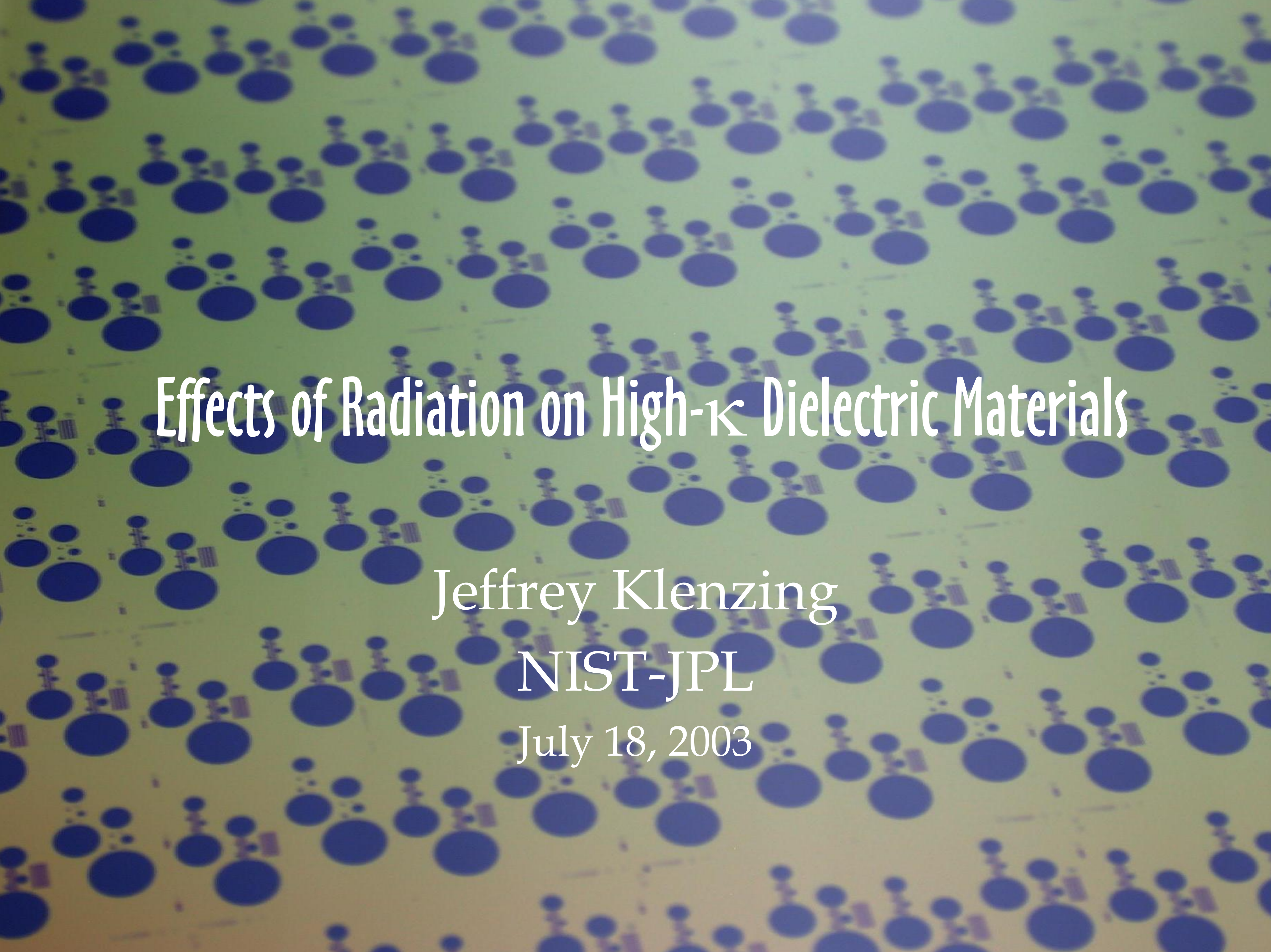


Effects of Radiation on High-κ Dielectric Materials

Jeffrey Klenzing

NIST-JPL

July 18, 2003

UTD

Introduction

AMERICAN INSTITUTE OF PHYSICS

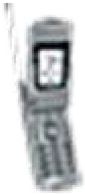
- Jeffrey Klenzing
  - University of Texas at Dallas
  - Graduation – May ‘04
  - Working with Dr. John Suehle
- AIP
  - American Institute of Physics
  - 2003 SPS-AIP National Internship Program

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

NASA
Jet Propulsion Laboratory
California Institute of Technology

Outline

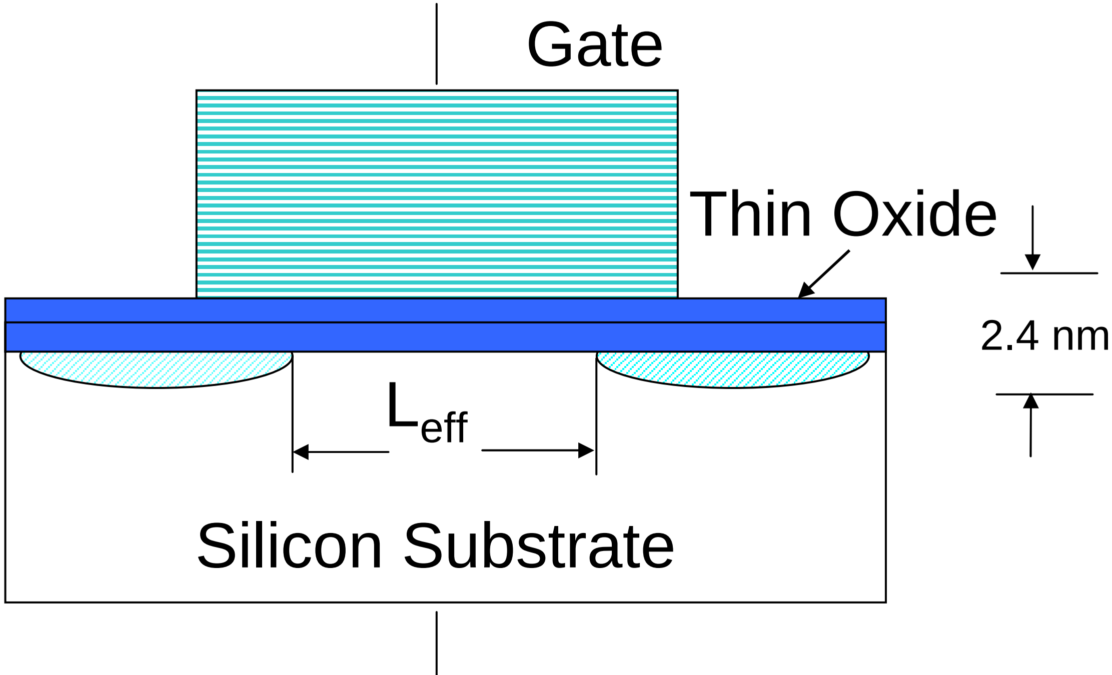
- SiO_2: Pushing the Limits
  - Why SiO_2 must be replaced
- JPL
  - Why the Jet Propulsion Laboratory is interested
- Experiment
  - What we are doing
- Preliminary Results
  - What we have done and where to go from here

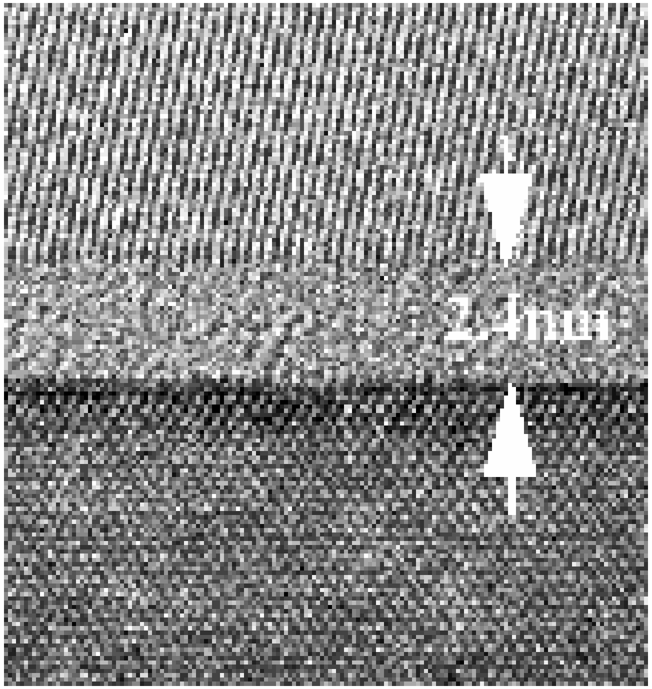


SiO_2: Pushing the Limits

- Demands for increased performance of electronic devices have skyrocketed over the last few years.
- Cell-phones, PDA's, digital cameras, digital video, and many combinations of the above as well.

SiO_2: Pushing the Limits





B. Weir, et al, IEDM 1997, p.73

$$I_{ds}= \frac{C_{ox}}{L^2}(V_{gs}-V_{th})^2$$

$$C_{ox}= \varepsilon A/t_{ox}$$

Must keep C_{ox} constant to maintain channel current (I_{ds}).

SiO_2: Pushing the Limits

- Increased performance relies on making the gate oxide thinner.
- Theoretically, higher κ would mean that a thicker film could be used.

$$C_{ox} = \varepsilon A / t_{ox}$$

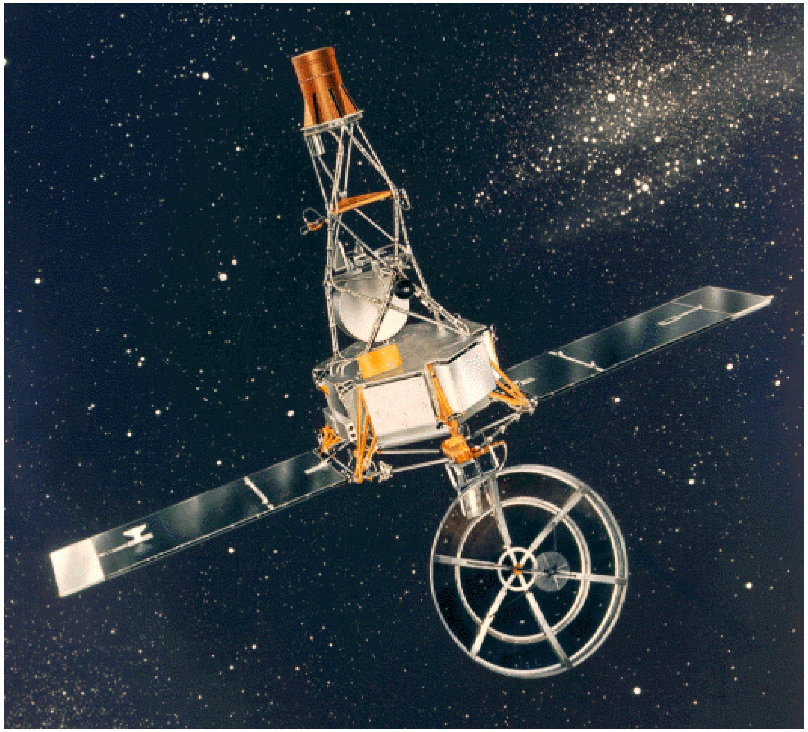
where

$$\varepsilon = \varepsilon_0 \kappa$$

SiO_2 has $\kappa = 3.9$

HfO_2 has $\kappa \sim 20\text{-}30$

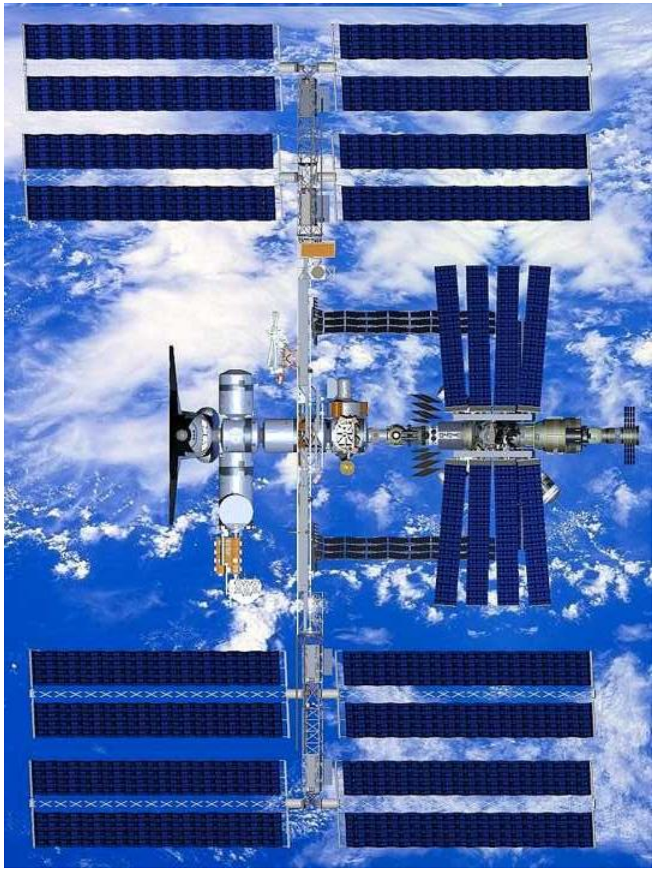
JPL: Deep Space Probes



- Space is **not** the best place for electronics:
  - Radiation
  - High-energy particles
- Repair service to the outer reaches of the solar system can be a problem.

JPL: Intel Inside

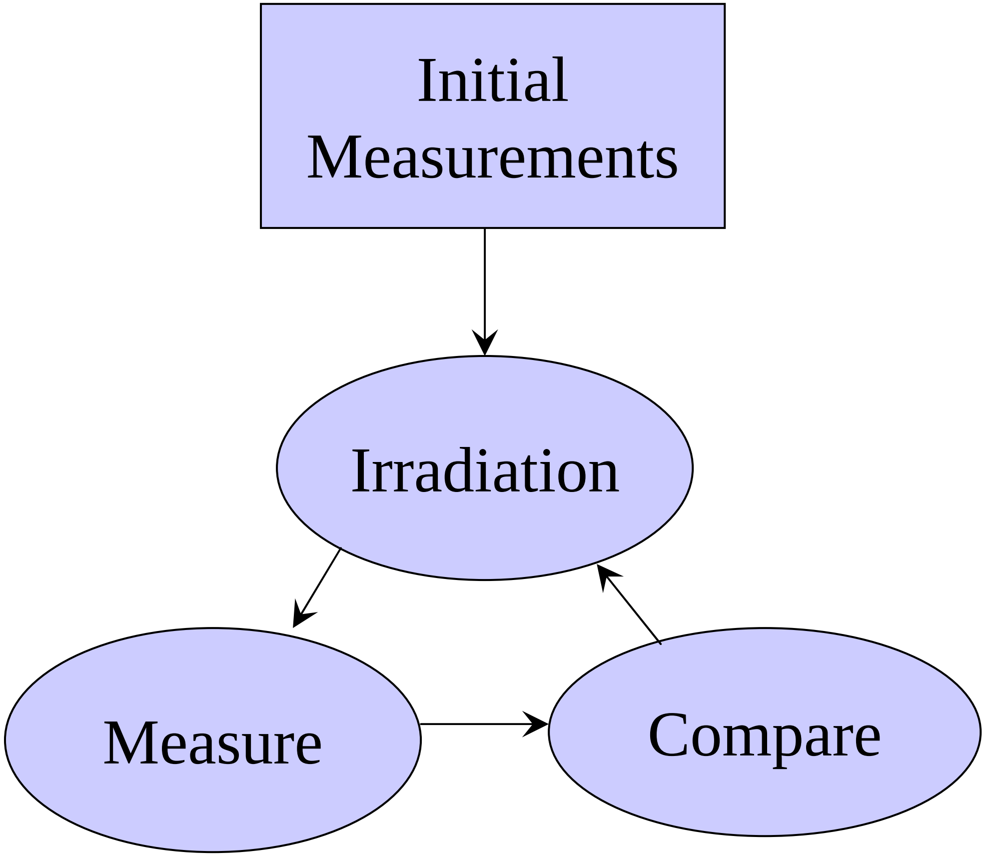
- Most of NASA's electronics are off-the-shelf.
  - Well characterized for
    - Radiation
    - Durability
- Currently controlled by the 386 chip.



Picture obtained from http://www.qsl.net/dg7ro/iss/picture.htm

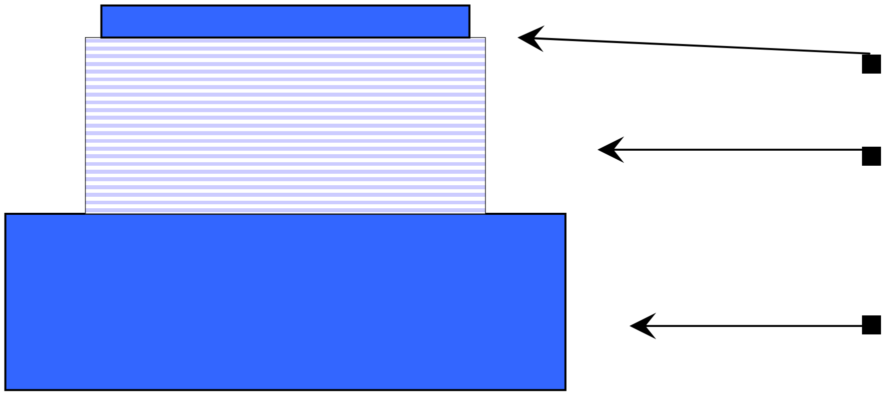
Proposed Experiment

- Determine reliability of high-κ dielectrics as a function of Total Ionizing Dose (TID)



Experiment: The Devices

- Produced by International Sematech, Inc.



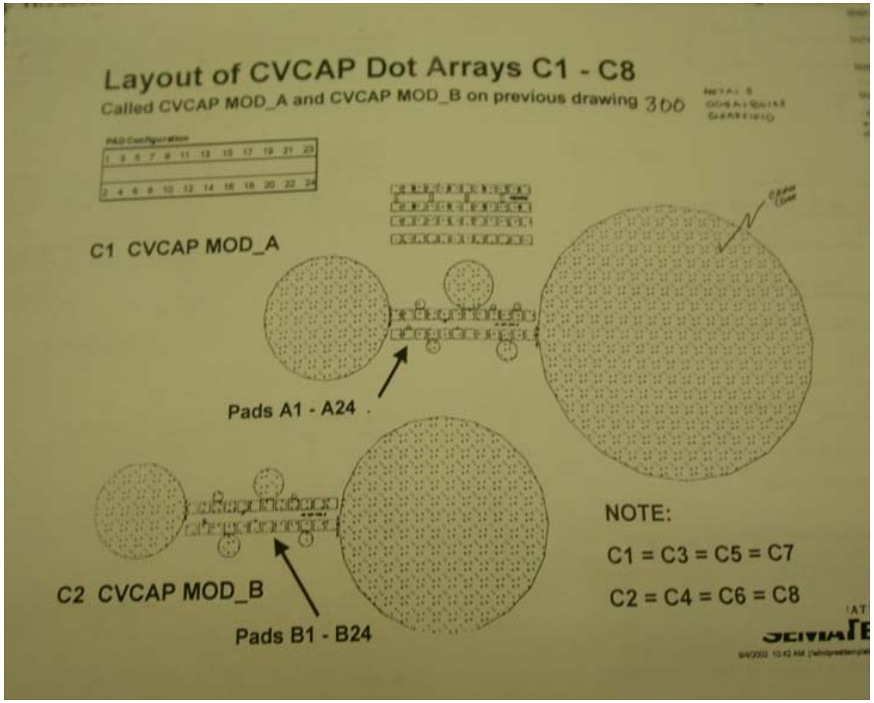
  - CVD TiN Gate
  - Monolayers of HfO_2 and Al_2O_3
  - Si Substrate

Experiment: The Devices

	Wafer 03	**Wafer 13**	**Wafer 17**
Ratio of HfO_2 to Al_2O_3	1:1	5:1	1:0
EOT* (Å)	19.8	23.57	15.19

* EOT = Equivalent SiO_2 Thickness

Experiment: The Layout



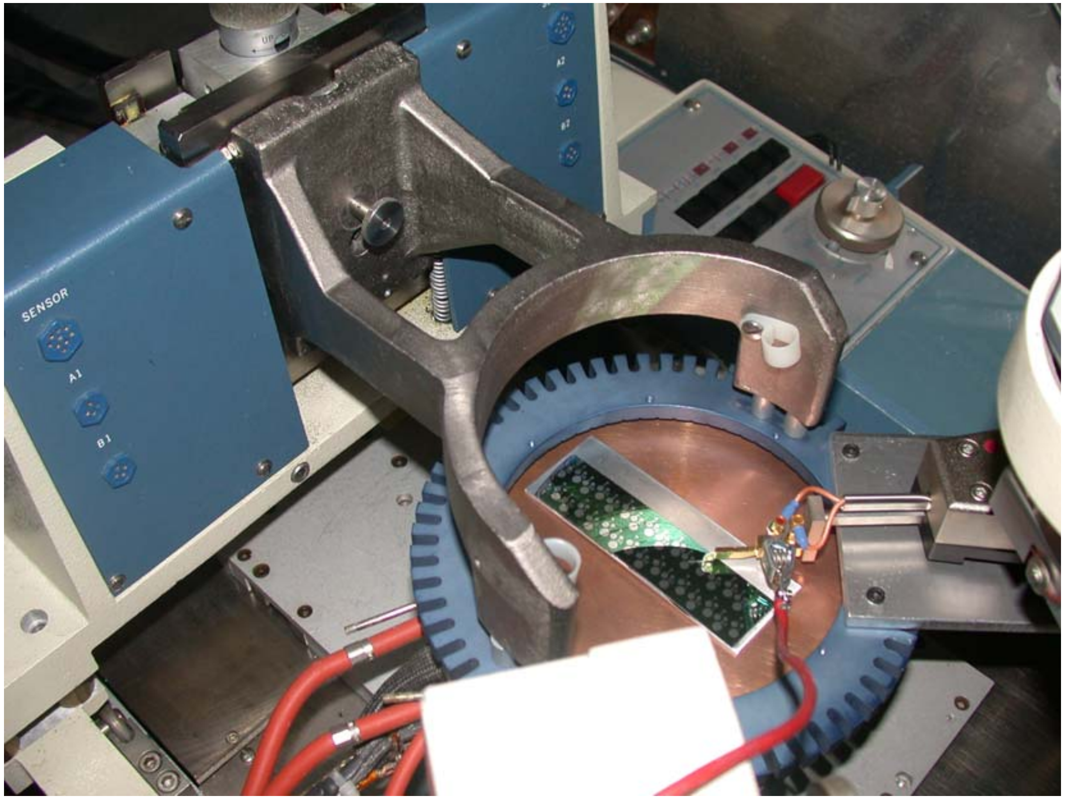
- Each set of devices has a variety of areas.

$$C_{ox} = \varepsilon_0 \varepsilon_r A / t_{ox}$$

$$C_{ox} / A = \varepsilon_0 \varepsilon_r / t_{ox}$$

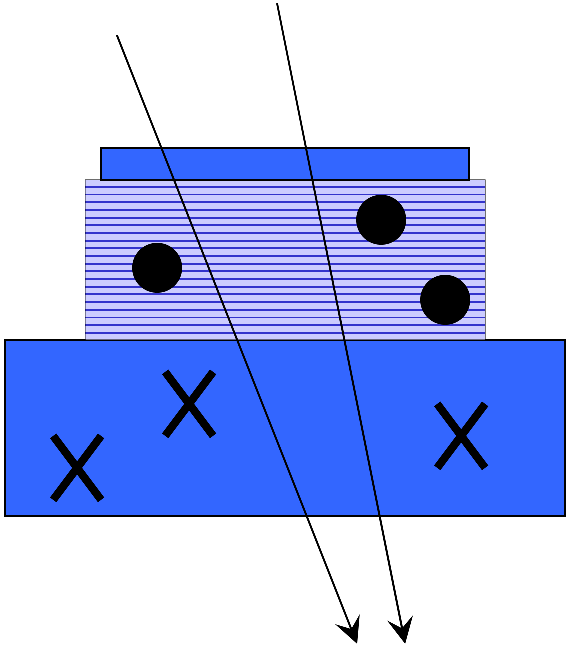
Experiment: Measurements

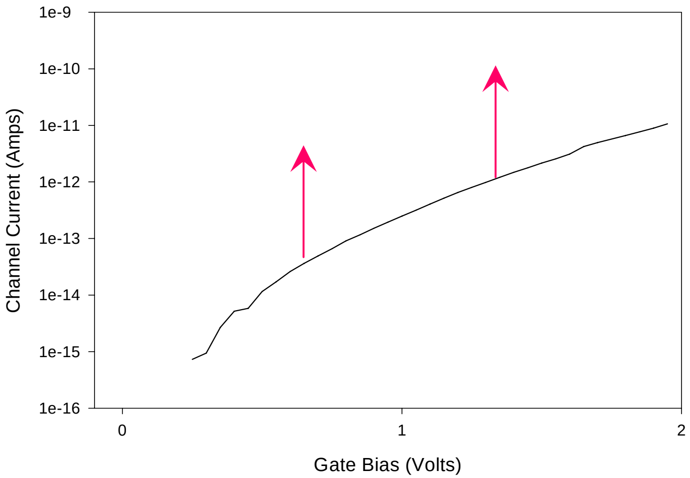
- Voltage Sweeps
    - Current
    - Capacitance

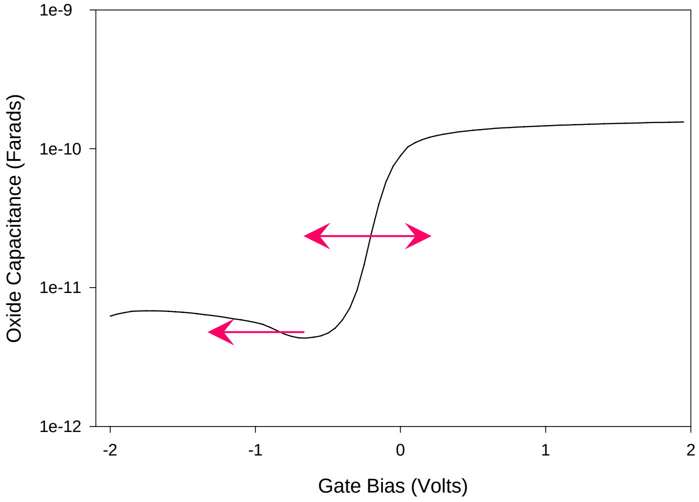


Experiment: Expectations

- Trapped Ions
- Fixed Charge
- Ionization Tracks

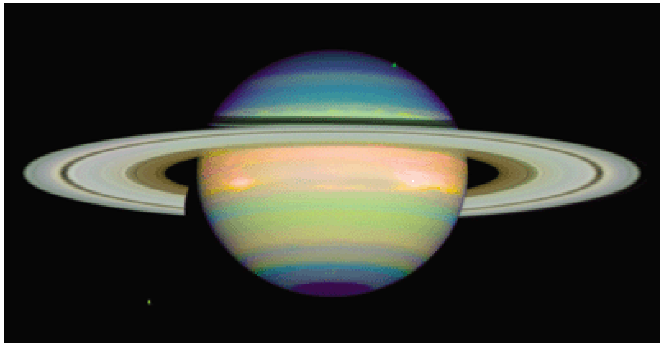






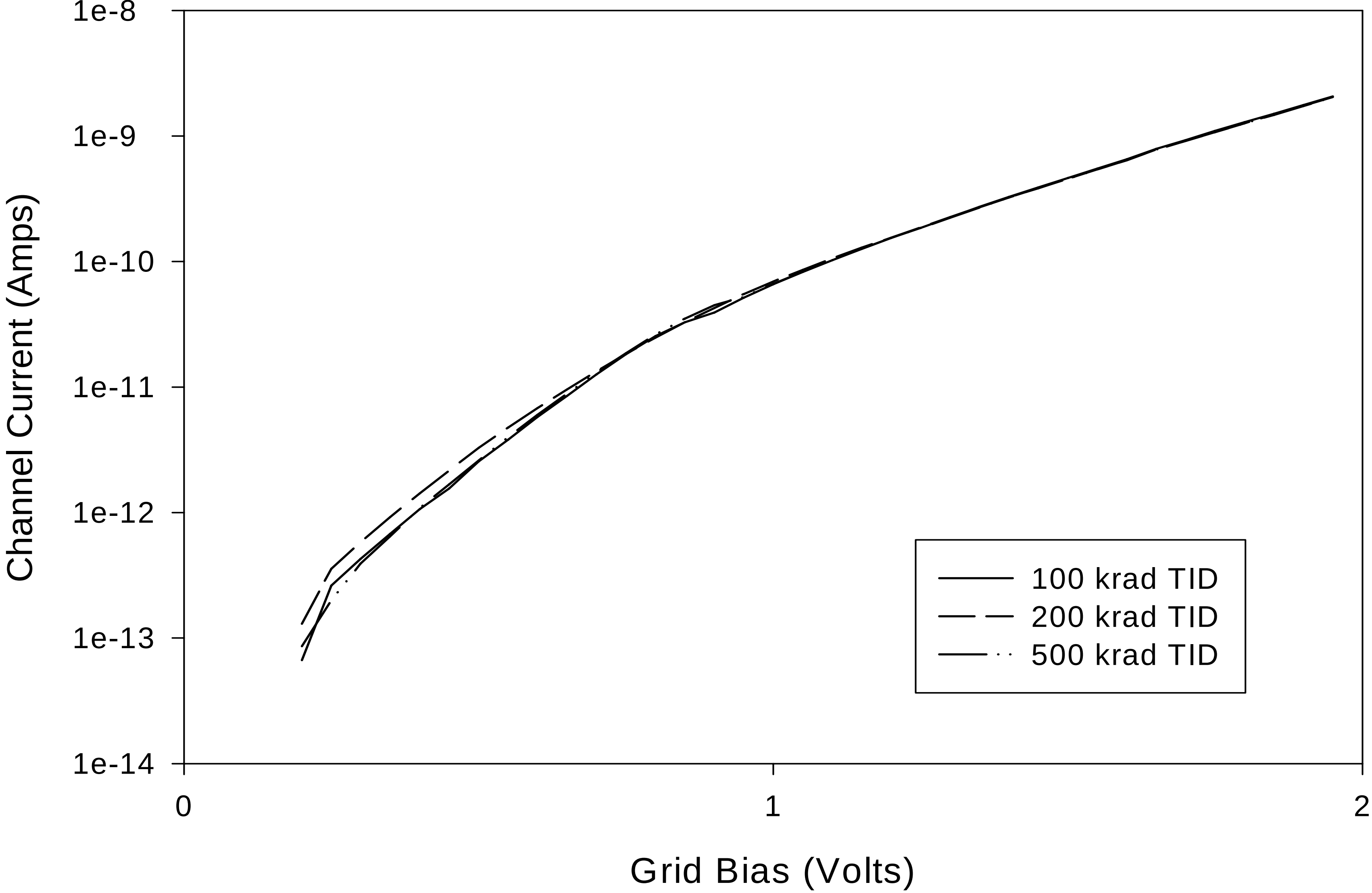
Preliminary Results

- Currently, IV and CV curves have been measured for up to 500 krad TID.
  - Earth Orbit
    - < 20 krad TID
    - Depends on altitude and inclination
  - Jupiter/Saturn Missions
    - > 1 Mrad TID

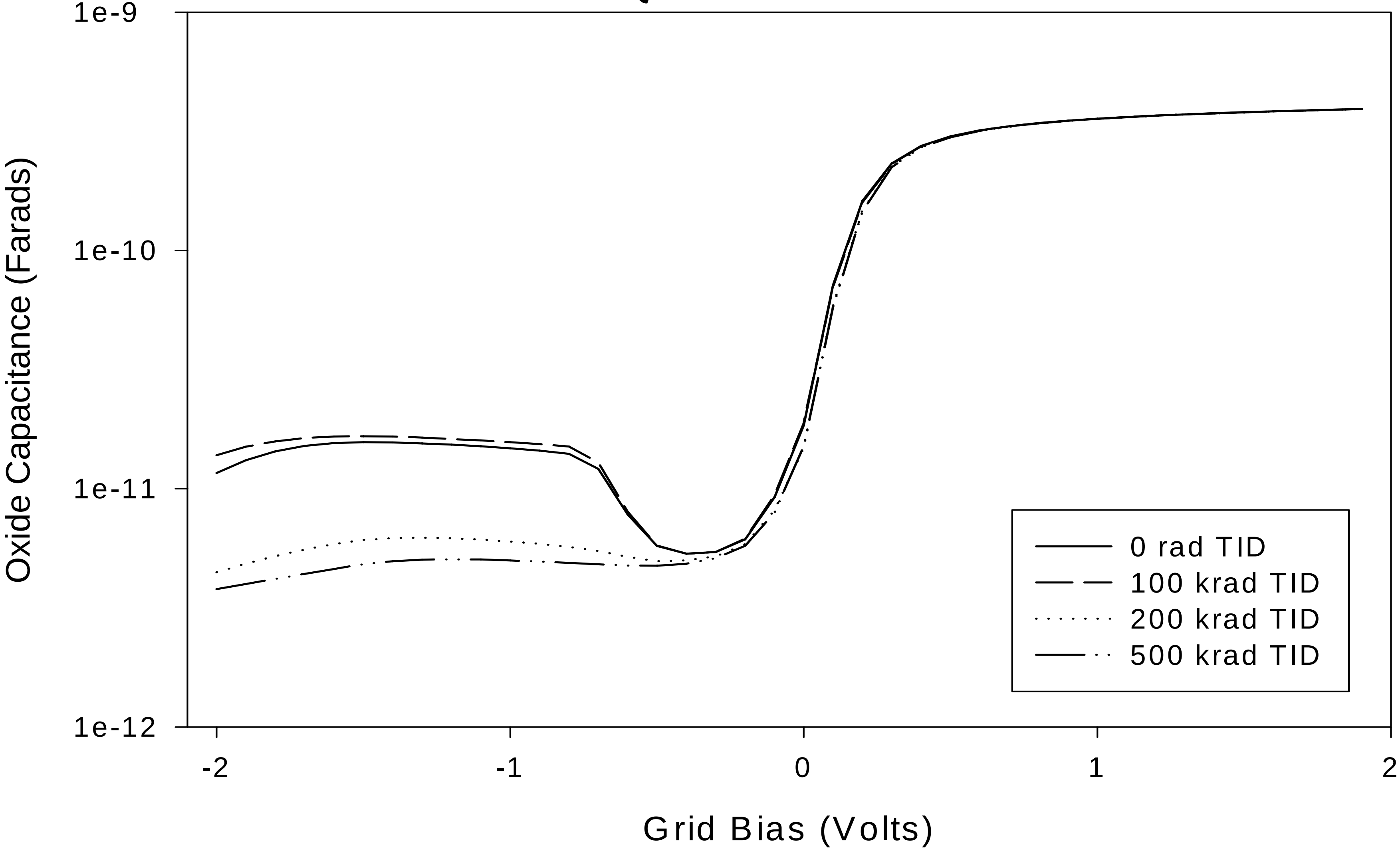


http://lasp.colorado.edu/tour/science_research/planetary/

Preliminary Results: IV Curves



Preliminary Results: CV Curves



Finally . . .

- At relatively low doses of radiation, the capacitance seems to be unaffected.
- Next Stages:
  - Higher dosages of radiation
  - Dielectric breakdown
  - Heavy ions
- Thanks and Appreciation to:
  - Dr. John Suehle
  - Dr. Eric Vogle
  - Dr. David Seiler