Proton Recoils in GaN & Upcoming RF GaN Work

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Acronyms/Abbreviations

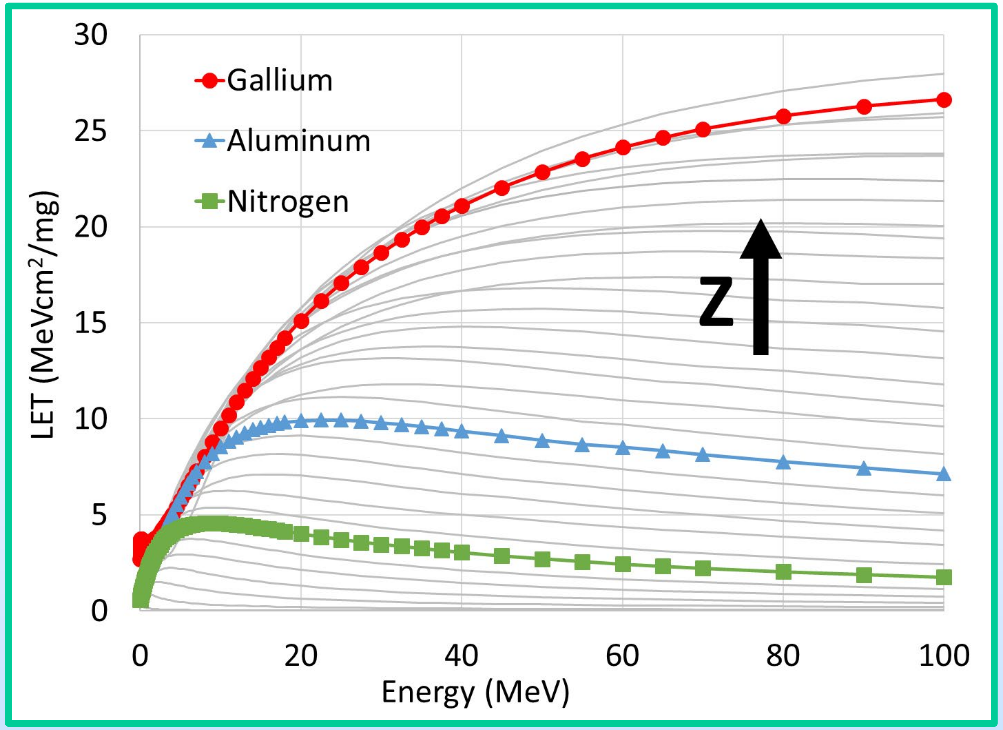
- AMP: Amplifier
- CIF: Center Innovation Fund
- COTS: Commercial Off The Shelf
- DC: Direct Current
- DDD: Displacement damage dose
- DUT: Device Under Test
- EMPC: Experimental and Mathematical Physics Consultants
- GSFC: Goddard Space Flight Center
- HEMT: High Electron Mobility Transistor
- LBNL: Lawrence Berkeley National Lab
- LLRF: Low Level Radio Frequency
- LET: Linear Energy Transfer
- MCNP: Monte Carlo N Particle
- NEPP: NASA Electronics and Packaging Program
- REAG: Radiation Effects and Analysis Group
- RF: Radio Frequency
- SEE: Single Event Effects
- SRIM: Stopping Ranges of Ions in Matter
- TID: Total Ionizing Dose

Outline

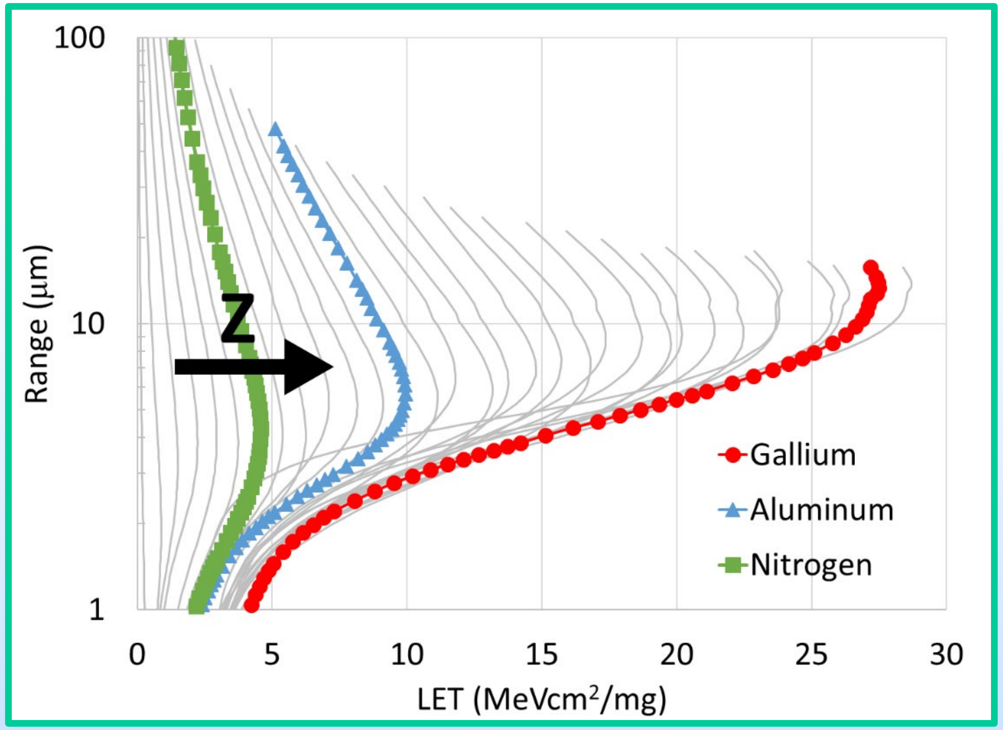
- Proton Recoils in GaN*
  - SRIM
  - MCNP
  - Results
  - Conclusion
  - Future work and implications
- RF GaN HEMTs
  - Motivation
  - DUT selection
  - Test bench
  - Challenges & Next steps

*All figures from J. Osheroff et al., "LET and Range Characteristics of Proton Recoil Ions in Gallium Nitride (GaN)," doi:10.1109/TNS.2021.3050980

Proton Recoils in GaN - SRIM



LET as a function of ion energy in GaN

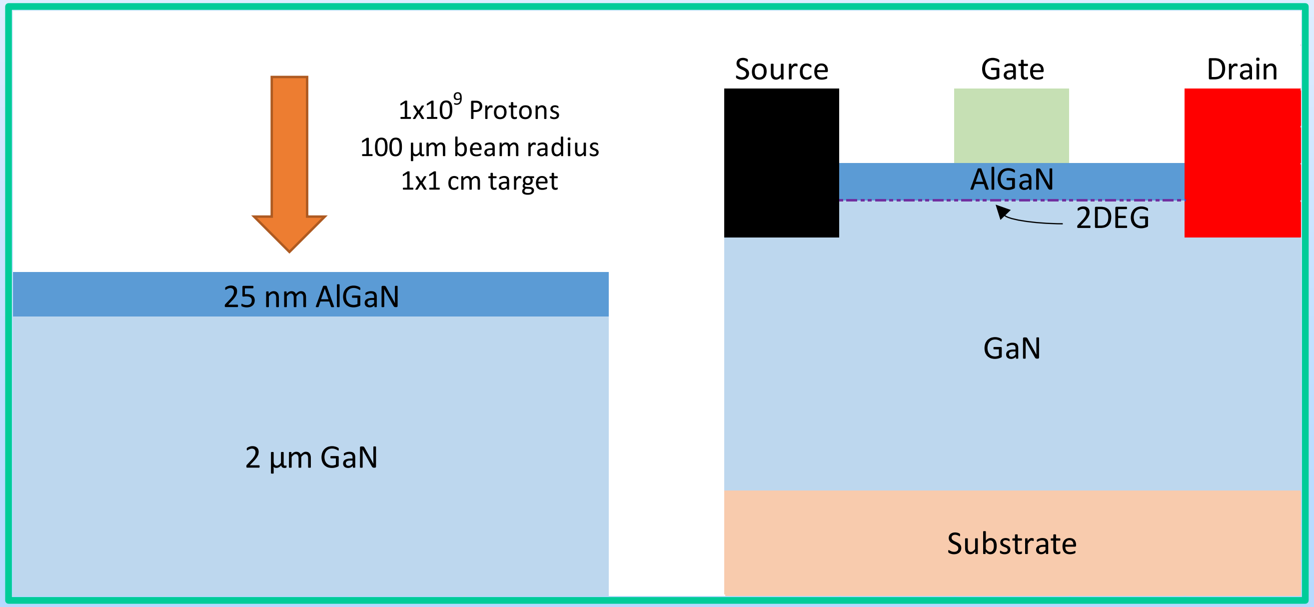


Range as a function of ion LET in GaN

- Stopping Ranges of Ions in Matter (SRIM) calculates the LET and range as a function of energy for a given ion species in a given material
- Hydrogen through Germanium* are all possible recoils

Proton Recoils in GaN - MCNP

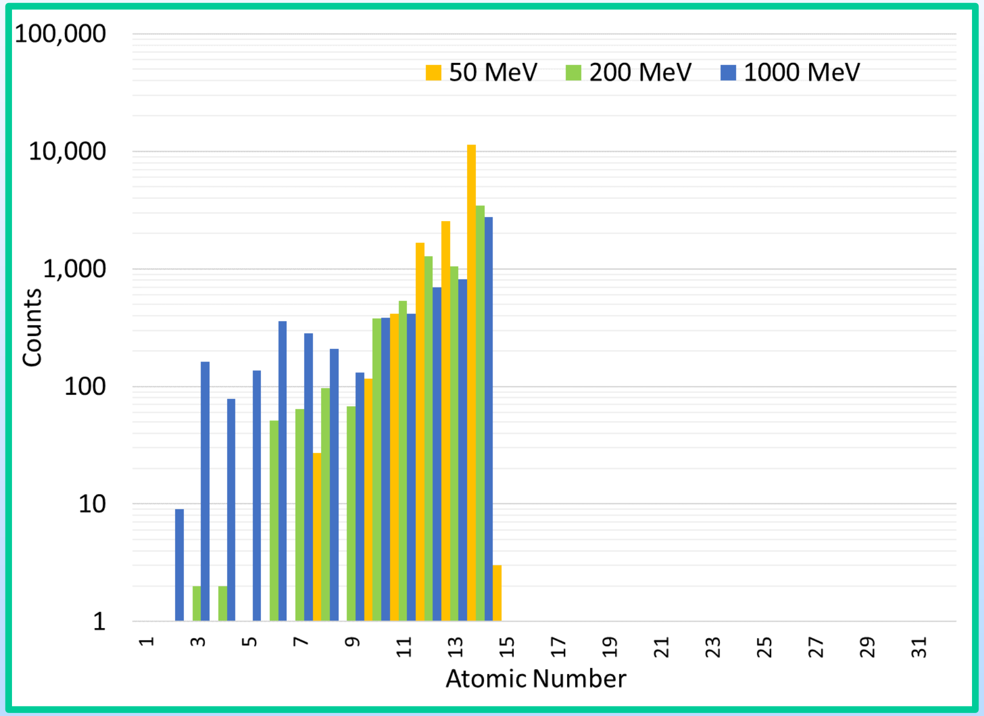
- MCNP simulations
  - $1x10^9$ incident protons at multiple energies 50-1000 MeV
  - Both GaN (see Fig. 3 below) and Si targets for comparison
  - Determine the actual populations of secondary recoil ions in GaN from proton irradiation
  - Determine the species and energy of each recoil



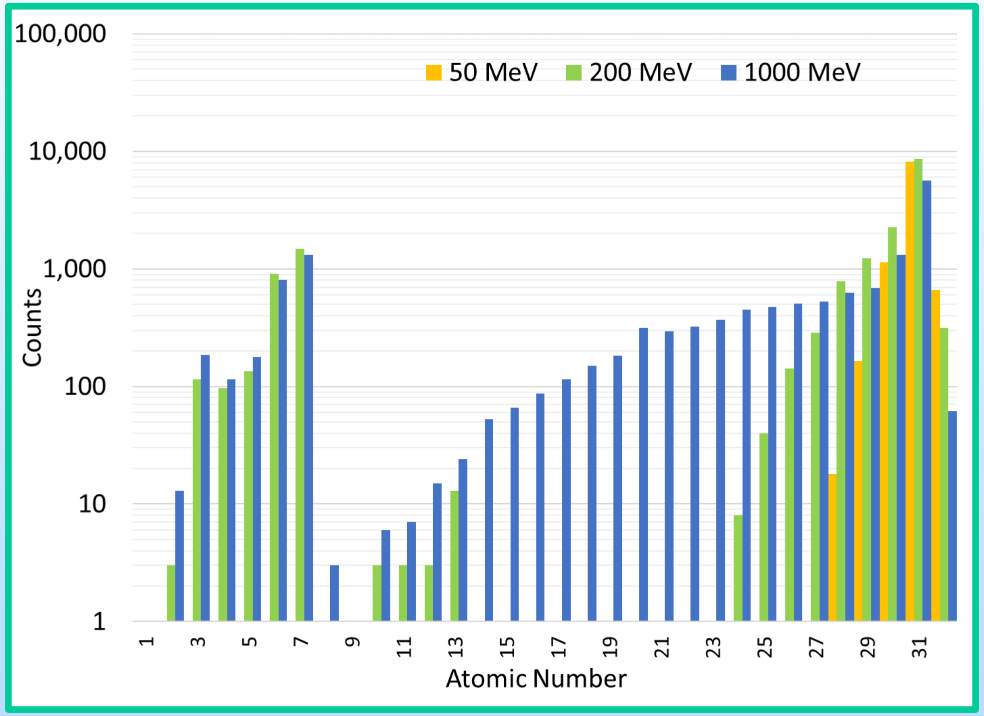
(left) Scenario for MCNPX simulations, including proton source and AlGaN/GaN target. (right) simple cross section of a typical GaN HEMT.

Proton Recoils in GaN - Results

- Higher Z ions present in GaN
  - Notable peaks around Si (N=14) for Si target
  - Notable peaks around N (N=7) and Ga (N=31) for GaN target



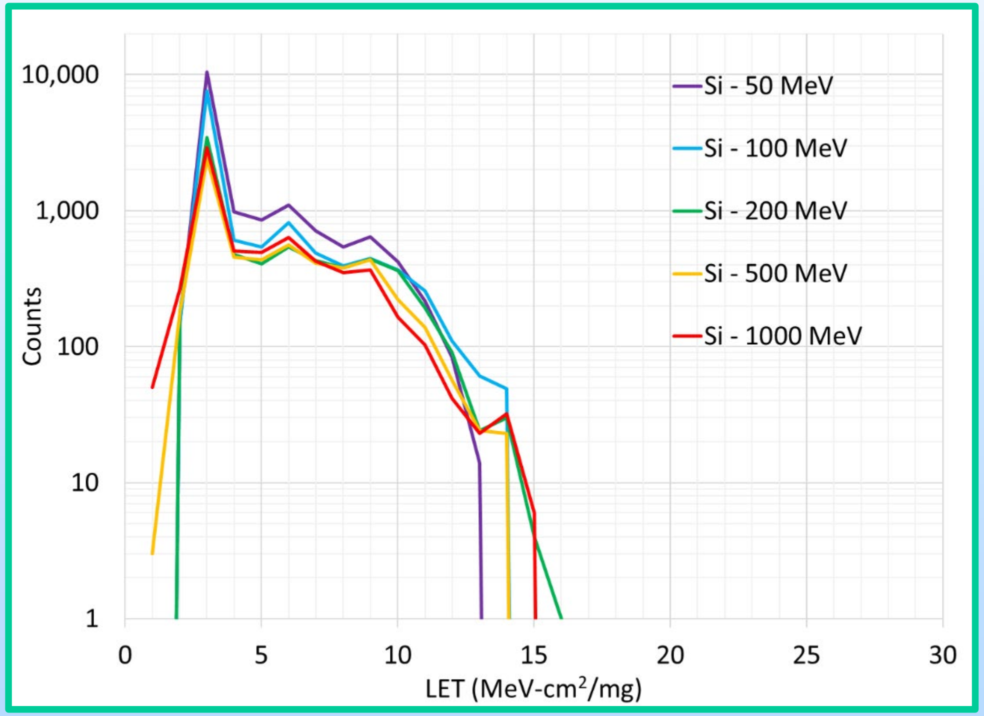
Recoil Ion population in Si for 50, 200, and 1000 MeV proton beams



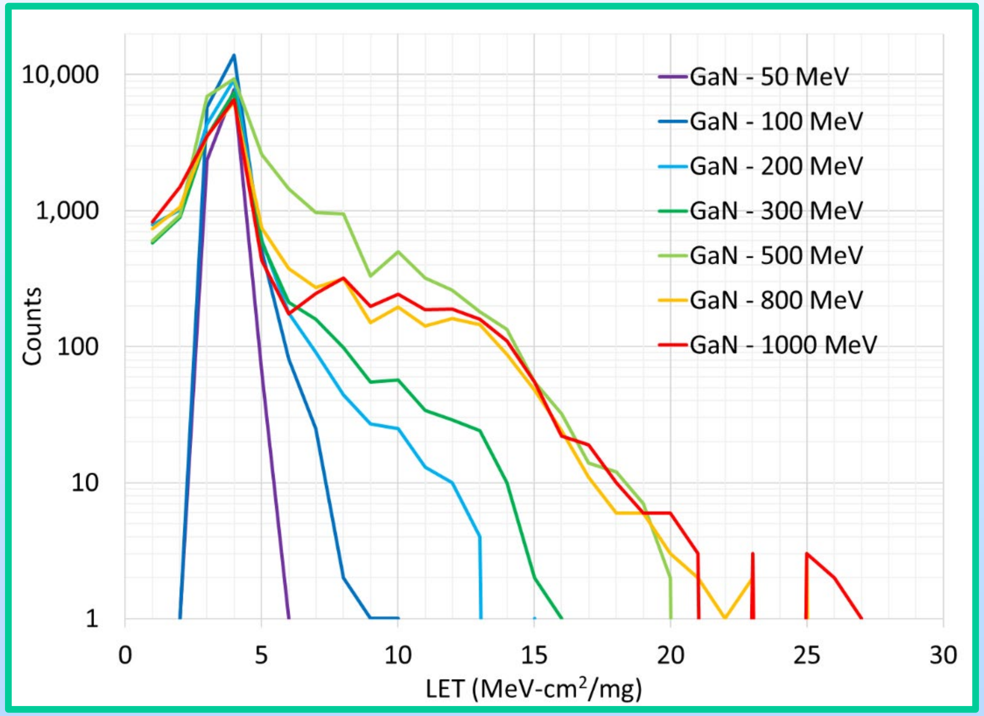
Recoil Ion population in GaN for 50, 200, and 1000 MeV proton beams

Proton Recoils in GaN - Results

- Recoil LET in Si is largely unaffected by incident proton energy between 50-1000 MeV
- In GaN, upper-end recoil LET increases with proton energy and exceeds that seen in Si, reaching up to ~27 MeV-cm^2/mg



LET of recoil ions in Si for various incident proton energies

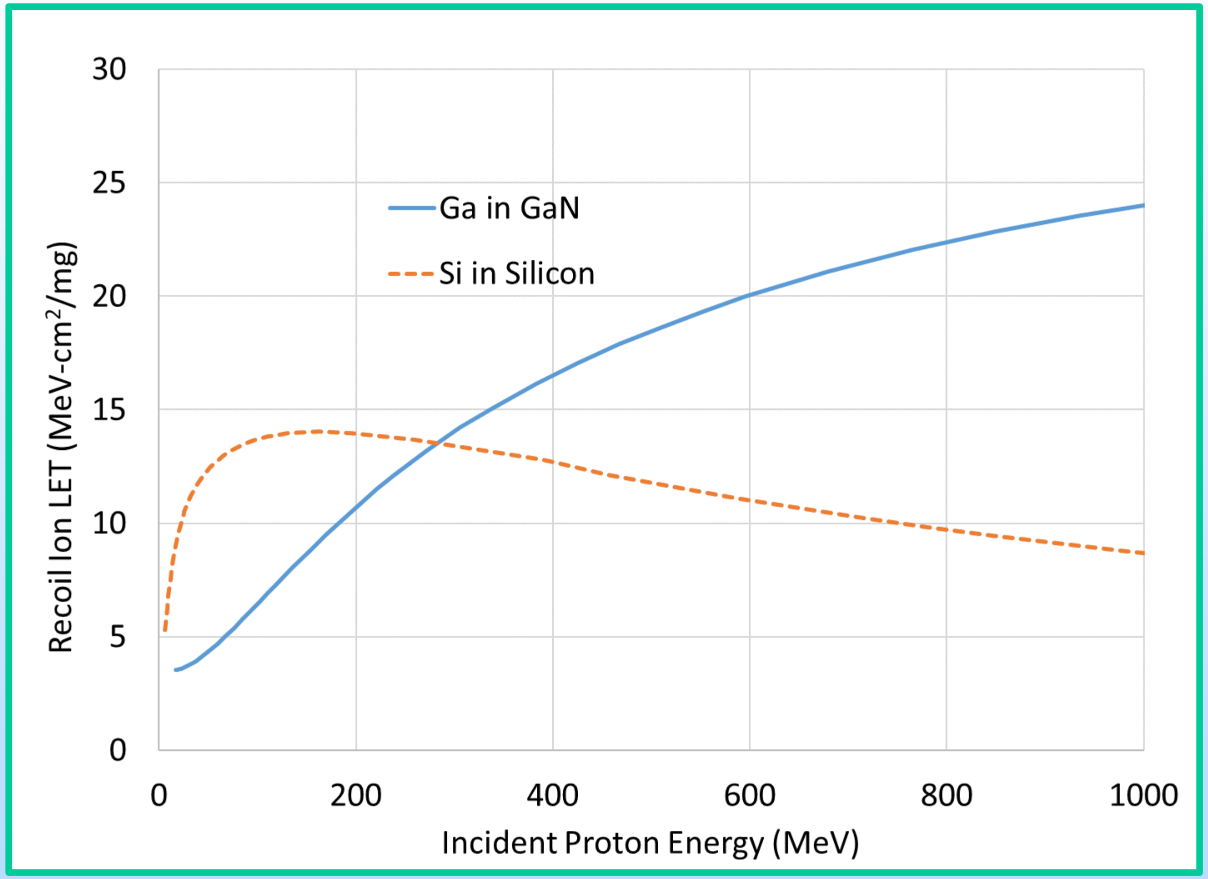


LET of recoil ions in Si for various incident proton energies

Proton Recoils in GaN - Conclusions

- Looking at individual recoil ions from the MCNP output we find that high LET recoils are dominated by elastic recoils

- Similar approximations can be made for GaAs, SiGe, diamond etc. based on target mass



Theoretical upper limit for Ga in GaN and Si in Si elastic "head-on" recoils

Proton Recoils in GaN – Future Work and Implications

- **Similar approximations can be made for GaAs, SiGe, diamond etc.**
- **High energy, high flux proton environments may pose an increased risk of SEE in GaN as opposed to Si**
- **In materials such as GaN that have high TID and DDD tolerance it may be possible to do proton SEE irradiations with a high enough fluence to achieve recoils with an LET of ~27 MeV-cm^2/mg**
- **Future work would include proton testing of known GaN devices with accompanying simulation (LET$_{TH}$ = 15-20 MeV-cm^2/mg with >500 MeV protons)**

RF GaN

RF GaN HEMT SEE testing – Motivation

- Worst-case radiation test conditions
  - RF mode vs. DC only
- Laser vs. heavy ion testing
- Device factors resulting in SEB susceptibility
  - Output power
  - Frequency range
  - Drain voltage

RF GaN HEMT SEE testing – DUT Selection

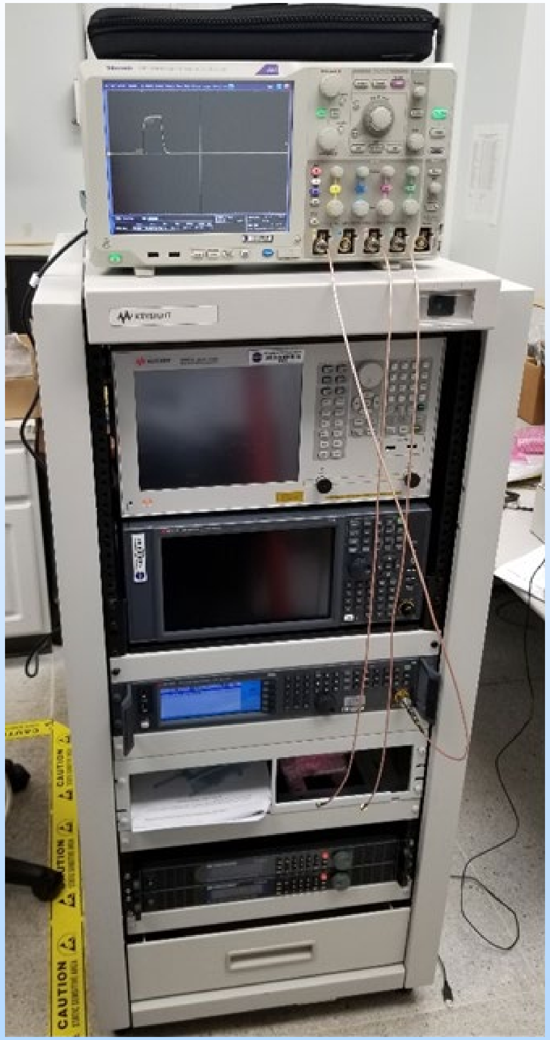
Table of Proposed Test Devices				
Manufacturer	Part #	Frequency Range (GHz)	V_{DS} (Volts)	Power (Watts)
CREE/Wolfspeed	CGHV59350F	5.2-5.9	50	450
CREE/Wolfspeed	CGHV59070F	4.4-5.9	50	76
CREE/Wolfspeed	CGH31240F*	2.7-3.1	28	240
CREE/Wolfspeed	CGHV40200PP	1.7-1.9 (up to 3)	50	218
Qorvo	QPA2237*	0.3-2.5	32	10

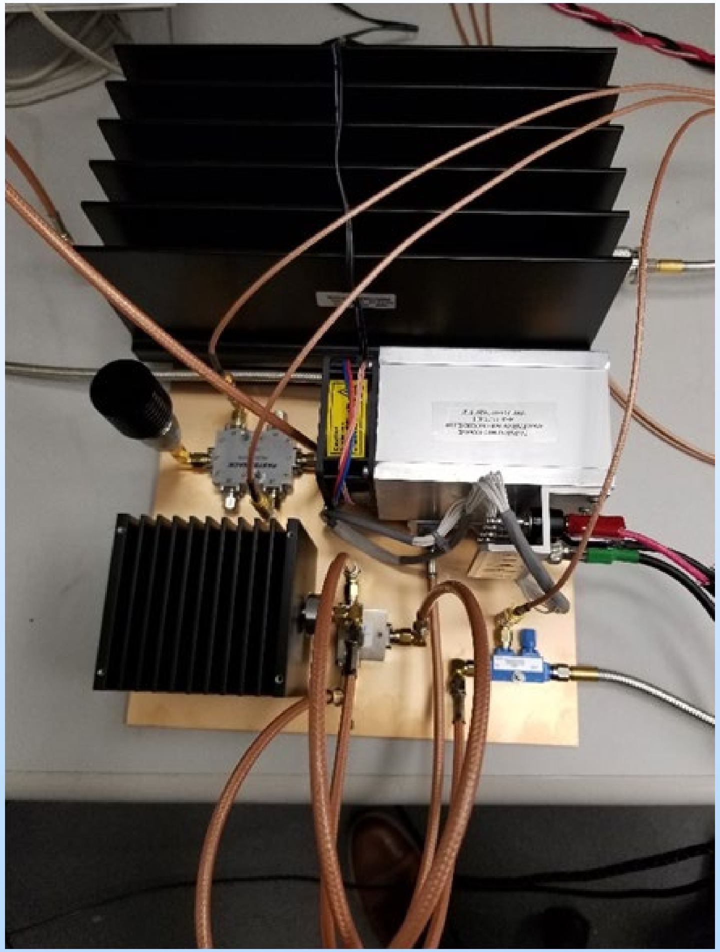
Table of proposed GaN HEMTs for SEE testing

DUTs selected to form matrix of voltage, frequency, and power properties

RF GaN HEMT SEE testing – Test Bench

- 2Gs/s Oscilloscope
- Network Analyzer
- Spectrum Analyzer
- LLRF Generator
- 2x Keithley 2400 series
  - DUT Gate
  - PRE-AMP control
- 2x BK Precision
  - High I for PRE-AMP Drain
  - High V for DUT Drain
- PRE-AMP
  - RF GaN HEMT technology!
- Various RF circuitry to deliver and dissipate power safely
- Data Acquisition system





RF test equipment at GSFC REAG Lab

RF GaN HEMT SEE testing – Challenges and Next Steps

- Cooling
  - Vibrational considerations for laser testing
    - Decoupled fan
  - Vacuum compatible cooling at LBNL
    - Liquid cooling
    - Power compatibility
- DUT acquisition for round 2 laser and heavy ion testing

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