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Modeling Single Event Effects in GaAs and GaN Devices from 14 MeV Neutron-Induced Photocurrent Pulses

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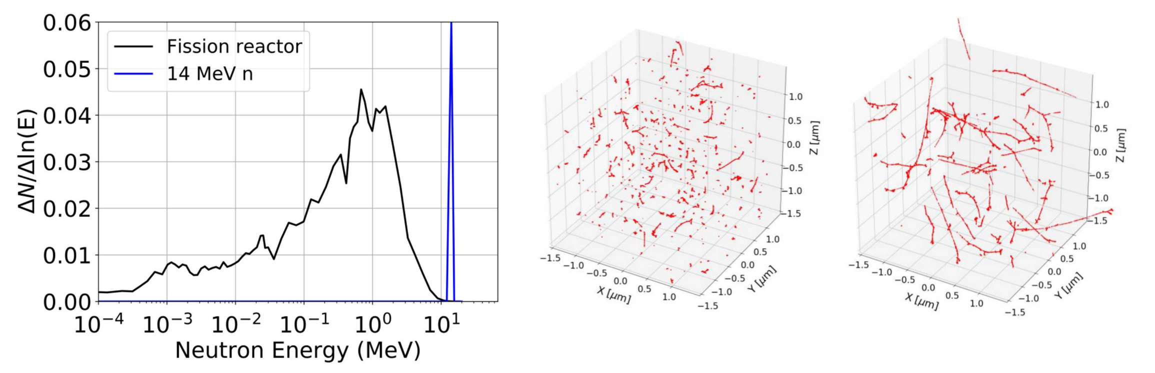
Introduction

Abstract: Recoils from 14 MeV neutrons impinging on Gallium Nitride (GaN) diodes and Gallium Arsenide (GaAs) heterojunction bipolar transistors (HBTs) were modeled and verified. Single recoil events were observed by measuring recoil photocurrent pulses. Good agreement was found between experiment and model.

- GaN and GaAs are favored in radiation hardness applications due to wide band gap, high critical breakdown field, high displacement energy
- 14 MeV neutron and recoil energy spectra vary significantly from conventional fission reactor spectra, requiring specific test environments
- Single event effects from ionization and deposited energy may lead to degraded device performance (stuck bits) or catastrophic failure (breakdown)
- Understanding energy response of neutron recoils in the device is critical to accurate predictive capabilities of device performance



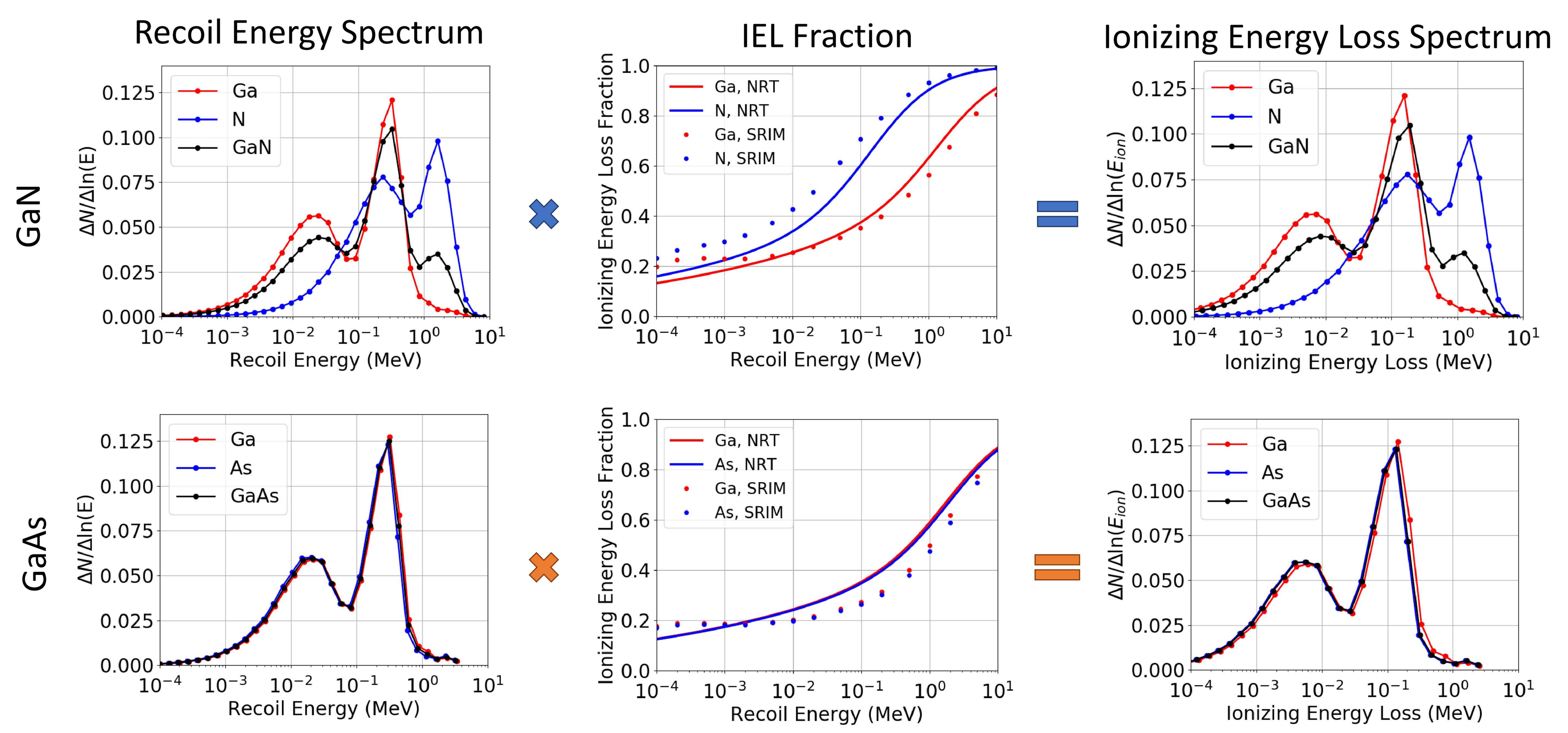
(left) Comparison of fission reactor spectrum to 14 MeV neutron spectrum. Recoil cascade simulations for fission spectrum (center) and 14 MeV neutrons (right). Fission reactor data from [1]

Model

- Nuclear reaction channels with 14 MeV neutrons modeled using EMPIRE code
- Compiled calculations yield recoil energy spectrum deposited into material from multiple channels
- Dominant reactions:
  - Elastic scattering (lower energy peaks); inelastic scattering, (n,2n) (higher energy peaks)
  - Minimal additional energy deposited into material from secondary charged particles
- Recoil energy ⇒ ionizing energy loss (IEL) fraction f_{IEL} in material via NRT model (or SRIM)

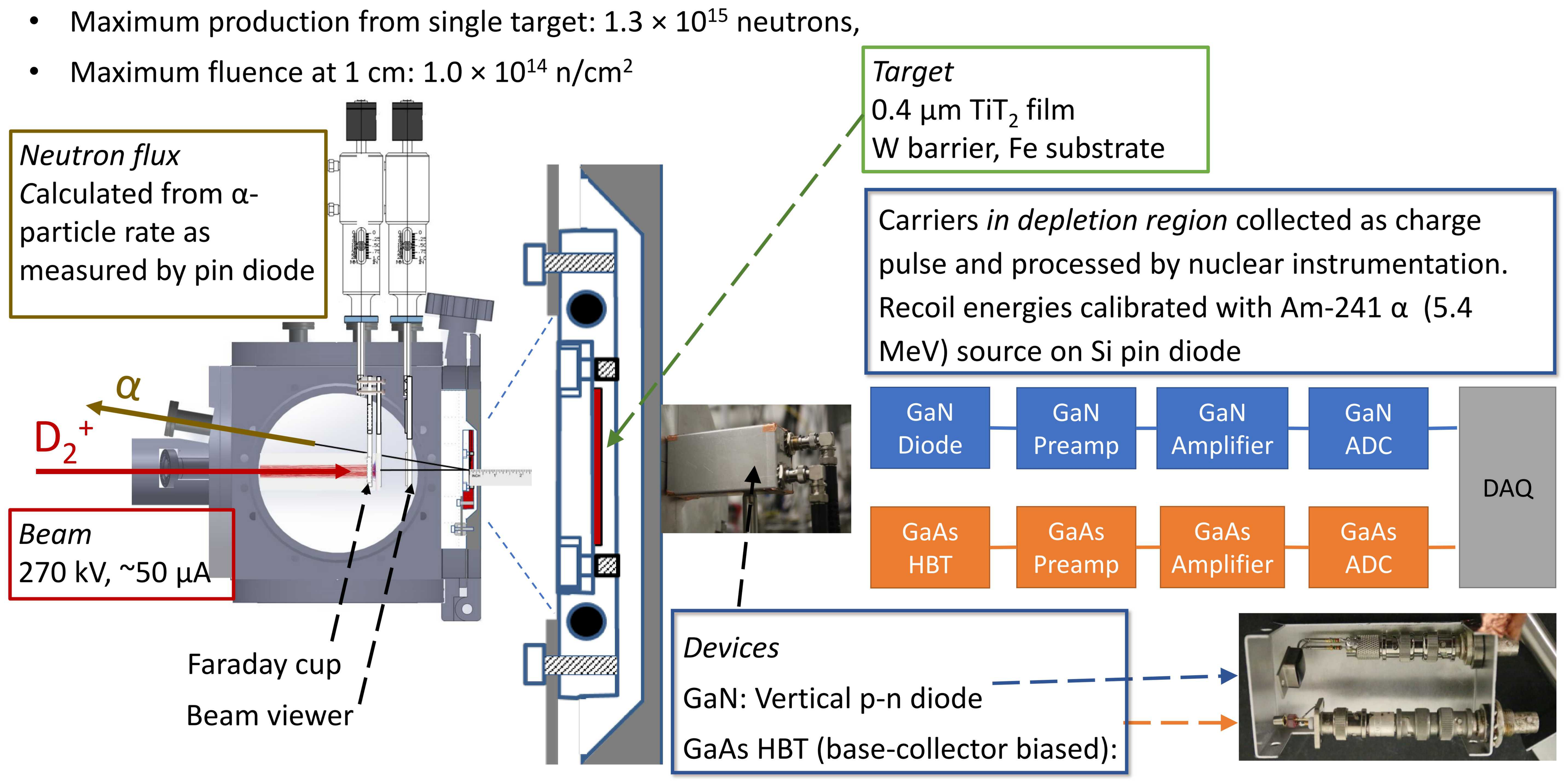
$$E_{ion} = E_{recoil} \cdot f_{IEL}(E_{recoil})$$

- **Result of IEL: downshift recoil spectrum in energy while relative probabilities $\frac{\Delta N}{\Delta E}$ remain unchanged**

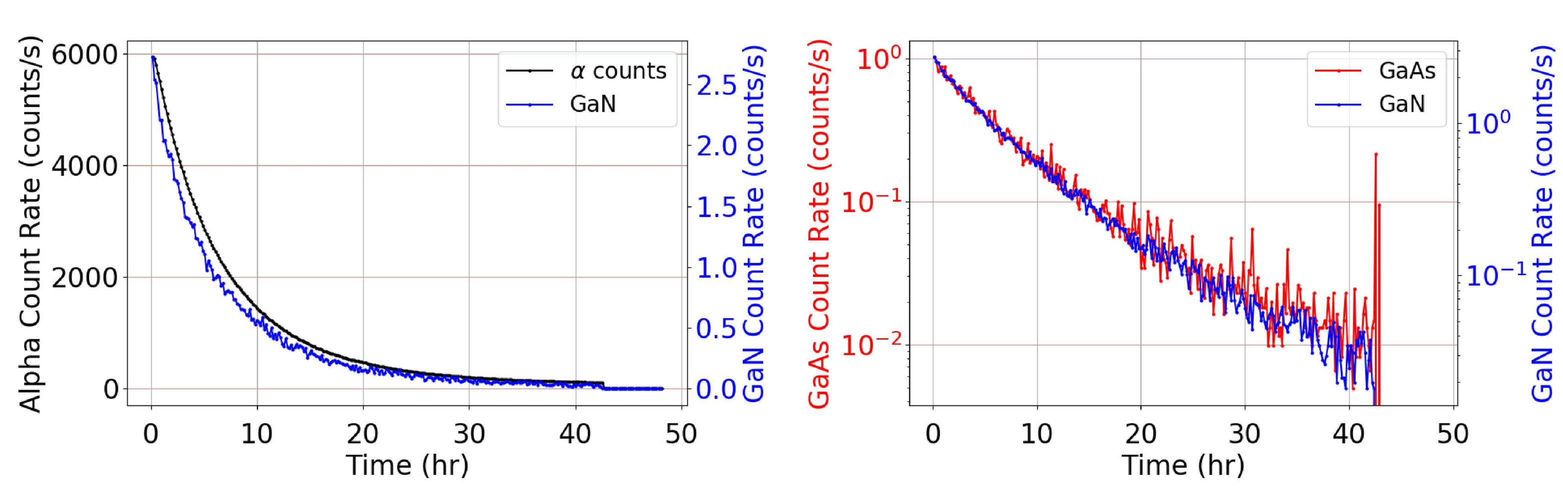


Experiment

- 14 MeV neutrons produced from D-T fusion reaction using new DTn endstation on Sandia Ion Beam Lab HVEE Implanter
- Maximum production from single target: 1.3×10^{15} neutrons,
- Maximum fluence at 1 cm: 1.0×10^{14} n/cm^2

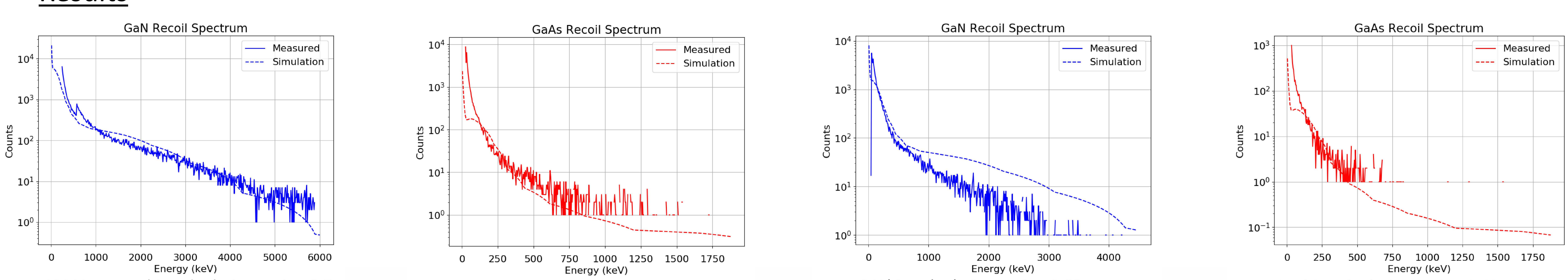


Verifying Neutron Recoil Detection



- Alpha count rate decay occurs due to beam (D)-target (T) isotope exchange, reducing available T in a single target:
- Neutrons and α's are produced at the same rate, recoils should obey similar rate decay
- Lower-level energy cutoffs (< ~200 keV, GaN, < ~50 keV, GaAs) are determined by filtering signals until device recoil detection rate matches the decay in the α count rate
- Low energy noise possibly from ambient gamma generation

Results



-100 V reverse bias, depletion region 2.5 µm
3.1×10^{12} n/cm^2, 174 hrs of runtime

-10 V reverse bias, depletion region 1.6 µm
6.3×10^{12} n/cm^2, 316 hrs of runtime

0 V bias, depletion region 0.60 µm
3.9×10^{12} n/cm^2, 176 hrs of runtime

0 V bias, depletion region 0.60 µm
3.0×10^{12} n/cm^2, 40 hrs of runtime

- GaN spectrum: matches within factor of 2 for E > 300 keV (29% of E_{ion} spectrum)
- GaAs spectrum: matches within factor of 2 for 100 keV < E < 750 keV (25% of E_{ion} spectrum)
- At low bias, high recoil energies (> 1 MeV, GaN; > 500 keV, GaAs) have ranges on the order of the depletion region. Mismatch in the high end of spectra likely due to energy deposition outside of depletion region.
- No permanent degradation in device performance by accumulated radiation damage confirmed by I-V measurement

Conclusions

- Accurate modeling of neutron photocurrent in energy regimes of >300 keV for GaN and >150 keV for GaAs
- Model accuracy strongly depends on the depletion of the device. Lower bias leads to loss of high-energy recoils
- Updated modeling is in progress to account for recoil cascades that escape or enter the depletion region mid-cascade

Acknowledgements

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References

[1] E. J. Parma, T. J. Quirk, et al., "Radiation Characterization Summary: ACRR-LB44-CC-32-cl", Sandia National Laboratories, Albuquerque, NM, USA, Sandia Report SAND2013-3406, Apr. 2013