SAND2012-2262P

Investigation of Ion Induced Radiation Effects in Semiconductor Device IAEA CRP #11016 SNL's approach and potential contribution

Gyorgy Vizkelethy
Sandia National Laboratories

SNL collaborators: Robert Fleming, Edward Bielejec, Darwin Selkirk

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

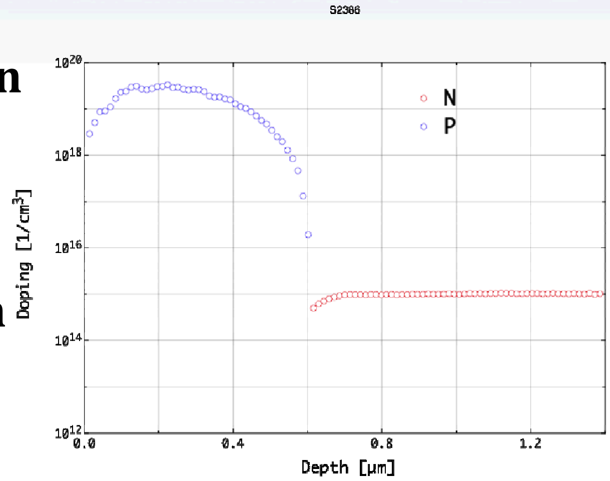
The goals of the CRP

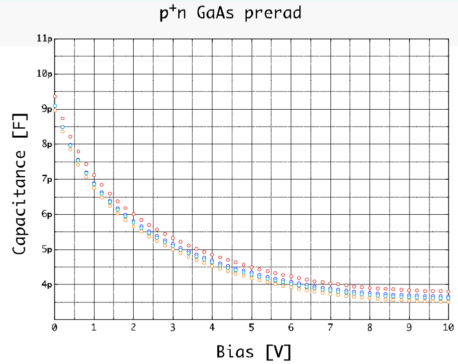
- **To gain deeper understanding how defects are created by MeV ion irradiation in semiconductors and how they affect the electrical properties of these materials**
  - Use IBIC/TRIBIC and other non ion beam methods (such as DLTS, PL, electrical characterization) to characterize damage in various semiconductor materials created by MeV ions
  - Develop models for the ion beam interactions with semiconductor materials and for IBIC/TRIBIC in these devices and validate these models
  - Establish an experimental protocol for the the damage characterization to make us able to compare result from different laboratories

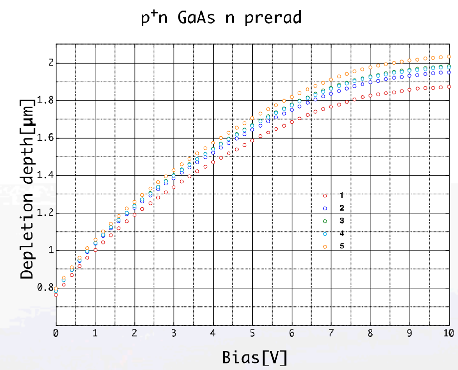
Sandia National Laboratories

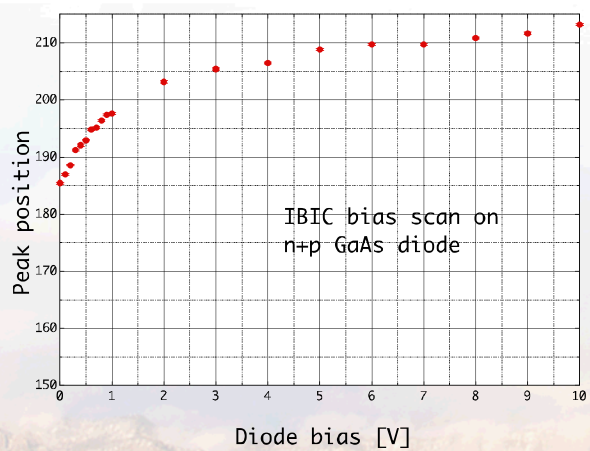
Pre characterization of the devices

- **Structural characterization (doping profiles, etc.)**
  - SIMS, spreading resistance, C-V
- **Electrical characterization**
  - C-V, I-V
- **Defect structure characterization**
  - DLTS
- **Other physical parameters**
  - For example PL for lifetime
- **IBIC/TRIBIC characterization**
  - MeV He or H beam



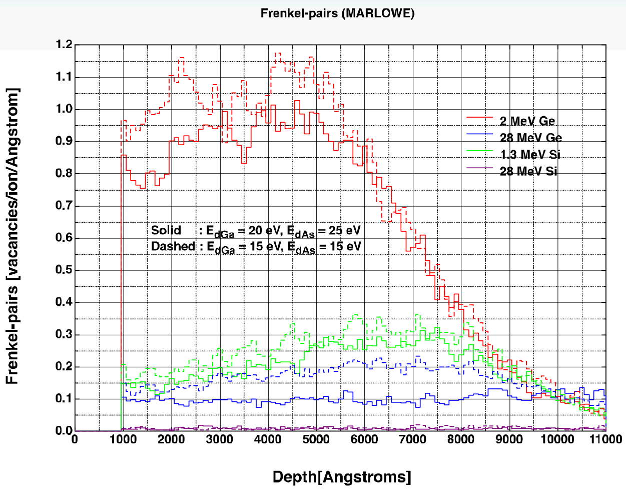


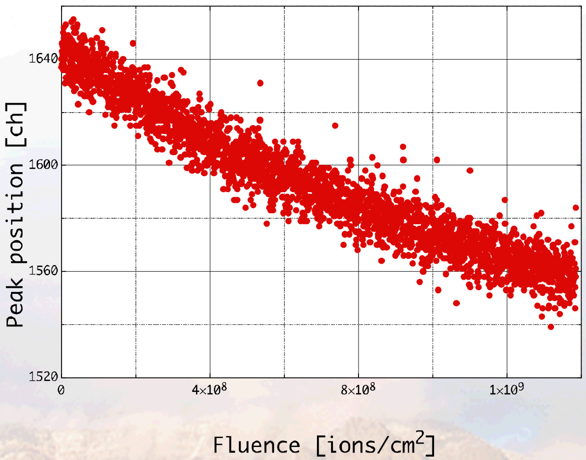




Irradiation

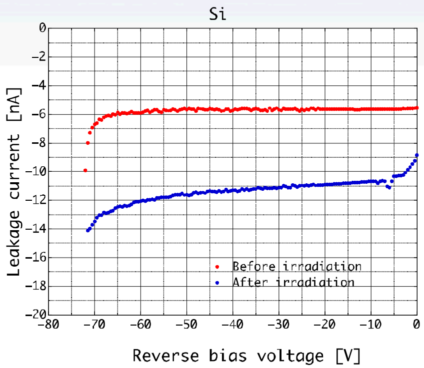
- **What kind of ion and what energy**
  - High energy ions produce uniform damage near the surface
  - Low energy ions have damage peaked at end of range
  - Heavy ions – clusters
  - Light ions - point defect
- **Raster or broad beam**
  - Broad beam – possible uniformity problem, uses up a whole device
  - Rastered – small area good for IBIC but bad for bulk techniques (DLTS)
- **In situ IBIC**

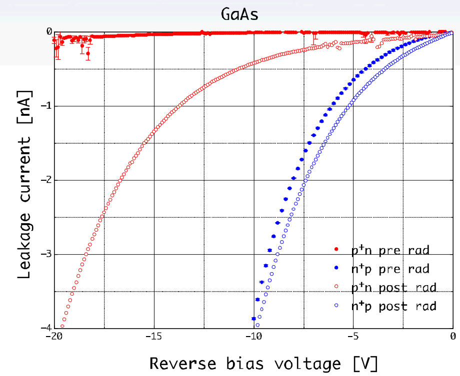


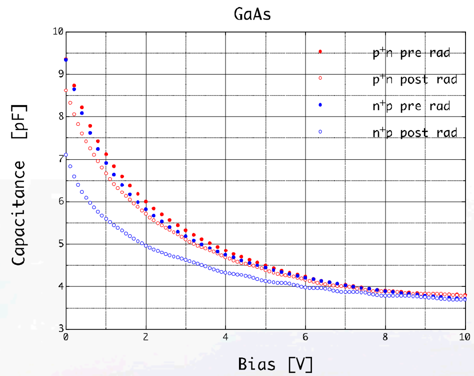


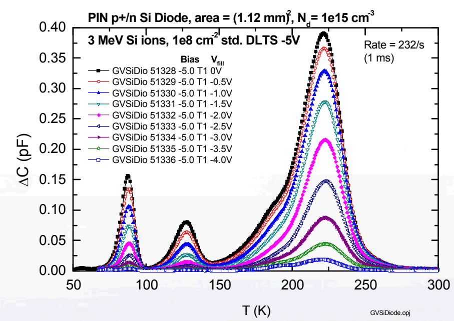
Post characterization non -IBIC

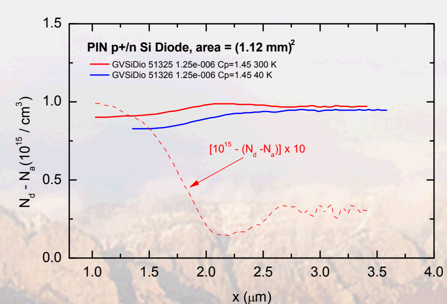
- **I-V**
  - Increasing leakage current
- **C-V**
  - Change in capacitance indicates charge trapped in defects
- **DLTS**
  - Identify defects, depth distribution, trapped charge

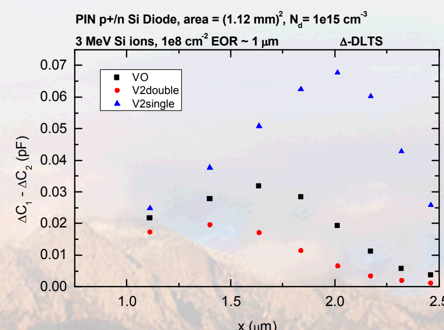








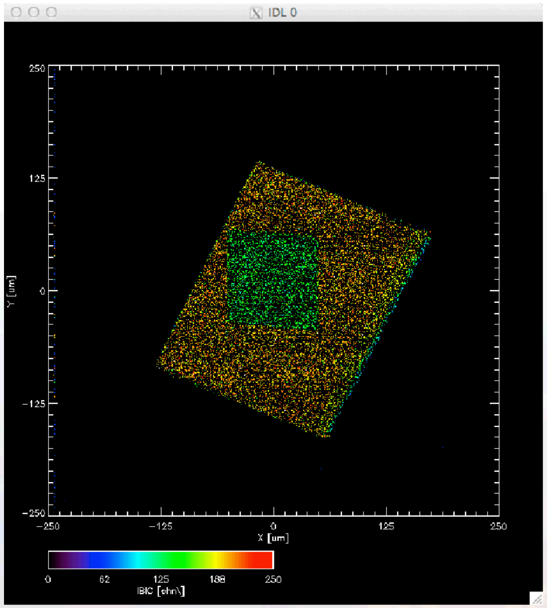


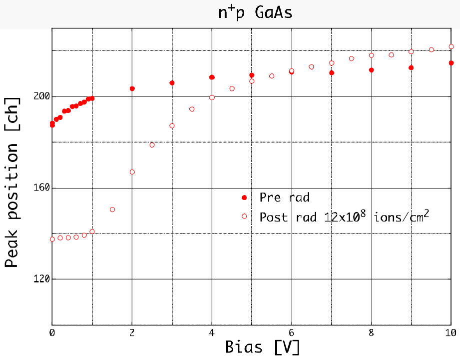


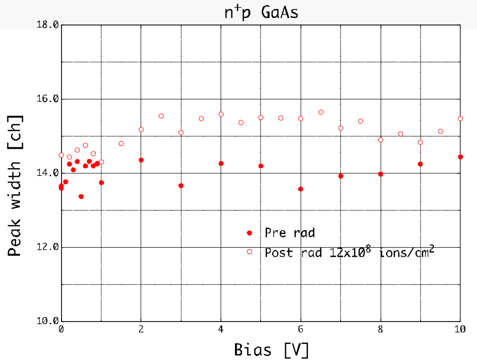
Sandia National Laboratories

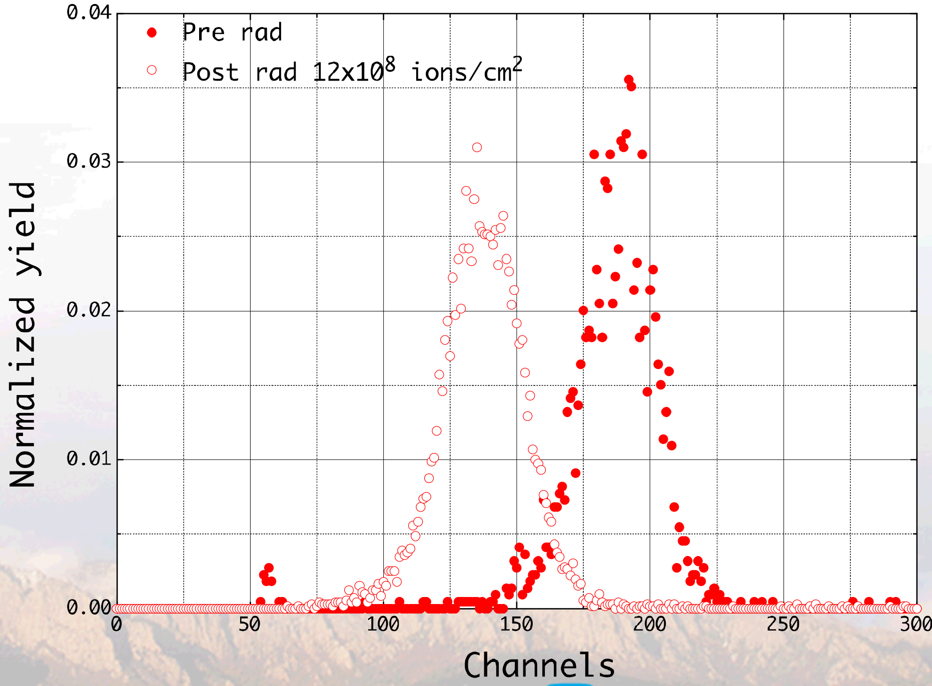
Post characterization IBIC

- **Changes in peak position, peak width, 2D maps**









Sandia National Laboratories

Modeling: Ion-Solid Interaction

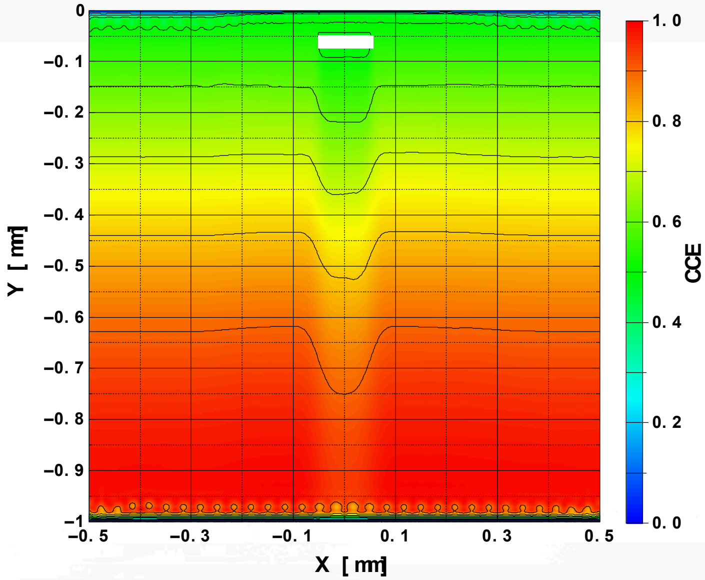
- **Binary Collision Approximation Codes**
  - Can handle high energies, needs parameters (displacement energy)
    - MARLOWE: crystals, polycrystalline and amorphous materials, not user friendly but quite precise and sophisticated
    - SRIM: only amorphous materials, very easy to use, over estimates damage, good for quick calculations
- **Molecular Dynamics Codes**
  - Low energies and small crystals, but needs fewer parameters, more first principle approach than BCA
    - Most codes are home grown although there are some that are more widespread (for example SNL's LAMMPS)

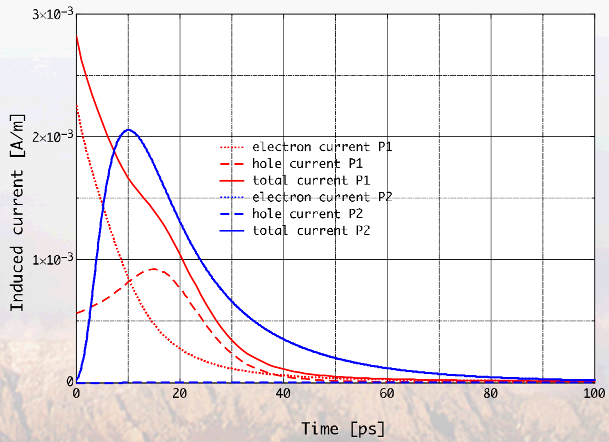
Modeling: Defect physics

- **Density Functional Theory (DFT) and its variations**
  - Calculates energy levels, etc.
- **Kinetic Monte-Carlo, Drift-Diffusion models**
  - Defect evolution

Modeling: IBIC/TRIBIC

- **Drift-diffusion model with stationary defects and application of Gunn's theorem (maybe the adjoint method when applicable)**
  - TCAD (expensive, no source code)
  - Some finite element software (COMSOL), needs to develop own model but more flexible
  - PISCES, or other codes to calculate electric fields





Sandia National Laboratories

SNL's capabilities

- 6 MV tandem van de Graaff with a heavy ion microprobe (<1 μm) for IBIC/TRIBIC and irradiation
- 3 MV single ended Pelletron with light ion microprobe (~ 100 nm) for IBIC/TRIBIC
- Several other implanters < 300 keV
- DLTS, PL, electrical characterization
- Modeling: MARLOWE, SRIM, COMSOL, > 80 CPU Linux cluster in the department, home grown 1D drift-diffusion code with defect evolution
- Available expertise (others than included in the project) for MD and DFT
- TEMs (one connected to the tandem) and SEMs (one on microbeam chamber) are available

Summary

The SNL team has the resources and expertise to successfully participate in the IAEA CRP #11016 and we are looking forward to collaborate with the other participants.