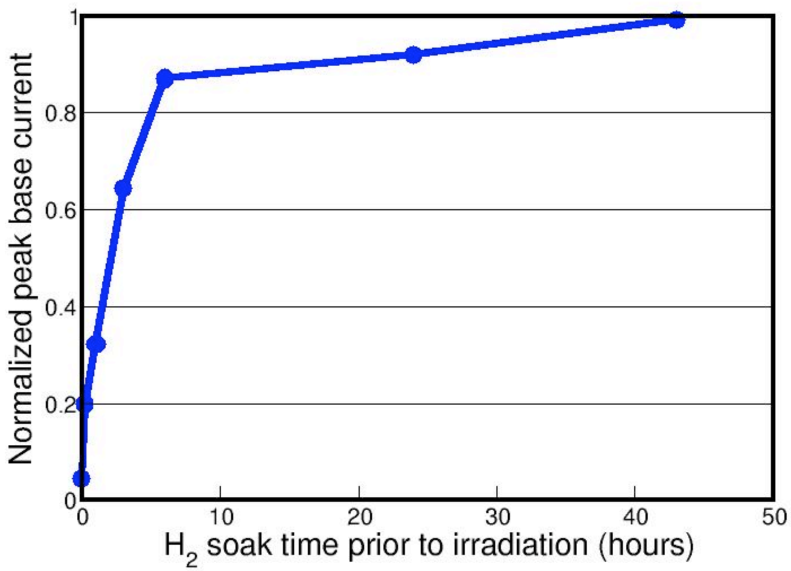


100 % H_2
μm
1.5
1.0
0.5
PSG
PSG
Al
Al
Al
SiO_2
SiO_2
$7*10^{19}$ cm^{-3}
$3*10^{19}$ cm^{-3}
$6*10^{17}$ cm^{-3}
$3*10^{17}$ cm^{-3}
-10
10
μm
C
B
E

H_2 concentration in base oxide



Rapid increase of hydrogen in gate region of bipolar device due to H_2 soak (simulated using FLOODS)



Similar to radiation response

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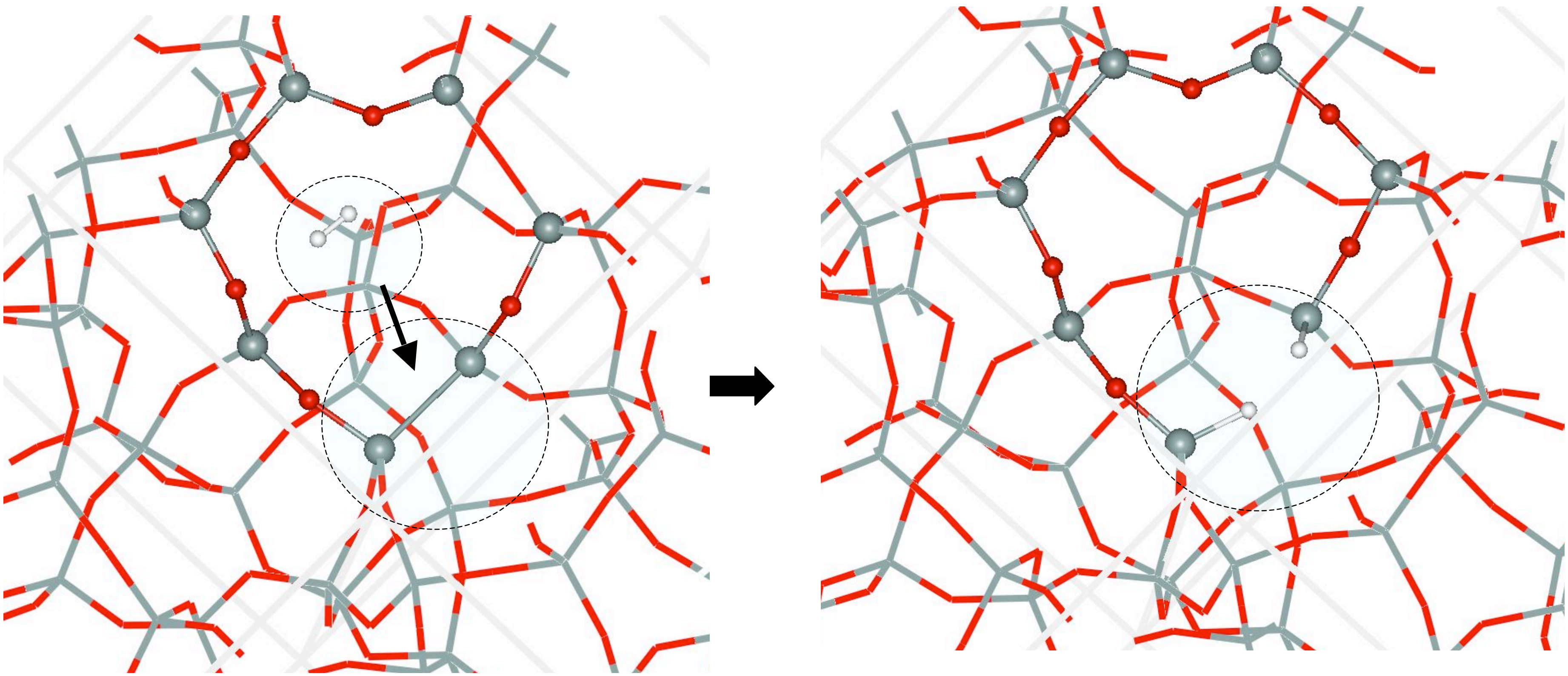
H_2 cracking at neutral O vacancy



$$H_2 + V_o \rightarrow \equiv Si\text{-}H + \equiv Si\text{-}H$$

Exothermic, energy gain 0.4-1.4 eV, activation energy 0.9-1.0 eV

H_2 cracking at different O vacancy sites

Structure	site 1	site 2	site 3	site 4	site 5	site 6
Energy gain (eV)	0.4	1.3	0.6	1.4	-0.14	0.5
Si-Si distance after cracking (Å)	3.43	3.72	3.58	3.69	3.23	3.59
Activation energy (eV)	0.9	1.0	1.0	-	-	-

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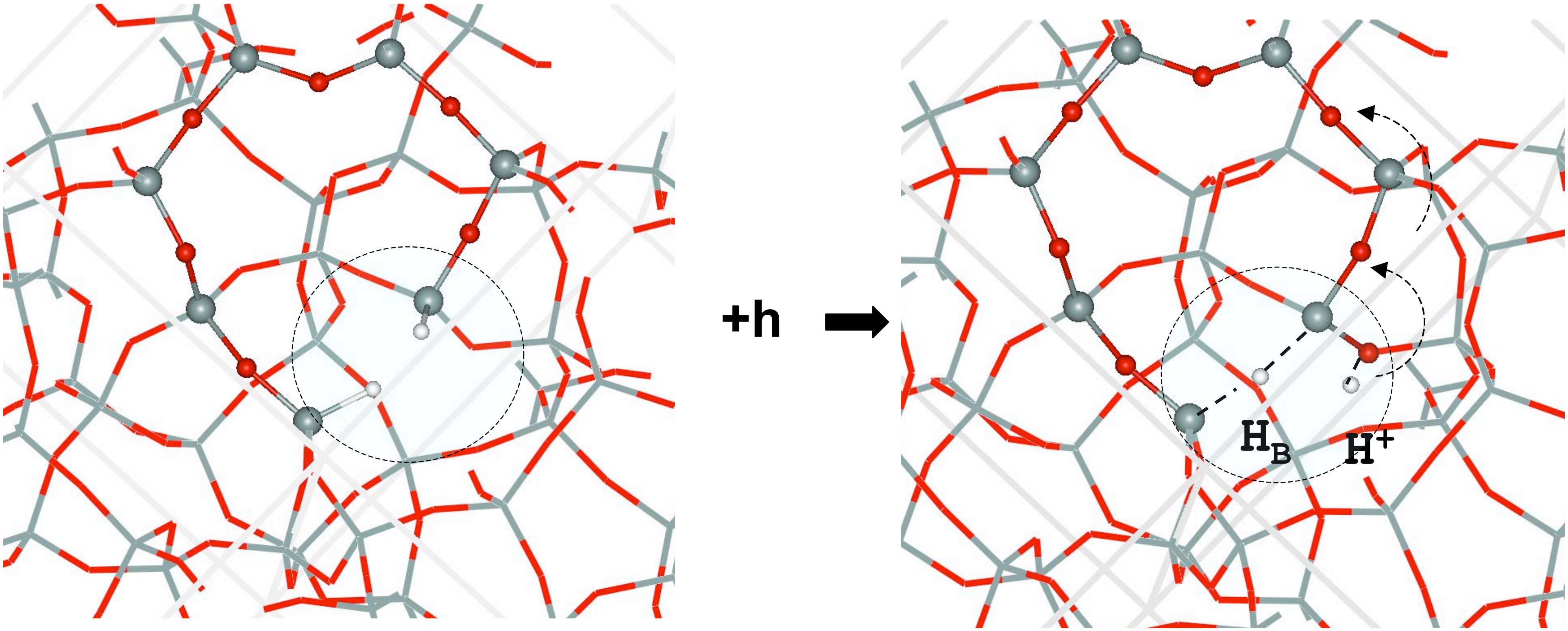
Proton release



$$h \quad + \quad 2\,(\equiv Si\text{-}H) \quad \rightarrow \quad H_B \quad + \quad H^+$$

Exothermic, energy gain 01.-0.3 eV, activation energy 0.7 eV

Migration energy of H^+ 0.6-0.8 eV

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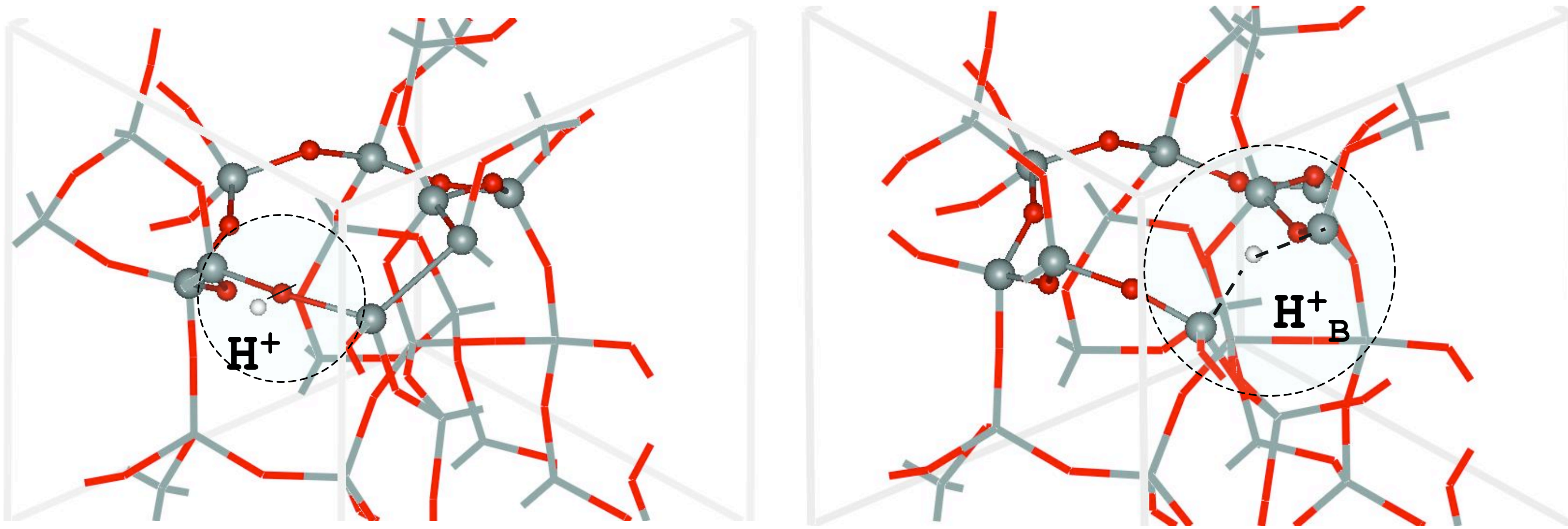
Charge trapping



H^{+} + V_{o} → H^{+}_{B} (deep hole trap)

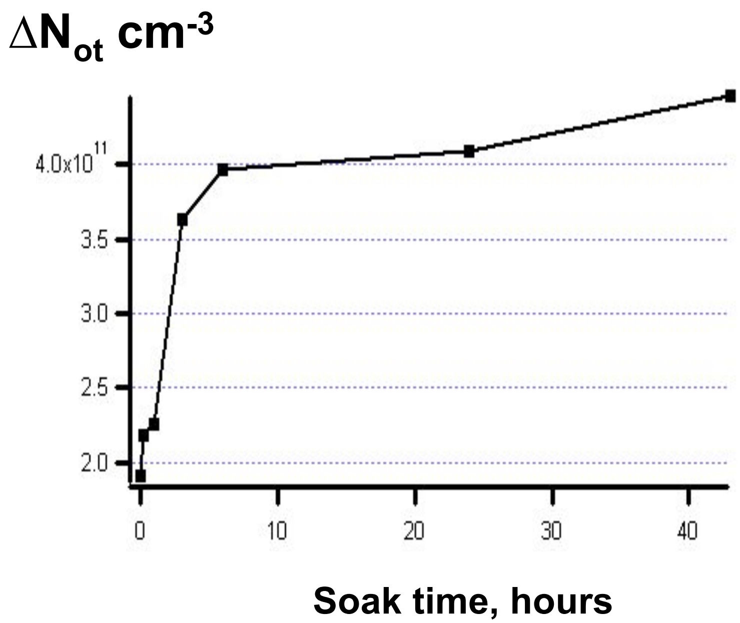
Exothermic, energy gain~0.9 eV

activation energy 0.7-0.9 eV

Charge trapping

In the bulk: $H^+ + V_o \rightarrow H^+_B$

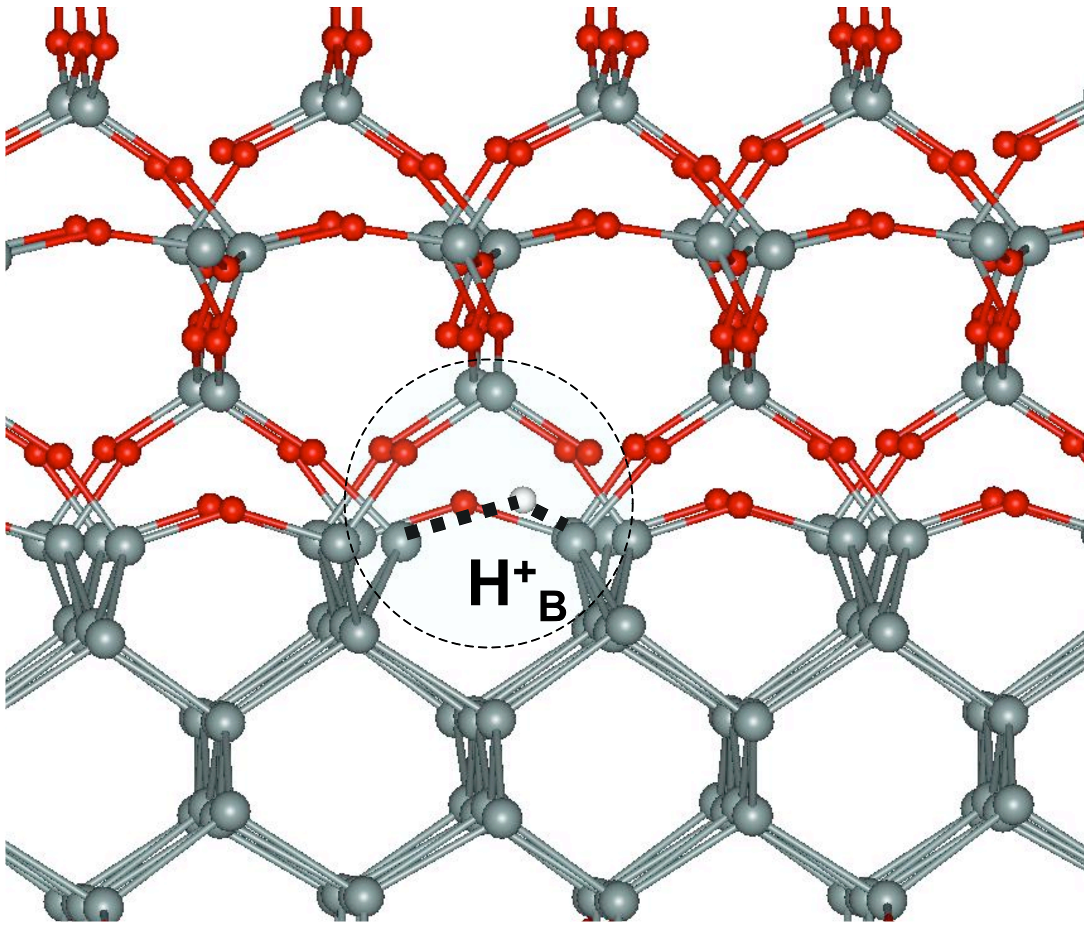
$$\frac{\partial N_{ot}}{\partial t} = \sigma_{V_o} \mu_{H^+} E \times [H^+][V_o] - N_{ot} / \tau_{N_{ot}}$$



Gate sweep,0.22 µm,
10 krad(SiO_2),
40 rad(SiO_2)/s

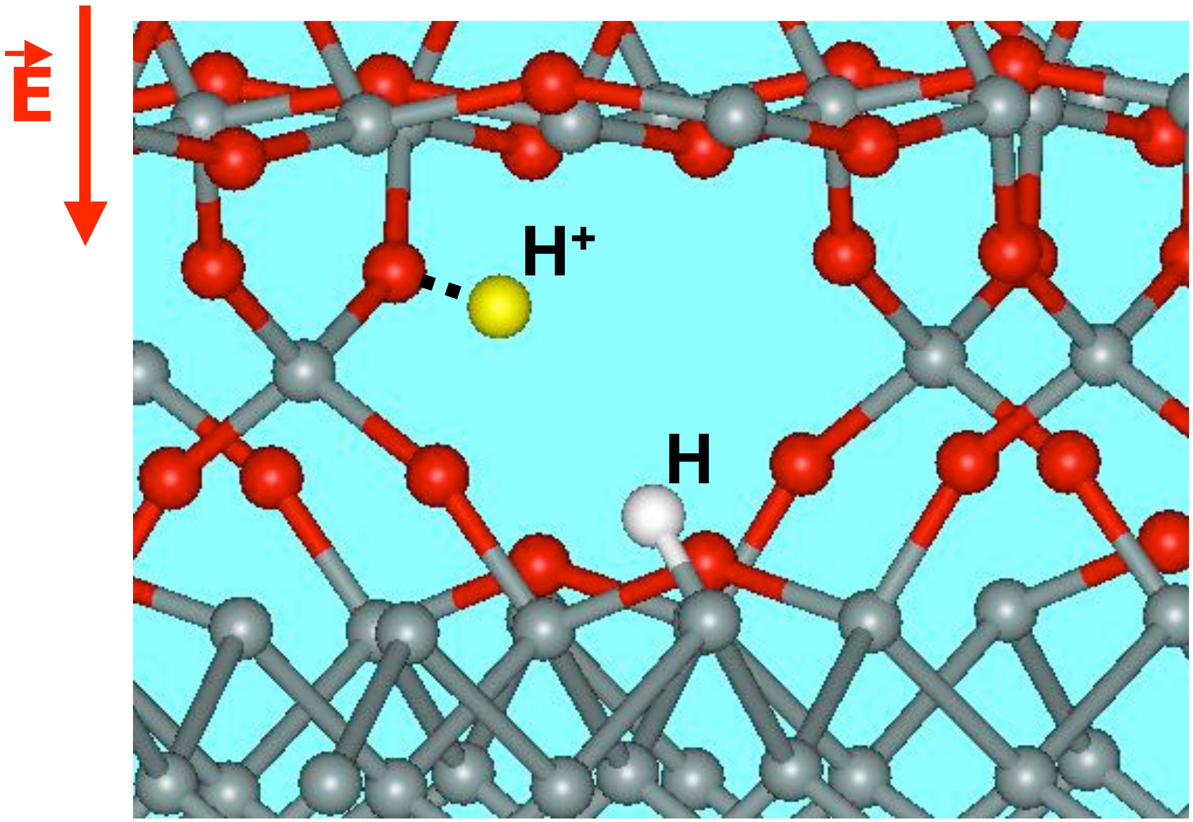
Can oxygen vacancy in bridge position at interface contribute to N_{it}?

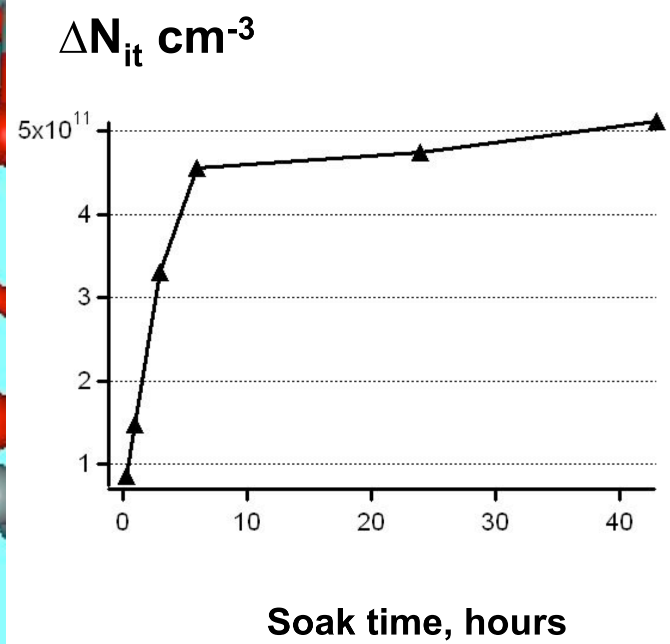
$\mathbf{H^+ + V_o \longrightarrow H^+_B}$ activation energy 0.7 eV, gain of energy 1 eV



Charge trapping at interface

Standard model of N_{it} formation





H^+ + Si-H ⟶ D^+ + H_2 , activation energy ~1 eV,

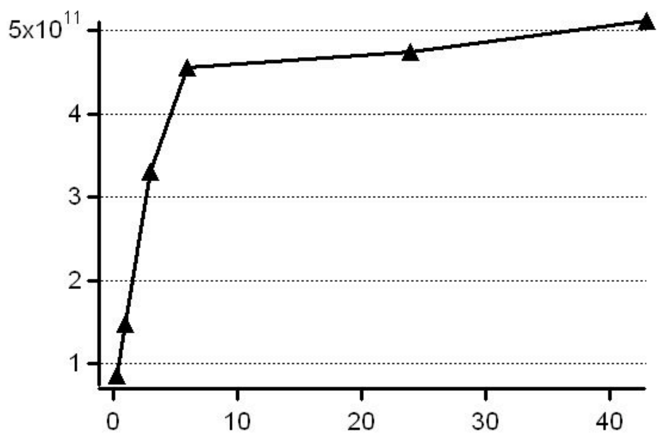
endothermic, loss of energy 0.3 eV

Charge trapping

At interface: $\mathbf{H^+ + V_o \longrightarrow H^+_B}$ activation energy 0.7 eV, gain of energy 1 eV

$$\frac{\partial N_{it}}{\partial t} = \sigma_{V_0} \upsilon_{th,H^+} \times [H^+][N_{V_o}] - N_{it} / \tau_{N_{it}}$$

ΔN_{it} cm^{-3}



Soak time, hours

Gate sweep,0.22 μm,
10 krad(SiO_2),
40 rad(SiO_2)/s

Conclusions

- Exposure to H_2 dramatically affects radiation response
- H_2 cracking reaction identified
- Proton generation mechanism proposed
- Proton trapping in the bulk and at the interface