*Risk Management of Microelectronics:*

# The NASA Electronic Parts and Packaging (NEPP) Program

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- NASA Electronic Parts Assurance Group (NEPAG)
  - A subset of NEPP
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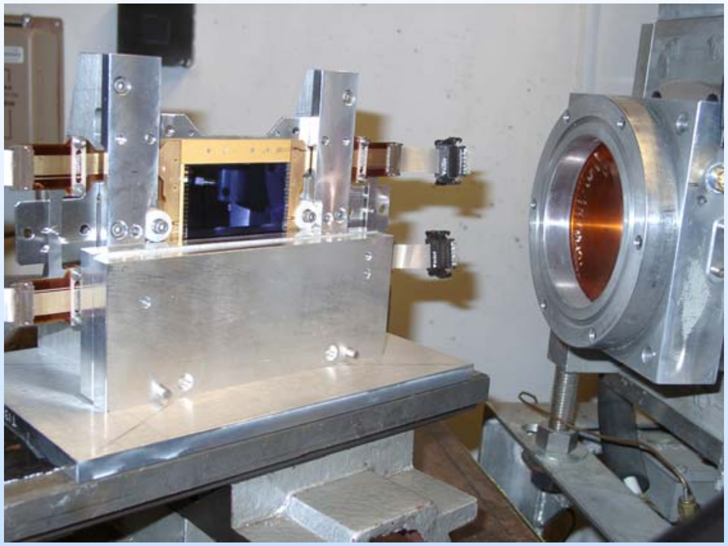
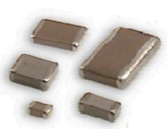
- Summary Comments

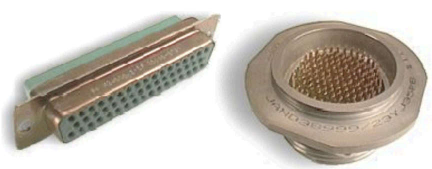


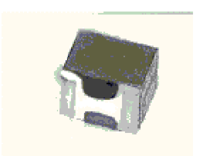
*Charge Coupled Device (CCD) ready for protons at UC Davis Crocker Nuclear Lab. Courtesy of NEPP Program and Defense Threat Reduction Agency (DTRA)*

# EEE Parts

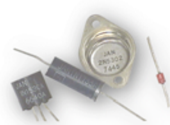
## Electrical
- Capacitors
- Resistors
- Transformers
- Wire& Cable
- Connectors



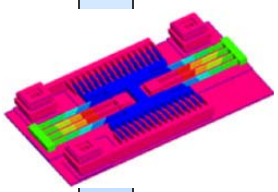


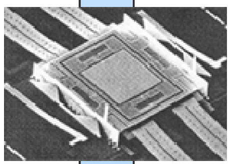


## Electronic
- Diodes
- Transistors
- Microcircuits
- Hybrids



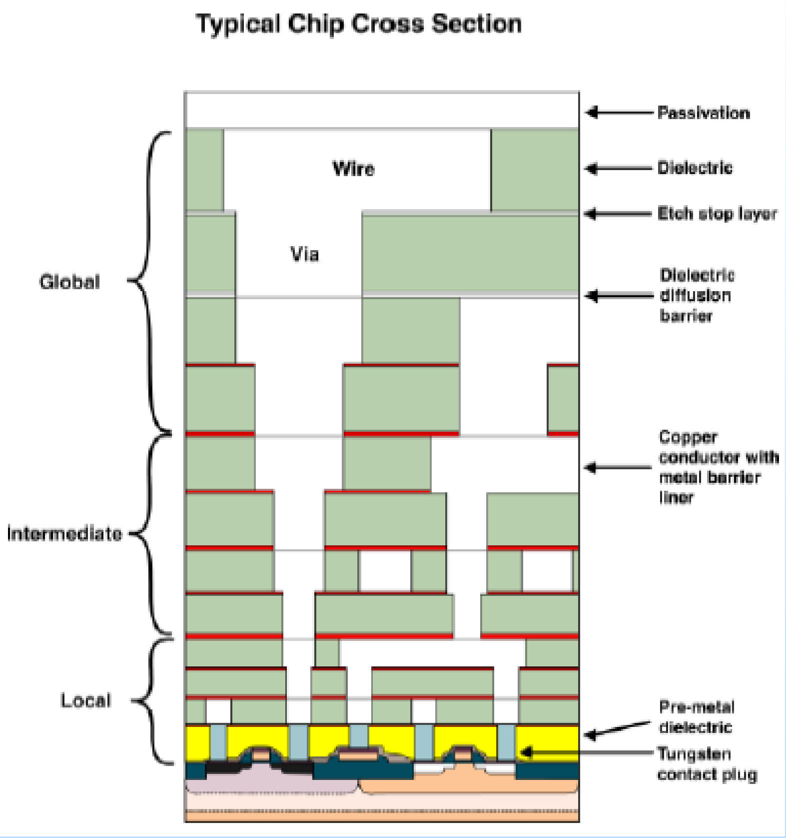

## Electromechanical
- Relays
- MEMS: Micro ElectroMechanical Systems
- MOEMS: Micro Optical ElectroMechanical Systems





# NEPP Mission

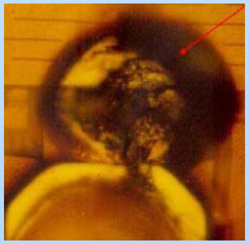
- **The NEPP mission is to provide guidance to NASA for the selection and application of microelectronics technologies, to improve understanding of the risks related to the use of these technologies in the space environment and to ensure that appropriate research is performed to meet NASA mission assurance needs.**



# NEPP Overview

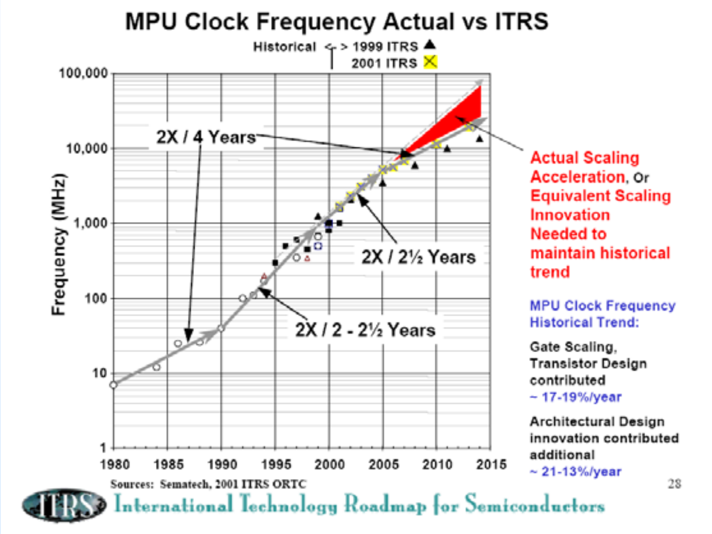
- **NEPP has been a One NASA success story for more than 15 years; 7 NASA Centers and JPL actively participate**
- **The NEPP Program focuses on the reliability aspects of electronic devices (integrated circuits such as a processor in a computer or optical components such as might be used in a communication link like in phone lines).**
- **There are three principal aspects of this reliability:**
  - **Lifetime, inherent failure and design issues related to the EEE parts technology and packaging,**
  - **Effects of space radiation and the space environment on these technologies, and**
  - **Creation and maintenance of the assurance support infrastructure required for mission success.**

*Electrical overstress failure in a commercial electronic device*



# NEPP Overview (Continued)

- **NEPP interests span EEE parts technologies from those just emerging from research to commonly-used "building block" parts for every mission**
- **NEPP is multi-disciplinary involving radiation, materials, test, experimentation, process and specification experts across the Agency**
- **NEPP has close, cooperative and long-standing relationships with government and non-government entities worldwide**
- ***NEPP provides a unique capability within the Agency to evaluate technologies in advance of mission needs, to provide assistance with risk management of technology insertion***

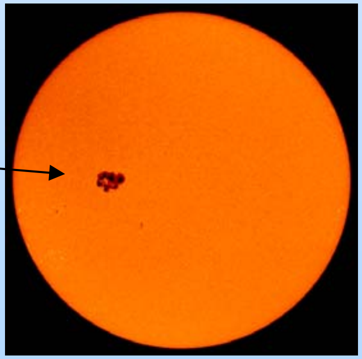



**Increasing device speed is a challenge for test, validation, and qualification**

# NEPP Program – Goals and Objectives

- **Main goal – *Mission reliability* to meet NASA exploration and science objectives**
  - ***Ensure reliability of missions by "smart" investments in EEE parts technology, knowledge gathering and research***
    - **Minimize engineering resources required to maximize space and earth science data collection**
- **NEPP objectives**
  - **Evaluate NASA needs for and reliability/radiation issues of new and emerging EEE technologies *with a focus on near to mid term needs***
    - **Explore failure mechanisms and technology models**
  - **Develop guidelines for technology usage, selection, and qualification**
  - **Investigate radiation hardness assurance (RHA)/reliability issues**
    - **Increase system reliability and reduce cost and schedule**

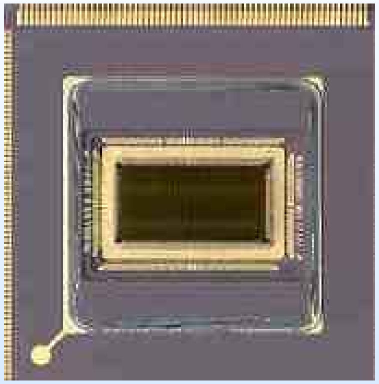
**"There's a little black spot on the sun today" –**
**A precursor to a solar event**



**SOHO Image**

# NASA EEE Parts Assurance Group (NEPAG), A Subset of NEPP

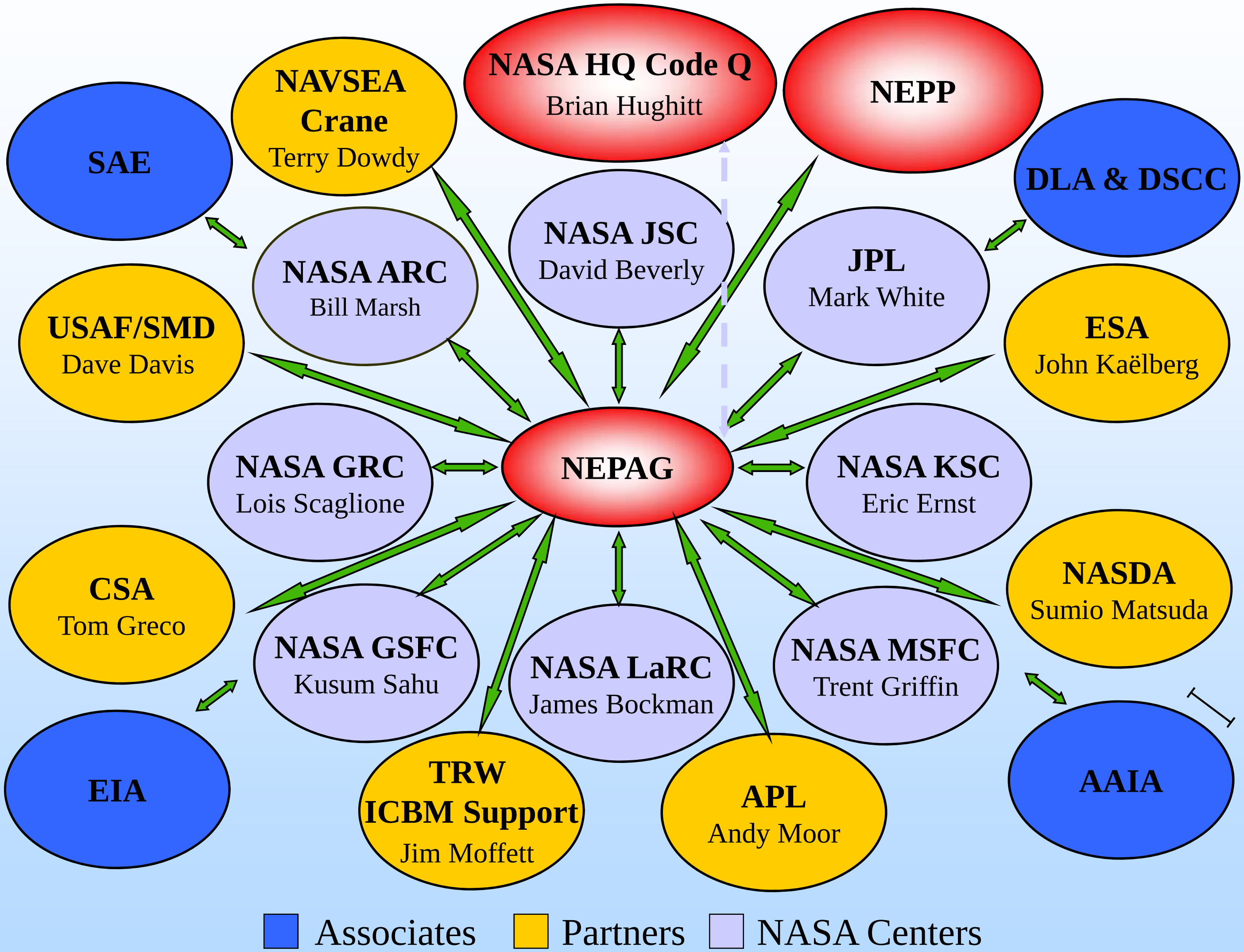
- **A flexible, multi-entity, multi-national,cooperative group**
  - **Organized and led by NASA**
- **Objective: To limit the number of EEE parts failures both on-orbit and on the ground**
  - **Emphasis is on mature and already deployed technologies**
- **Develops tools, shares information & resources as One NASA**
  - **Supports vendor audits, specification reviews and problem part investigations in support of US MIL system**
  - **Supports efforts of non government standards bodies:**
    - **Electronic Industries Alliance (EIA) and JEDEC**
  - **Investigates problems and performs focused evaluations on "basic" technologies, notably passives**
- **Complements NEPP focus and objectives *One Continuum***



**ACTEL RTSX72S FPGA**

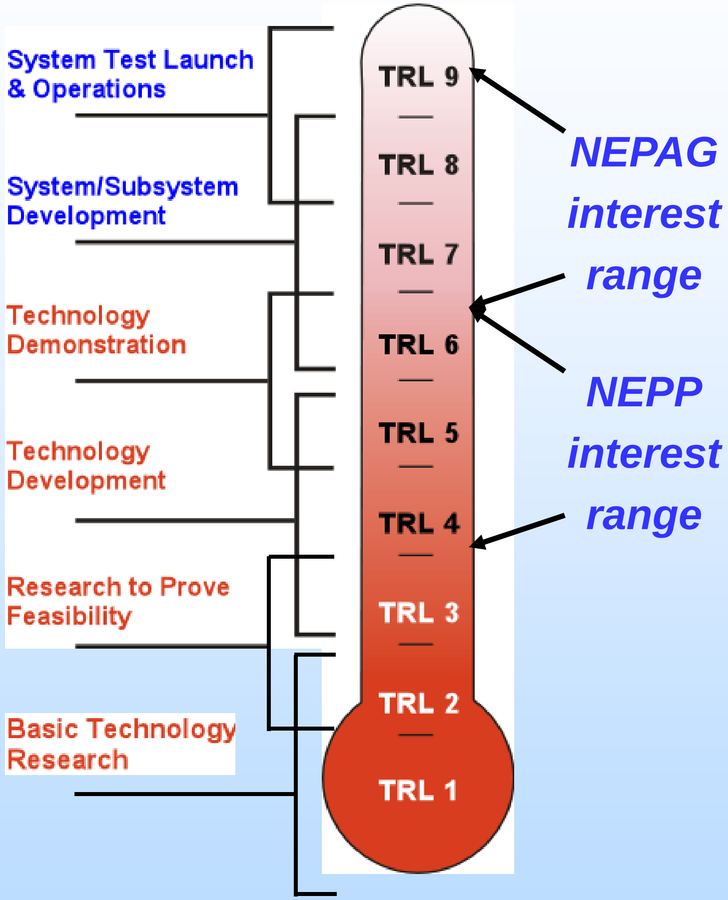
**A part that passed "standard" qualification, but requires more complex testing**

# NEPAG "Extended Family"



# Insertion of New Technologies – A NASA Mission Perspective

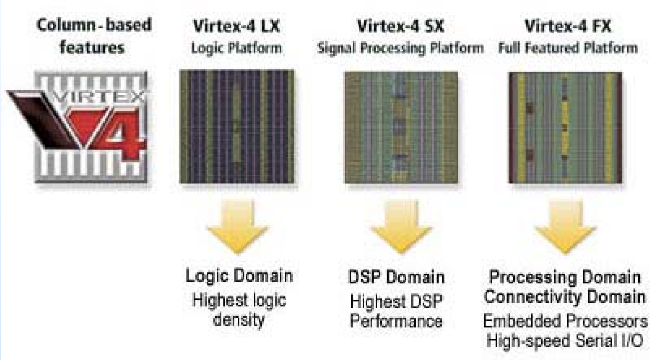
- **NASA mission timeframes rarely allow for a technology development path**
  - **For a 2008 launch, for example, technology freeze dates are likely 2005 or earlier**
    - **Technology must be moderately mature when a mission is being developed**
      - ***There may be time to qualify (test) a device, but there may not be time to develop/validate a new technology solution!***
    - **Risk versus performance reward for using less mature or commercial off-the-shelf (COTS) technologies**
- **Technology development and evaluation programs need to be in place prior to mission design**
  - ***Strategic planning for/by NEPP on technologies is critical***




*NASA Technology Readiness Levels (TRLs)*

# NEPP FY05: Large Issue Focus

- **Pre-FY05, NEPP focused on many small efforts providing incremental results**
  - **Tasks took multiple years to provide product**
    - **Albeit useful, timeliness was borderline**
    - **Task-sharing common between centers**
      - **Managerial challenge for keeping each task focused**
  - ***Inadequate return for NASA needs***
- **FY05: Fewer efforts, but with larger return per task**
  - **Principle 1: Attack technologies with best return on investment**
    - **Not all major areas able to covered with existing NEPP funding profile**
  - **Principle 2: Utilize "centers of excellence" from existing expertise**
  - **Principle 3: Continue and maximize leverage and partnering**
    - **Technology advancement is rapid**
    - **Procurement of samples and performance of testing is <u>very expensive</u>**
    - **NEPP does not have the resources to "go it alone"**



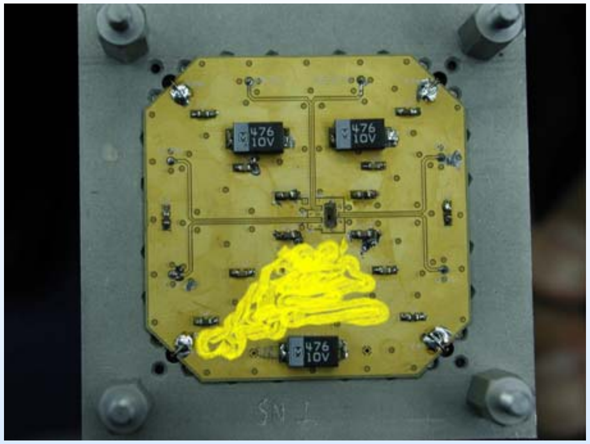

**Complex new FPGA architectures include hard-cores: processing, high-speed I/O, DSPs, programmable logic, and configuration latches.**
**Joint program with AFRL, MDA, and NAVSEA for evaluation**

# Hypothetical New Technology Part Qualification Cost

| *Item* | *Cost* | *Note* |
|---|---|---|
| **Parts Procurement** (500-1000 devices for testing only) | **$25-1000K** | Individual device costs can run from cents to tens of thousands |
| **Standard Qualification Tests** | **$300K** | |
| **Radiation Tests and Modeling** | **$200K** | Assumes total dose and single event (heavy ion) only |
| **Failure Modes Analysis** | **$200K** | Out-of-the-box look at the "hows and whats" for non-standard research required for qualification |
| **Additional Tests, Modeling, and Analysis based on Failure Modes** | **$300K** | |
| **Total cost for one device type** | **$1.025-2M** | Not all new technologies will meet standard qualification levels: technology limitations document |

# The New NEPP Operating Philosophy

- **<u>Short</u>** list of **<u>key</u> technologies**
- **Proposals** in **these areas** given **priority**
- **Center specialties** will also be **supported**
- **Maximize partnerships** with other **NASA technology programs, government agencies, industry,** and **academia**
- **<u>Quality</u> not quantity** for deliverables
- **Our Goal: NEPP products used by <u>every</u> NASA project**



***High-speed test fixture for evaluation of emerging technology devices. Fixture designed by Mayo under DARPA and OGA funds. Testing sponsored by NEPP and DTRA.***

# Sample Partnership Matrix

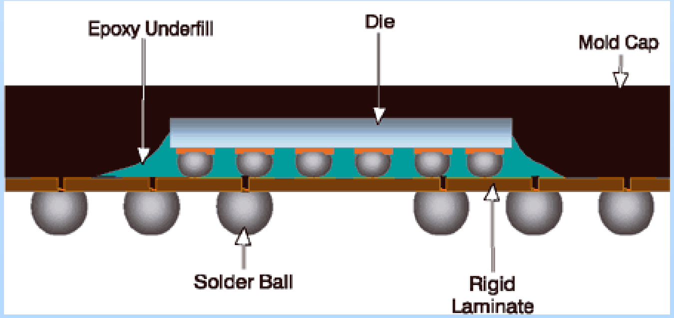
| Task Area | Other Government | Industry | University | NASA |
|---|---|---|---|---|
| SiGe Radiation | DARPA, OGA, AFOSR – in-kind; DTRA – direct funding, in-kind | Jazz Semiconductor, IBM – test samples, Mayo Foundation – mitigation design, packaging | Auburn, Georgia Tech, Arizona State, Vanderbilt – modeling and data analysis | H&RT BAA - (Georgia Tech) |
| Sensor Technology | AFRL – test samples, joint test; DTRA – direct funding, in-kind | Ball Aerospace, Raytheon, Full Circle Research – joint test and data analysis | U of Arizona, U of Hawaii | Prometheus, JWST, HST WFC3 |
| Emerging NVMs | AFRL, MDA, OGA – in-kind; DTRA – direct funding; NAVSEA Crane, MDA, DTRA – CRAM IPT | BAE Systems – CRAM, Freescale Semiconductor – Si Nanocrystal, LSI Logic /Nantero/Seakr – Carbon Nanotube, Honeywell/Freescale – MRAM | Vanderbilt | Prometheus – co-evaluation CRAM, FeRAM |

# NEPP Focus Tasks for FY05

- Field Programmable Gate Arrays (FPGA's)
  - Low-cost replacement for custom ASICs
    - Flexibility for reconfigurable systems
  - Reliability and radiation issues
- Non-volatile Memories (NVM's)
  - Used to store program code and, in some cases, flight telemetry
  - The widely-used Hitachi EEPROM is reliability suspect
  - All NVM's have reliability and radiation concerns
- Advanced Mixed Signal
  - NEPP will examine reliability, radiation, and extreme environment performance
- Scaled CMOS
  - Continuous reduction of feature size
  - Reliability and radiation performance unpredictable
- Board-Level Radiation Assessment
  - Controversial but promises lower cost and application specificity
- Lead-free
  - NASA can cope with lead-free solder, but lead-free plating??
  - Tin whisker threat

# Focus 1: FPGAs

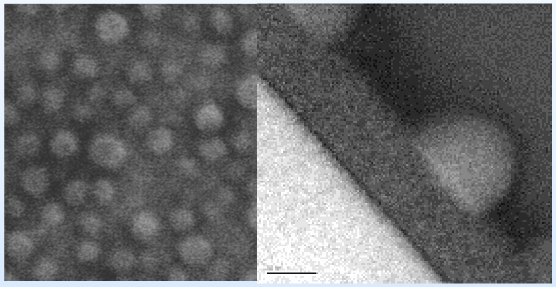
- **Why Field Programmable Gate Arrays (FPGA's)?**
  - **Ubiquitous usage on ALL NASA craft**
  - **Industry-wide concern**
  - **Competing philosophies and technologies available**
- **FY05 NEPP Plans include**
  - **GSFC**
    - **Develop qualification guidance via testing for NEW ACTEL RTSX(U) devices**
      - **Investigate reliability, design, and radiation performance**
      - **Tie-in to Aerospace Corp-led investigation**
    - **Provide similar insight into other FPGA devices/technologies**
      - **Antifuse and Flash-based devices**
    - **Partner with others for evaluation of state-of-the-art commercial reprogrammable devices**
      - **Tie-ins to Exploration Systems efforts for a Radiation Tolerant FPGA development**
    - **Radiation evaluation of base technologies used on FPGAs**
  - **JPL**
    - **Develop qualification guidance for reprogrammable FPGAs**
      - **Emphasis on Xilinx family, but others to be tested as well**
    - **Support industry-led consortia for radiation testing of Xilinx Virtex-II Pro device**
      - **Xilinx, Seakr, LANL, SNL, other partners**
  - **Develop database of FPGA device knowledge to apply to usage and qualification**




***Complex packages complicate "parts" issues***

# Focus 2: NVMs

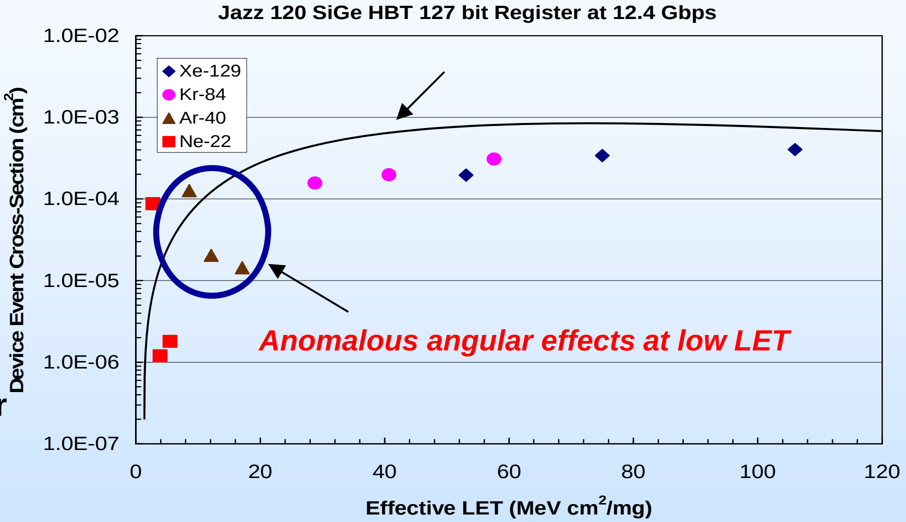
- **Why NVMs?**
  - **Ubiquitous usage on ALL NASA craft**
  - **Current commercial solutions have known issues**
    - **Hitachi EEPROM (obsolete) and commercial Flash devices**
  - **Current military/space devices have limited density, slow performance,..**
- **FY05 NEPP Plans include**
  - **GSFC**
    - **Evaluate radiation tolerance of emerging technology NVMs including**
      - **Chalcogenide-based memory (CRAM)**
        - » **AFRL, OGA funded technology development**
        - » **Integrated Product Team includes NEPP, Draper Labs, NAVSEA, MDA, OGA**
      - **Silicon nanocrystal technology (Freescale Semiconductor)**
        - » **Co-funded evaluation by Defense Threat Reduction Agency (DTRA)**
      - **Magnetoresistive Random Access Memory (MRAM) (Honeywell with Freescale)**
        - » **Development funded by DoD**
      - **Carbon nanotube (LSI Logic with Nantero Corp)**
        - » **Actual samples expected off commercial line in 3QFY05!**
        - » **Partial OGA funding**
  - **JPL**
    - **Investigate problems with Hitachi EEPROM and recommend mitigation**
    - **Develop qualification guidance for existing technologies**
    - **Evaluate reliability for subset of GSFC radiation evaluation technologies**
      - **Add reliability and radiation tests on new Flash devices**



*Silicon nanocrystal device (courtesy of Freescale Semiconductor). Radiation evaluation sponsored by NEPP, DTRA, and Freescale*

# Focus 3: Advanced Mixed Signal

- Silicon Germanium (SiGe) and Competing Technologies
- Why SiGe?
  - Commercially available (IBM, ATMEL, others)
  - Highly desirable speed and noise characteristics
    - RF systems, high accuracy instruments
  - Known radiation sensitivity to single event upsets
- FY05 NEPP Plans include
  - GSFC
    - Evaluate radiation tolerance of IBM processes and competing InP and other solutions including
      - Co-funded by DTRA, DARPA, OGA
      - Develop test methods, technology models, and evaluation of hardening solutions (OGA funded)
    - Work performed by GSFC, Vanderbilt University, Georgia Tech, Mayo Foundation
      - Also includes development of new test techniques for high-speed technologies that DoD technology programs are baselining
  - GRC
    - Investigate reliability of SiGe under extreme cold temperature usage

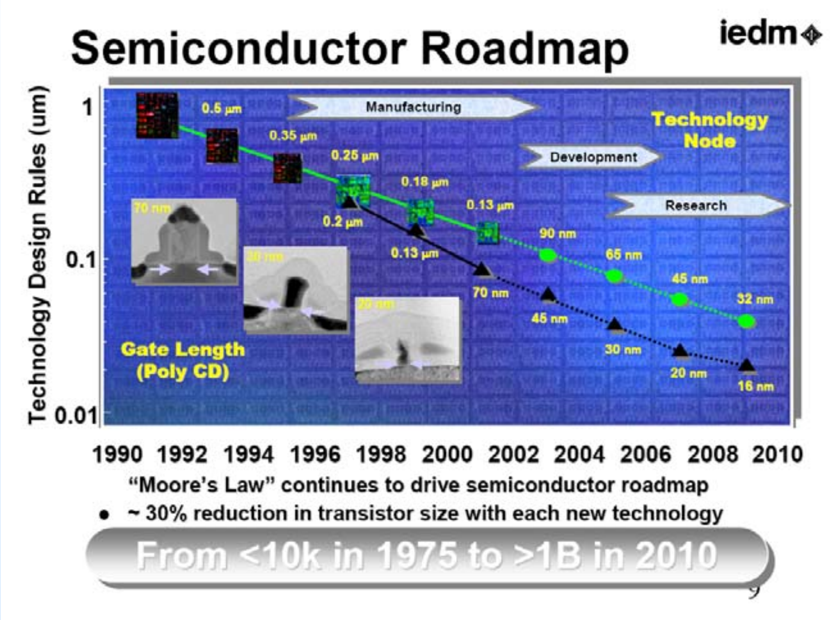



*Effects of heavy ions on SiGe devices at 12 GHz speeds notes anomalous charge collection of this high-speed technology; Drawn line represents expected response with "standard" models.*

*Impact is CHALLENGE for predicting in-flight performance.*

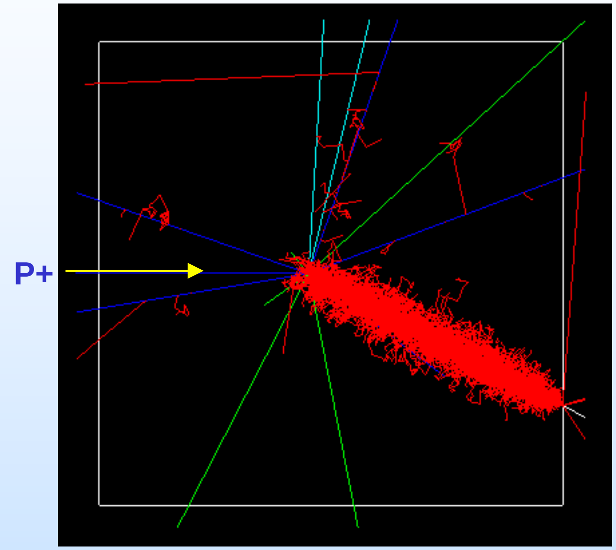
# Focus 4: Scaled CMOS

- **Why Scaled CMOS?**
  - Definition: Feature size reduction of digital semiconductor processes
    - Current state-of-the-art is 90nm feature size
    - Most commercially available products are between 180 and 90nm
  - Changes in processes may require modification to qualification methods or LIMITATIONS to usage
    - Insight aids DoD radiation hardening programs (processes and hardened-by-design)
      - Hardened foundries need to understand challenges
- **FY05 NEPP Plans include**
  - GSFC
    - Evaluate radiation tolerance of Scaled CMOS w/DoD and industry partners including
      - Texas Instruments (65nm process)
      - LSI Logic (180-130nm processes)
        - » Seeking a process for NASA ASIC designs cheaper with known radiation and reliability capabilities
        - » LSI is now planning to RE-ENTER MIL/SPACE market based on collaboration
      - MOSIS (ISI) Foundry Services (3 generations from IBM and TSMC)
        - » Aids NASA in technology selection; aids DARPA in Hardened By Design Program
      - Other 90nm devices (TSMC, Fujitsu) as commercially available
  - JPL
    - Provide reliability database gathering of 90nm technologies



# Focus 5: Board-Level Radiation

- **Why Commercial Boards?**
  - **Definition: Boards featuring commercial-grade electronics are used in large-scale space systems such as Space Station and Shuttle**
    - **Relatively benign radiation environment**
      - **Trapped protons and limited cosmic ray (heavy ion) exposure (but not ZERO)**
        - » **Solar event heavy ions an issue**
    - **Proton testing for Station provides some risk management for cosmic rays, but the question is: how much?**
- **FY05 NEPP Plans include**
  - **JSC**
    - **Evaluate existing datasets on commercial devices having proton and heavy ion data**
      - **Is there correlation between the datasets?**
    - **Model proton interactions in silicon**
      - **1 in $10^6$ protons causes a nuclear reaction in Silicon**
        - » **Test runs of $10^{13}$ protons required for even minimal statistics**
      - **With billion plus transistor devices and potential use of >1000 of the same device (ex: solid state recorders), small probabilities become finite**




**Sample 100 MeV proton reaction in a 5 um Si block.**
**Reactions have a range of types of secondaries and LETs.**
***(after Weller, 2004)***

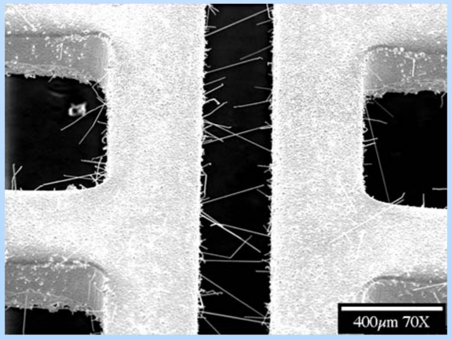
# Focus 6: Lead-Free

- **Imminent Japanese and European legislation will ban lead (Pb) use in electronics (2006)**
  - **No direct effect on US but commercial world must switch**
  - **Tin-lead solders ubiquitous in space electronics from the outset**
  - **Lead-free solders require higher process temperatures**
  - **No long-term experience with the new alloys**
    - **Thermal cycle, vibration and shock performance unproven**
  - **MSFC monitors industry progress, funds research by CAVE**
    **(Center for Advanced Vehicle Electronics at Auburn University)**
  - **BUT …**
- **Immediate concern for NASA is lead-free plating**
  - **Pure tin is commercial industry's plating of choice**
  - **Tin whiskers are known threat to spacecraft survival**
  - **GSFC performs tests, monitors and collates industry experience**
  - **NEPP influences industry groups: NEMI, JGPP, JEDEC, CALCE**

## Industry Lead Consumption

| Product | Consumption (%) |
|---|---|
| Storage Batteries | 80.81 |
| Paints, Ceramics, Pigments, Chemicals | 4.78 |
| Ammunition | 4.69 |
| Sheet Lead | 1.79 |
| Cable Covering | 1.40 |
| Casting Metals | 1.13 |
| Brass / Bronze Billets and Ingots | 0.72 |
| Pipes, Traps, Extruded Products | 0.72 |
| Solder (Excluding Electronic Solder) | 0.70 |
| Electronic Solder | 0.49 |
| Miscellaneous | 2.77 |

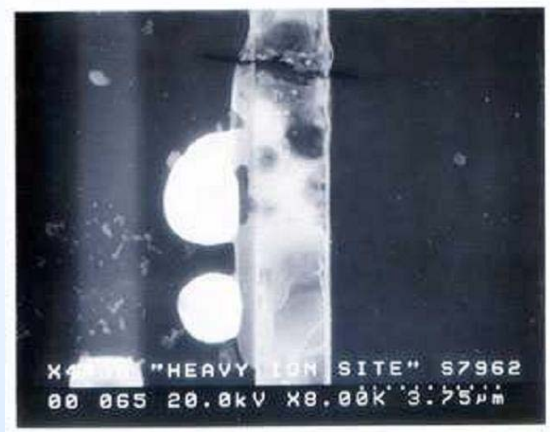
**Source: Advancing Microelectronics, September/October 1999. p. 29**



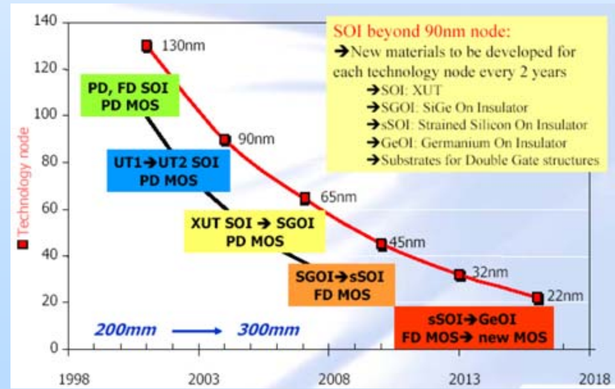

**Whiskers from matte tin. NEMI test sample. Courtesy Peter Bush, SUNY**

# Summary Comments

- **Technology needs to be strategically planned**
  - **Long-term needs and not point solutions**
- **Mission risk revolves around radiation and reliability "unknowns"**
  - **Need a significant effort in advance of mission timelines for new technology development/testing/modeling**
    - **Infrastructure required to support technologies**
      - **Schedules don't allow time for creating new capabilities once mission design has started**
    - **Lower TRL technologies need evaluation as well**
- **Updated tools and models are required to reduce risk of new technology insertion**
- **Easy access to flight technology testbeds desired to validate technology modes**
  - ***Ground-testing can mitigate some risk without flight data, but new technologies may have more complex space environment issues (synergistic environment)***




**Latent damage from a single particle strike can cause failures post-event**




**Next Generation SOI: Weak or no body ties will not solve SEU problems**

# Insertion of New Technologies
## *The Big Picture Approach*

- Develop knowledge-base of existing technology information
- Determine reliability/radiation gaps
- Perform ground-based tests where appropriate
  - May be sufficient to "qualify" for a specific mission, but not generically for all
- Develop technology-specific models/test protocols
  - Performance Predictions
- Validate models with flight data
  - Requires in-situ environment monitoring

*Non-NEPP funded flight hardware*