Heavy Ion Radiation Effects Microscopy

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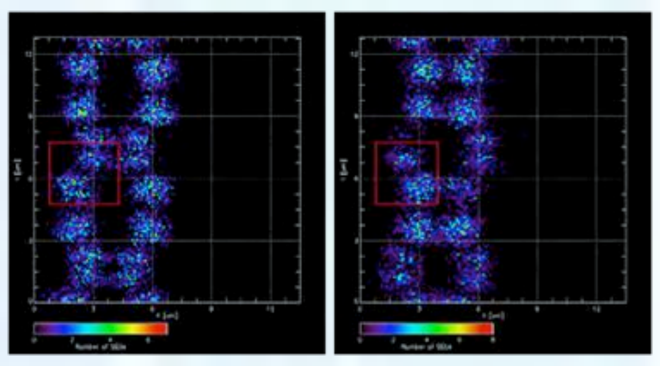
Problem

Background

Advancing IC technology is hindering our ability to microscopically study radiation effects

Radiation Effects Microscopy

Typical single event upset (SEU) map showing upset locations in SRAMs depends on the state of the memory cell

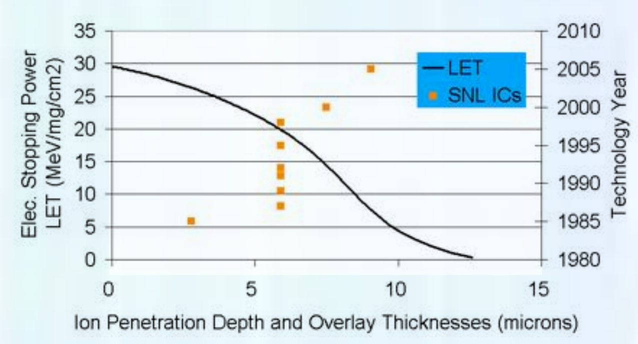


All 0s All 1s

- Radiation effects microscopy (REM) – used to engineer radhard ICs by pinpointing radiation intolerance to single-event effects
- Traditional REM uses focused, scanned microbeam from ion accelerator

Developing IC Technology

50 MeV Cu on IC

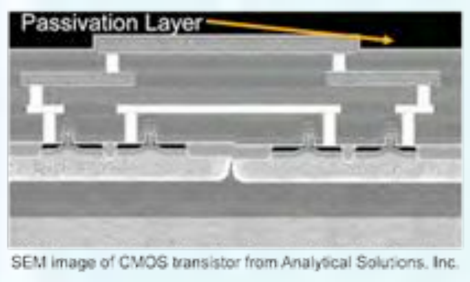


- New technologies continually increase the overlayer thickness on ICs, limiting our ability to probe the active region and study the devices using the tandem.
- Current Sandia technology has 9 µm of overlayers, which is generations behind industry and will continue to increase

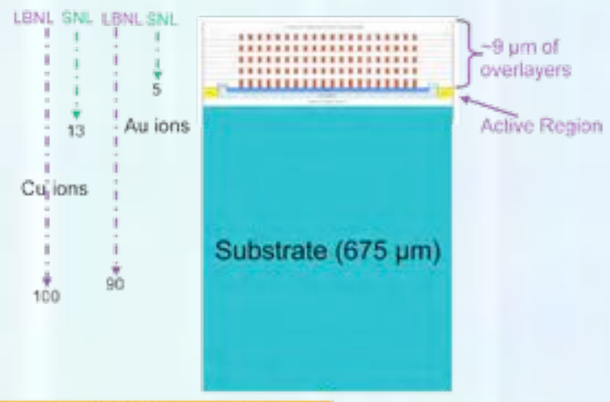
Project Goal

Require high-energy heavy ions to penetrate overlayers with sufficient linear energy transfer (LET) for REM studies

- Metal, dielectric and passivation layers (as well as flip-chip) → hundreds of microns of material → only high-energy ion beams can penetrate
- Current GeV ions from cyclotron: a potential solution, but extremely hard to focus due to high magnetic rigidity and poor energy resolution



SEM image of CMOS transistor from Analytical Solutions, Inc.



- Goal: To develop a REM technique which allows for the range/LET of a heavy ion cyclotron beam with the spatial resolution of a microbeam

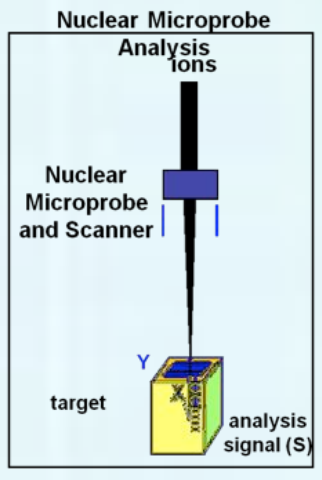
Approach

Hypothesis

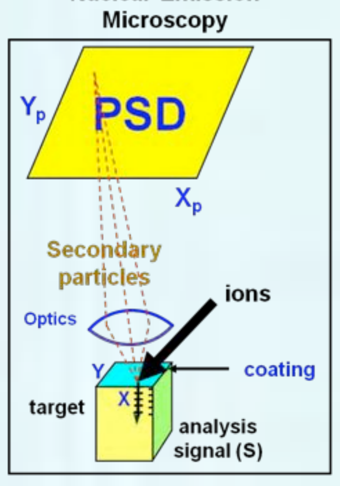
Instead of traditional nuclear microprobe analysis (focused, scanned ion beam), use a form of nuclear emission microscopy

- Use secondary particles (photons) emitted from the location of the ion impact to determine the position of the ion
- Rely on photons and the ion beam induced charge (IBIC) to image radiation sensitivity

Nuclear Microprobe Analysis



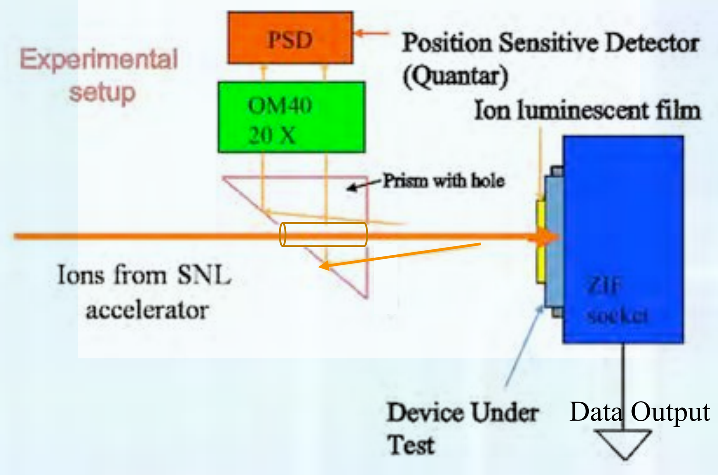
Nuclear Emission Microscopy



IPEM Technique

Developed IPEM system on nuclear microprobe line on SNL's tandem accelerator

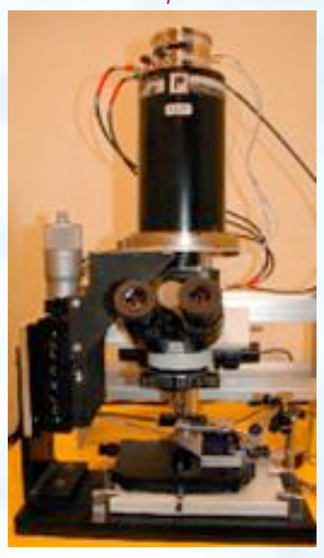
- Ions have two major interactions
  1) Ions hit luminescent film and get ion beam-induced luminescence (IBIL)
  2) Ions hit chip and create ion beam induced charge (IBIC) and possibly upsets
- Photons produced by film detected with single photon position-sensitive detector (PSD)
- Record photon and IBIC signals in coincidence

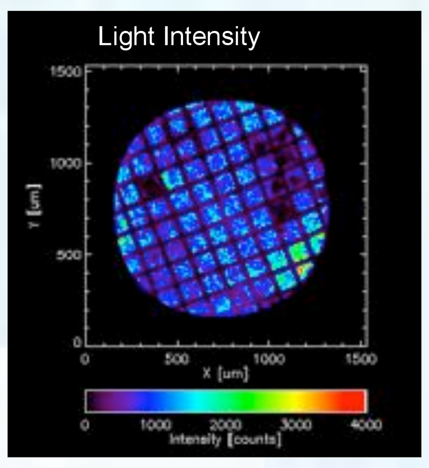


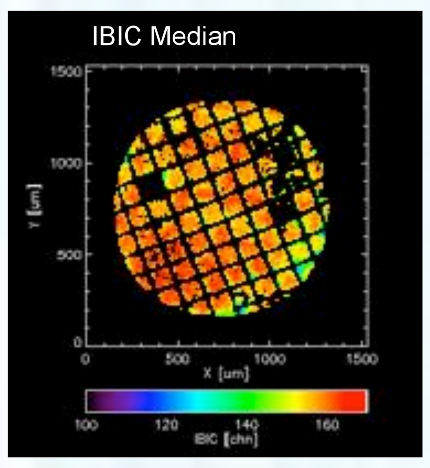
Results

This tabletop version of the IPEM was used for proof-of-concept and to study various luminescent materials

Tabletop IPEM



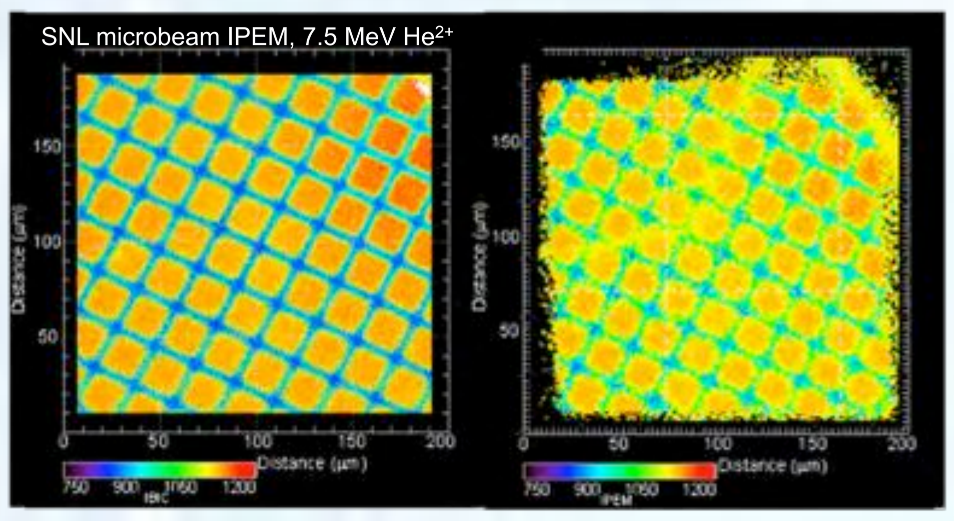




- **Pros**: Simple design/implementation, easy for basic materials studies
- **Cons**: Limited ion penetration, no single event effects

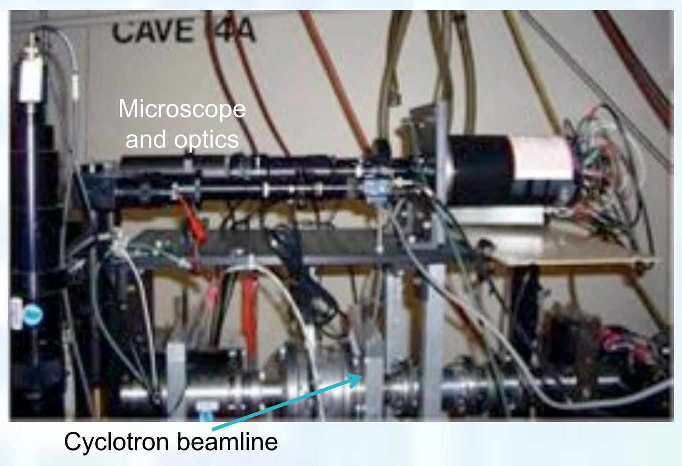
Development for Heavy Ions – Accelerator at SNL

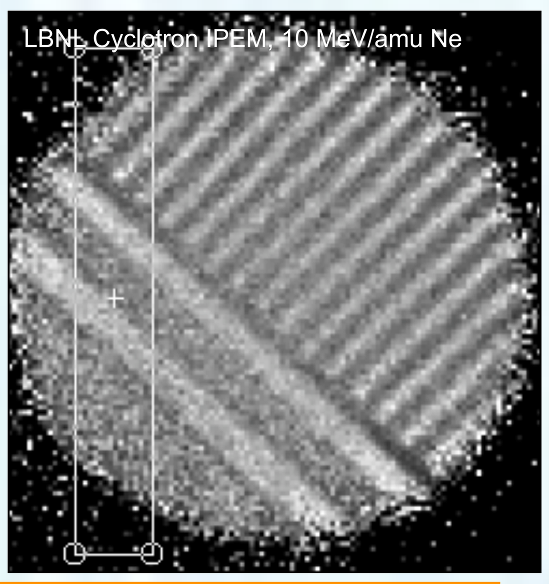
- IPEM system installed on SNL's tandem accelerator
- Sample: Diode + 1000 mesh TEM grid + 5 µm GaN film
- IBIC (left) and IPEM- IBIC (right) images
- Signal from diode put in coincidence with photons arriving at detector
- See damage, cracks in GaN



- **Pros**: Various ions/energies, Best spatial resolution achieved (~2.5 µm)
- **Cons**: In a vacuum chamber, limited ion penetration

Development for High-energy Heavy Ions – 88" Cyclotron at LBNL



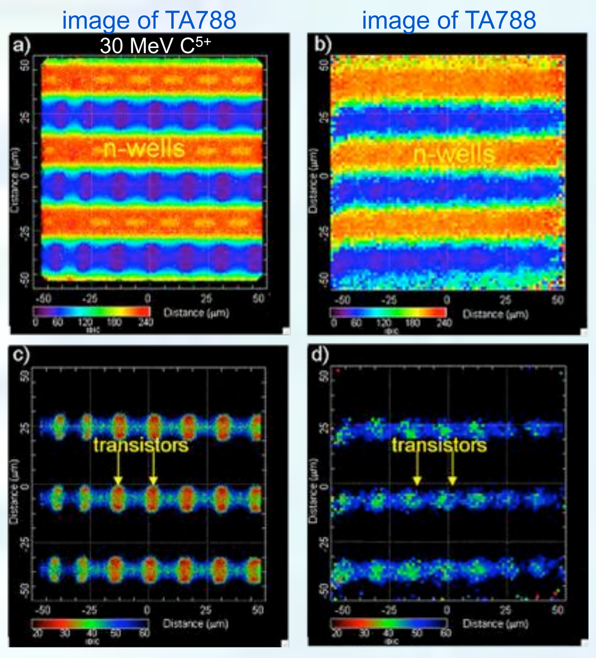


- **Pros**: Great ion penetration depth with high LET, Easily change ion species; In-air operation
- **Cons**: Remote automation, Limited facilities/time, Still being developed/optimized

Significance

Focused beam IBIC and IPEM IBIC from SNL

SNL microbeam IBIC image of TA788 SNL IPEM/IBIC image of TA788



- Future of heavy ion radiation effects microscopy depends on developing scanned microbeams and/or emission microscopes that can be easily used on cyclotrons
- IPEM provides a reasonable solution, and its continuing progress is promising
- The cyclotron IPEM has been installed and is operational

- With IPEM, we can study any structure with high energy heavy ions with ~5 µm resolution to obtain radiation effects information deep into the active region of devices

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