National Aeronautics
and Space Administration

Nonvolatile Memory Technology for Space Applications

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Introduction
Nonvolatile Memories

- Flash (NAND, NOR)
- Charge Trap
- Nanocrystal Flash
- Magnetic Memory (MRAM)
- Phase Change--Chalcogenide, (CRAM)
- Ferroelectric (FRAM)
- CNT
- Resistive RAM

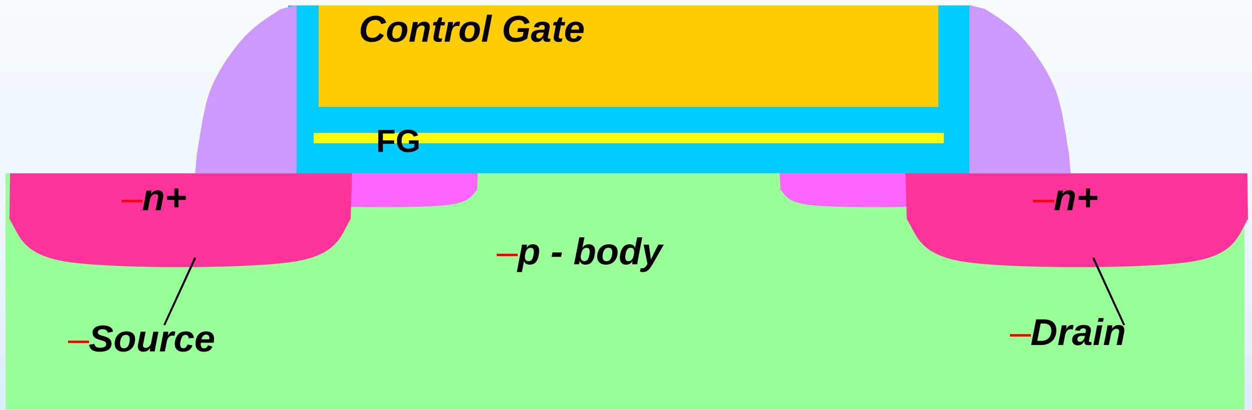
Flash Background

– *Disadvantages*
- *Slow programming*
- *Wear out*
- *Scaling/retention*

– *Advantages*
- *Cost per bit*
- *Low power*

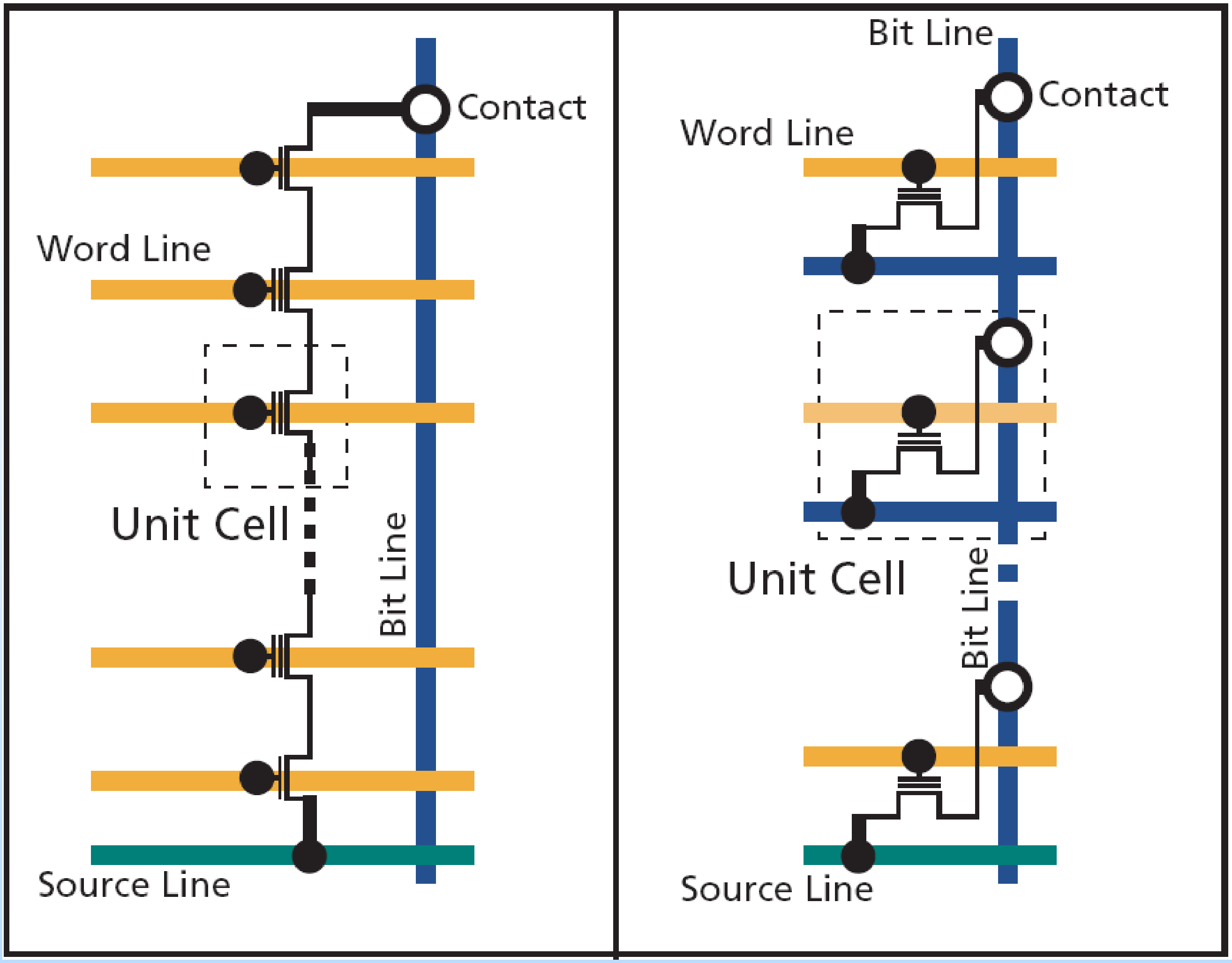
– *Bottom Line: Heavily used in hand-held, battery-powered consumer electronics (cell phones, iPods, digital cameras, MP3)*

Floating Gate Transistor



- **Write (Program) operation—Fowler-Nordheim (FN) injection of electrons into FG**
- **Erase operation—FN injection of electrons from FG to substrate**
- **Repeated P/E operations cause damage to tunnel oxide**

Flash Architectures



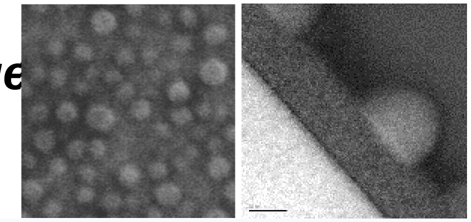
– ***NAND***

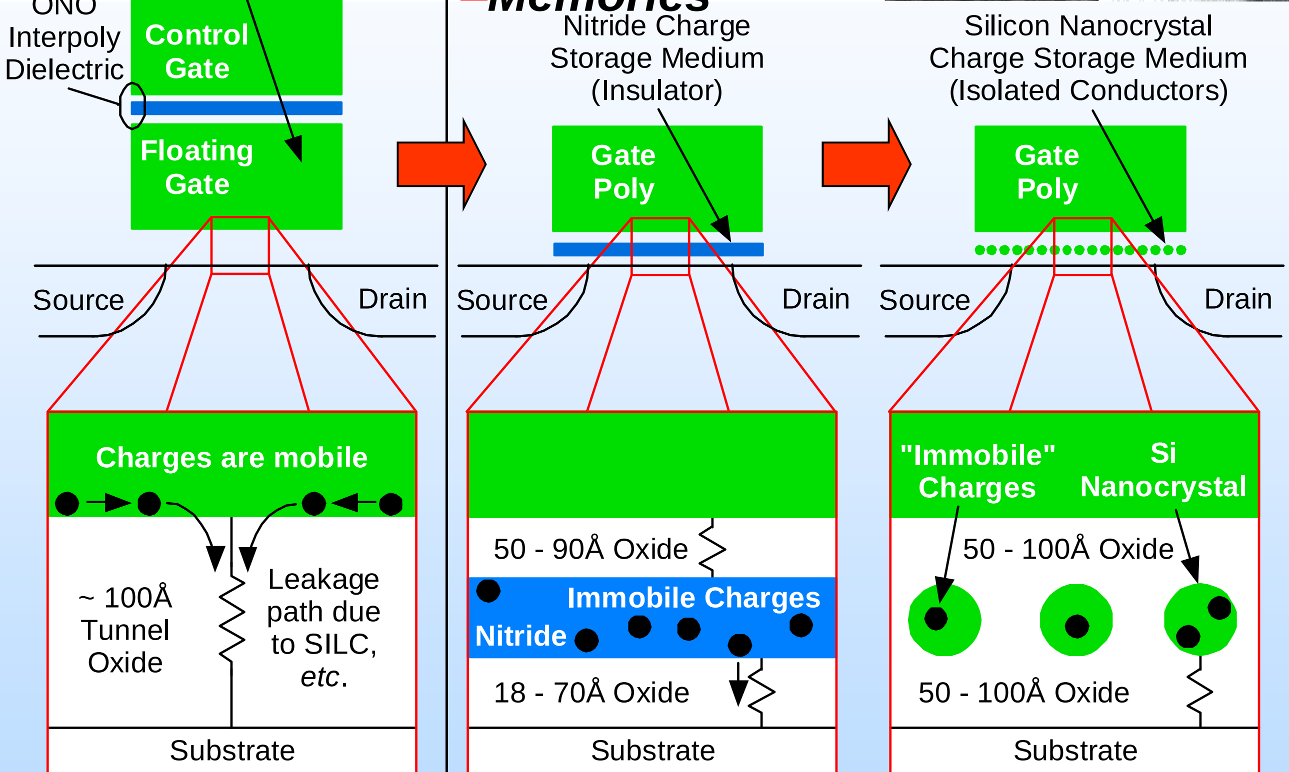
– ***NOR***

Flash Radiation Response

- TID response frequently very good for NAND
- NOR TID not so good
- SEU bit error rate very good compared to most volatile memories
- Control logic errors (SEFIs) are biggest problem, mitigation strategies very important

–Thin Film Storage –Nonvolatile –Memories





–Floating Gate – SONOS –Nanocrystal

–(oxide/nitride/oxide)

Evaluation of Non-Volatile Memory

–Description: ***This is a continuation task for evaluating the effects of scaling (<100nm) , new materials, etc. on state-of-the-art (SOTA) non-volatile memory (NVM) technologies. The intent is to:***

- ***Determine inherent radiation tolerance and sensitivities,***
- ***Identify challenges for future radiation hardening efforts,***
- ***Investigate new failure modes and effects, and***
- ***Provide data to technology modeling programs.***

–Testing includes total dose, single event (proton, laser, heavy ion), and proton damage (where appropriate). Test vehicles are expected to be a variety of non-volatile memory devices as available including Flash (NAND and NOR), magnetic, phase change, etc…

–Angular effects as well as statistical analysis are key considerations.

FY10 Plans:

–Probable test structures

-Flash (NAND)

- **-Samsung 8G, (SLC and MLC), Micron (8G), Numonyx (4G)**
- **-Micron 128G stack, Micron 64G monolithic**

-Flash (NOR)--Spansion 1G MirrorBit

-Phase change --Numonyx

-FRAM--TI hardened and unhardened

-MRAM—Avalanche Spin Torque

–New tests:

– - Reliability study, retention after radiation exposure and cycling

–Test Guideline

– - Develop draft guideline for radiation testing

Schedule:

NVM Radiation T&E	2009			2010								
	O	N	D	J	F	M	A	M	J	J	A	S
Monitor MRAM, CRAM, CNT, and FeRAM progress	■	■	■	■	■	■	■	■	■	■	■	■
Micron 128G Stack-SEE				◆								
Numonyx 4G NAND TID, SEE								◆		◆		
Sams, Micron 8G SEE								◆			◆	
Sams, Mic Retention Test				◆	◆	◆	◆	◆	◆	◆	◆	◆
Micron TID			◆							◆		
Current Spike Report					◆							
Test Reports					◆		◆		◆	◆		◆
Spin Torque MRAM TID									◆			

PI: GSFC/Oldham; JPL/Irom

Deliverables:

-Test reports and quarterly reports

-Submissions to IEEE NSREC (TNS and REDW) and SEE Symposium.

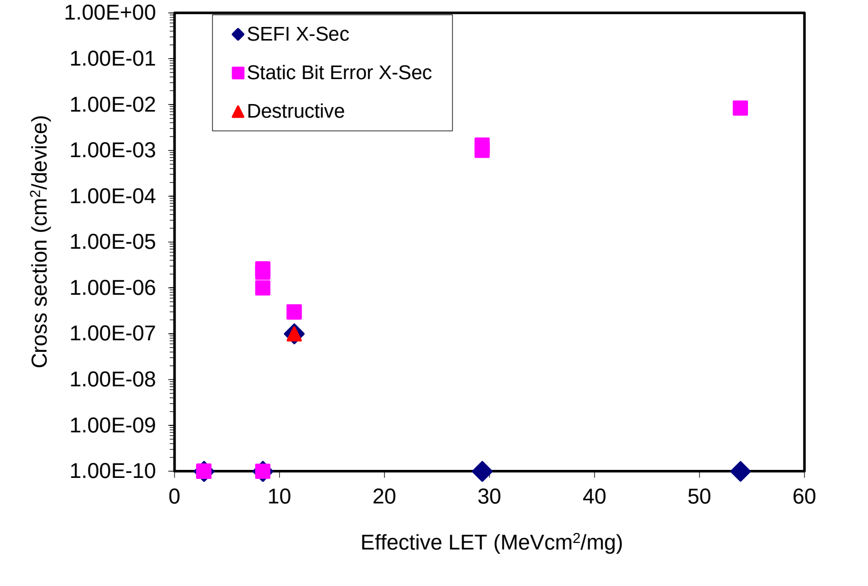
-Draft test and application guideline.

NASA and Non-NASA Organizations/Procurements:

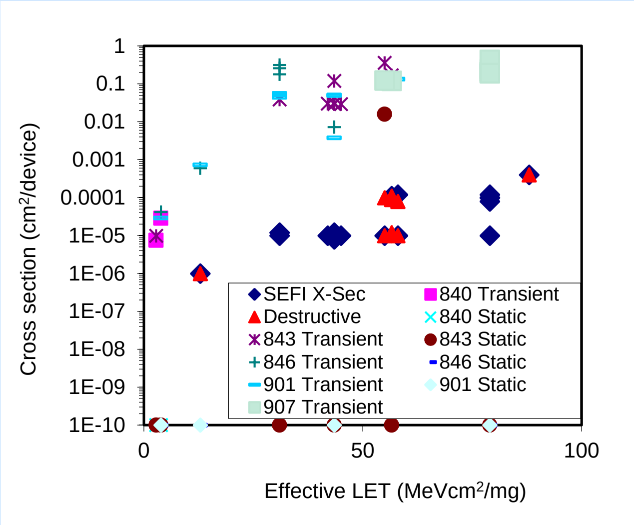
Beam procurements: TAMU, IUCF, REF
NASA Flight Project Funds (Magnetospheric MultiScalar -MMS)
Partners: SWRI, Samsung, Micron, Numonyx, Avalanche Semiconductor, Unity

Evaluation of *Non-Volatile Memory Goals*

- **Utilize flash memories as test vehicles for radiation effects understanding of scaled CMOS**
- **Characterize advanced hardened and unhardened nonvolatile memories. This includes:**
- **New materials**
- **New technologies and architectures**
  - **Current flash operate at 3.3V, 40 MHz**
  - **Increase speed with new 45 nm (16G SLC)**
- **Identify new failure modes—including combined effects**
- **Develop new test methods and identify mitigating strategies**



New failure modes



Expected Impact to Community

- NVM has always been critical in some applications, e.g., critical flight data, and flight control software
- Solid state NVM starting to be used in SSR (Solid State Recorders), replacing volatile memories
- Solid state NVM has speed advantage over hard disk drives
- NAND flash has advantage over most alternatives in cost per bit

Nonvolatile Memory Evaluation Status

- **Phase Change—samples obtained from Numonyx, SEE and TID testing performed**
- **STT-MRAM—Avalanche to supply test structures, TID proton test planned**
- **CNT—LM to supply test structures, unclear when**
- **FeRAM—TI, compare response of hardened and unhardened versions**
- **Cypress NVSRAM—samples received, laser test planned**
- **Unity—transistor-less RAM, to supply test structures**

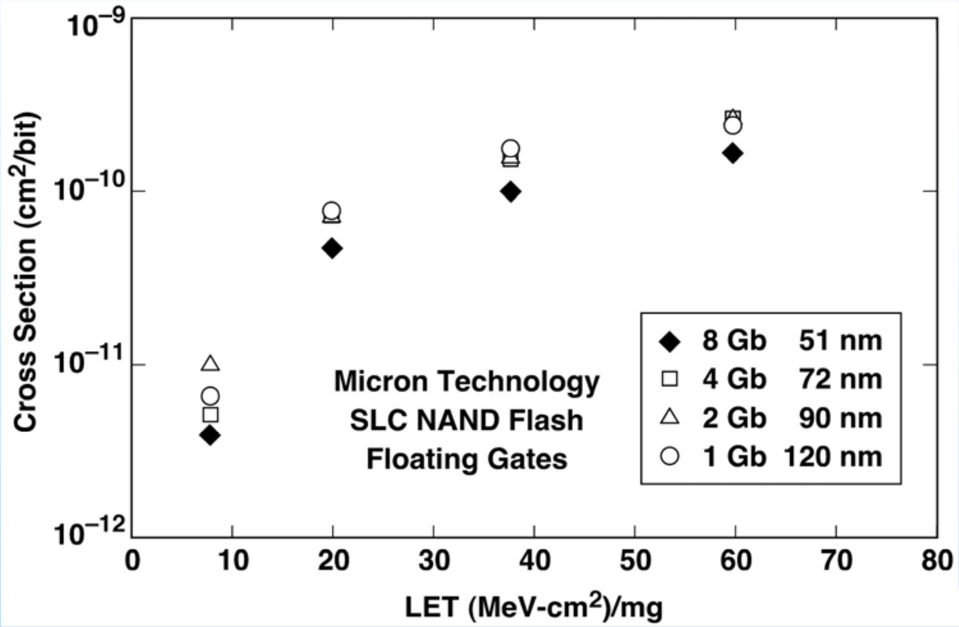
Non-Volatile Memory Schedule

FY10 Deliverables	Quarter Due	Quarter Completed	Notes
Micron 8G, 64G Flash HI Tests	Test 4QFY10 Report 1QFY11		
Micron 32G MLC HI Test	1Q FY10	1Q FY10	NSREC 2010 DW
Numonyx 4GTID/HI tests	TID 4QFY10 HI 3QFY10	HI 3Q FY10	
Spansion 1G MirrorBit NOR TID	Test 4QFY10 Report 4QFY10		Postponed from FY09
Micron 32G MLC TID	2Q FY10	2Q FY10	NSREC 2010 DW
Micron, Samsung Retention Tests	Begin 4QFY10 Continue FY11		NSREC paper to be submitted for July 2011
SP-MRAM TID Test	3QFY10		

Highlights/Accomplishments

Single Event Upset Results

- **SEU events were measured at BNL on SLC devices (1, 2, 4 & 8Gb).**
- **All three samples showed excellent agreement.**
- **No noticeable scaling effect in the range of 120-72 nm**
- **Error bars smaller than plotting symbols**
- **There is a reduction in the SEU cross section at 51 nm feature size.**

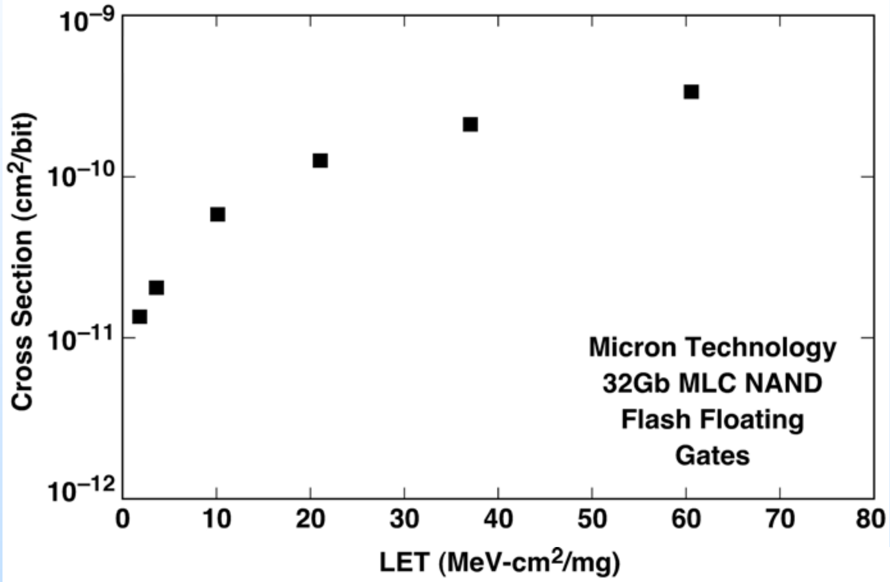


– ***Measured SEU cross-sections for Micron Technology SLC NAND flash memories. Only minimal dependence on feature size.***

Highlights/Accomplishments

Single Event Upset Results

- **The three samples measurements show excellent agreement.**
- **The FG SEU cross-section per bit is on the order of 3×10^{-10} cm^2/bit. Error bars smaller than plotting symbols.**
- **The FG SEU rate is $5.1x10^{-9}$ per bit per day for the background GCRs environment.**
- **Micron 32G MLC NAND, 32 nm technology.**

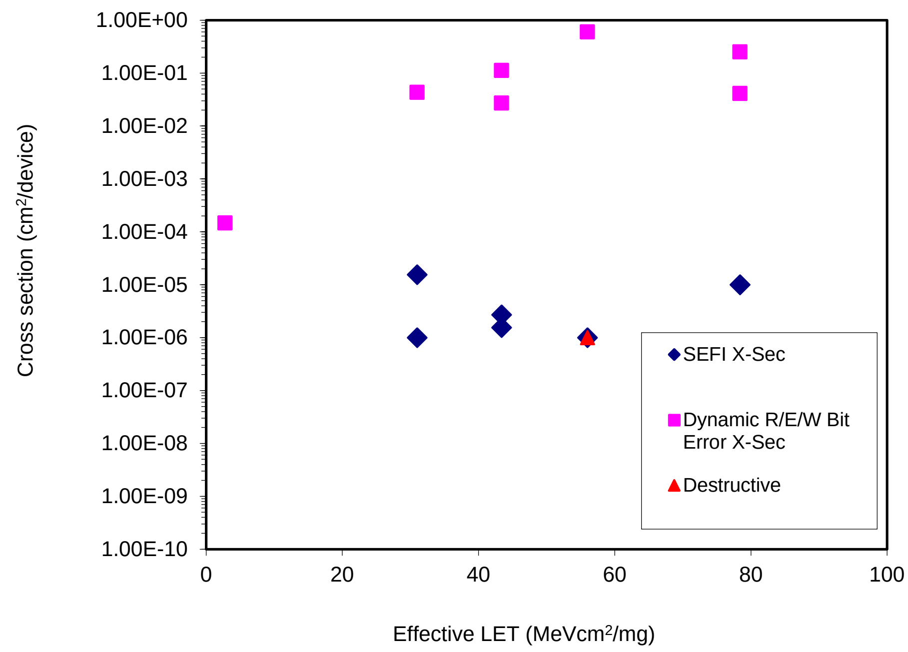


–***SEU cross-section for Micron Technology 32Gb MLC NAND flash memory, order of magnitude smaller than 8G MLC***

Highlights/Accomplishments

Numonyx 4G NAND SEE Test Results

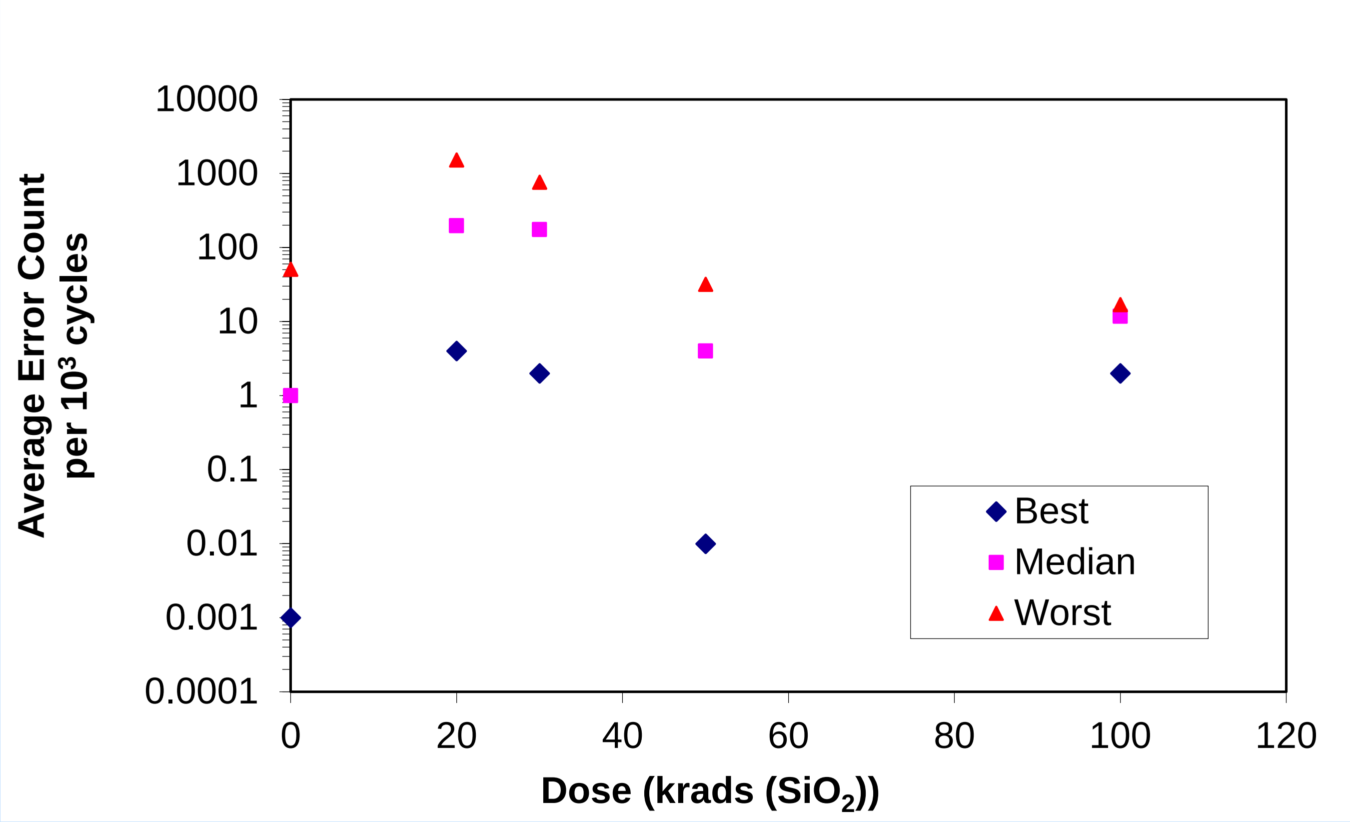
- ***One destructive event after 2.3x10^{7}*** **Xe ions/cm^{2},** ***equivalent to 2.7x10^{9} years in geosynchronous orbit***
- ***SEU rate manageable, especially with EDAC***
- ***SEFI impact unclear, mitigation required***



– ***Not enough data to endorse for flight programs, yet, but initial results are promising***

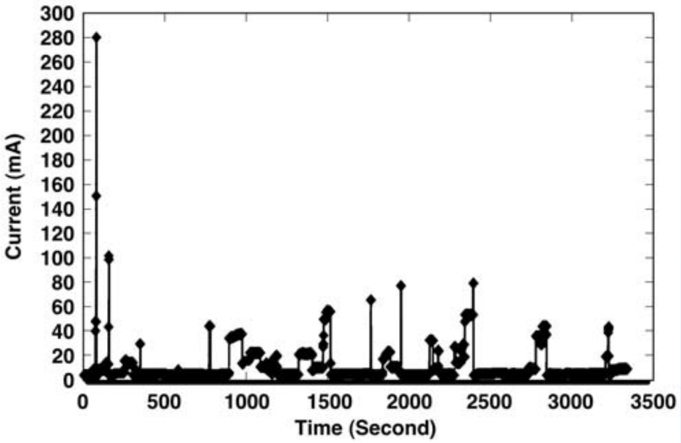
Highlights/Accomplishments

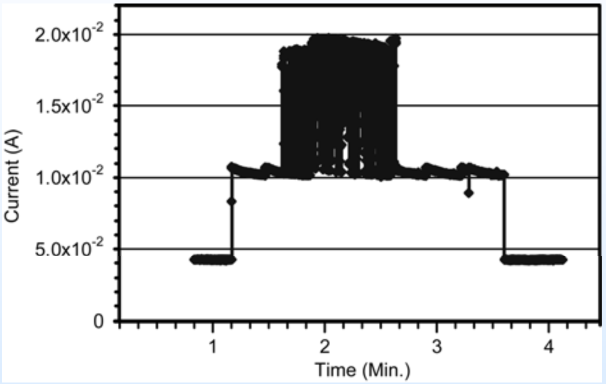
Reliability/Endurance Study

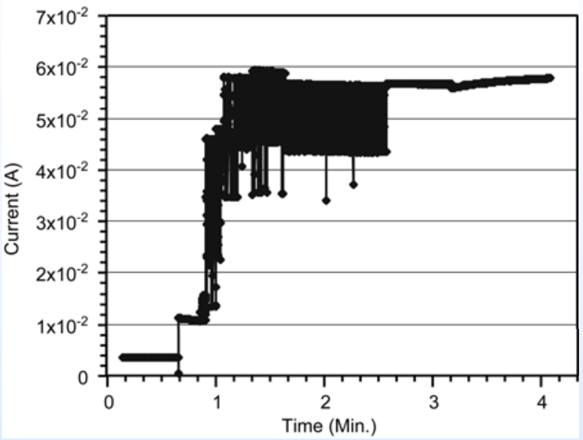


No clear indication that radiation exposure reduces flash endurance

Highlights/Accomplishments
Current Spikes







- ***Current spikes observed in some experiments, not in others***
- ***Two joint experiments have failed to explain differences***
- ***Agreed to disagree, for now***

▪Phase Change Highlights

- Heavy ion testing performed at TAMU
- Chalcogenide storage element appeared to be
  "bullet proof"
- Unhardened commercial substrate suffered SEL
- TID better than 100 krads (SiO_2)

Plans (FY10/11)

- Reliability study—retention after cycling and radiation exposure
- Characterize Micron single die, SLC 64G NAND (25 nm)
- Compare SLC/MLC response (e.g., Samsung 8G)
- Prepare draft test guideline document for NVM testing
- Monitor development of new NVM technologies, perform testing as test vehicles become available