Modeling the Effects of Hydrogen on Dose Rate Response

Jie Chen[1], Hugh Barnaby[1], Bert Vermeire[1]
Ron Pease[2], Philippe Adell[3]

[1]Electrical Engineering, ASU, Tempe, AZ
[2]RLP Research, Las Lunas, NM
[3]JPL, Pasadena, CA

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MURI

Topics

Effect of hydrogen on dose rate sensitivity

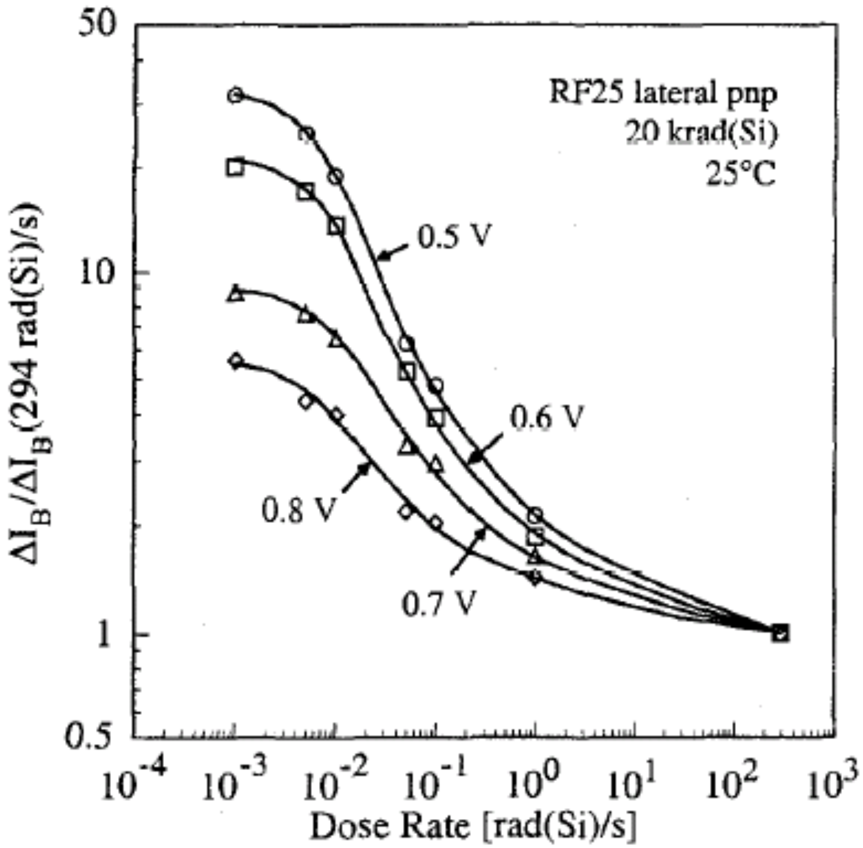
- ELDRS mechanism and modeling
- Results of TID exposure at different dose rates in H environment.
- Modeling the effect of H on ELDRS.

Using hydrogen as an accelerated test method

- Latest experimental results showing hydrogen can be used to bound LDR response

ELDRS in Bipolar Devices

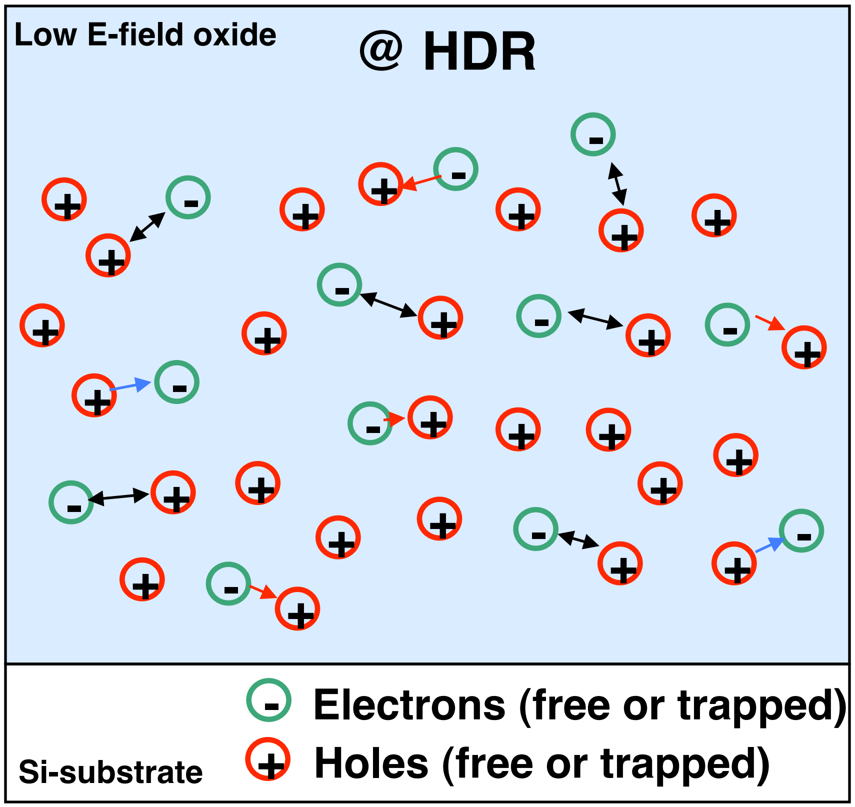
- **Enhanced Low Dose Rate Sensitivity in bipolar devices**



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

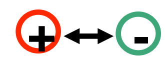
Some Key ELDRS Processes

ELDRS really is: Reduced High Dose Rate Sensitivity

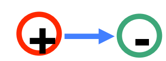


High space charge induced localized E-field @ HDR

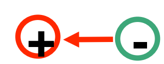
- **Increases recombination of n^-/p^+**



- **Increases probability of trapped n^-, recombining with free holes**



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



Modeling ELDRS

Using COMSOL Multiphysics FEM Simulator at ASU, the following model equations can be simultaneously solved to model dose rate response.

Electrostatics:

$$\frac{\partial E_{ox}}{\partial x} = \frac{q}{\varepsilon_{ox}}(p^{+} - n^{-} + N_{H^{+}})$$

Carrier Drift/diffusion, reaction, recombination:

$$\frac{\partial p^{+}}{\partial t} = g_o f_y \dot{R}_D - r_{H^{+}} p^{+} N_{DH} - \sigma_{rcomb} n^{-} p^{+} - \frac{\partial f_{p^{+}}}{\partial x}$$

$$\frac{\partial n^{-}}{\partial t} = g_o f_y \dot{R}_D - \sigma_{rcomb} n^{-} p^{+} - \frac{\partial f_{n^{-}}}{\partial x}$$

$$\sigma_{rcomb} = \text{constant}$$

Proton drift/diffusion, reaction:

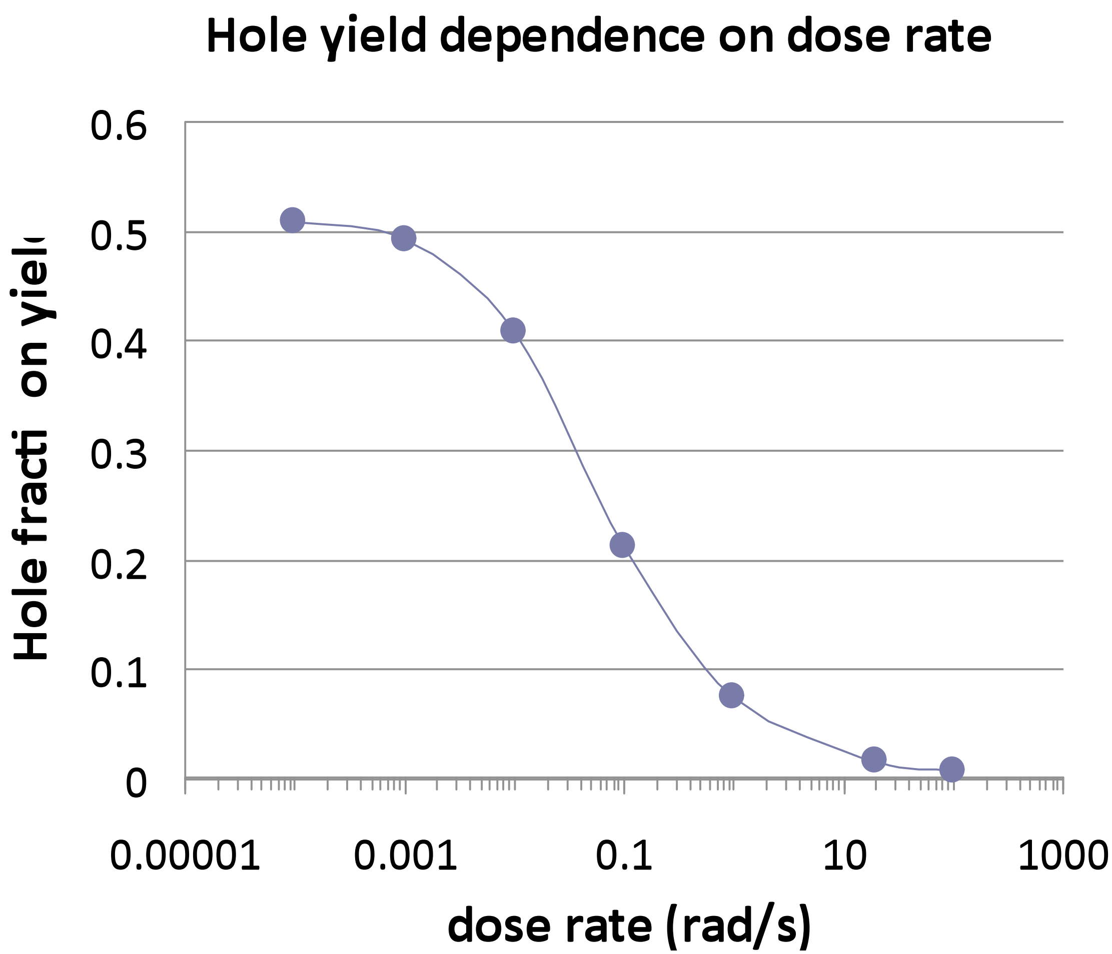
$$\frac{\partial N_{H^{+}}}{\partial t} = r_{H^{+}} p^{+} N_{DH} - \frac{\partial f_{H^{+}}}{\partial x}$$

$$\frac{\partial N_{it}}{\partial t} = r_{Si^{+}} N_{H^{+}} (N_{SiH})$$

Modeling ELDRS

ELDRS mechanism simulation

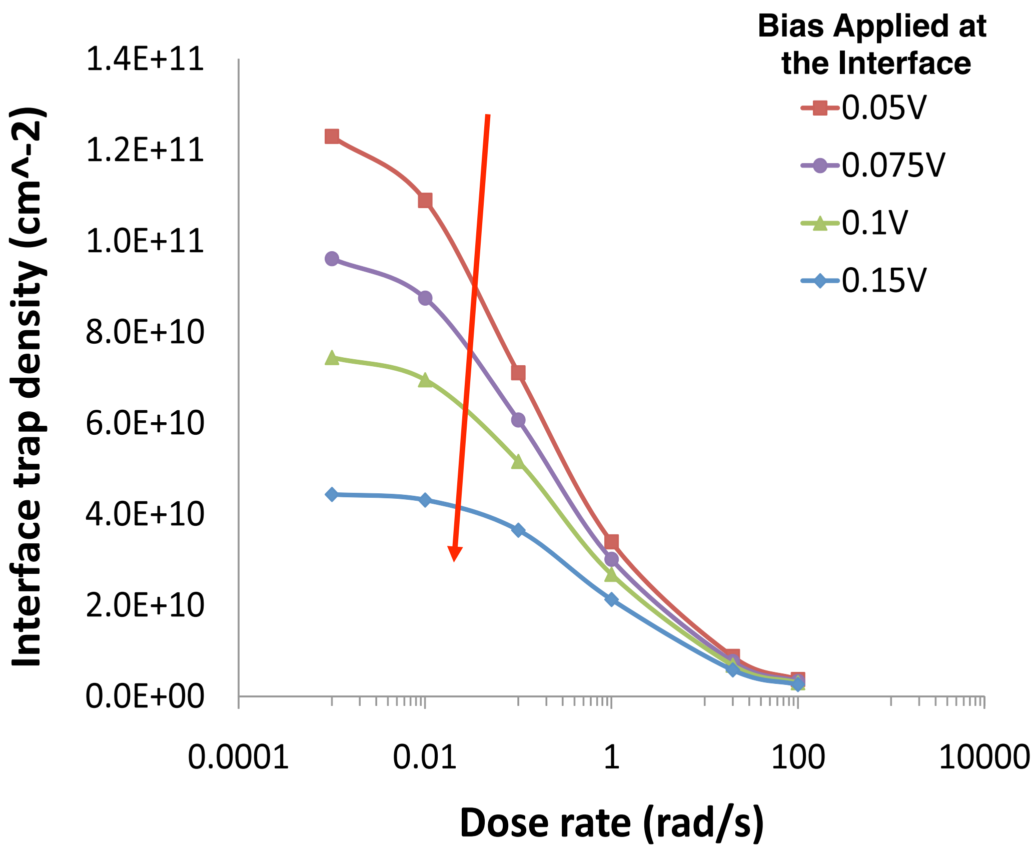
- Reduced hole yield at HDR due to increased n^-/p^+ recombination caused by space charge.
- Hole yield directly affects H^+ and N_{it} generation.



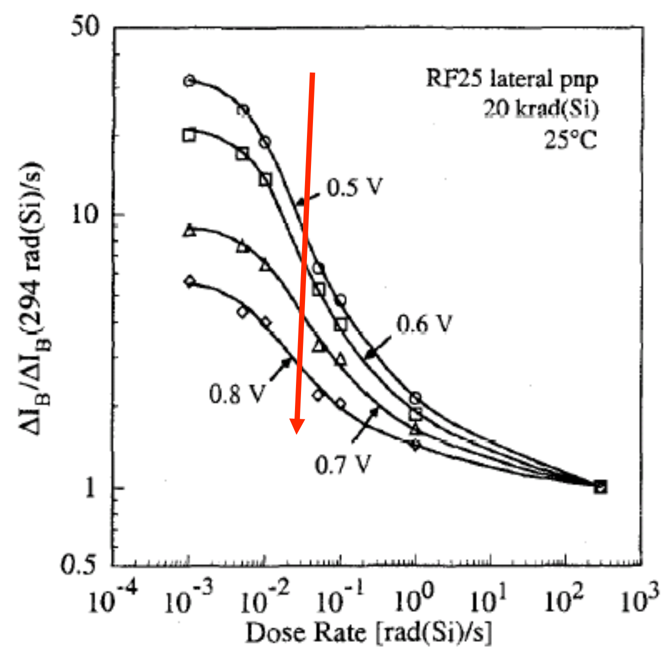
MURI 2009

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

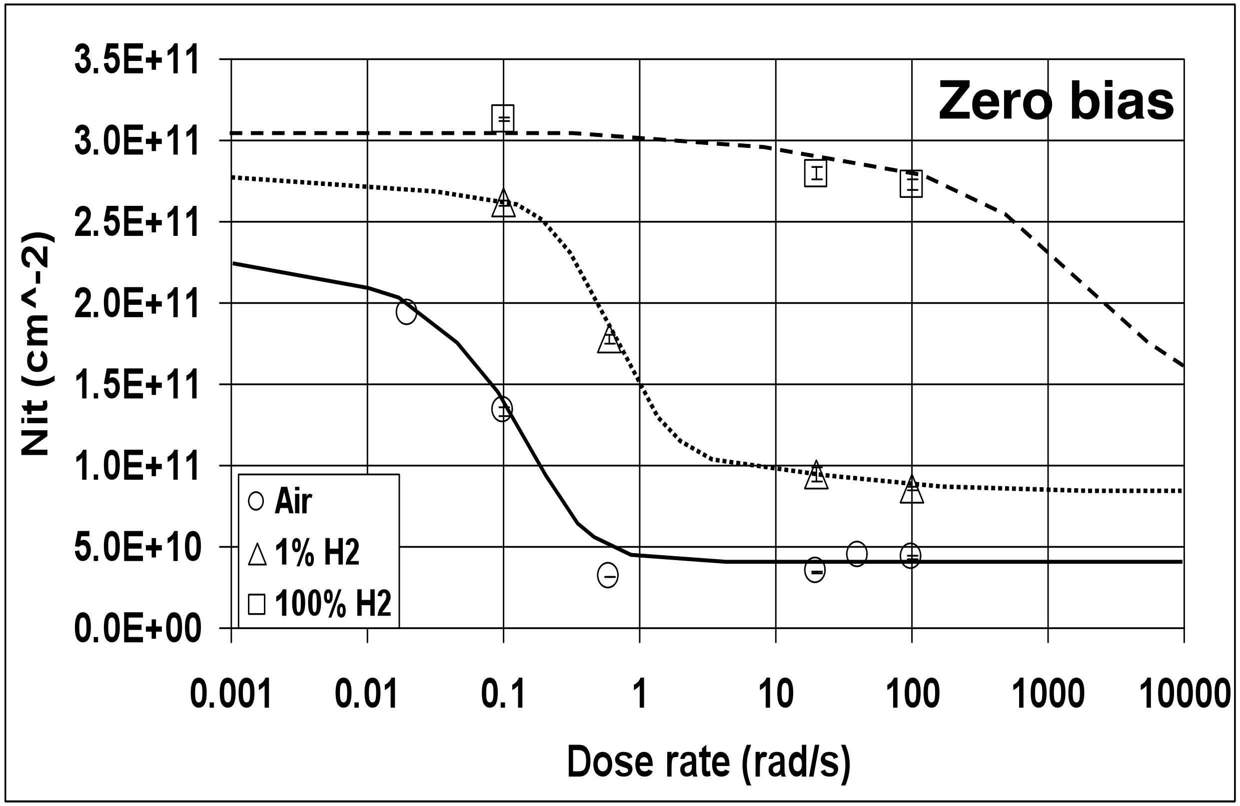


Presenting at NSREC 2009

Effect of H_2 on ELDRS

Latest ELDRS/ H_2 Experiment on bipolar parts

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

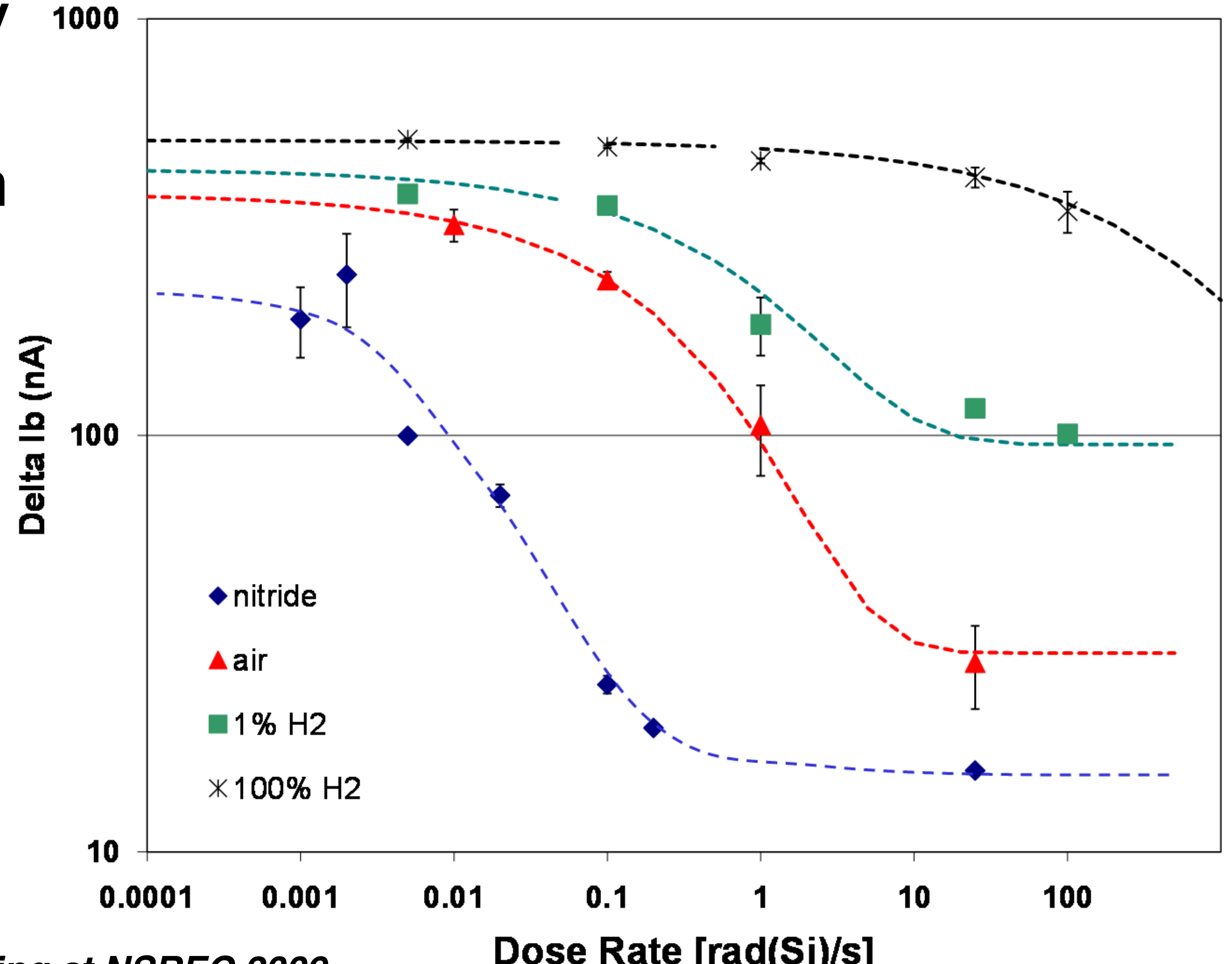


Presenting at NSREC 2009

Effect of H_2 on ELDRS

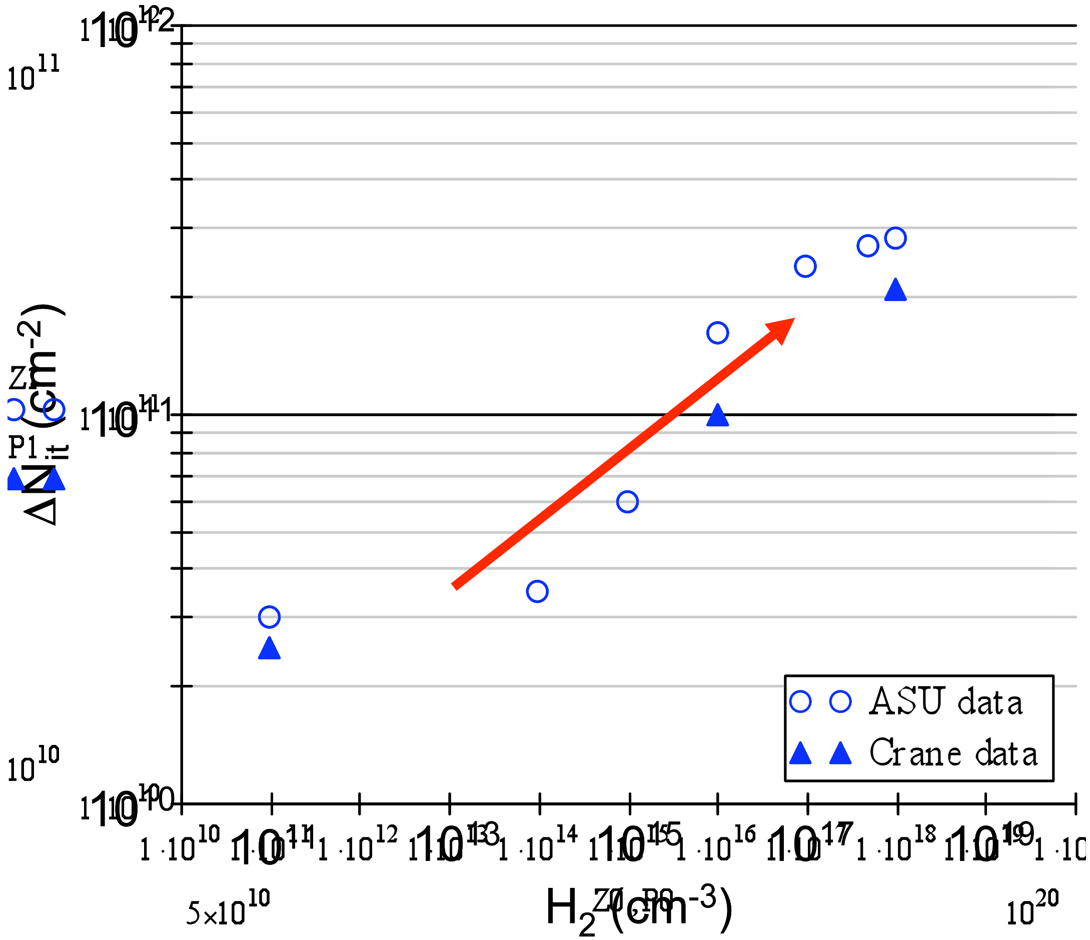
Latest ELDRS/ H_2 Experiment on bipolar parts

- LM193, linear bipolar dual comparator, performed at JPL.



Presenting at NSREC 2009

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**

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

or

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

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

Impact of Hydrogen on ELDRS

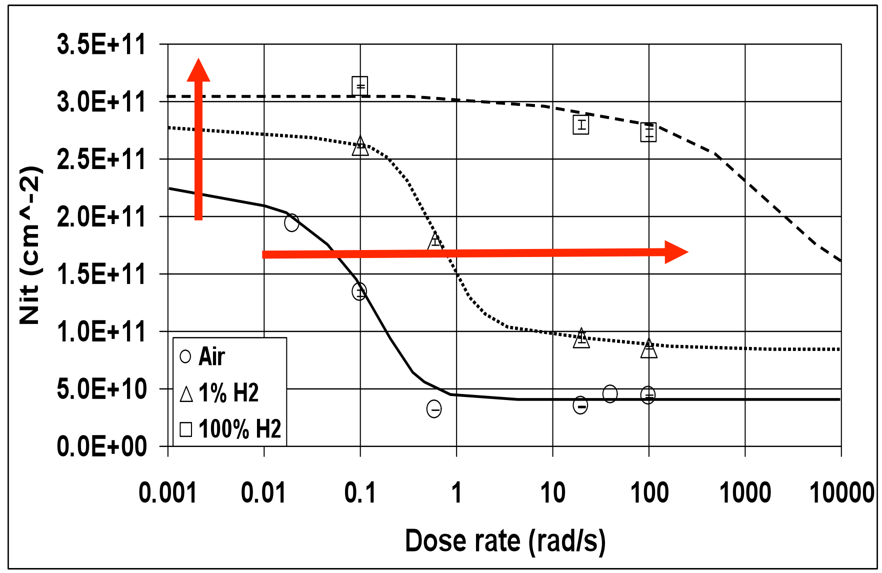
ELDRS response also changes with H_2

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

With high hydrogen content these are competing with

$n^- + D^+ \rightarrow D$
$p^+ + n^- \rightarrow X$
$p^+ + D \rightarrow D^+$
p^+ remain in oxide

Shift in dose rate curve due to H_2:



Modeling ELDRS with Hydrogen

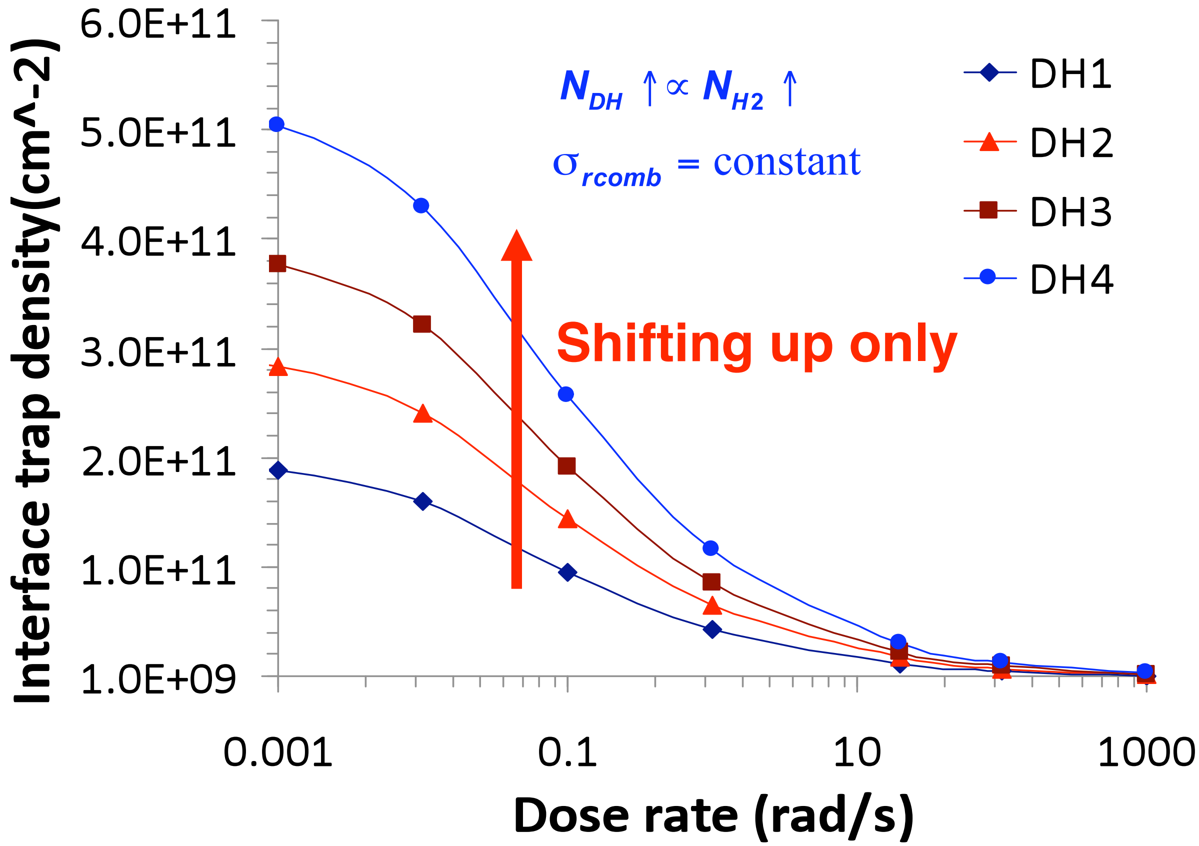
$$\frac{\partial E_{ox}}{\partial x} = \frac{q}{\varepsilon_{ox}}(p^+ - n^- + N_{H^+})$$

$$\frac{\partial p^+}{\partial t} = g_o f_y \dot{R}_D - r_{H^+} p^+ N_{DH} - \sigma_{rcomb} n^- p^+ - \frac{\partial f_{p^+}}{\partial x}$$

$$\frac{\partial n^-}{\partial t} = g_o f_y \dot{R}_D - \sigma_{rcomb} n^- p^+ - \frac{\partial f_{n^-}}{\partial x}$$

$$\frac{\partial N_{H^+}}{\partial t} = r_{H^+} p^+ N_{DH} - \frac{\partial f_{H^+}}{\partial x}$$

$$\frac{\partial N_{it}}{\partial t} = r_{Si^+} N_{H^+} (N_{SiH})$$



- **Modeling change of N_{DH} as an increasing function of ambient H_2 concentration.**
- **σ_{recomb} stays constant as H_2 increases.**

Modeling ELDRS with Hydrogen

$$\frac{\partial E_{ox}}{\partial x} = \frac{q}{\varepsilon_{ox}}(p^+ - n^- + N_{H^+})$$

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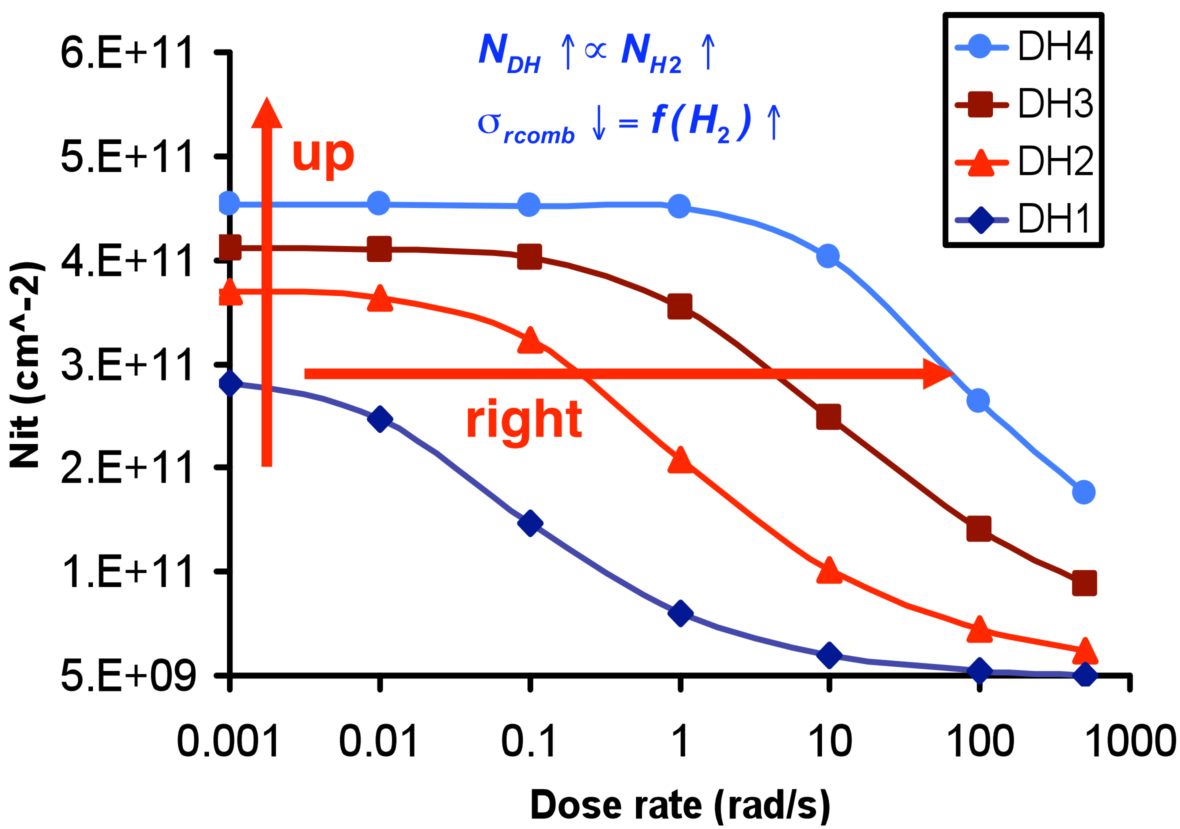
$$\frac{\partial n^-}{\partial t} = g_o f_y \dot{R}_D - \sigma_{rcomb} n^- p^+ - \frac{\partial f_{n^-}}{\partial x}$$

$$\frac{\partial N_{H^+}}{\partial t} = r_{H^+} p^+ N_{DH} - \frac{\partial f_{H^+}}{\partial x}$$

$$\frac{\partial N_{it}}{\partial t} = r_{Si^+} N_{H^+}(N_{SiH})$$



- **Modeling change of N_{DH} as an increasing function of ambient H_2 concentration.**
- **σ_{recomb} decreases as H_2 increases.**

Charge Yield Experiment

Hole continuity equation in ELDRS model

$$\frac{\partial p^+}{\partial t} = g_o f_y \dot{R}_D - r_{H^+} p^+ N_{DH} - \sigma_{rcomb} n^- p^+ - \frac{\partial f_{p^+}}{\partial x}$$

$$\sigma_{rcomb} \propto f(r_{np}, \eta)$$

r_{np} = *rate constant*

η = *efficiency*

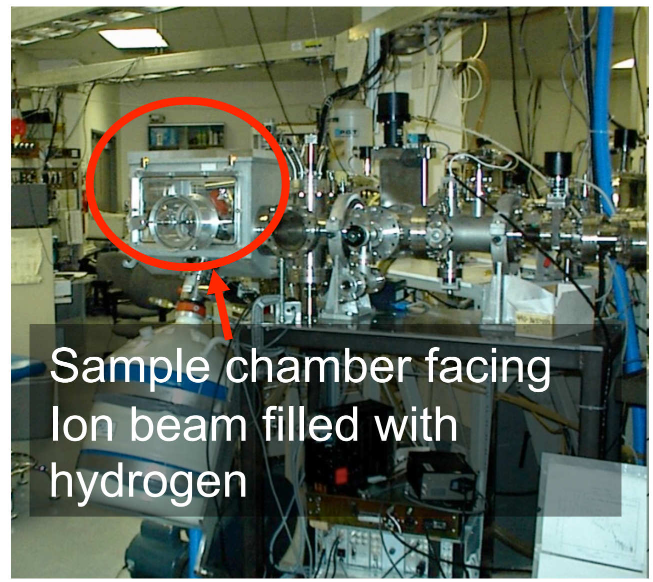
After Groves & Greenham, Physical Review B, 2008

If the ***increase*** of hydrogen concentration ***decreases*** the recombination efficiency, then σ_{recomb} is decreased:

$$H \uparrow \Rightarrow \sigma_{rcomb} \downarrow$$

This lead to shift in transition dose rate in device dose rate response.

Charge yield measurement **can be performed under different hydrogen ambients to provide proof .**

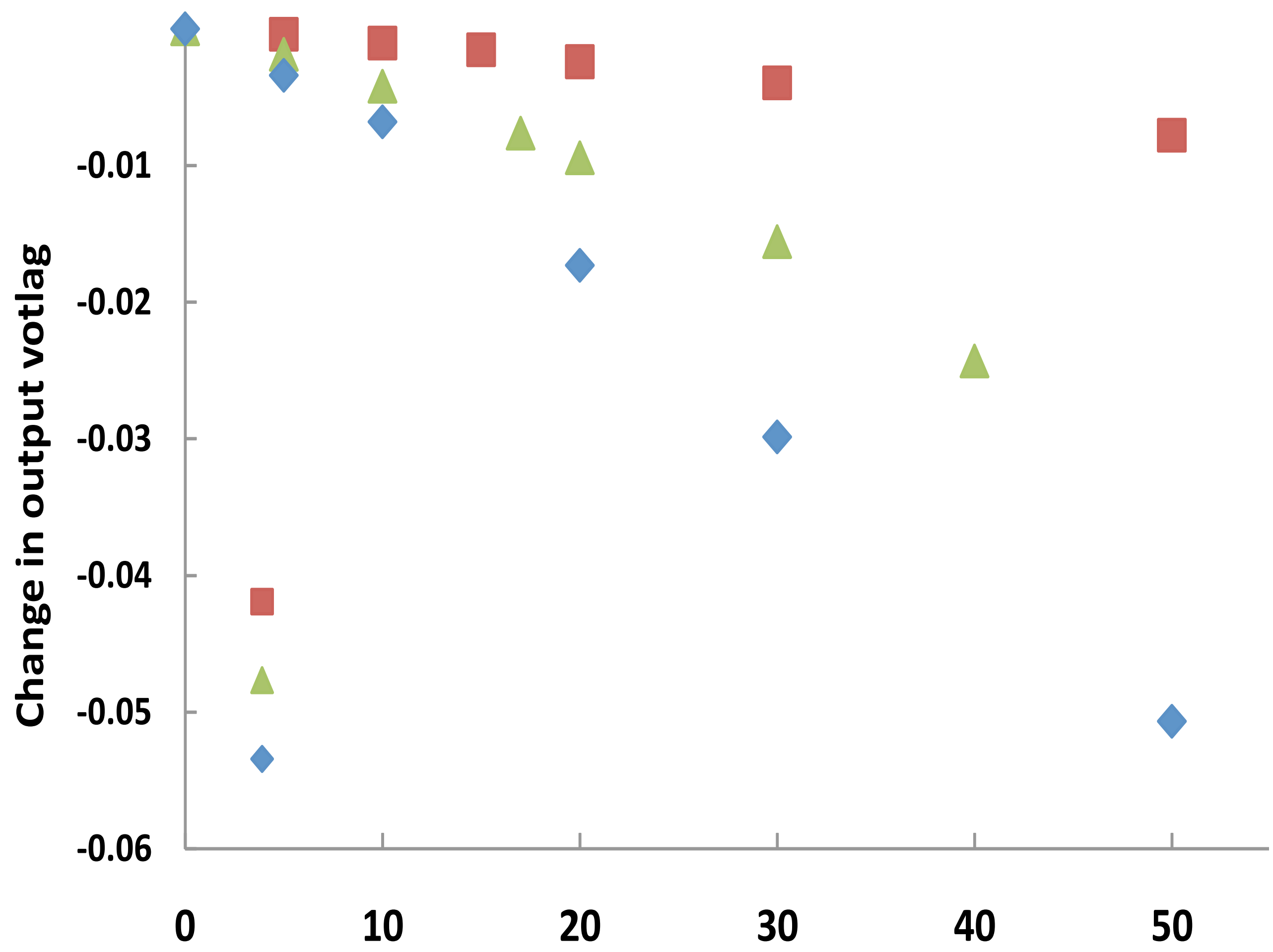


Using a pulsed proton beam (@ASU) to generate carriers and measure hole yield.

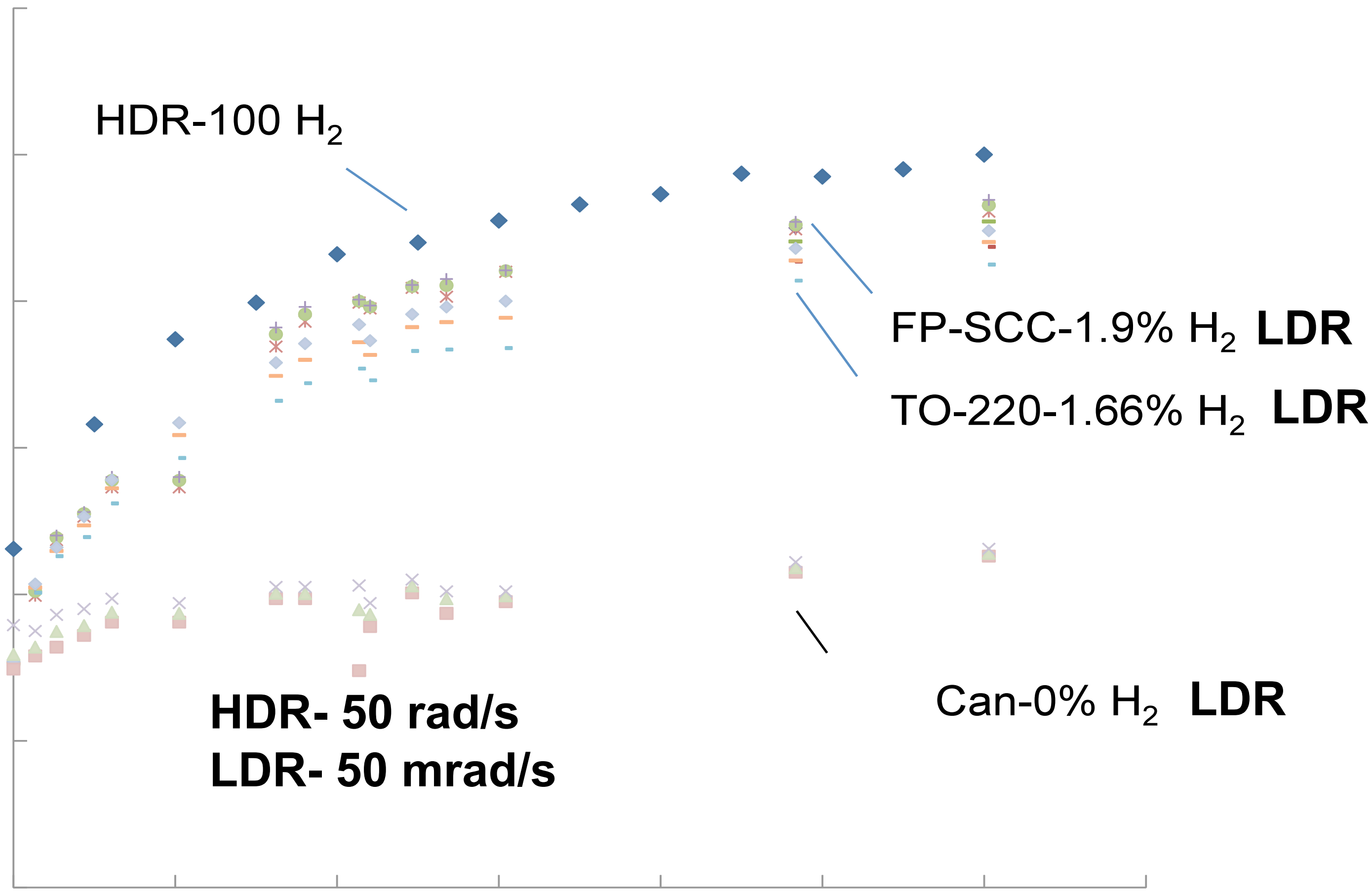
Accelerated ELDRS test in H_2

- Testing parts in 100% H_2 at HDR was suggested as possible accelerated test to screen parts for worst case LDR response
  - TNS December 2008, Pease, et al, p.3169
  - RADECS 2008, Pease, et al, Invited paper on ELDRS
- Paper accepted at NSREC09 to validate method
  - NSREC09, E-3, "Irradiation with molecular hydrogen as an accelerated hardness assurance test method", P. C. Adell, et al
  - Data on NSC LM193, Linear Tech LT1019 and Intersil HSYE-117RH
  - Planned data on AD590, OP42 and LT27

JPL data- LT1019 voltage reference



JPL data- 117 regulator



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.
  - Model simulations suggest e/h recombination coefficient, σ_{recomb} is a function of hydrogen concentration.
  - Changing σ_{recomb} can produce similar shifts in dose rate response observed in the data.

- Accelerated testing using hydrogen
  - Recent experiments on bipolar parts strongly suggest that hydrogen can be used during HDR testing to bound low dose rate responses of bipolar parts.