Effects of hydrogen on device total ionizing dose and dose rate response

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MURI

Topics

Effect of hydrogen on dose rate sensitivity

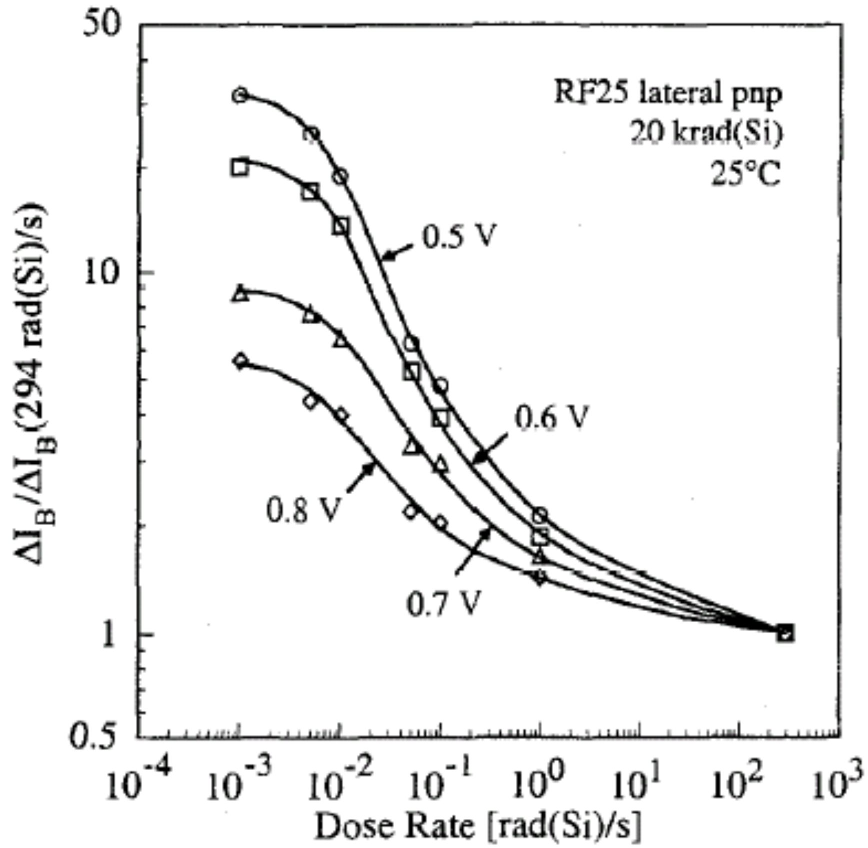
- ELDRS mechanism and modeling
- Results of TID exposure at different dose rates in H environment
- Modeling the effect of H on ELDRS

Effects of hydrogen on TID and annealing response (Covered in Appendix)

- Previous TID experiment in hydrogen
- Un-biased annealing in air/hydrogen

ELDRS in bipolar devices

- **Enhanced Low Dose Rate Sensitivity in bipolar devices**



After Witczak et al,
IEEE Trans. Nucl. Sci., 1998

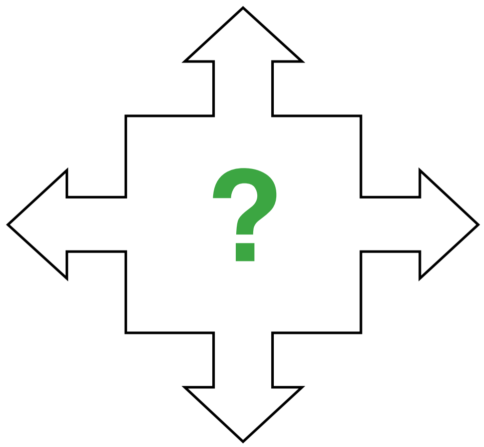
Existing ELDRS Models

Space Charge Model

After Rashkeev, Cirba, Fleetwood, Schrimpf, Witczak, Michez, Pantelides, TNS 2002.

Trapped e^- Model

After Boch, Saigné, Schrimpf, Vaillé, Dusseau, Lorfèvre, TNS 2006.



H_2 cracking model

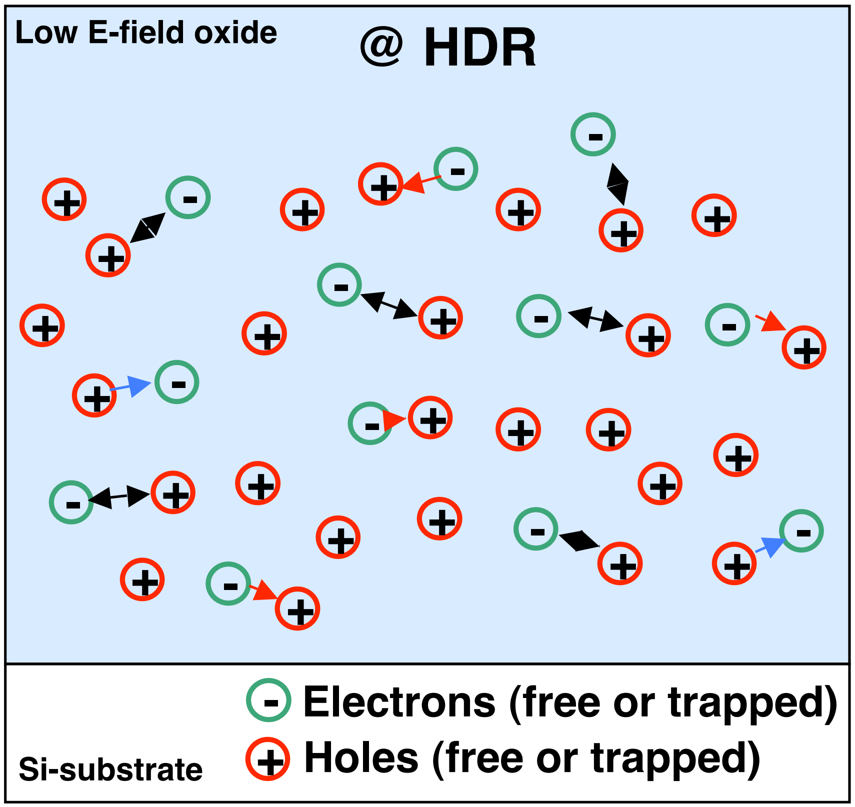
After Hjalmarson, Pease, Witczak, Shaneyfelt, Schwank, Edwards, Hembree, Mattsson, TNS 2003.

Other competing reaction models

After Freitag and Brown, TNS 1997.

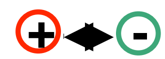
Some Key ELDRS Processes

ELDRS really is: Reduced High Dose Rate Sensitivity

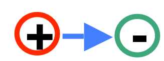


High space charge induced localized E-field @ HDR

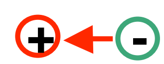
- Increases recombination of n^-/p^+



- Increases probability of n^- trapping, recombining with free holes



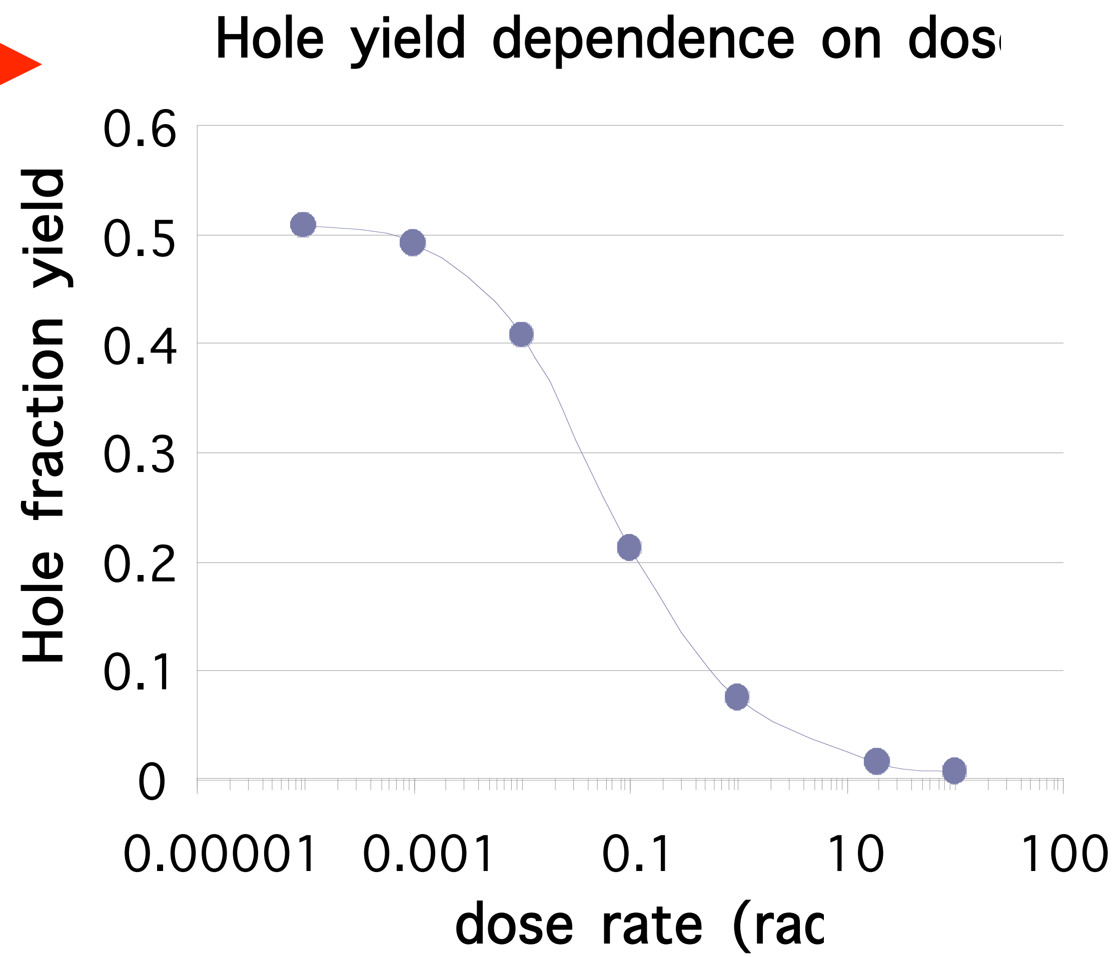
- Increases probability of trapped p^+ annihilation by n^-



Modeling ELDRS

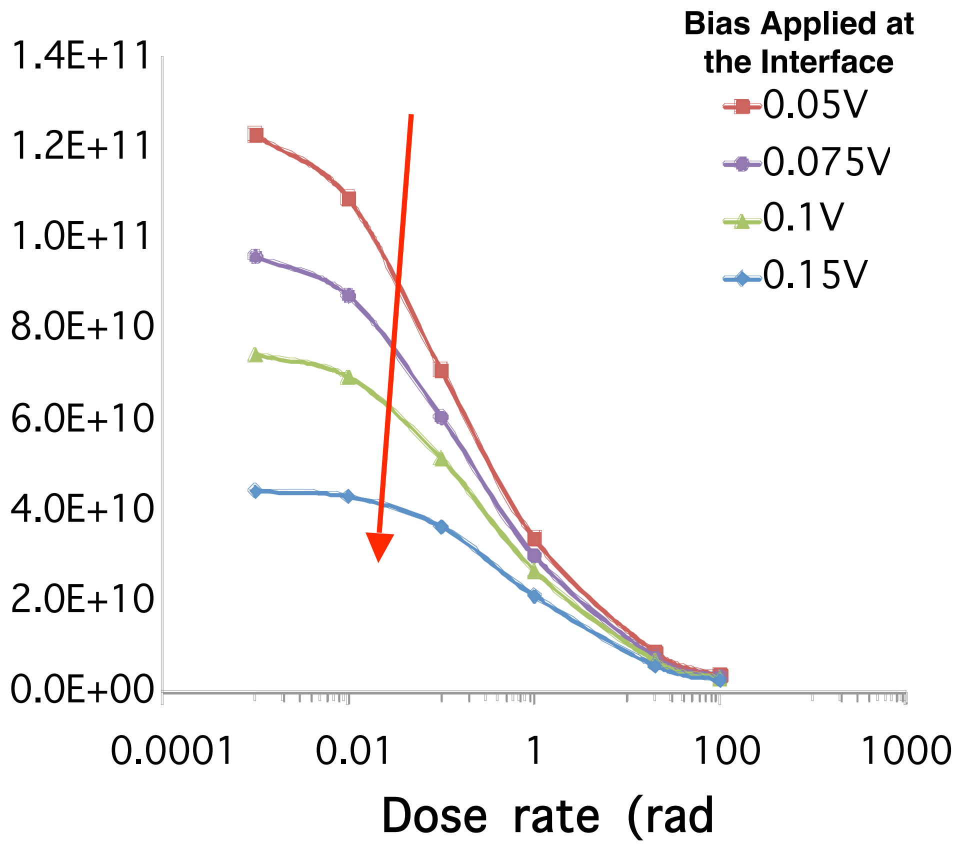
ELDRS mechanism simulation

- Using 2D COMSOL FES @ASU
- Reduced hole yield at HDR due to increased n^-/p^+ recombination caused by space charge
- Hole yield directly affects H^+ and N_{it} generation

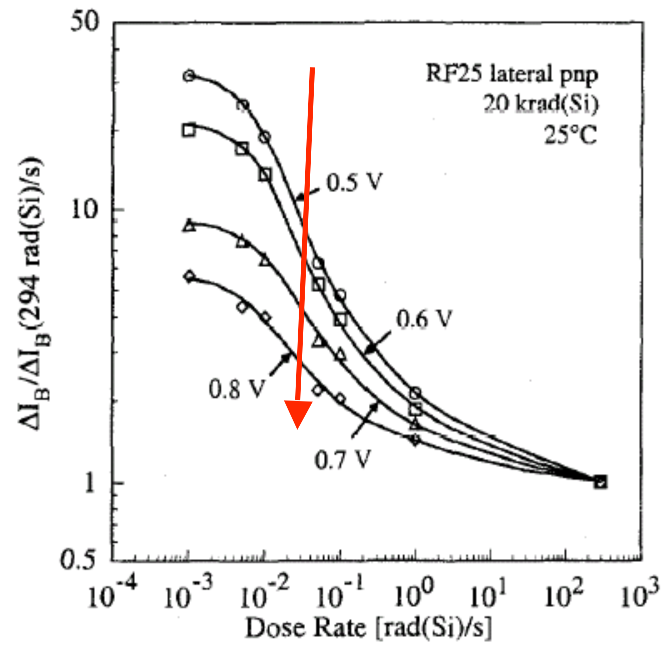


Modeling ELDRS

- **Hole flux is affected by applied E-field**
- **Appied E-field directly affects ELDRS response**



After Witczak et al, IEEE Trans. Nucl. Sci., 1998

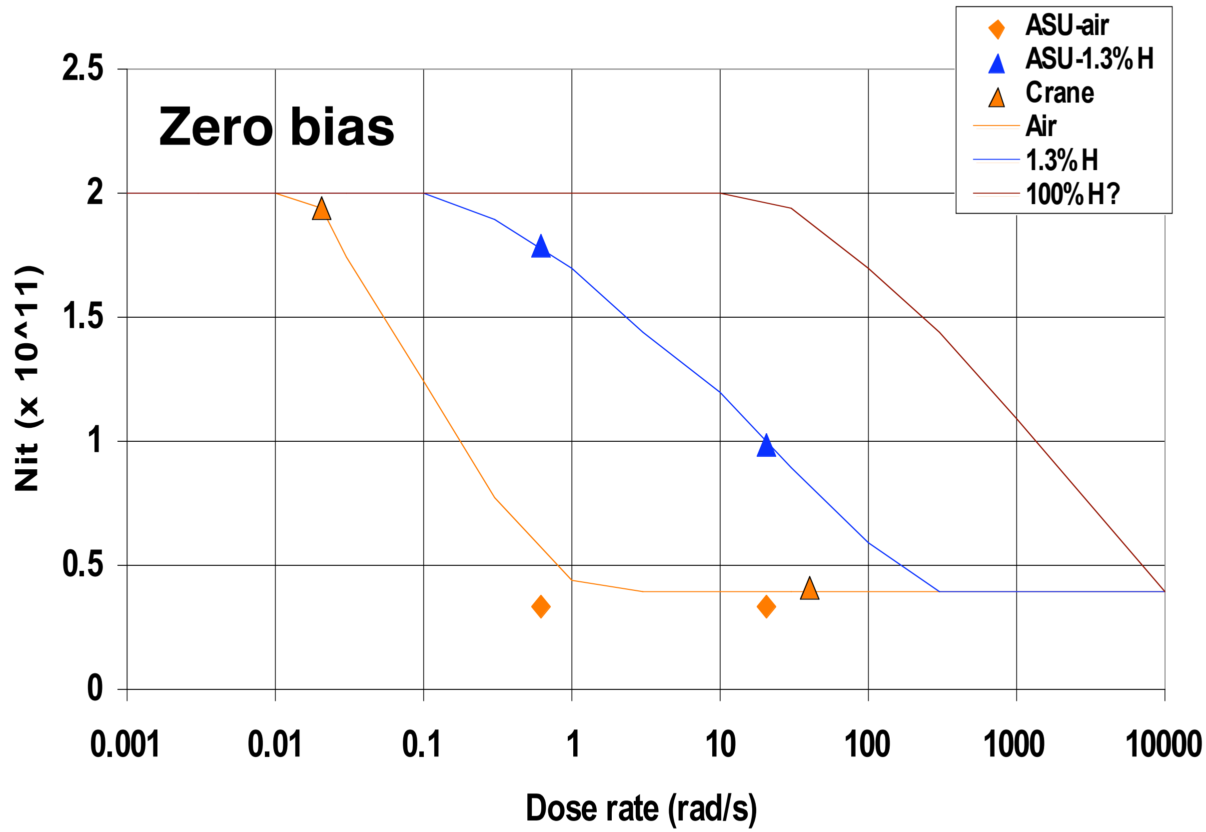


MURI 2008

Effect of H_2 on ELDRS

ELDRS/H_2 Experiment on bipolar parts

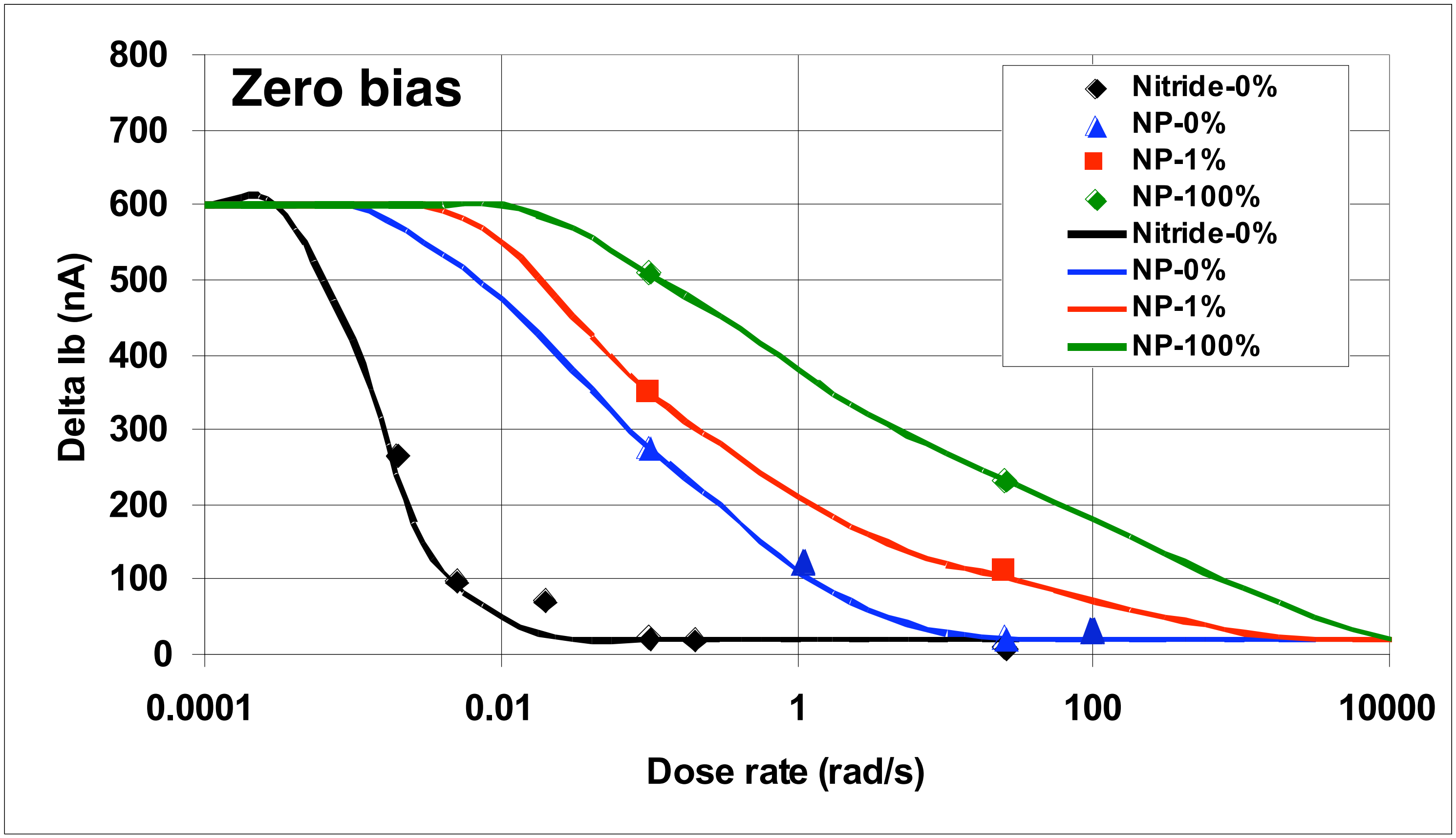
- Gated bipolar test structures (GLPNP) with P-glass passivation (ASU).



Presenting at NSREC 2008

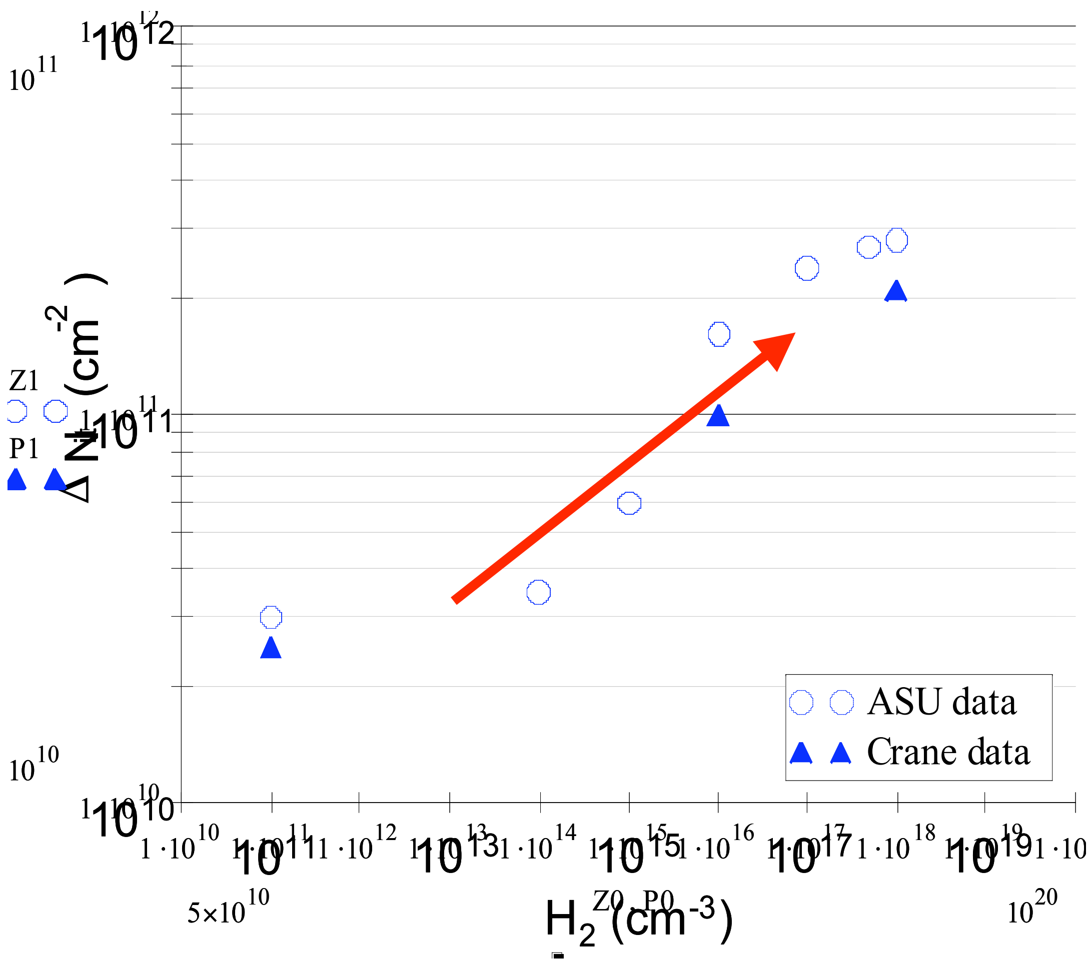
Effect of H_2 on ELDRS

ELDRS/H_2 Experiment on bipolar parts (LM193)



Presenting at NSREC 2008

Effect of H_2 on radiation response



- **GLPNPs exposed to 30krad Co-60 gamma rays at 20rad/s**
- **Enhanced buildup in N_{it} as H2 concentration increases due to H_2 cracking reactions**

$$H_2 + 2D \rightarrow 2DH$$

After Chen et al, IEEE Trans. Nucl. Sci., 2007

Impact of hydrogen on ELDRS

ELDRS response also changes with H_2

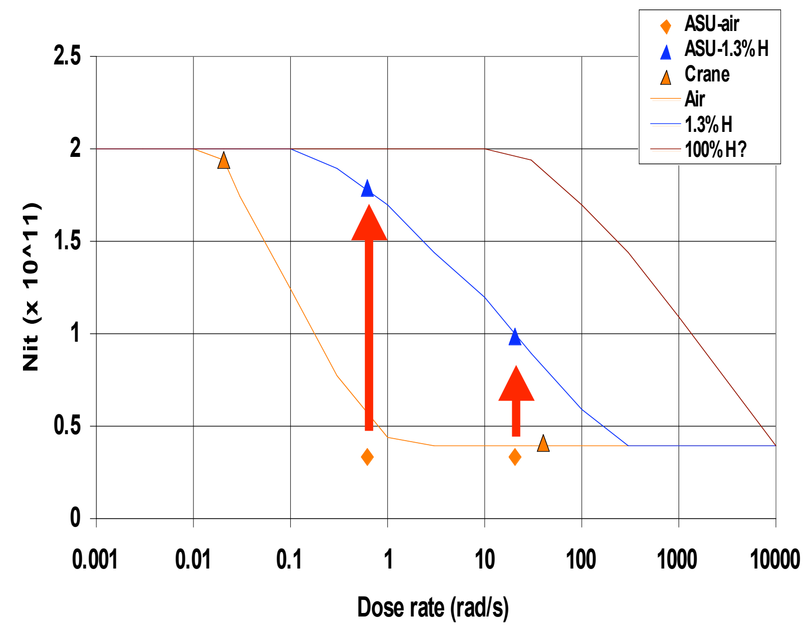
@ HDR

$H_2 + 2D \rightarrow 2DH$ ★
$p^+ + DH \rightarrow D + H^+$ ★

Competing with

$n^- + D^+ \rightarrow D$
$p^+ + n^- \rightarrow X$
$p^+ + D \rightarrow D^+$
p^+ leaving oxide

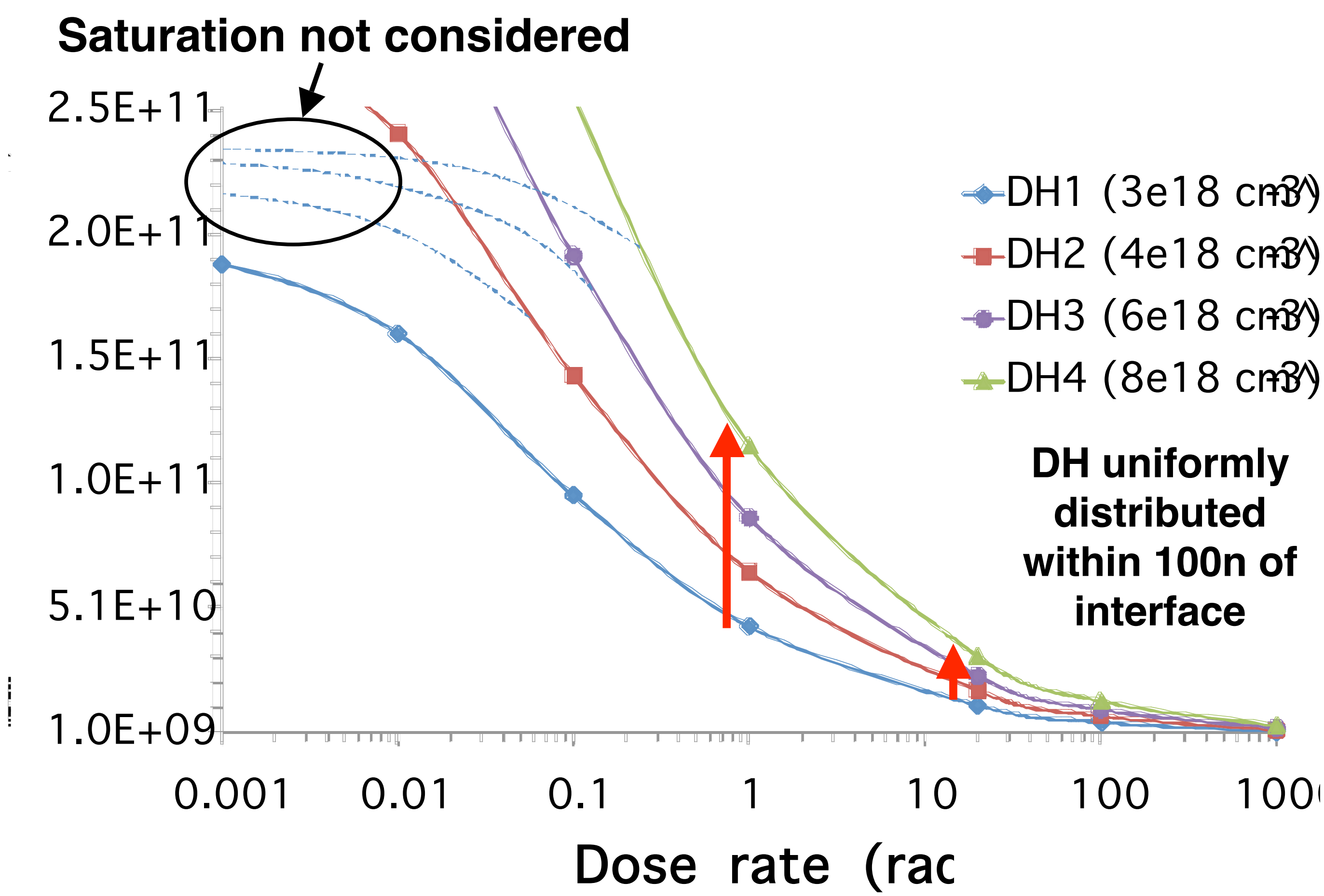
Shift in dose rate curve due to H_2:



★ **Becoming more competitive with high hydrogen concentration**

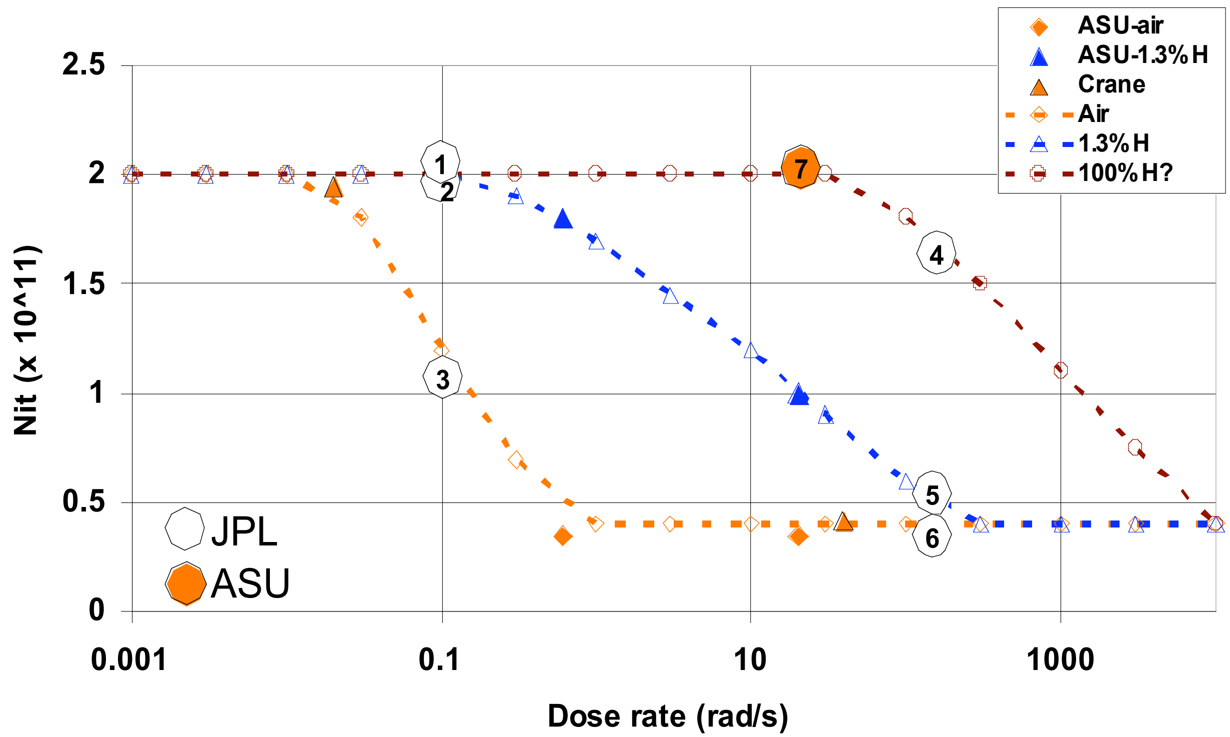
Modeling ELDRS with Hydrogen

Comsol 2D ELDRS simulation with 4 different H concentrations



Ongoing experiments

- **ELDRS Experiment is planned for April and May, 08**
  - **All test devices are P-glass passivated devices showing ELDRS**
  - **Devices will have either air and 100% H_2 in radiation environment**
  - **Data points will be taken at 0.1 rad/s, 150 rad/s, and 20 rad/s**



Summary

- **Effect of hydrogen on ELDRS**
  - **Hole yield is dependent on dose rate**
  - **High hydrogen concentration in low-field oxide shifts the ELDRS response of bipolar devices.**
  - **Preliminary simulations shows good qualitative response.**

- **Annealing experiments after TID exposure in H_2**
  - **No signification annealing of N_{it}.**
  - **Large differences in N_{ot} annealing slopes.**
  - **Differences in annealing slope maybe due to spatial distribution of H-induced trapped charge (p^+ or H^+).**

Future work

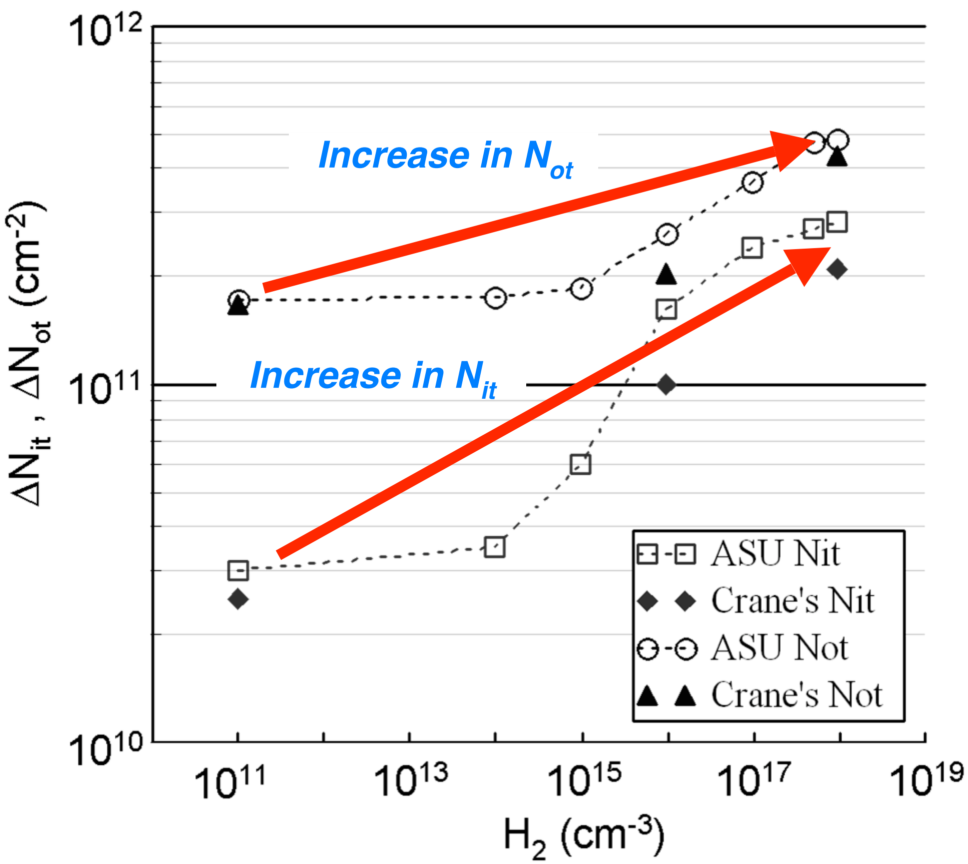
- Isochronal annealing and study the effect of E-field and spatial distribution of H-induced trapped charge.
- REOS (Sandia) and COMSOL(ASU) modeling of ELDRS and TID response.
- FTIR and ERD (Elastic Recoil Detection) measurements on H-defect properties in samples irradiated in H_2.

Appendix

Effects of hydrogen on TID and annealing response

- Previous TID experiment in hydrogen
- Un-biased annealing in air/hydrogen
- Biased annealing in air

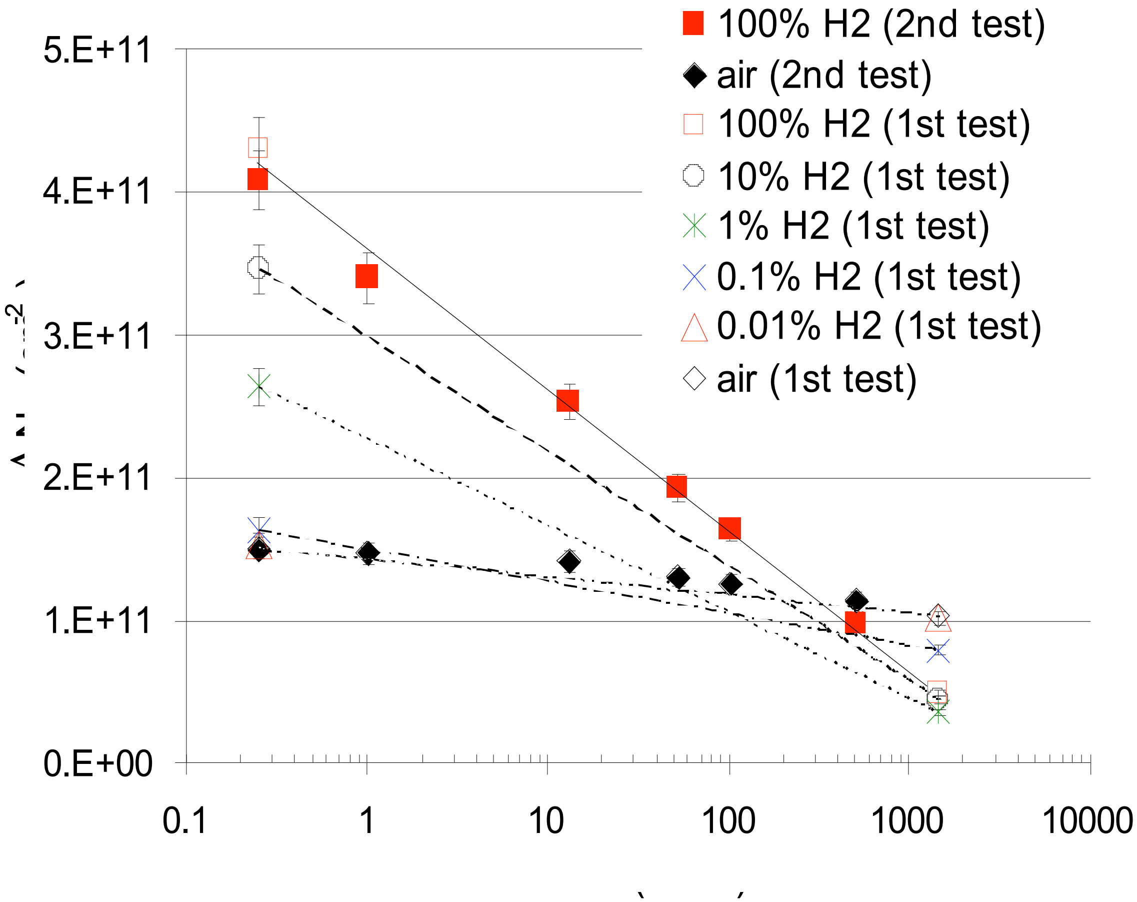
Enhanced TID degradation in H_2



- **BJTs exposed to 30krad Co-60 gamma rays**
- **Enhanced buildup in N_{it}**
- **Enhanced buildup in N_{ot}**

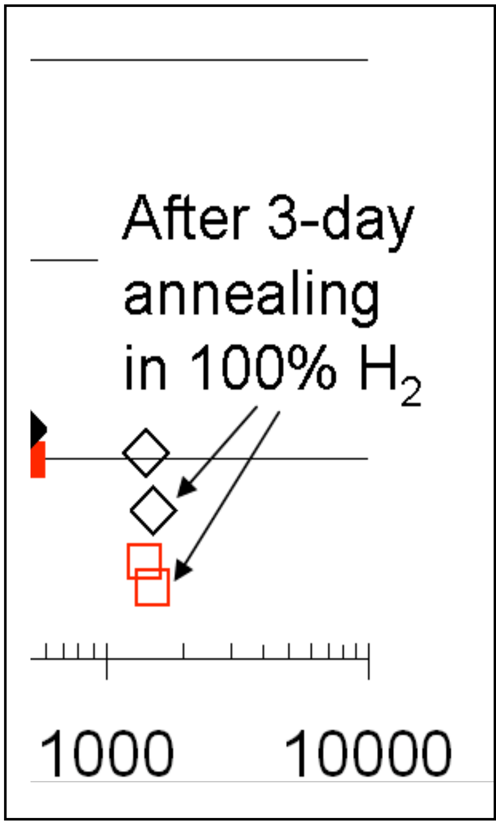
After Chen et al, IEEE Trans. Nucl. Sci., 2007

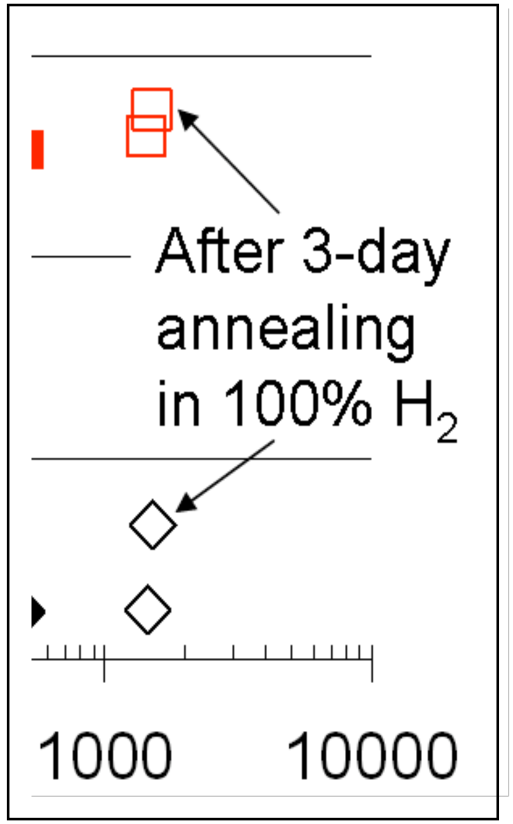
Annealing in air



- **Anneal with no bias**
- **N_{ot} anneal slope greater for higher H_2**
- **Annealing experiments on N_{it} showed little change at room temperature**

Annealing in 100% H_2





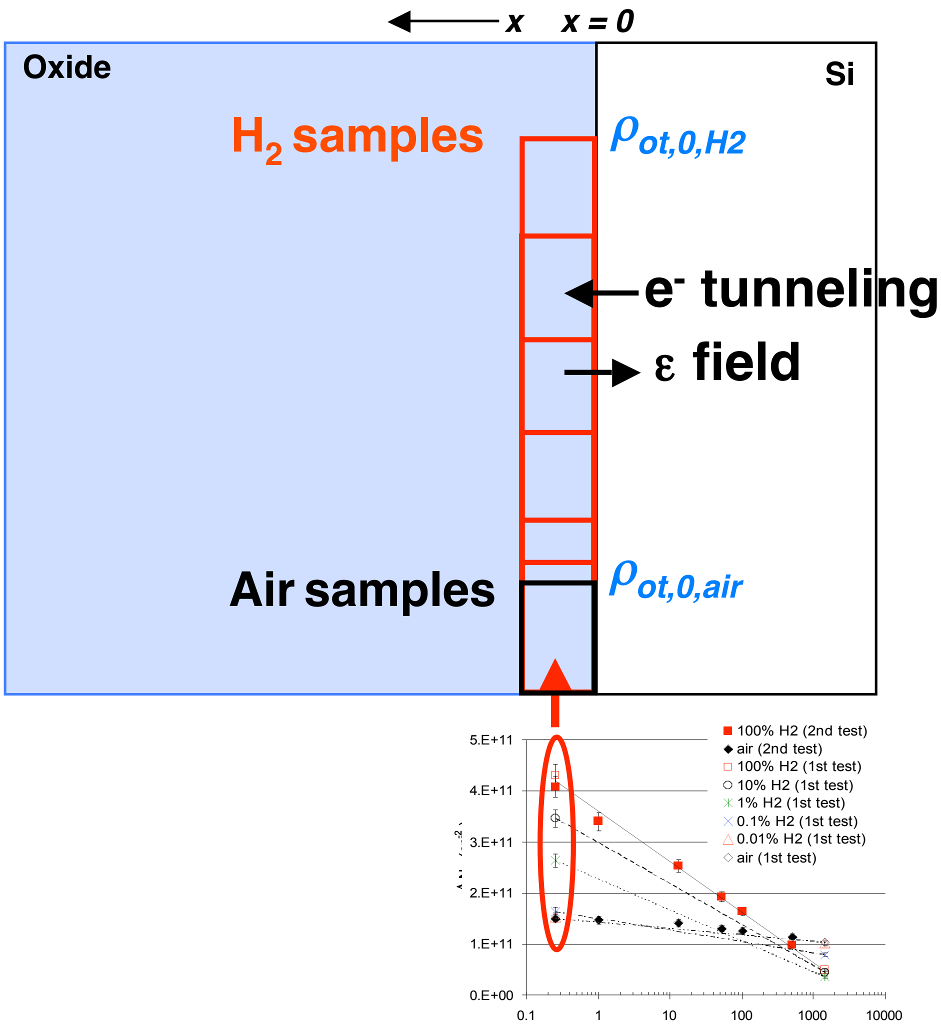
- **Anneal with no bias**
- **Sudden drop of N_{ot} corresponds w/ increase of N_{it}**
- *** $H_2 + D^+ \rightarrow DH + H^+$**

**** After Mrstik & Rendell, IEEE Trans. Nucl. Sci., 1991***

Brief Summary of Results

	Post Irradiation	Annealing in Air	Annealing in 100% H_2
Samples irradiated H_2	N_{ot} ↑	N_{ot} ↓	N_{ot} ↓
	N_{it} ↑	N_{it} ↓	N_{it} ↑
Samples irradiated in Air	N_{ot} ↑	N_{ot} ↓	N_{ot} ↓
	N_{it} ↑	N_{it} ↓	N_{it} ↑

Mechanism of N_{ot} Annealing



$$\frac{\partial \rho_{ot}(x,t)}{\partial t} = -g(x,t)\rho_{ot}(x,t)$$

$$\rho_{ot}(x,t) = \rho_{ot,0}(x)e^{-\alpha t e^{-\beta x}}$$

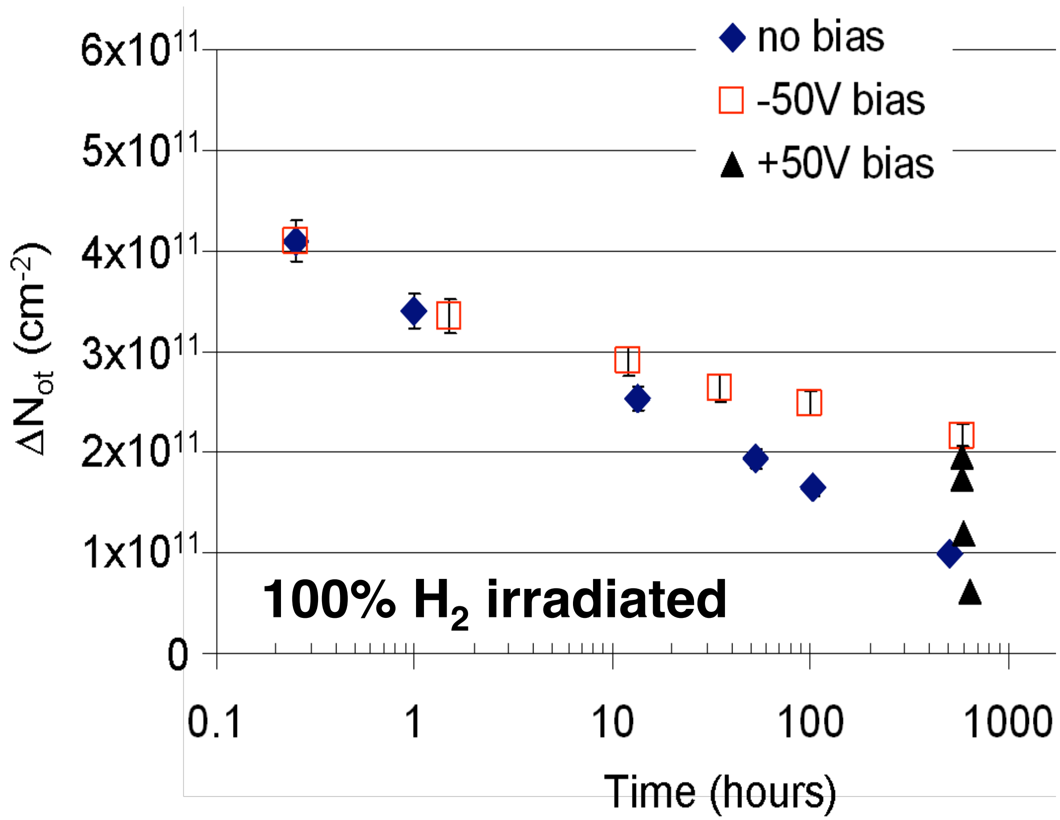
If assuming uniform spatial distribution near the Si/SiO$_2$ interface and low E-fields in the oxide:

$$\Delta N_{ot}(t) \approx \frac{-q\rho_{ot,0}}{\beta}\ln(\alpha t)$$

After Mclean, TNS, 1976

Biased annealing results

Biased annealing behavior of rad-induced N_{ot}



- With applied bias, change in annealing rate.
- Usually the tunneling equation is solved numerically with a E-field dependent tunneling probability:

$$g(x,t) = \alpha(E)\exp(-Z(E))$$

After Mclean, TNS, 1976