Wide Band-Gap (WBG) and Power Device Testing Update 2022

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Special thanks to Jean-Marie Lauenstein

Acronyms/Abbreviations

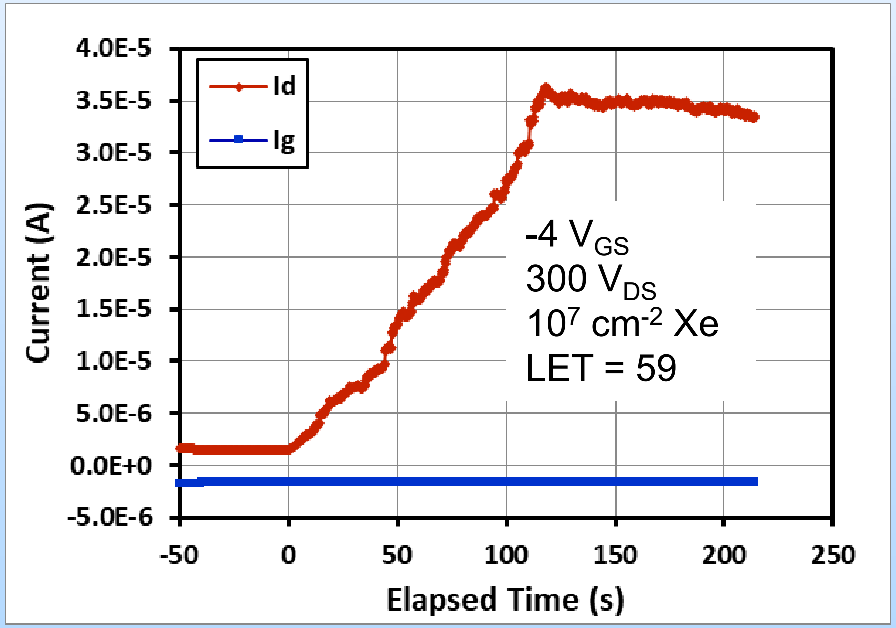
- AFRL: Air Force Research Laboratory
- AMP: Amplifier
- CIF: Center Innovation Fund
- COTS: Commercial Off The Shelf
- DC: Direct Current
- DDD: Displacement damage dose
- DUT: Device Under Test
- EPC: Efficient Power Conversion
- FET: Field Effect Transistor
- FLUKA: FLUktuierende KAskade/Fluctuating Cascade
- GEANT: GEometry ANd Tracking
- GSFC: Goddard Space Flight Center
- HEMT: High Electron Mobility Transistor
- HV: High Voltage
- JBS: Junction Barrier Schottky
- JEDEC: Joint Electron Device Engineering Council
- 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
- nSEE: neutron Single Event Effects
- NSRL: NASA Space Radiation Laboratory
- REAG: Radiation Effects and Analysis Group
- RF: Radio Frequency
- SEB: Single Event Burnout
- SEE: Single Event Effects
- SBIR: Small Business Innovation Research
- SRHEC: Strategic Radiation-Hardened Electronics Counsel
- SRIM: Stopping Ranges of Ions in Matter
- SSDI: Solid State Devices Inc.
- TAMU: Texas A&M University
- TID: Total Ionizing Dose
- TM: Test Method
- WANDA: Workshop for Applied Nuclear Data Activities
- WBG: Wide Band Gap

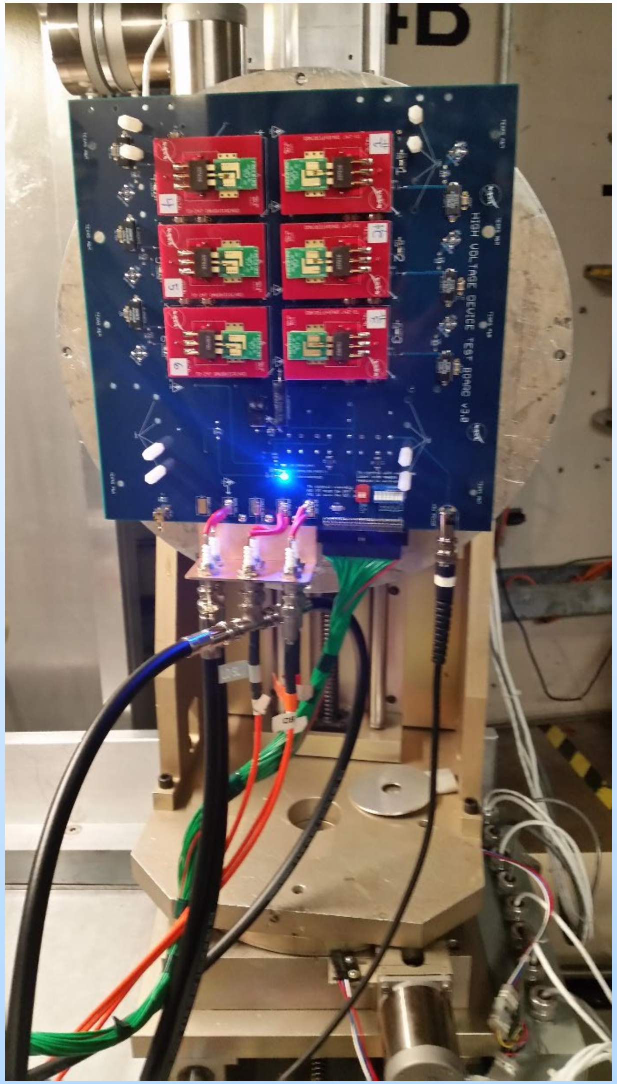
Outline

- Previous
  - EPC Space FBG20N18C & FBG30N04C
  - Microchip JANSR2N7593
- Ongoing
  - LogiSiC SiC Diodes
  - SSDI GaN
  - RF GaN HEMTs
- Future
  - AFRL β-Ga_2O_3
- NEPP WBG Community Updates
- New WBG Test Capabilities

EPC-SPACE Rad-Hardened GaN HEMTs

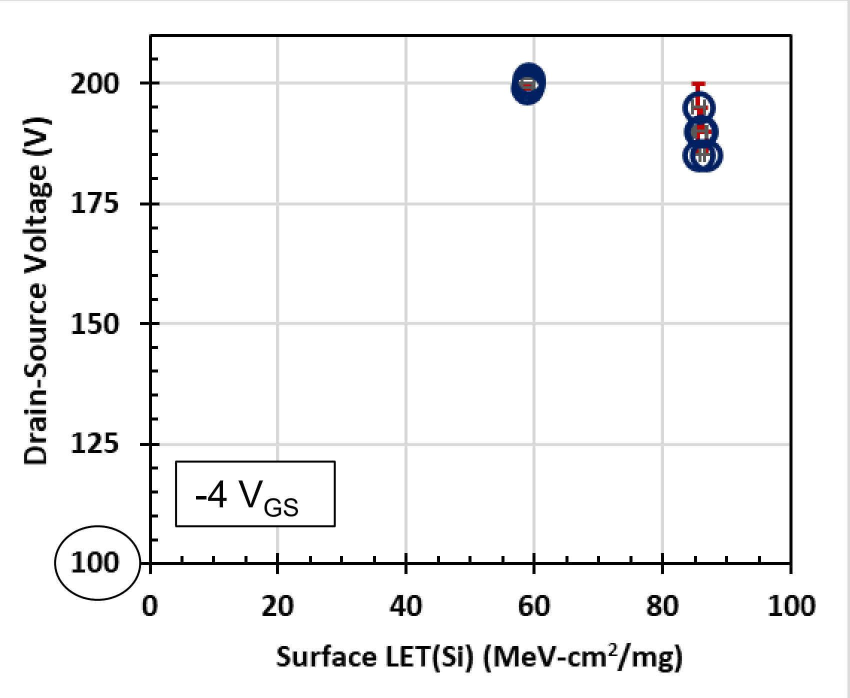
- **FPG30N04 (300 V, 4 A)**
  - No SEB at 300 V at LET=86 MeV-cm^2/mg
    - (10 MeV/u Au)
  - Leakage current degradation onset ~250 V
  - I_{DSS} remains in spec (increased by ~20 uA)



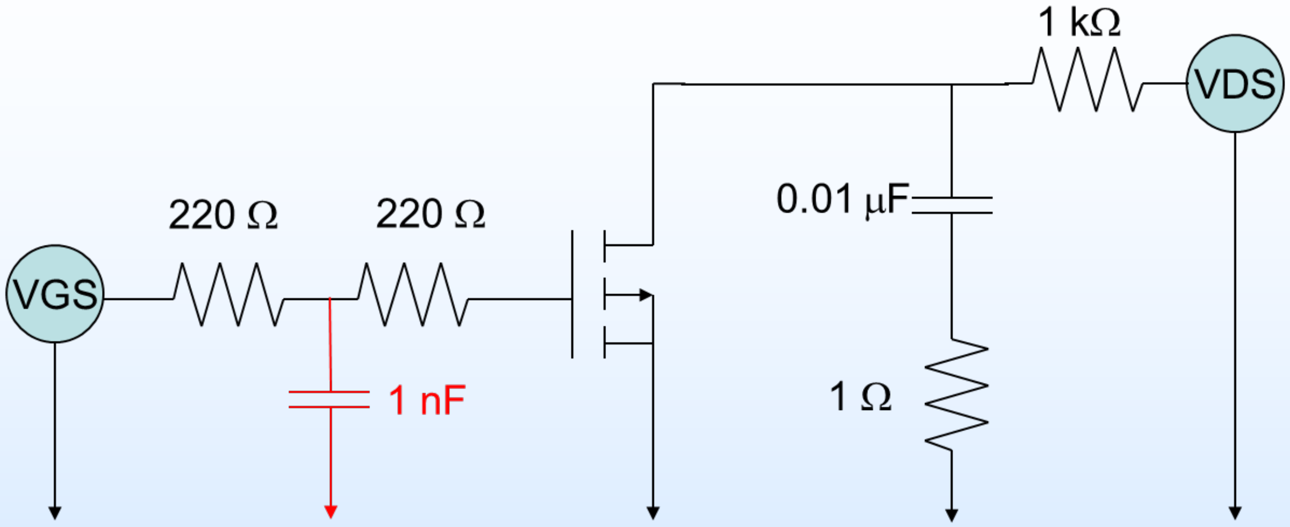


EPC-SPACE Rad-Hardened GaN HEMTs

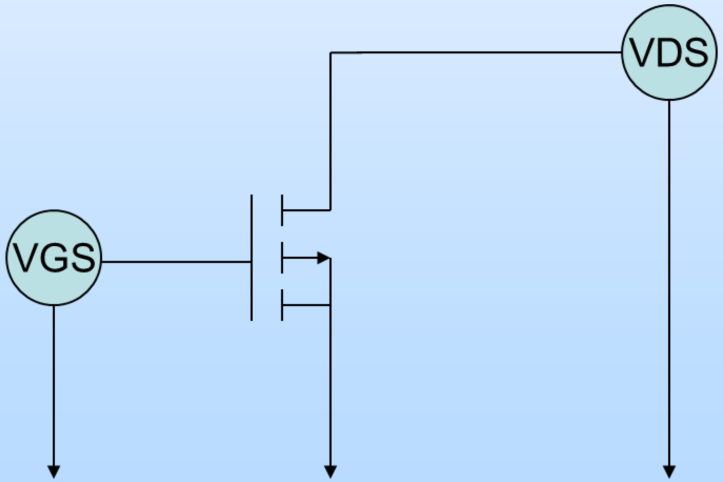
- **FPG20N18 (200 V, 18 A)**
  - **No SEB at LET = 59 MeV-cm²/mg**
    - (10 MeV/u Xe)
  - **SEB at 190 V at LET = 86 MeV-cm²/mg**
    - (10 MeV/u Au)
    - **No SEB at 185 V**
    - Part-part variability
    - **SEB threshold in agreement with EPC-SPACE setup**
  - Degradation differed between setups:
    - **No degradation with NASA setup**
    - **EPC-SPACE shows leakage current degradation**



Test Setups: NASA GSFC vs. EPC-SPACE



- **NASA-GSFC:**
  - MIL-STD-750, TM1080 circuit
    - Removed gate cap on some tests
    - Gate R issue: rising Ig can result in ΔV_{GS}
      - Irradiated at -4 V_{GS} to prevent device turn-on



- **EPC-SPACE:**
  - No gate filter, no stiffening cap
  - Was worst-case in this test campaign

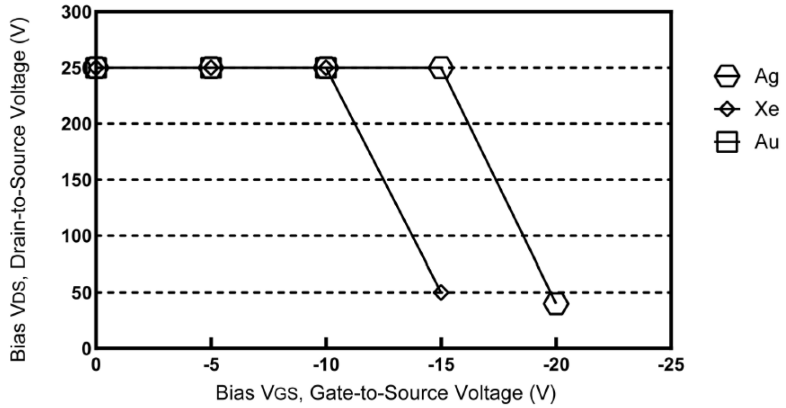
Microchip JANSR2N7593

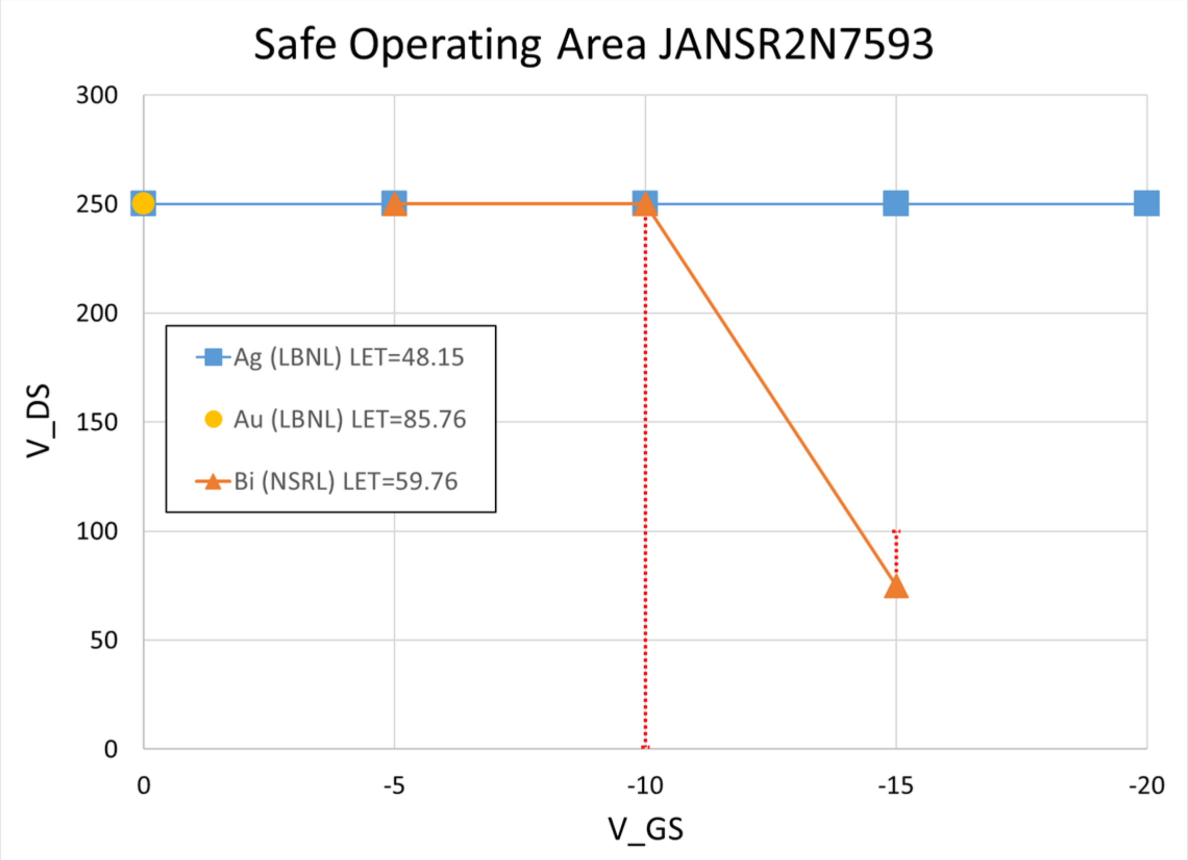
Table 2-1. Safe-Operating Area Profile

Parameter	Description	Environment		V_{DS} (V)				
Ion species	Typical LET (MeV/(mg/cm^2))	Typ Energy (MeV)	Typ Range (µm)	V_{GS} = 0 V	V_{GS} = 5 V	V_{GS} = 10 V	V_{GS} = 15 V	V_{GS} = 20 V
Ag	44.9 (44 ±5%)	1267 (1350 ±5%)	111.2 (125 ±5%)	250	250	250	250	40
Xe	63 (61 ±5%)	1007 (825 ±5%)	74.3 (66 ±5%)	250	250	250	50	
Au	90 (90 ±5%)	1489 (1489 ±5%)	83.2 (80 ±5%)	250	250			

The following figure shows the safe-operating area of the MRH25N12U3/JANSR2N7593U3 device.

Figure 2-1. SEE Safe-Operating Area

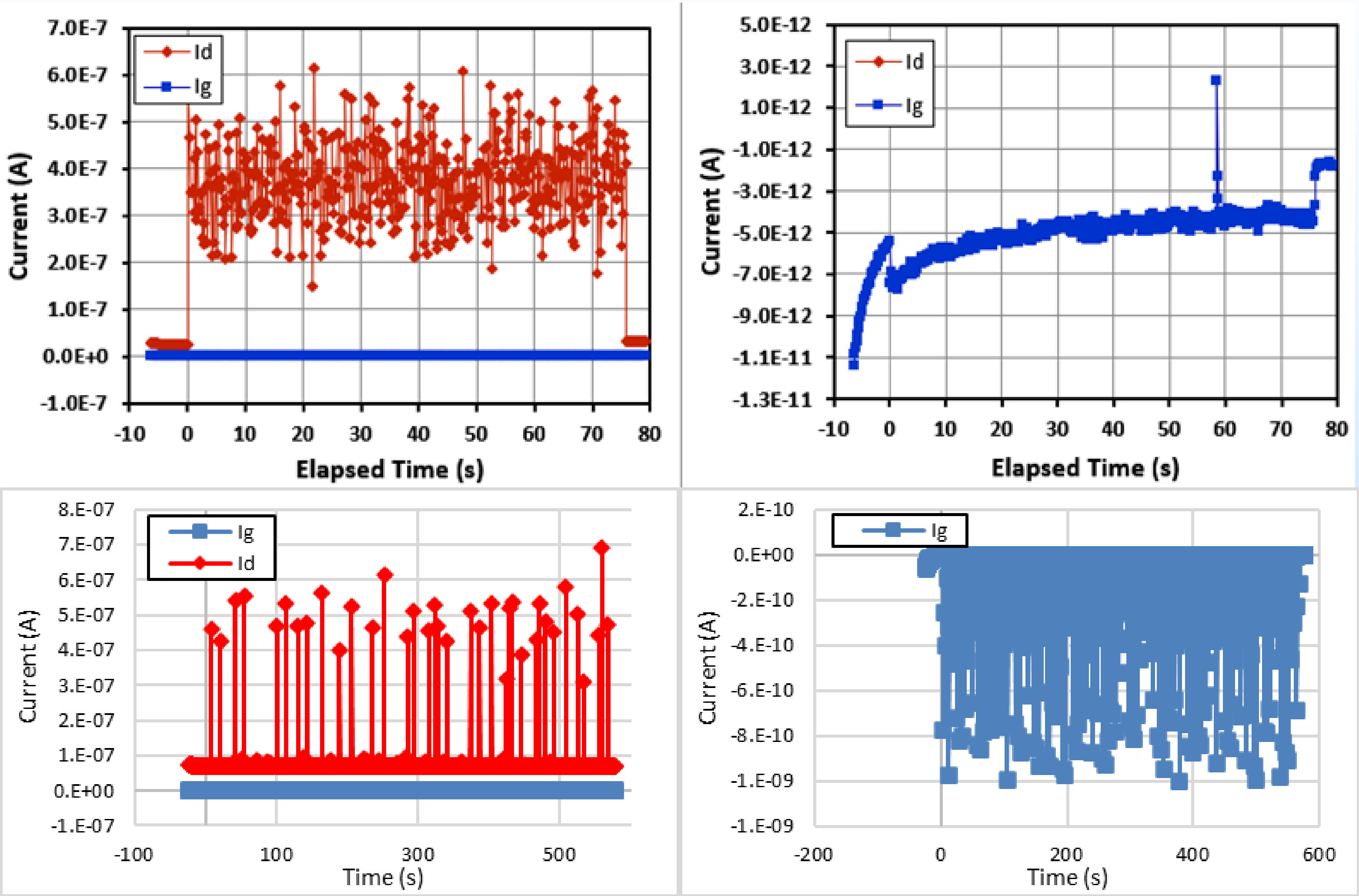




https://ww1.microchip.com/downloads/en/DeviceDoc/00004034A.pdf

Microchip JANSR2N7593

- **Top**
  - LBNL
  - Au - 86 MeV-cm²/mg
  - -20 V_{GS}, 250 V_{DS}
- **Bottom**
  - NSRL
  - Bi - 60 MeV-cm²/mg
  - -10 V_{GS}, 200 V_{DS}
- **Note time structure of beam**
- **Gate current washout makes it difficult to examine leakage increase or transients**



LogiSiC SiC Diodes

- **1200 V JBS SiC Diodes**
  - SBIR deliverable
- **Goal: Improved SEB tolerance with minimal increase in R_{DS_ON}**

Challenges

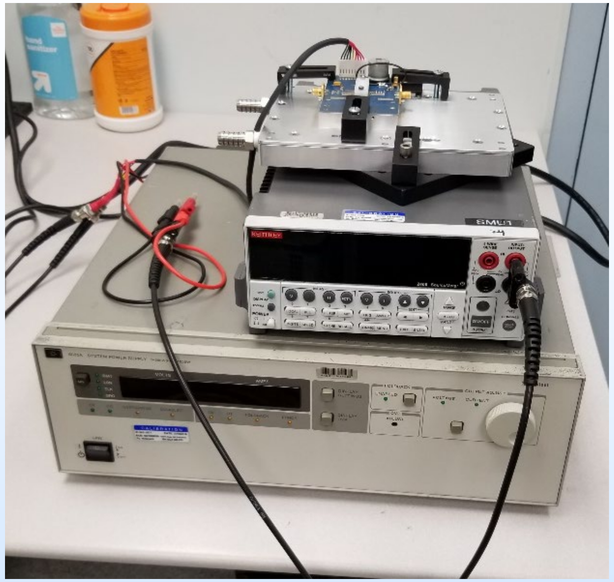
- **LogiSiC is now owned by SC Devices**
- **3.8-4 mm epoxy coating**
  - Possible chemical removal solution
- **Parylene-C replacement needed**
- **Possible Alternative: Re-package new devices**

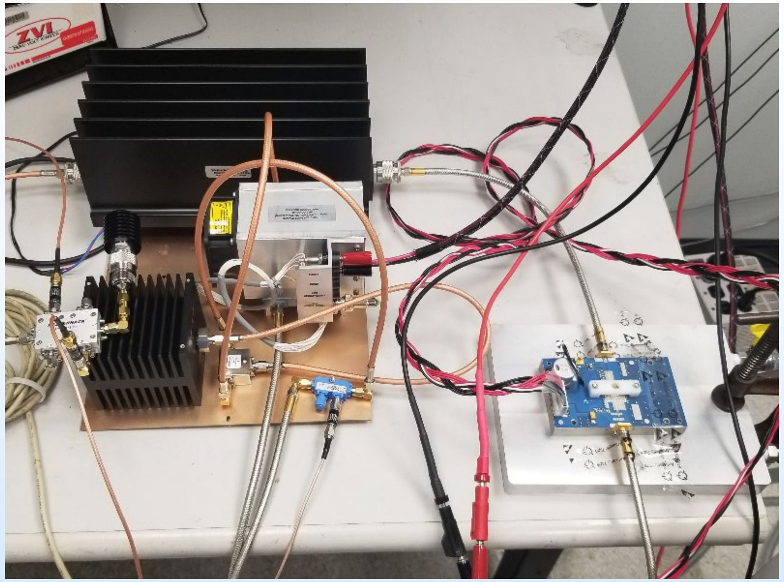
SSDI GaN

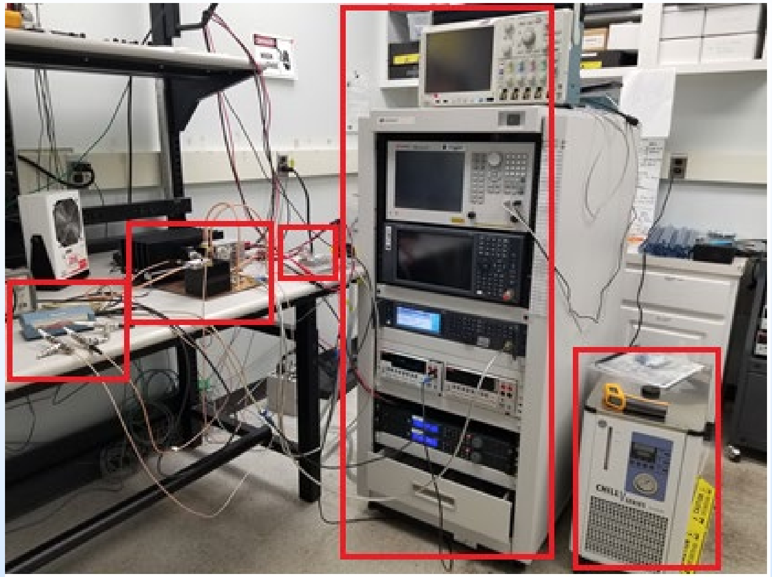
- Part #: SGF15D100
- GaN FET Normally-On
- I_D = 15 A
- V_{DS} = 1000 V
- R_{DS_ON} = 160 mΩ typical

- Targeting August/September Test at LBNL or TAMU
- SSDI has innovative solutions to produce a normally off device
- New TO-257/258 Daughtercards

RF GaN HEMTs







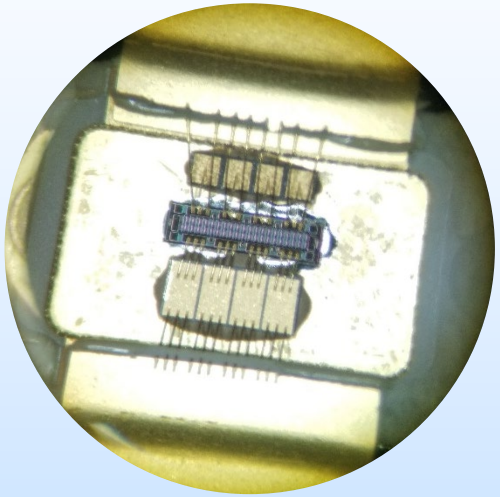
DC ONLY Test Bench

RF Test Bench

Data acquisition system and interface to LabVIEW control software, RF circuitry (center) for amplification and safe dissipation of RF power, device under test (DUT) evaluation board and cold plate, RF & DC supply and diagnostic equipment, chiller for liquid cooling.

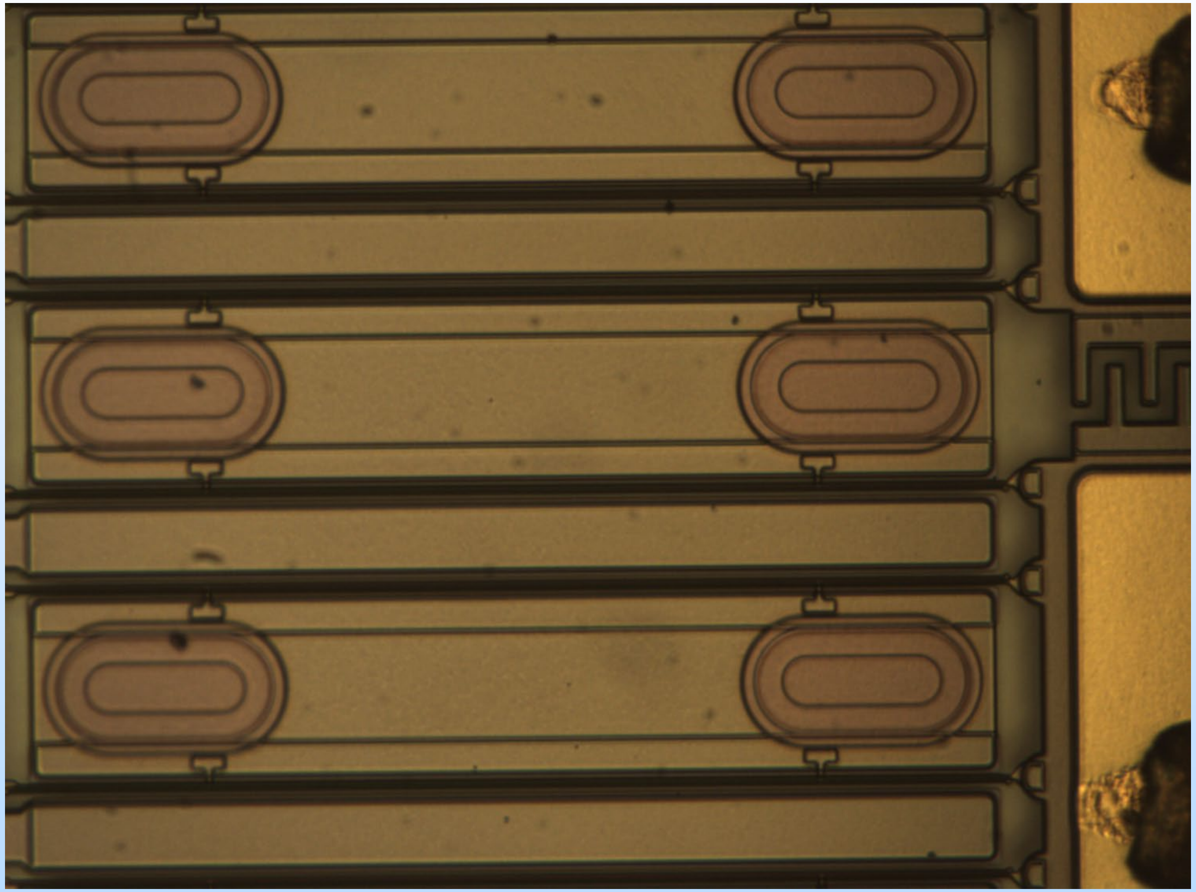
RF GaN HEMTs

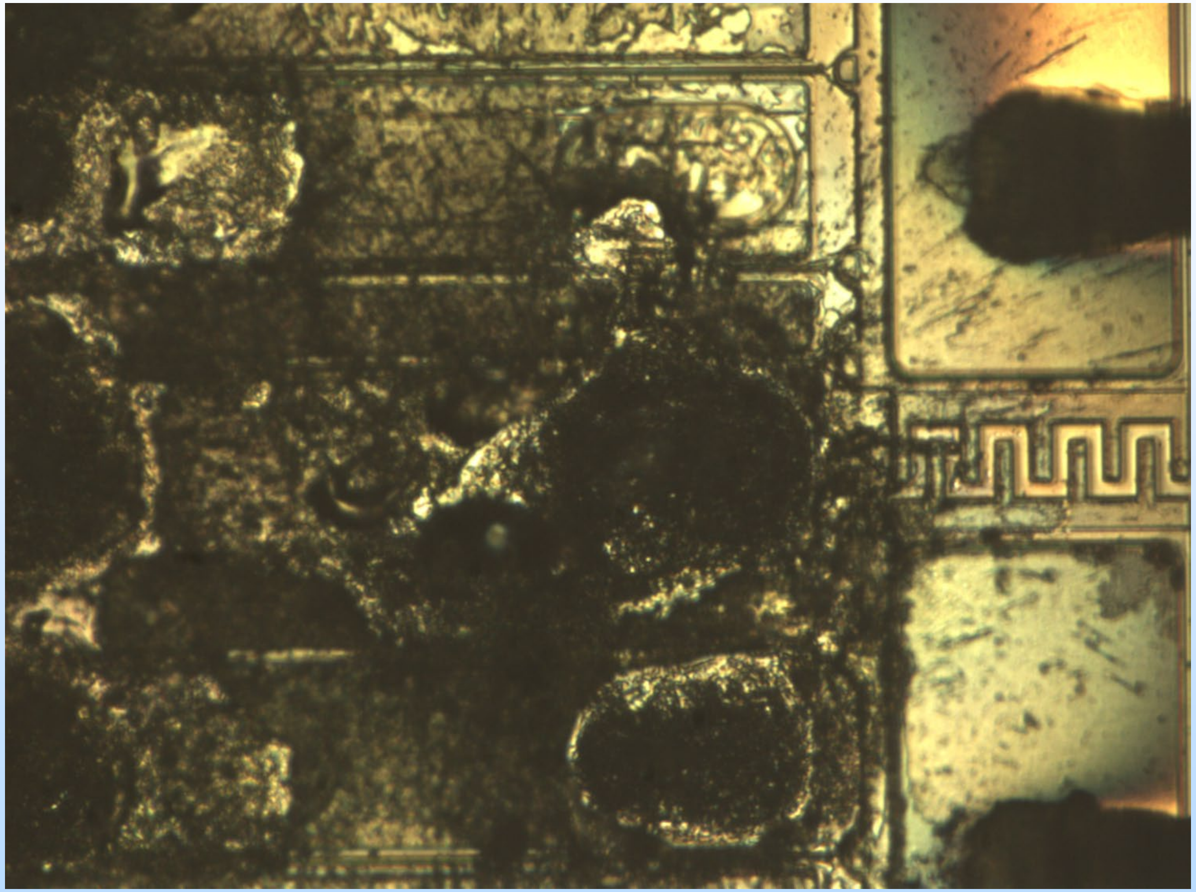
Part #	Drain Voltage	Power In	Power Out	Gate Voltage	Frequency Range	
					Min	Max
CGHV59350F	50V	46 dBm	302 W	-3V (OFF)	5.2	5.9
CGHV59070F	50V	35.5 dBm	90 W	-2.8V (OFF)	4.4	5.9
CGHV40200PP	50V	38 dBm	250W	-3V (OFF)	1.7	1.9
CGHV35150F	50V	39 dBm	170W	-3V (OFF)	2.9	3.5



De-lidded CGHV59070F

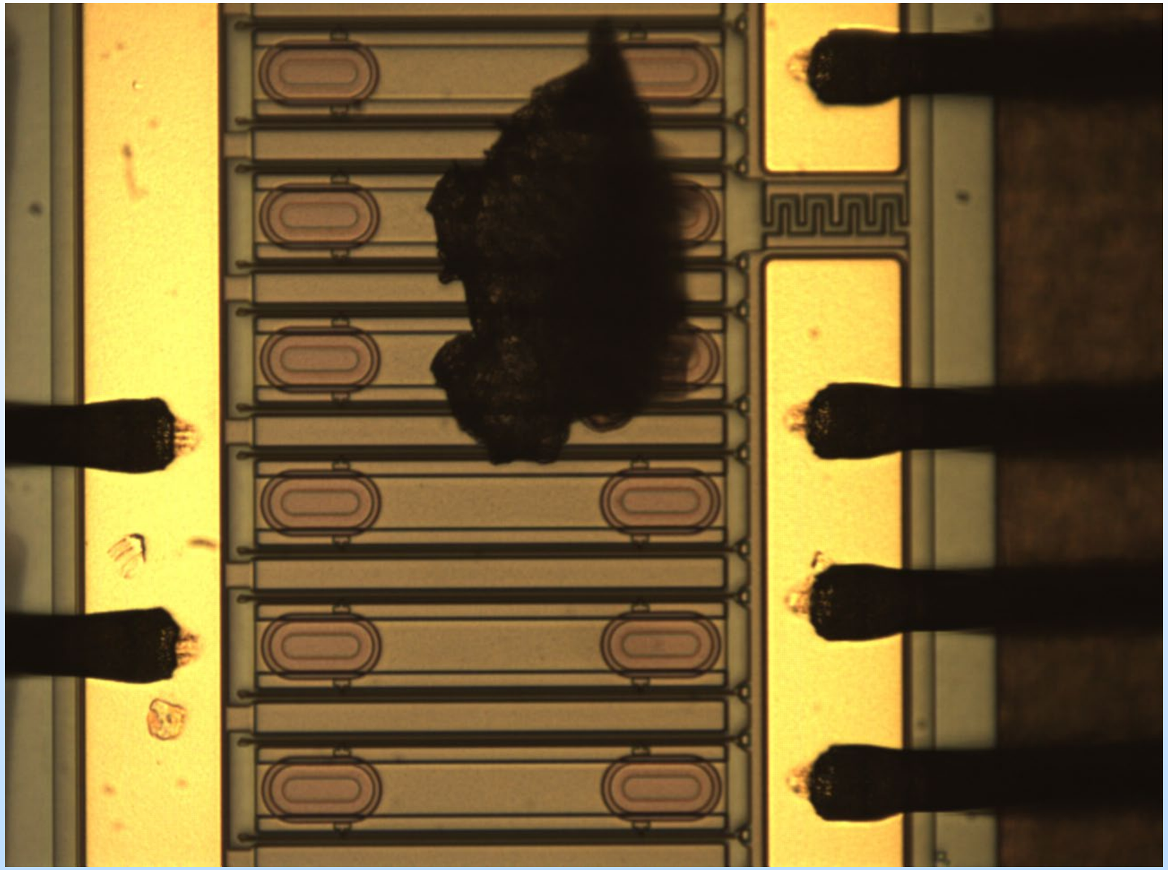
CGHV59350F – Laser Induced SEE





80x Objective

CGHV59350F – Electrical Stress



RF GaN HEMTs – Next Steps

- **More Laser testing of other devices**
- **Address challenges of electrical fragility**
  - Possible delidding damage
- **Heavy ion testing**

AFRL β-Ga_2O_3

TABLE I. Calculated prime transistor parameters for a 1.2 kV rated vertical power transistor. Assumptions for the calculation are listed in Fig. 5. The prime transistor figures of merit $R_{ON} \cdot Q_{OSS}$ and $R_{ON} \cdot E_{OSS}$ are ~3× better than for 4H–SiC and ~20% better than for bulk GaN.

		V_{RATING} = 1200 V				
Parameter	Unit	Si	Si SJ	4H–SiC	Bulk GaN	β-Ga_2O_3
R_{ON}	(mΩ cm²)	227	6.84	1.8	0.589	0.189
Q_{OSS}	(nC/cm²)	313	6260	2150	2710	7080
E_{OSS}	(μJ/cm²)	125	250.4	857	1082	2829
$R_{ON} \cdot Q_{OSS}$	(mΩ nC)	71 051	42 818	3870	1596	1338
$R_{ON} \cdot E_{OSS}$	(mΩ μJ)	28 375	1713	1543	637	535

Andrew J. Green et al., "β-Gallium oxide power electronics", APL Materials 10, 029201 (2022) https://doi.org/10.1063/5.0060327

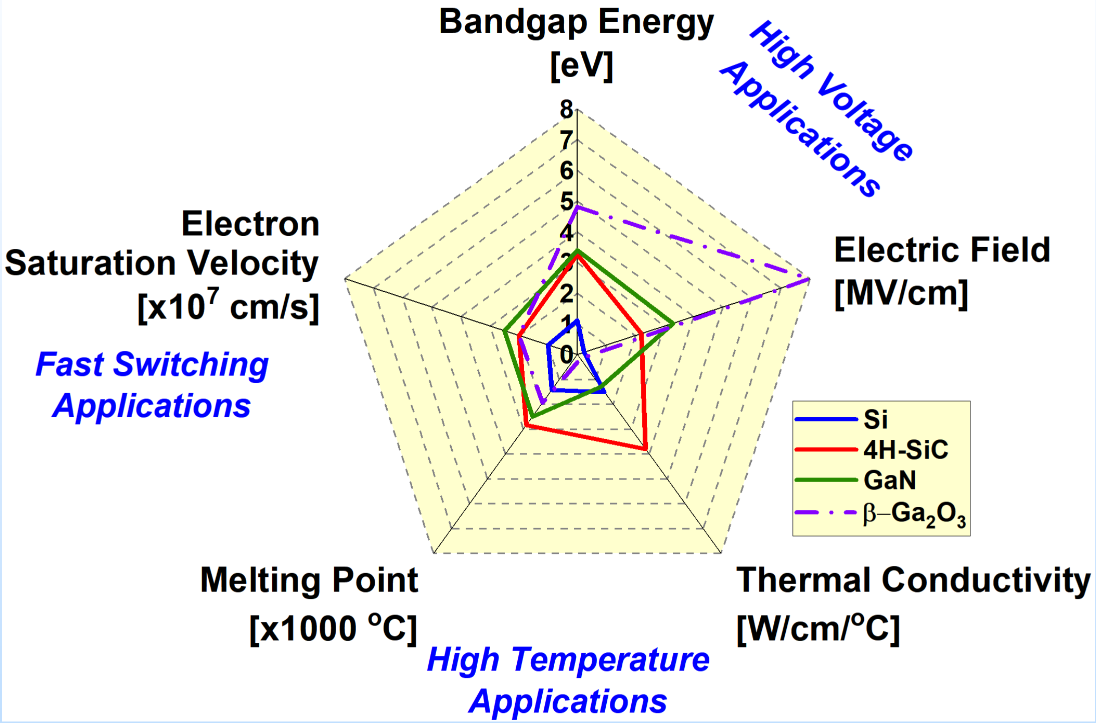


Image courtesy of Jean-Marie Lauenstein, NASA

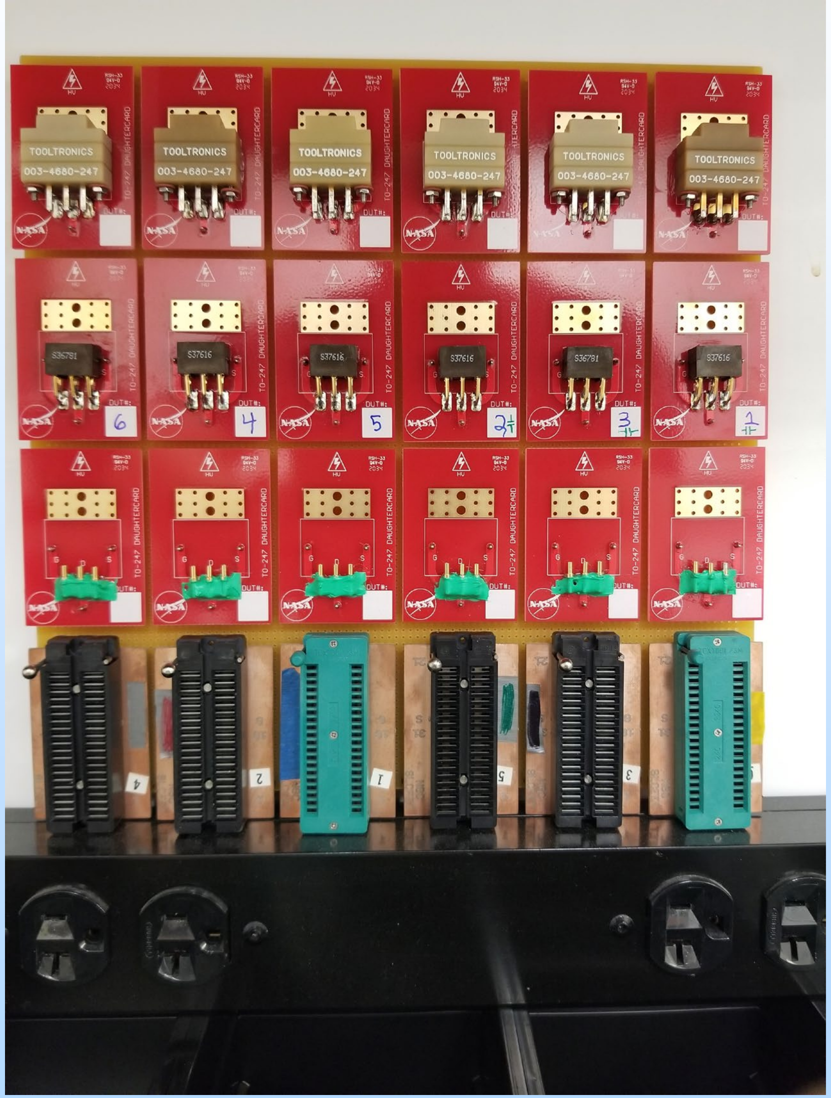
NEPP WBG Community Updates

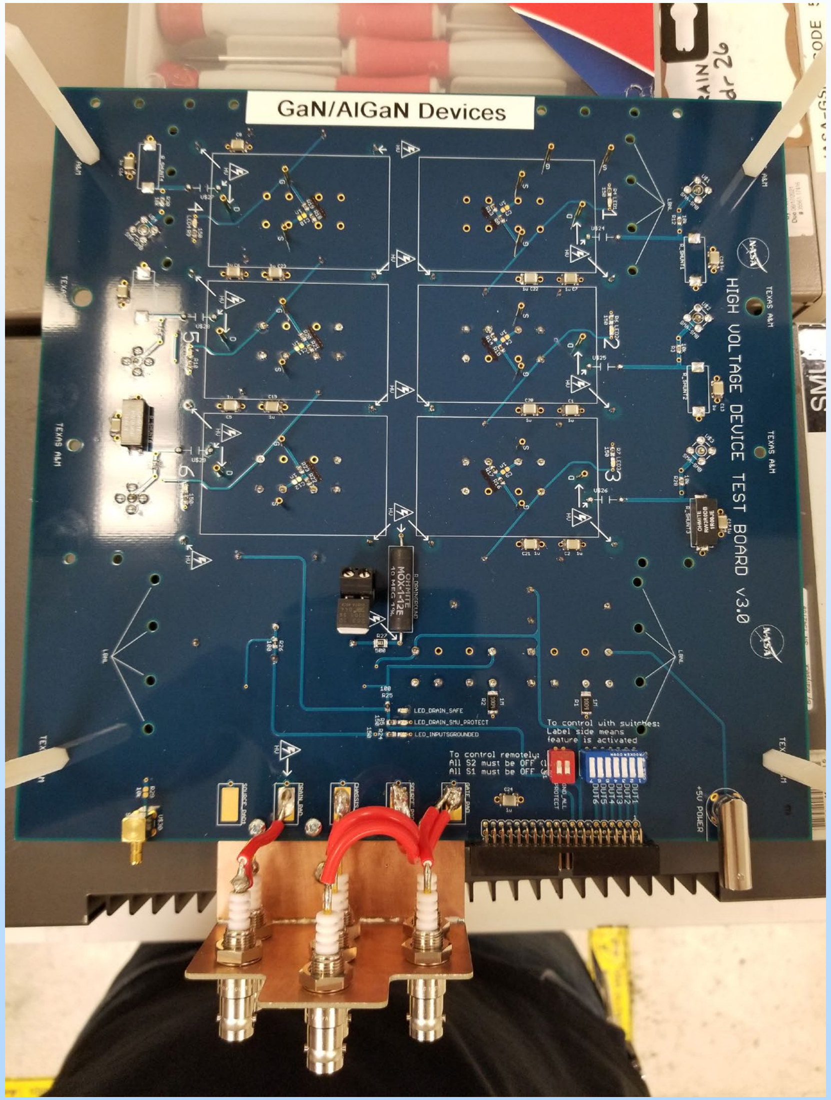
- JEDEC - TM 1082
  - Based off TM 1080
  - Specific to Schottky Diodes
- Nuclear Data Group - 2022 WANDA
  - Presented "LET of Recoil Ions in Space Flight Electronics"
  - Communicate Nuclear Data needs of the radiation effects on electronics community
  - Data feeds into tools like SRIM, MCNP, GEANT, FLUKA, etc.
- SRHEC – nSEE

Expanding WBG Test Capabilities

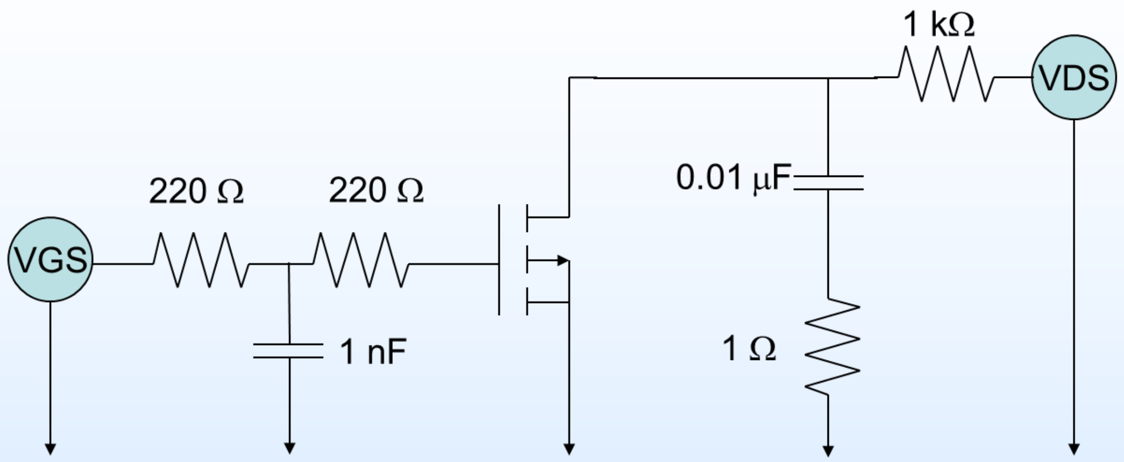
- **Left – Daughter cards for new power device test boards (TO-247 HV, TO-247, TO-258/257, custom DIPs fabricated in house, SMD 0.5 etc.)**

- **Right – New GaN specific Power device test board**

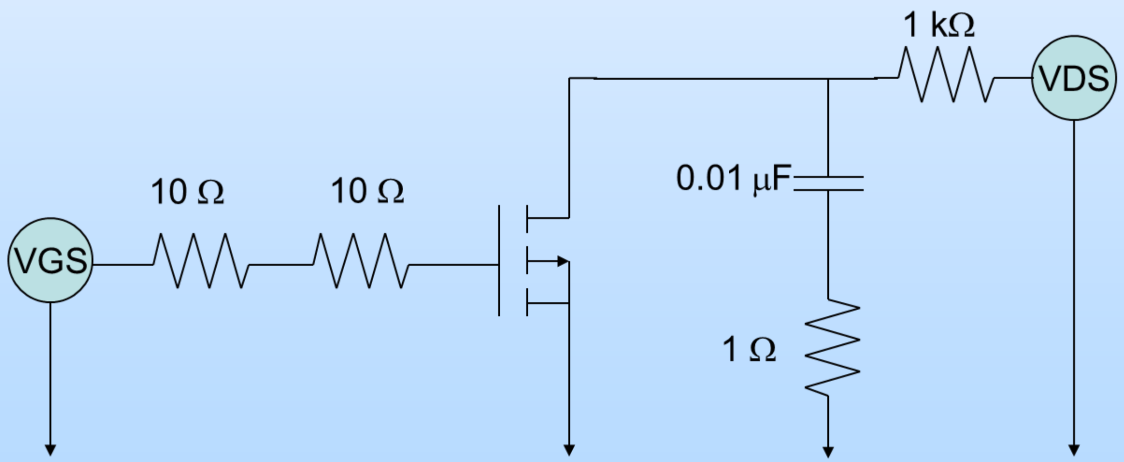




Test Setups: Standard vs. New



- **Standard NASA GSFC Board:**
  - MIL-STD-750, TM1080 circuit
    - Gate R issue: rising Ig can result in ΔV_{GS}



- **New GaN Board**
  - Small Gate resistance
    - Guards against inadvertent device turn on upon ion strike

Questions???

Feel free to reach out to me at:

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