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Similarities between Ionizing Radiation Effects and Negative-Bias Temperature Instability (NBTI) in MOSFET Devices

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Outline

- The phenomena
  - NBTI
  - Radiation Effects
- Previous Work
- Our Work
  - Interface traps
  - Hole traps
    - Recoverable charge
    - Non-recoverable charge
- Combined model
  - Hole injection
  - Hydrogen cracking
  - Hydrogen reactions
- REOS
- Picture physics
- Future Work
- Conclusions

The Phenomena (simple version)

- NBTI
  - High electric fields heat holes
  - Hot holes release hydrogen thereby depassivating interface traps
- Radiation effects
  - Ionizing radiation creates holes
  - Holes release hydrogen
  - Hydrogen creates interface traps

In both cases, injected holes cause damage

Previous Work

- Reaction-Diffusion model (Alam and others)
  - Hydrogen released near the interface
  - Steady-state reaction kinetics
  - Rate determined by hydrogen diffusion

$$P_bH^0 + h^+ \rightarrow P_bH^+$$

$$P_bH^+ \rightarrow P_b^+ + H^0$$

- Oxide traps (Grasser and others)
  - Hole tunnel to oxygen vacancy traps
  - Threshold voltage shift determined by fraction of charge permanently trapped

Hydrogen Cracking

- Holes tunnel to oxygen vacancies
- Molecular hydrogen cracked to release protons
- Protons create interface traps

Very similar to the radiation effects mechanism

Extended Model

- Holes are injected into the oxide
  - Most tunnel to oxide traps
  - Some may release hydrogen from passivated traps
- Hydrogen is released
  - Directly from passivated interface traps
  - Through the cracking mechanism
- Consequences
  - Stress
    - Hydrogen released
    - Protons flow towards the gate
  - Recovery
    - Interface traps created
    - Some charge permanently trapped
    - Most charge tunnels back to the substrate

Initial Conditions

- Pragmatic method based on thermal processing
  - Anneal the sample at elevated temperatures in a hydrogen environment
  - The consequence is a nonequilibrium state

Interface Traps Reactions

- Reactions
  - Passivation
  - De-passivation
  - Hydrogen dimerization

$$P_b^0 + H^0 \leftrightarrow P_bH^0$$

$$P_bH^0 + H^0 \leftrightarrow P_b^0 + H_2^0$$

$$H^0 + H^0 \leftrightarrow H_2^0$$

Vacancy Reactions (Hydrogen Cracking)

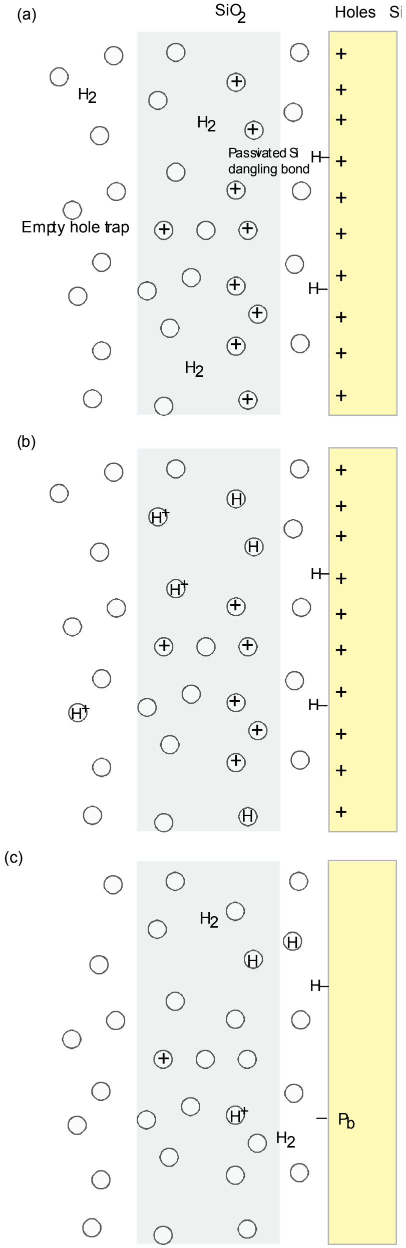
- Reactions
  - Hole capture $V_O{}^0 + h^+ \leftrightarrow V_O{}^+$
  - Cracking $V_O{}^+ + H_2{}^0 \leftrightarrow V_O H_2{}^+$
  - Proton release $V_O H_2{}^+ \leftrightarrow V_O H^0 + H^+$

  - Hole capture $V_O H^0 + h^+ \leftrightarrow V_O H^+$
  - Proton release $V_O H^+ \leftrightarrow V_O{}^0 + H^+$

REOS Calculations

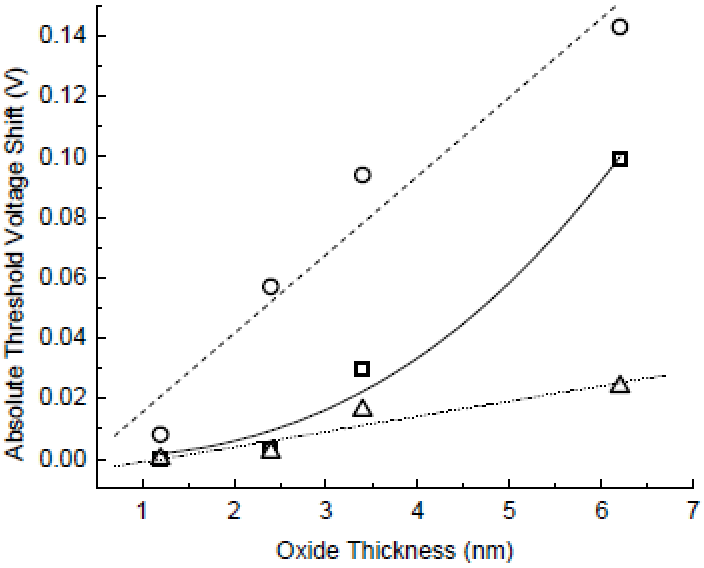
- Electrical
    - Solve drift-diffusion equations
    - Include tunneling
- Chemistry
    - Solve defect reactions
    - Include temperature effects

Picture Physics



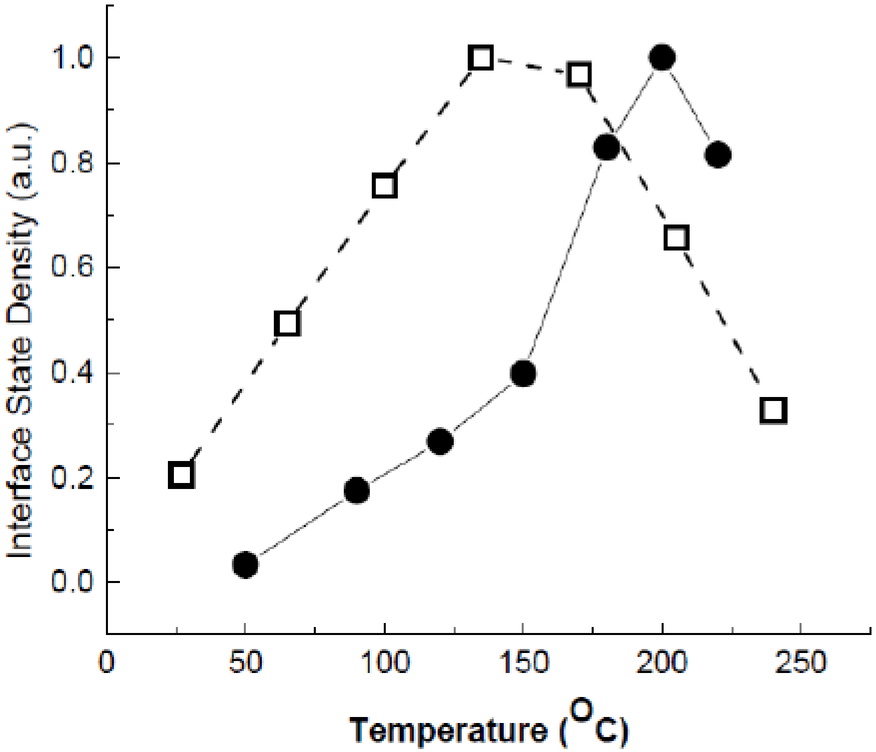
Thickness Dependence

- Explanation
  - All molecular hydrogen consumed
  - More available in thicker oxides
  - Thus larger effect



Temperature Dependence

- Explanation
  - The annealing reaction becomes dominant at high temperatures
  - Explains radiation effect and NBTI data



Conclusions

- Physics similarities
    - Interface traps
    - Hydrogen cracking mechanism
- Experiments consistent with hydrogen cracking
    - Thickness dependence of threshold voltage shifts
    - Temperature dependence of the interface trap density