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Possible Interactions between Sandia National Laboratories and the University of Arkansas Center for μEP

Center for MicroElectronics-Photonics Seminar
University of Arkansas-Fayetteville

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

Outline

- Who I am?
- What am I doing at the University of Arkansas?
- Primary Job
  - Sandia National Laboratories
  - Description of Applied Nuclear Technologies Department Activities
- What do I hope to offer the U of A and the Center for μEP?
  - Conduit for new relationships with SNL
  - Mentoring for students (graduate and undergraduate)

Who am I?

- Background
  - HS diploma from Mena High School [Mena, ARKANSAS] (1992)
  - B.A. (Physics) – Hendrix College [Conway, ARKANSAS] (1996)
    - Senior Topic: “Large Ring Laser Interferometers As a Potential Detector of Seismic Waves”
  - M.S. (Health Physics) – Texas A&M (1998)
    - Thesis: “Energy Deposition Spectra of Simultaneous Electron Emissions from Low Energy Protons”
  - Ph.D. (Nuclear Engineering) – Texas A&M (2001)
    - Dissertation: “Radiation Effects on the Cell-Cell Communication of Mammalian Cells”
  - Technical Staff Member in the Applied Nuclear Technologies Department (Sandia National Laboratories) since July 2001

Why U of A?

- Telecommuting arrangement with SNL will allow me to move closer to family
  - Arrangement made necessary due to family health issues
  - Decided to relocate to Northwest Arkansas
  - Agreement with SNL requires a fixed schedule and work location (even though work takes place off-site)
    - Difficult to arrange this at home with a young child
- Last December, I sent an email to Professor Vickers with what we both considered to be an interesting proposal. Here is a summary:
  - Benefits for U of A and μEP Program
    - New possibilities for collaborations and contacts for U of A faculty/students with SNL staff members
    - "Cheap" and motivated adjunct faculty
      - Mentor for students (undergraduate and graduate)
  - Benefits for SNL
    - Contact with a University Program that could provide a pipeline of new talent for SNL
    - Office space for a staff member
- This seminar/workshop represents the first of many (I hope) interactions with U of A faculty and students.

Sandia National Laboratories

- Sandia is a multi-program lab, primarily doing national defense R&D, energy, and environment projects
- Mission Areas
  – Nuclear Weapons
  – Nonproliferation and Assessments
  – Military Technologies and Applications
  – Energy and Infrastructure Assurance
  – Homeland Security and Defense
- “Our highest goal is to become the laboratory that the U.S. turns to first for technology solutions to the most challenging problems that threaten peace and freedom for our nation and the globe.”

Sandia National Laboratories History

- 1945 – Z Division of Los Alamos Laboratory (located in Albuquerque) during Manhattan Project
- 1949 – Sandia Corporation formed to manage Sandia Laboratory
- 1950's – Developed technologies that allowed weapons to sit in the stockpile for years with little maintenance
- 1956 – New laboratory in Livermore, CA across from Lawrence Livermore Laboratory (Edward Teller)
- 1960 – Laminar Flow Clean Room designed by Sandia
- 1966 – Helped locate bomb lost over Palomares, Spain
- 1970's – Designed accident resistant containers for nuclear materials
- 1972 – Began anti-terrorism activities
- 1973 – Began work on alternative energy (solar and wind) technologies, enhanced fossil fuels recovery, and fusion development
- 1983 – Contributed to SDI
- 1991 – SNL designed radar used in Desert Storm
- 1996 – Achieved >1 Tera-flops on the ASCI Red super-computer
- 2001 – Sandia-developed decontamination foam used to neutralize anthrax in Capitol Hill buildings
- 2004 – Introduced the shoulder-length, carbon-composite Sandia Gauntlets as a direct response to U.S. military needs in Iraq

Sandia National Laboratories

Primary Responsibilities

- Experimentalist/Analyst in the Radiation Effects Sciences Center
  - Experiments are performed in the facilities that I will describe later.
  - Pre- and Post-experiment analyses include modeling & simulation, dosimetry selection, and interpretation of active and passive dosimetry.
    - Experiment conditions are compared with environments that might be faced by a fielded system (weapon, satellite, etc.).
- Code developer
  - High-fidelity, multi-physics, parallel neutron/gamma transport code
    - Principal interface with new users
    - Responsible for Verification & Validation of the code
    - Code team analyst for interface with electrical simulation codes

Applied Nuclear Technologies Department

- Responsible for neutron/gamma portion of the Radiation Effects Sciences (RES) program at SNL
  - Develop and qualify dosimetry for mixed n/γ environments
  - Design and conduct of experiments for the development and validation of models describing n/γ production and transport
  - Tailor and characterize radiation test environments
  - Maintain and advance tools and methods for characterizing n/γ environments
- Responsible for the development, validation, and application of the NuGET code within the Advanced Simulation & Computing (ASC) program.
  - NuGET is a state-of-the-art code describing the production and transport of n/γ.
    - Models n/γ interactions with materials, components, and systems.
- Responsible for Directed Stockpile Work (DSW)
  - Analyses and testing for the definition of radiation hardness requirements
  - Support the design and qualification of components and systems in hostile and fratricide radiation environments
- Responsible for supporting the Nuclear Facilities Operations Staff in developing the appropriate test environments for meeting experimenter needs

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Radiation Facilities

- Reactors
  - Annular Core Research Reactor (ACRR)
  - Sandia Pulse Reactors (SPR-II and SPR-III)
- Bremsstrahlung Sources
  - Saturn Accelerator
  - HERMES III Accelerator
  - SPHINX Accelerator
- Gamma Sources
  - Gamma Irradiation Facility (GIF)
  - Low Dose Rate GIF
- Others
  - Z-Accelerator
  - Hot Cell Facility
  - Auxiliary Hot Cell Facility
  - Radiation Metrology Laboratory (RML)

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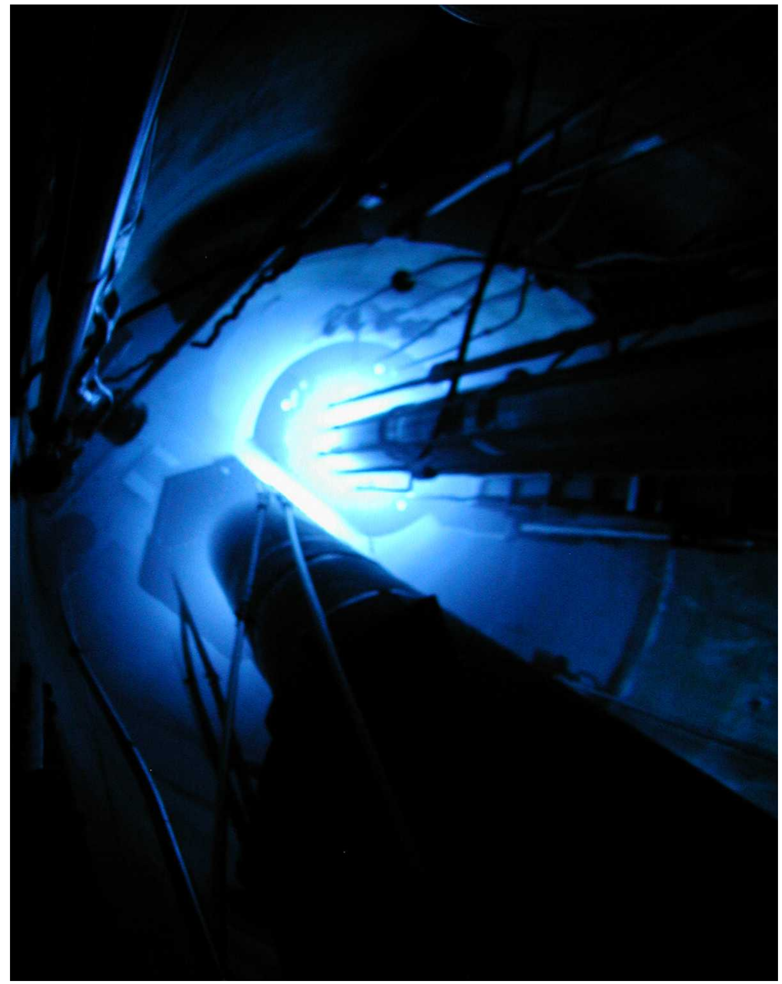
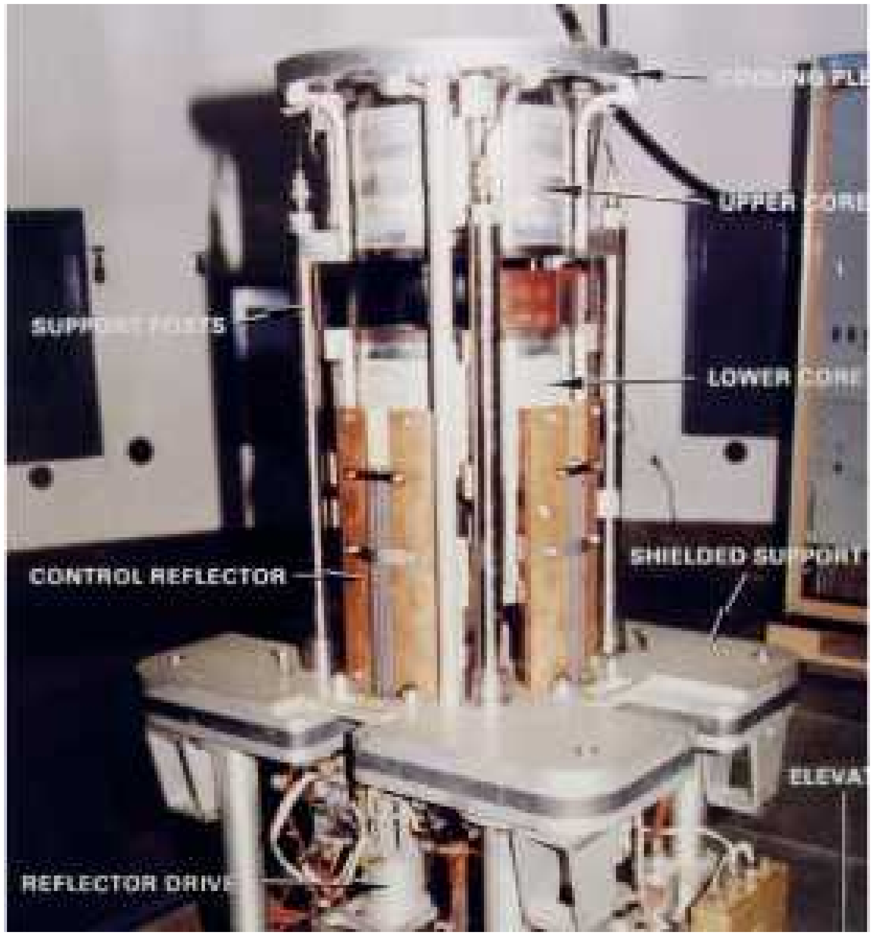
Annular Core Research Reactor (ACRR)

- Pool-type Reactor
  - Unique $BeO-UO_2$ fuel allows fuel temperatures up to 1400^{o}C
  - Pulse, steady-state and tailored transient rod withdrawal operation
- Performance Characteristics
  - Pulses
    - ~$3.00 reactivity insertion
    - ~30,000 MW peak power
    - 6.5 ms pulse width
    - 300 MJ of energy released
  - Steady-State
    - ~2.4 MW reactor power



Sandia Pulse Reactor III (SPR-III)



- Fast burst reactor
  - Unmoderated cylindrical assembly of HEU alloyed with molybdenum
  - Capable of pulse and steady-state operations
- Performance Characteristics
  - Pulses
    - ~$1.13 reactivity insertion
    - 450^{o}C ΔT
    - 76 μs pulse width
    - 8.0 x 10^{18} n/cm^2-s peak flux
  - Steady-State
    - 10 kW reactor power
- Currently, SPR-III is awaiting removal from SNL

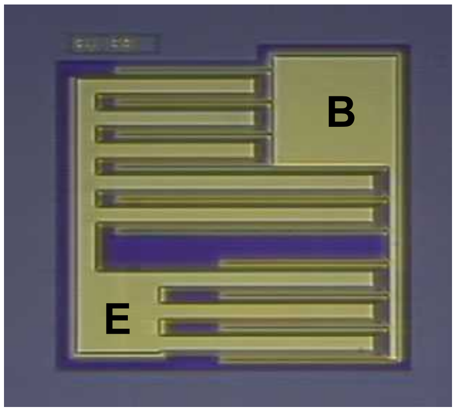
Gamma Irradiation Facility (GIF)

- ^{60}Co Gamma Sources
- Three Irradiation Cells
- High Dose Rates
  - 100-1000 krad/hr
- In-Cell Irradiation Capabilities
  - Electronic component hardness, survivability, and certification tests for military and commercial applications
  - Radiation effects on material properties
  - Radiation effects on organic materials
  - Designed for mixed environment testing (e.g., steam and radiation, heat and radiation, etc.)

Current Interests

- Active and passive mixed-field (neutrons/gammas) dosimetry
  - We try to separate neutron contributions from the gamma contributions to dosimeters
- Uncertainty quantification
  - Experiment Results
  - Test Conditions
  - Modeling & Simulation
- Neutron damage equivalence in electrical devices
  - Silicon & GaAs Bipolar Transistors
  - MOS Field-Effect Transistors (Si, GaAs, GaN)
  - Photovoltaic Cells
  - Photodiodes
  - Optical Couplers

Let's Consider an Example Application: Motorola MMBT2222LT1 NPN Transistor

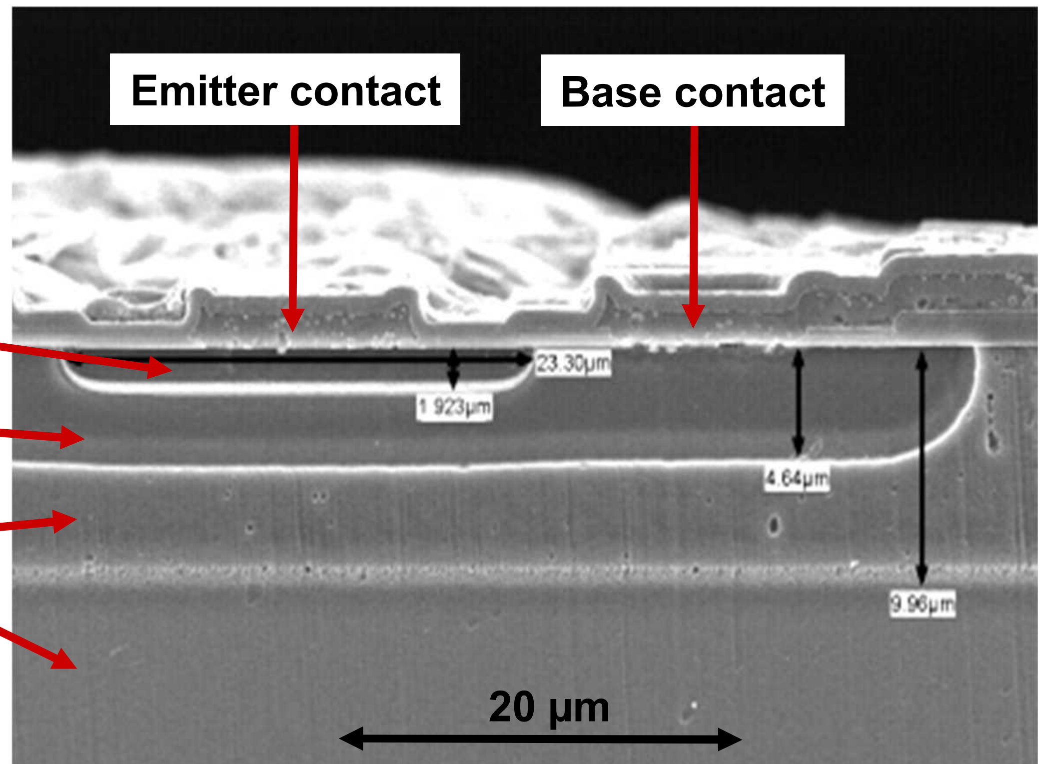


Emitter (n-type)

Base (p-type)

Collector region:
- **n - doped epi**
- **n^+- doped substrate**

Scanning electron microscopy cross-section image

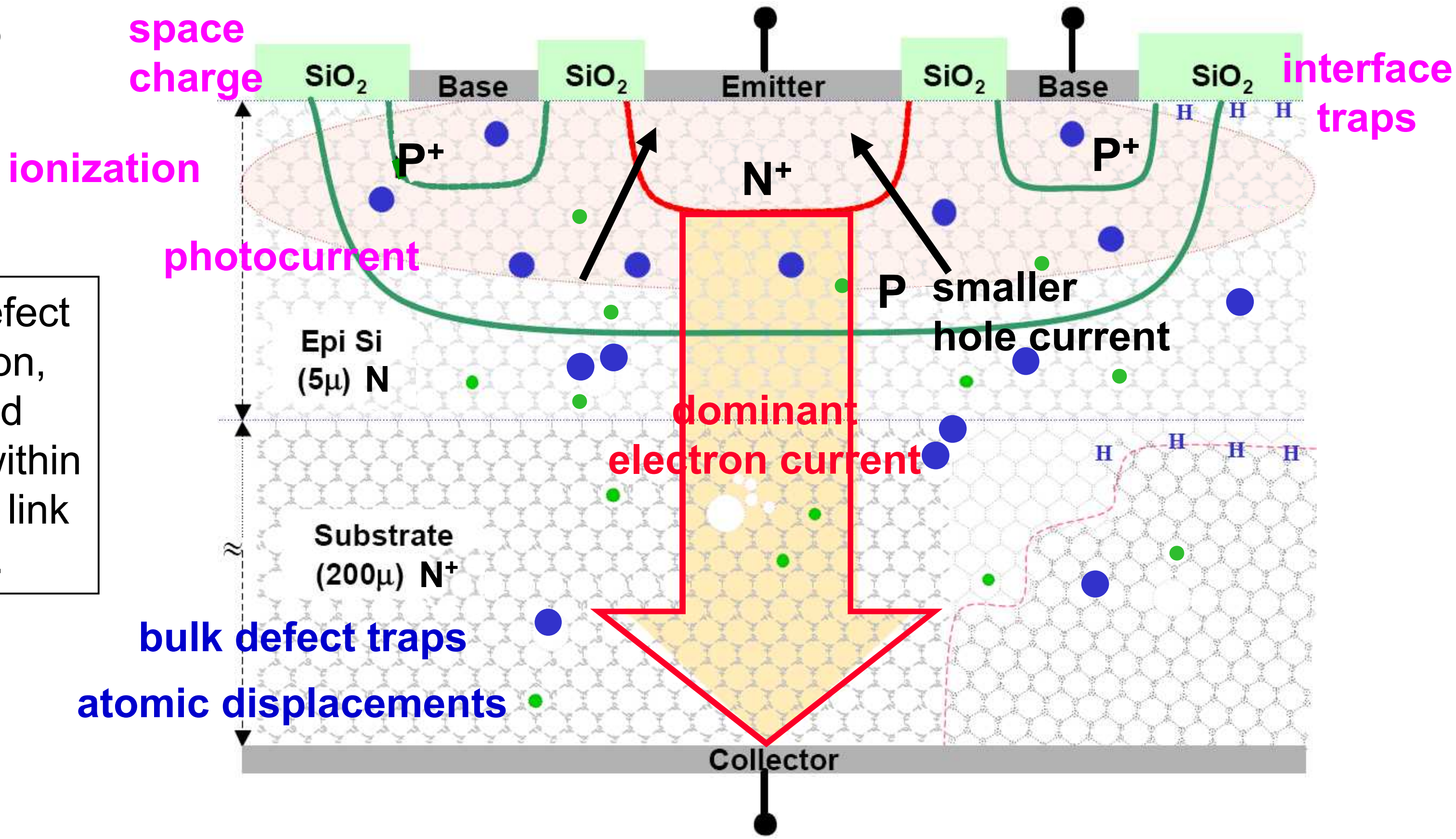


Radiation Effects in Si BJT

<u>The principal effect of neutron irradiation</u>:

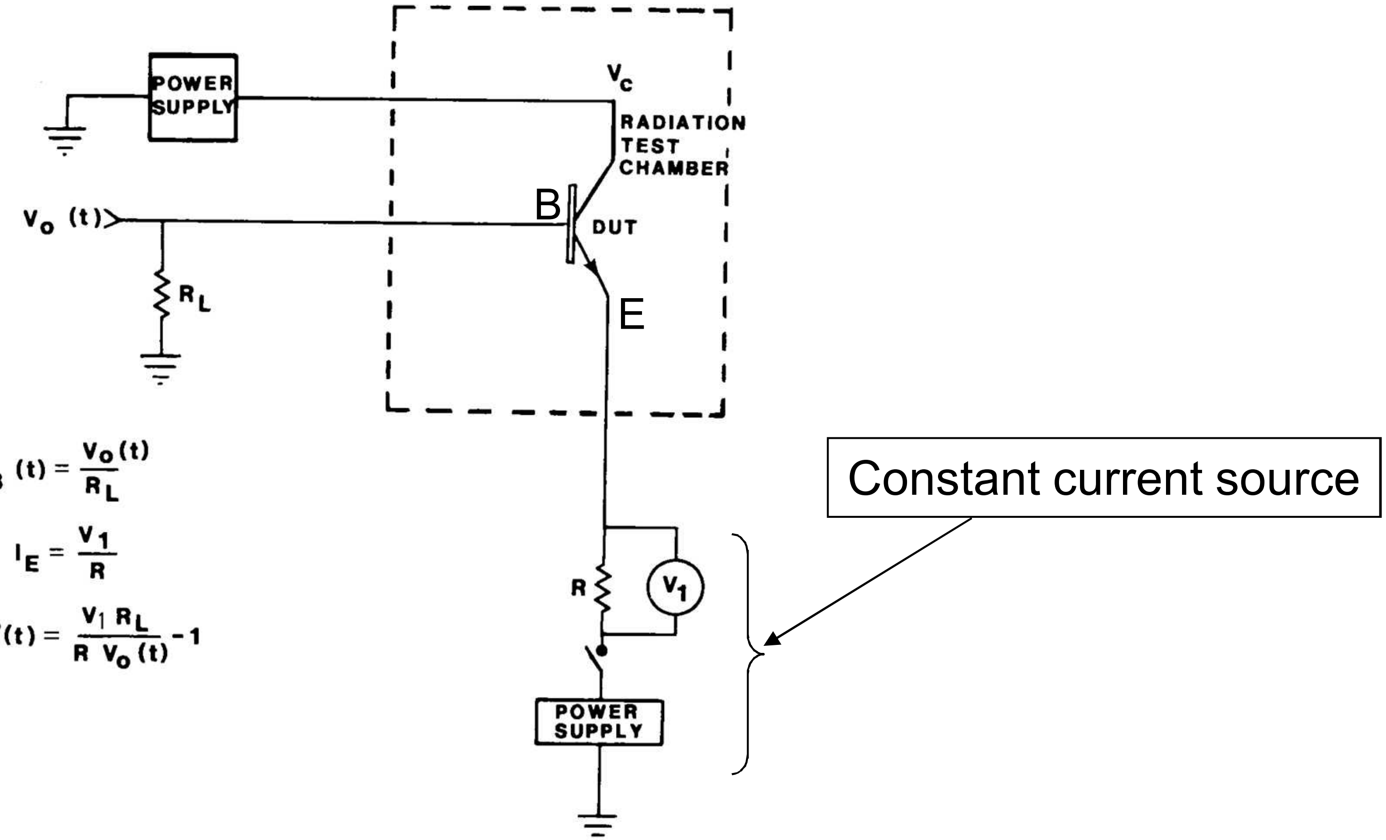
Electron-hole recombination at bulk defect traps in and near the base increases the hole current and thereby reduces the gain of the transistor.

Gain: $\beta = I_c/I_b$



GOAL: Model defect creation, evolution, annihilation, and charge transport within the transistor and link to circuit level.

A standard exists for Si BJT gain degradation measurements: ASTM Standard F 980M-96[1]



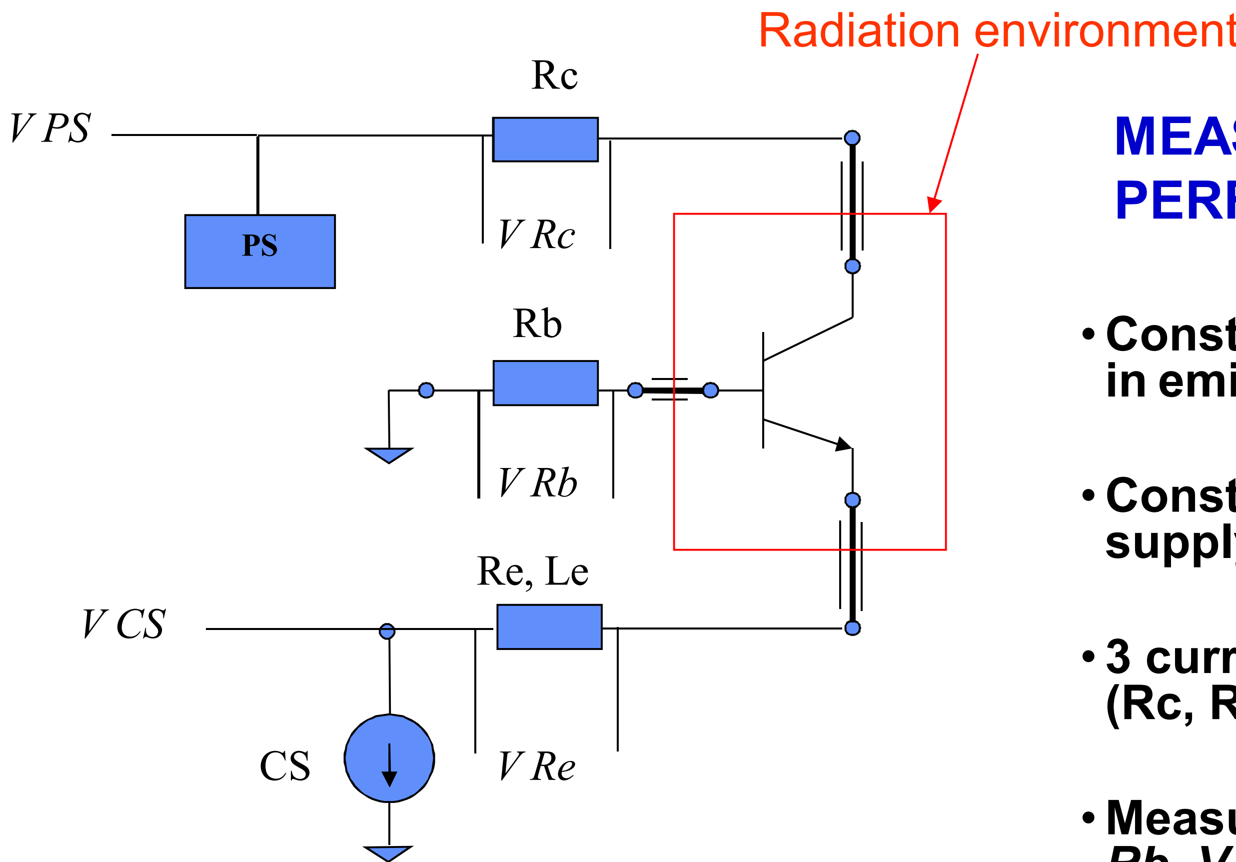
$$I_B(t) = \frac{V_O(t)}{R_L}$$

$$I_E = \frac{V_1}{R}$$

$$\beta(t) = \frac{V_1 R_L}{R V_O(t)} - 1$$

[1] Standard Guide for Measurement of Rapid Annealing of Neutron-Induced Displacement Damage in Silicon Semiconductor Devices

We are inventing new experiments and creating the new standard to meet our goal



$I_c = V_{Rc}/R_c$ $I_b = V_{Rb}/R_b$ $I_e = V_{Re}/R_e$

MEASURE THE DEVICE PERFORMANCE IN ALL THREE LEGS

- **Constant current source (CS) in emitter leg**
- **Constant voltage power supply (PS) in collector leg**
- **3 current viewing resistors (Rc, Rb, Re)**
- **Measure *V PS, V CS, V Rc, V Rb, V Re***

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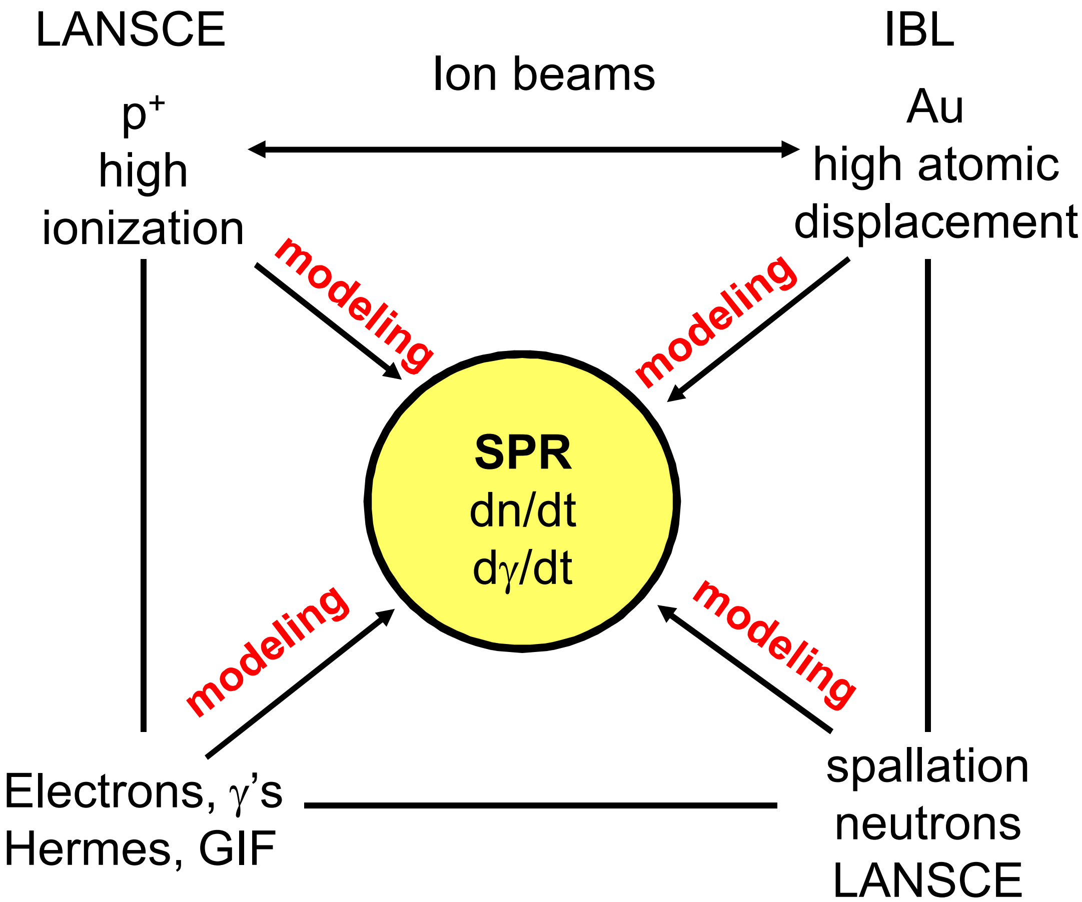
We must qualify our systems in the fast transient neutron environment w/o SPR-III. HOW?



Draw in other capabilities (test and modeling) as available

ACRR required to evaluate response to longer pulses and to evaluate late time annealing curve

Possible Synergies of μEP with Applied Nuclear Technologies Organization at SNL

- Radiation response and hardness testing/modeling of current technologies
  - QASPR activities
    - Modeling and simulation of devices/circuits in fast transient neutron environments
      - Si
      - GaAs
  - Active radiation dosimeters
    - Dosimeter electrical responses
    - Thermal transport from radiation heating in dosimeters
- Computational physics
  - New models for neutron damage (gain degradation) in electronic devices
  - Computational code verification and model validation
    - Techniques
    - Metrics
  - Advanced uncertainty quantification
- Radiation response and hardness testing/modeling of new technologies
  - Micro Electro-Mechanical Systems (MEMS) devices
  - Electro-Optic devices

Possible Synergies of μEP with Other Organization at SNL

- Microsystems Science, Technology & Components Organization
  - Microelectronics Development Laboratory (MDL)
  - Microsystems and Engineering Sciences Applications (MESA)
  - Photonics
  - Packaging
  - Micro-machines
  - Micro-sensors
  - Micro-power
  - "Chem Lab on a Chip"
- Center for Integrated Nanotechnologies
  - Nano-bio-micro Interfaces
  - Nano-photonics and Nano-electronics
  - Complex Functional Nanomaterials
  - Nano-mechanics
  - Theory and Simulation
- Computational Biology
  - Molecular and Coarse-grained Particle Simulation Methods
  - Hydration and Solvation
  - Protein Structure Determination
  - Metabolic, Regulatory and Signaling Networks
  - Neural Modeling
  - Informatics
  - Structure-based Design
- Manufacturing Science and Technology
  - Advanced Machine Processes for Microfabrication
  - Model Based Manufacturing
  - Rapid Prototyping
  - Electronic Fabrication
  - Electronic Packaging

Conclusions

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