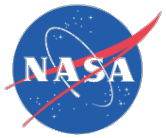

The Effects of Thermal Cycling on Gallium Nitride and Silicon Carbide Semiconductor Devices for Aerospace Use

Richard L. Patterson, NASA GRC
Ahmad Hammoud, VPL/NASA GRC

ABSTRACT: Electronics designed for use in NASA space missions are required to work efficiently and reliably under harsh environment conditions. These Include radiation, extreme temperatures, thermal cycling, to name a few. Preliminary data obtained on new Gallium Nitride and Silicon Carbide power devices under exposure to radiation followed by long term thermal cycling are presented. This work was done in collaboration with GSFC and JPL in support of the NASA Electronic Parts and Packaging (NEPP) Program.

NEPP Third Electronics Technology Workshop
NASA Goddard Space Flight Center
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NASA Working Group on Wide-Band Gap Semiconductors: A NEPP collaborative effort between GSFC, GRC, and JPL to address reliability of GaN & SiC Devices under radiation & thermal cycling

GRC NEPP-Task #:12-0281

Title : Reliability of Gallium Nitride (GaN), Silicon Carbide (SiC), Silicon Germanium (SiGe), Silicon-On-Insulator (SOI), and Advanced Mixed Signal Devices for Extreme Temperature Space Missions

GRC Manager: Richard L. Patterson

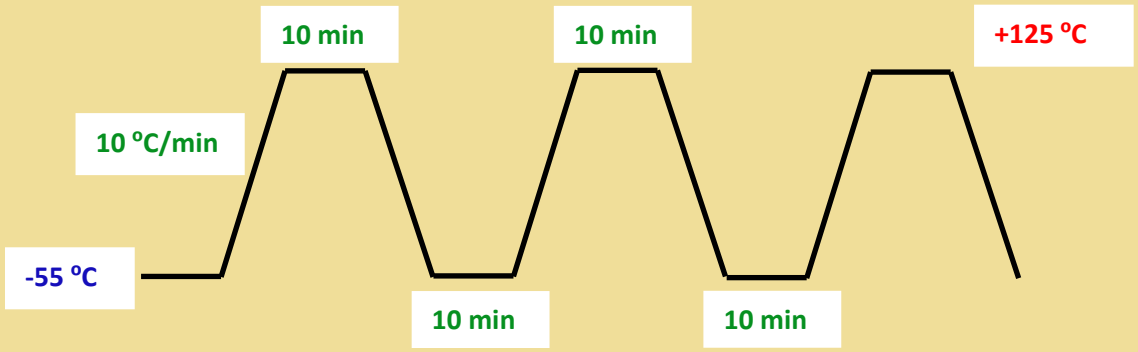
Thermal Cycling & Reliability of Electronics:

- Various methods exist for performing thermal cycling tests to address reliability of electronics for long-term use.
- Existing Standards suggest various temperature rates & dwell times. Number of cycles are inconsistent, & synergistic effects are not covered.
- Standards generally address thermally-induced fatigue in solder joints, interconnects, and material interfaces, etc.

Temp Min/Dwell Time	Temp Max/Dwell Time	Standard
-65 ºC/30 min	125 ºC/30 min	MIL-STD-202 DM 107C
-65 ºC/30 min	150 ºC/30 min	MIL-STD-202 DM 107C
-25 ºC/10 min	125 ºC/10 min	EIAJ ED-4701-3
-40 ºC/10 min	85 ºC/10 min	IEC60749
-55 ºC/30 min	100 ºC/10 min	IPC0701A
-55 ºC/10 min	85 ºC/10 min	MIL-STD-883, Method 1010
-65 ºC/10 min	150 ºC/10 min	MIL-STD-883, Method 1010
-55 ºC/10 min	85 ºC/10 min	JEDEC JESD22-A104
-65 ºC/10 min	150 ºC/10 min	JEDEC JESD22-A104

Test Plan:

- Perform long-term thermal cycling on devices per profile below:
  - Total # of Cycles 1000
  - Temperature rate of change: 10 ºC/min
  - Temperature range: -55 ºC to +125 ºC
  - Soak time at extreme temperatures: 10 min
- Repeat measurements on devices during cycling
- Perform measurements after conclusion of cycling activity



Test Setup

Parameters Investigated:

- I-V Output Characteristics
- Gate Threshold Voltage, V_{TH}
- Drain-Source On-Resistance, $R_{DS(on)}$
- Transconductance, g_m
- Tests performed at room temperature

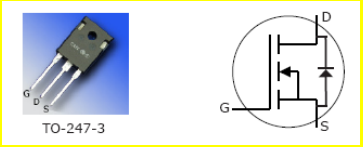
Equipment Used:

- SONY/Tektronix 370A Curve Tracer
- Keithley 238 Source-Measure-Units

GRC Work Completed

Devices subjected to long-term (1000 cycles) thermal cycling

CREE 150 W, SiC Power MOSFET
Vds= 1200 V, Id (max) = 33 A
N-Channel Enhancement Mode, Part # CMF20120D



3 Samples Not-irradiated

CREE 120 W, RF Power GaN HEMT
Vds = 28 V, Depletion Mode
Part # CGH40120F

# of Samples	Condition	Ion	Energy (MeV)	LET	Range (μm)	Dose (rad)
2	Irradiated	Kr	1250	25.4	150	406400
7	Control (un-irradiated)					

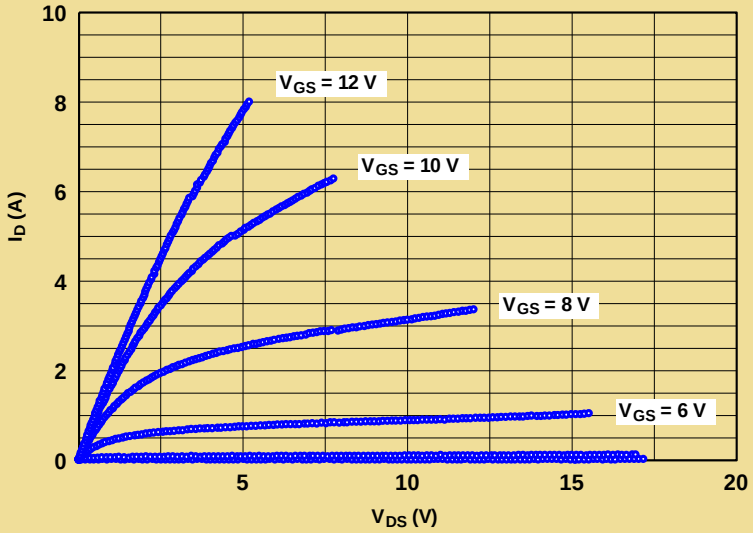
GRC On-Going Work

Devices subjected to long-term thermal cycling

EPC Enhancement-Mode GaN Power Transistors			
Type	Specs	# of Samples	Condition
EPC1001	100 V, 25 A	4	Irradiated
		4	Control (un-irradiated)
EPC1010	200 V, 12 A	2	Irradiated
		4	Control (un-irradiated)
EPC1012	200 V, 3A	2	Irradiated
		3	Control (un-irradiated)
EPC1014	40 V, 10 A	3	Irradiated
		4	Control (un-irradiated)

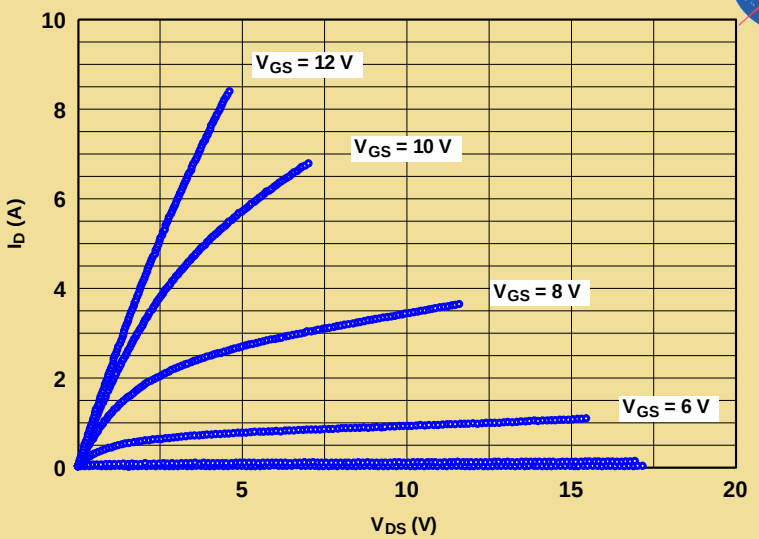
RESULTS (Un-irradiated SiC MOSFETs)

CMF20120D
Device 2



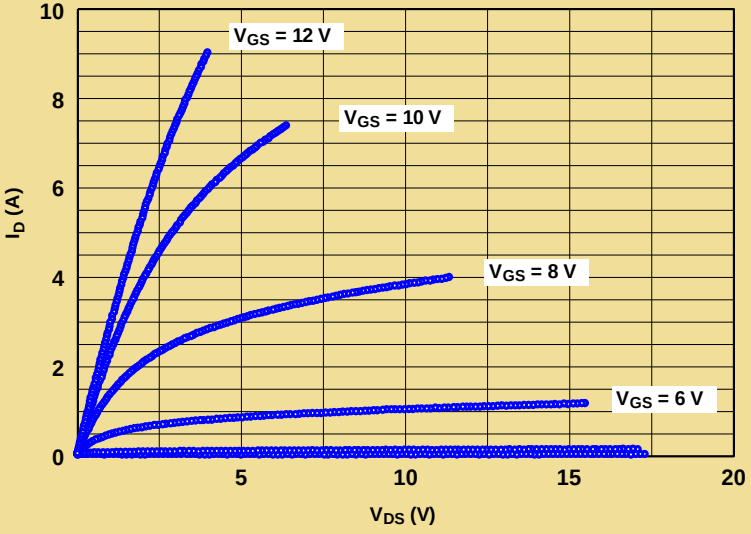
Pre-Cycling

CMF20120D
Device 2



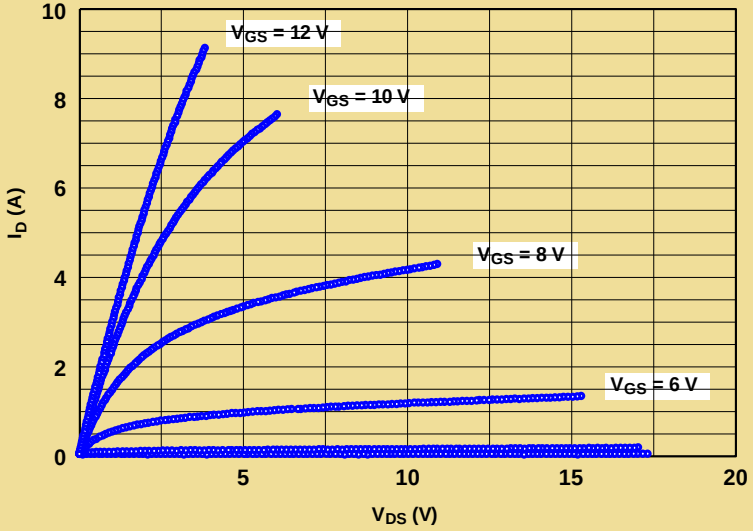
After 250 Cycles

CMF20120D
Device 2



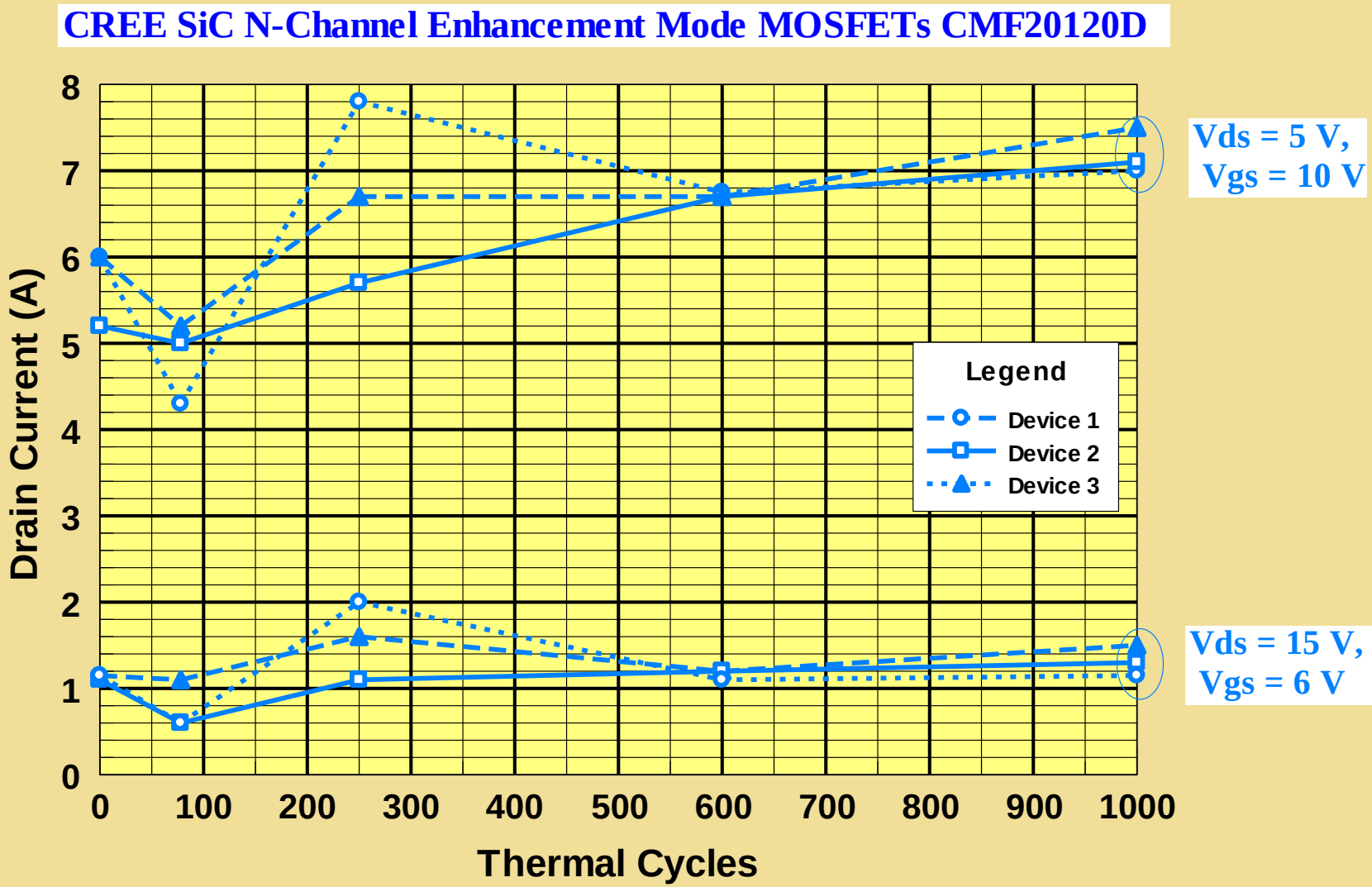
After 600 Cycles

CMF20120D
Device 2



After 1000 Cycles

RESULTS (Un-irradiated SiC MOSFETs)



RESULTS (Un-irradiated SiC MOSFETS)

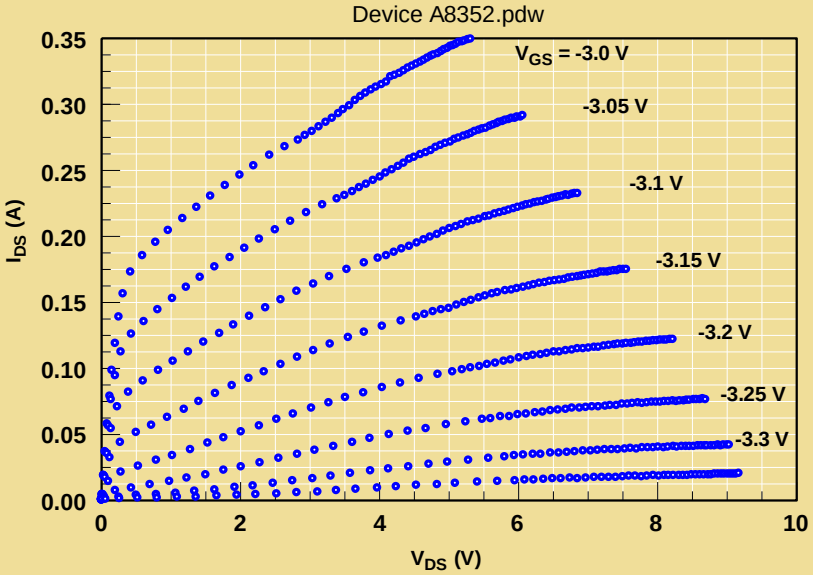
CREE CMF20120D

Device	Pre-Cycle		After 78 Cycles		After 250 Cycles		After 600 Cycles		After 1000 Cycles	
	V_{TH} (V)	R_{DS} (mΩ)	V_{TH} (V)	R_{DS} (mΩ)	V_{TH} (V)	R_{DS} (mΩ)	V_{TH} (V)	R_{DS} (mΩ)	V_{TH} (V)	R_{DS} (mΩ)
1	2.85	640	2.88	631	2.85	480	2.77	380	2.79	360
2	2.61	550	2.56	520	2.49	480	2.54	370	2.50	354
3	2.51	480	2.51	568	2.47	460	2.48	310	2.42	337

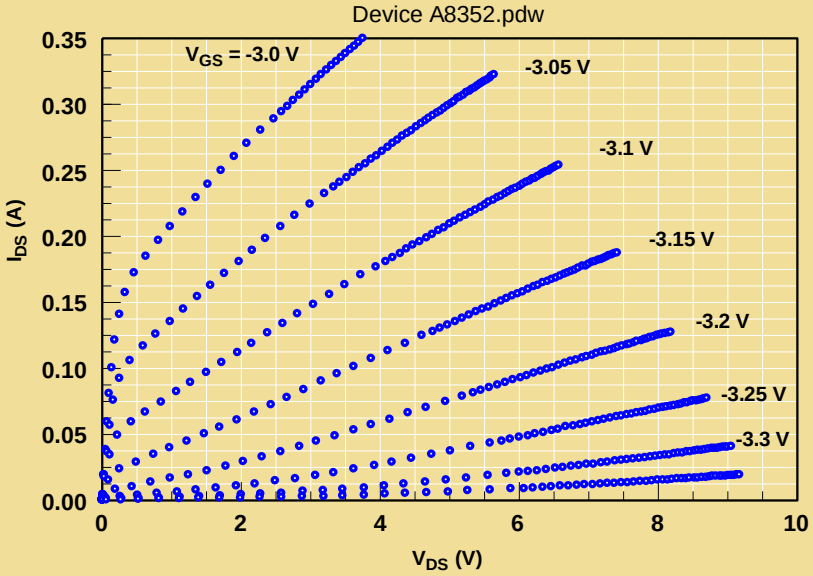
OBSERVATIONS

- All devices maintained functionality after 1000 cycles
- The three MOSFETs experienced a slight decrease in V_{TH} and a modest decrease in $R_{DS(ON)}$ upon cycling
- No alteration in device packaging

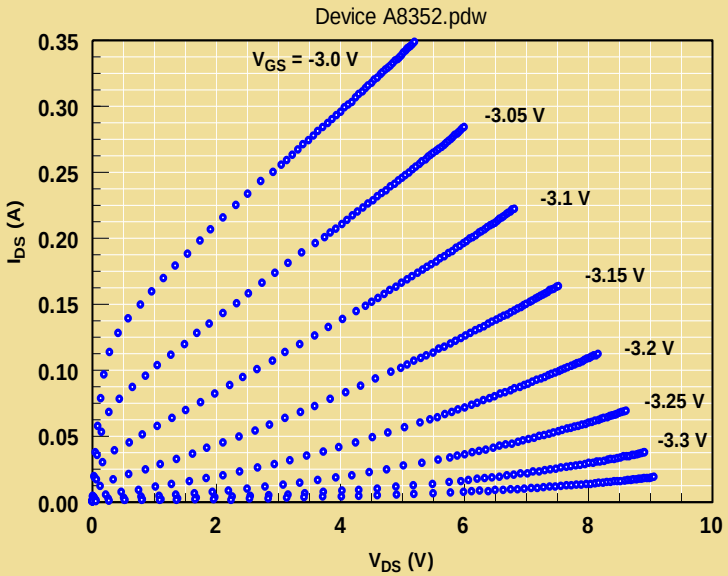
RESULTS (Irradiated CREE GaN HEMT)



Pre-Cycling

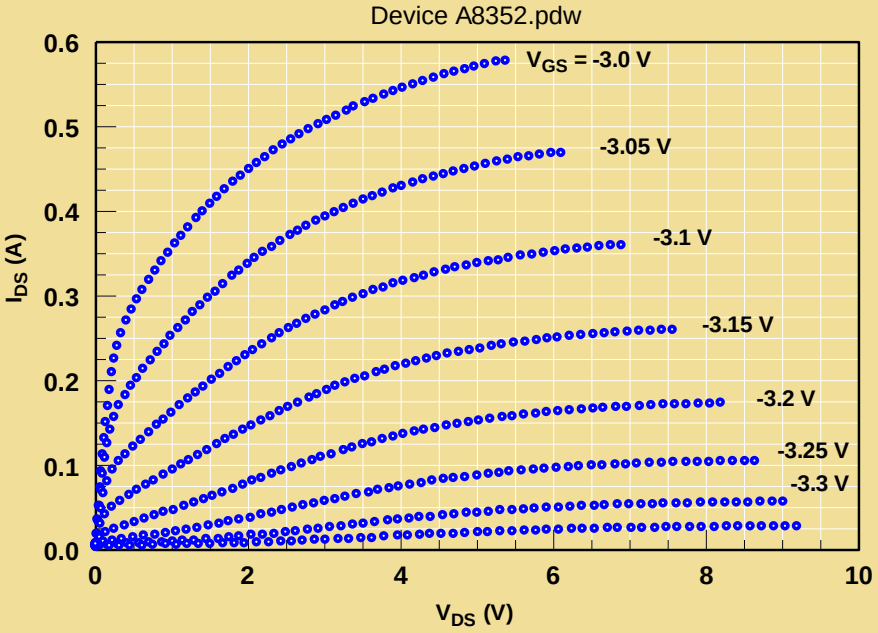


After 78 Cycles

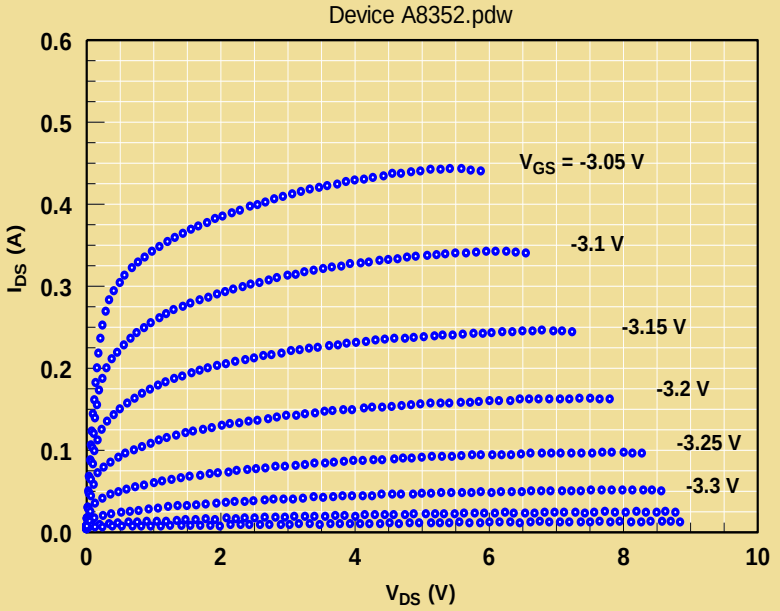


After 250 Cycles

RESULTS (Irradiated CREE GaN HEMT)



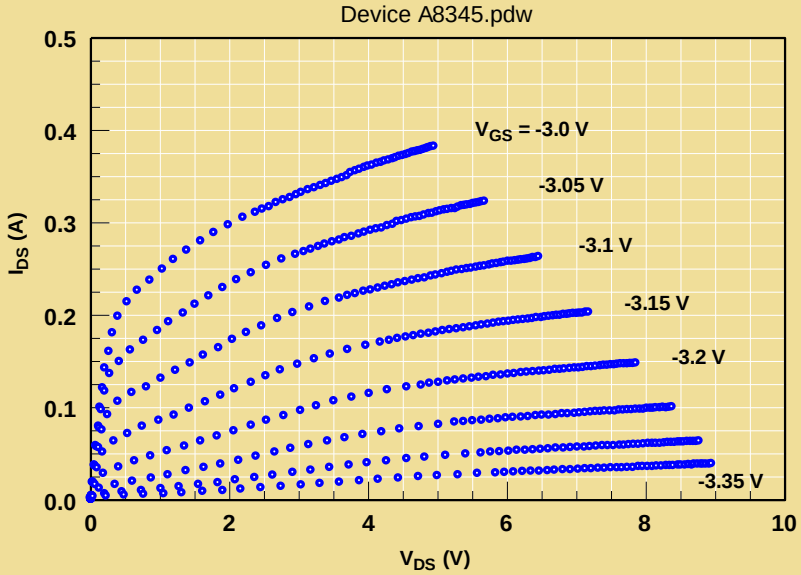
After 600 Cycles



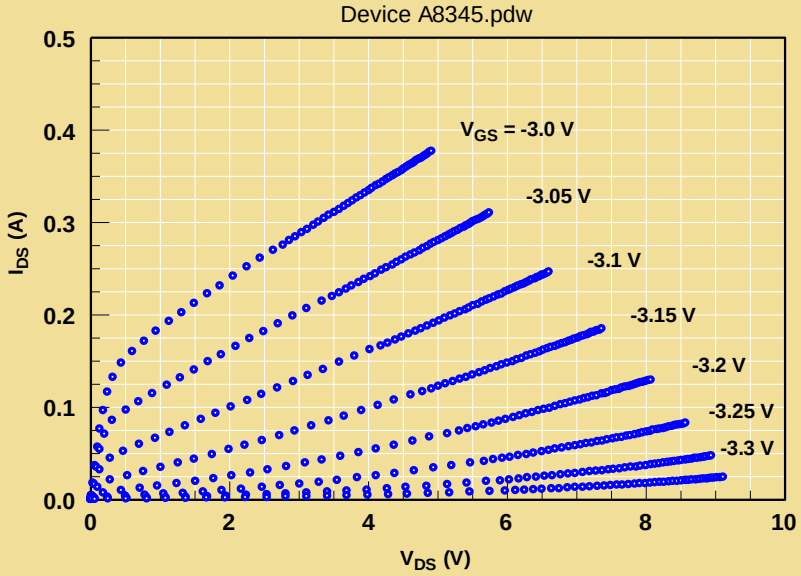
After 1000 Cycles

Device (Irradiated)	Pre-Cycle		After 78 Cycles		After 250 Cycles		After 600 Cycles		After 1000 Cycles	
	V_{TH} (V)	g_m (mS)	V_{TH} (V)	g_m (mS)	V_{TH} (V)	g_m (mS)	V_{TH} (V)	g_m (mS)	V_{TH} (V)	g_m (mS)
A8352	-3.375	790	-3.335	1840	-3.345	1840	-3.390	2260	-3.350	1920

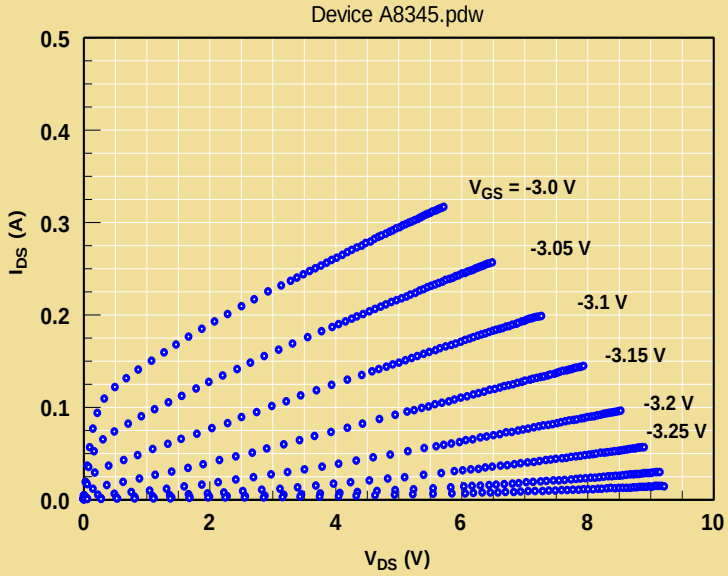
RESULTS (Un-irradiated CREE GaN HEMT)



Pre-Cycling

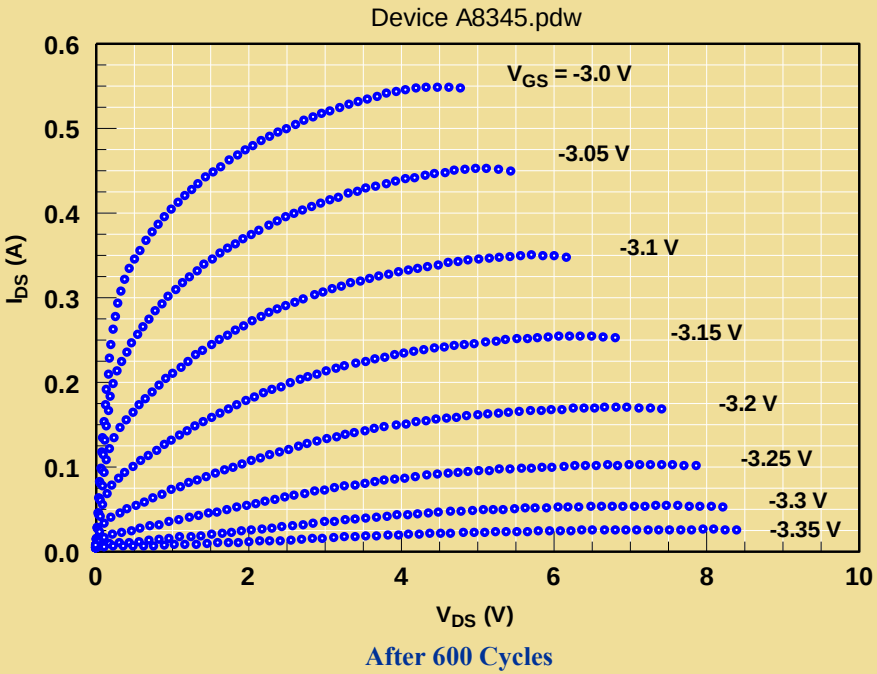


After 78 Cycles

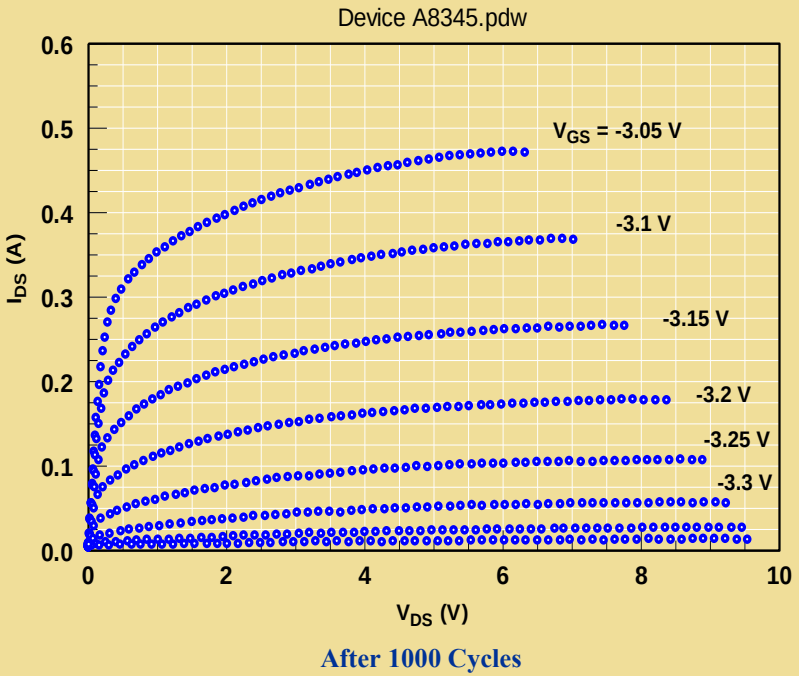


After 250 Cycles

RESULTS (Un-irradiated CREE GaN HEMT)



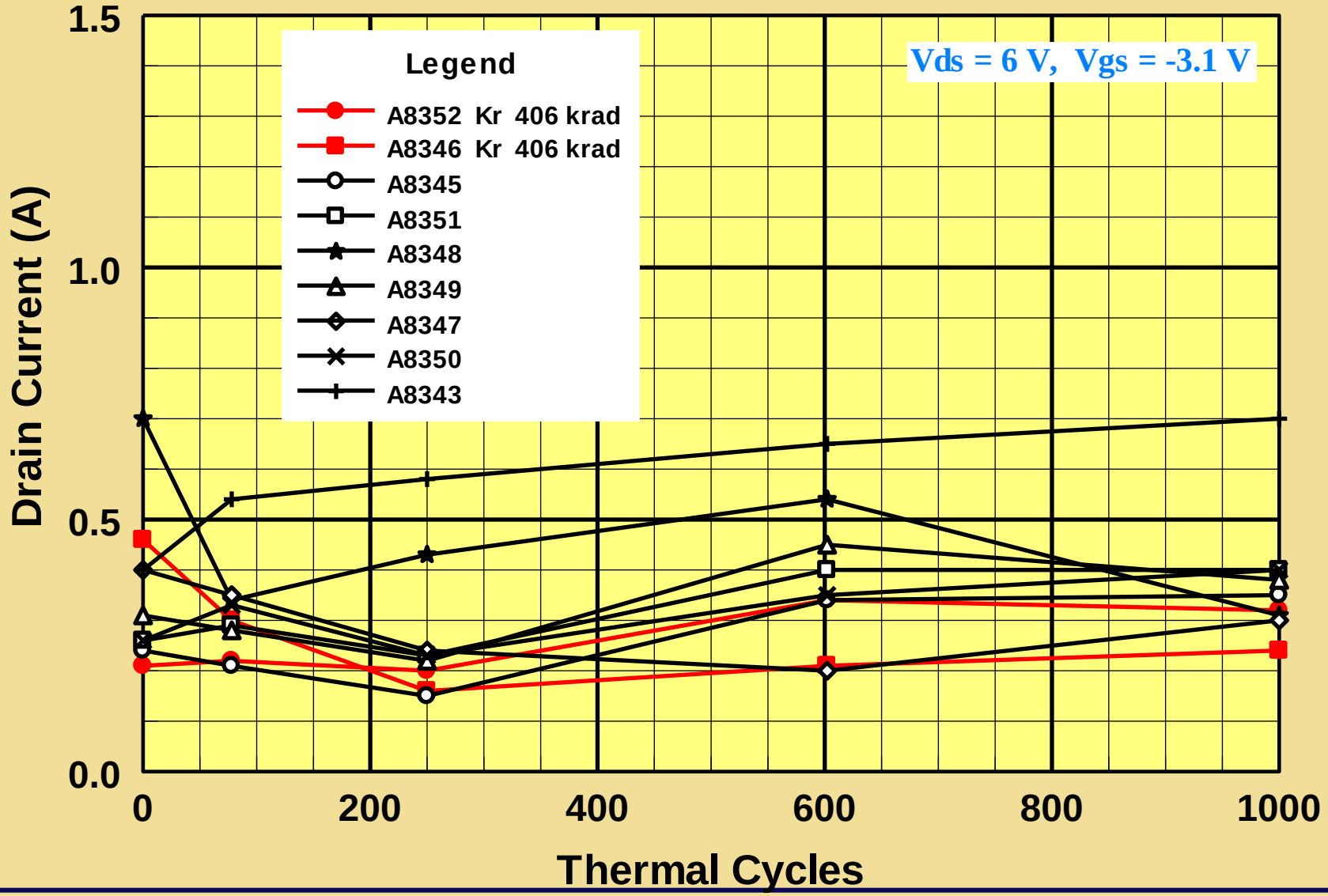
After 600 Cycles



After 1000 Cycles

Device (Control)	Pre-Cycle		After 78 Cycles		After 250 Cycles		After 600 Cycles		After 1000 Cycles	
	V_{TH} (V)	g_m (mS)	V_{TH} (V)	g_m (mS)	V_{TH} (V)	g_m (mS)	V_{TH} (V)	g_m (mS)	V_{TH} (V)	g_m (mS)
A8345	-3.375	890	-3.380	1740	-3.325	1440	-3.40	2060	-3.35	2040

Cree GaN HEMT CGH40120F Mixed Samples
Two Samples Post Irradiation by Kr Ions, 1250 MeV, 406.4 krad
Seven Samples Not Irradiated



OBSERVATIONS

- All nine CREE GaN HEMTs remained functional after 1000 cycles between -55 ^{0}C & +125 ^{0}C
- Effects of thermal cycling was the same for both control & irradiated samples. The induced changes due to cycling included slight variation in V_{TH}, modest increase in trans-conductance, and slightly higher I_D values for given base conditions
- No changes observed in device packaging or terminations

GRC On-going Work

Devices presently undergoing thermal cycling

EPC1001 E- Mode GaN Power Transistor (100V, 25A), passivated die form						
# of Samples	Condition	Ion	Energy (MeV)	LET	Range (μm)	Dose (rads)
1	Irradiated	Au	2342	84.7	122.9	22718
1	Irradiated	Xe	1569	98.8	124.5	8301.5
1	Irradiated	Xe	1569	50.9	124.5	7886.8
1	Irradiated	Xe	1569	98.8	124.5	15838
4	Control					

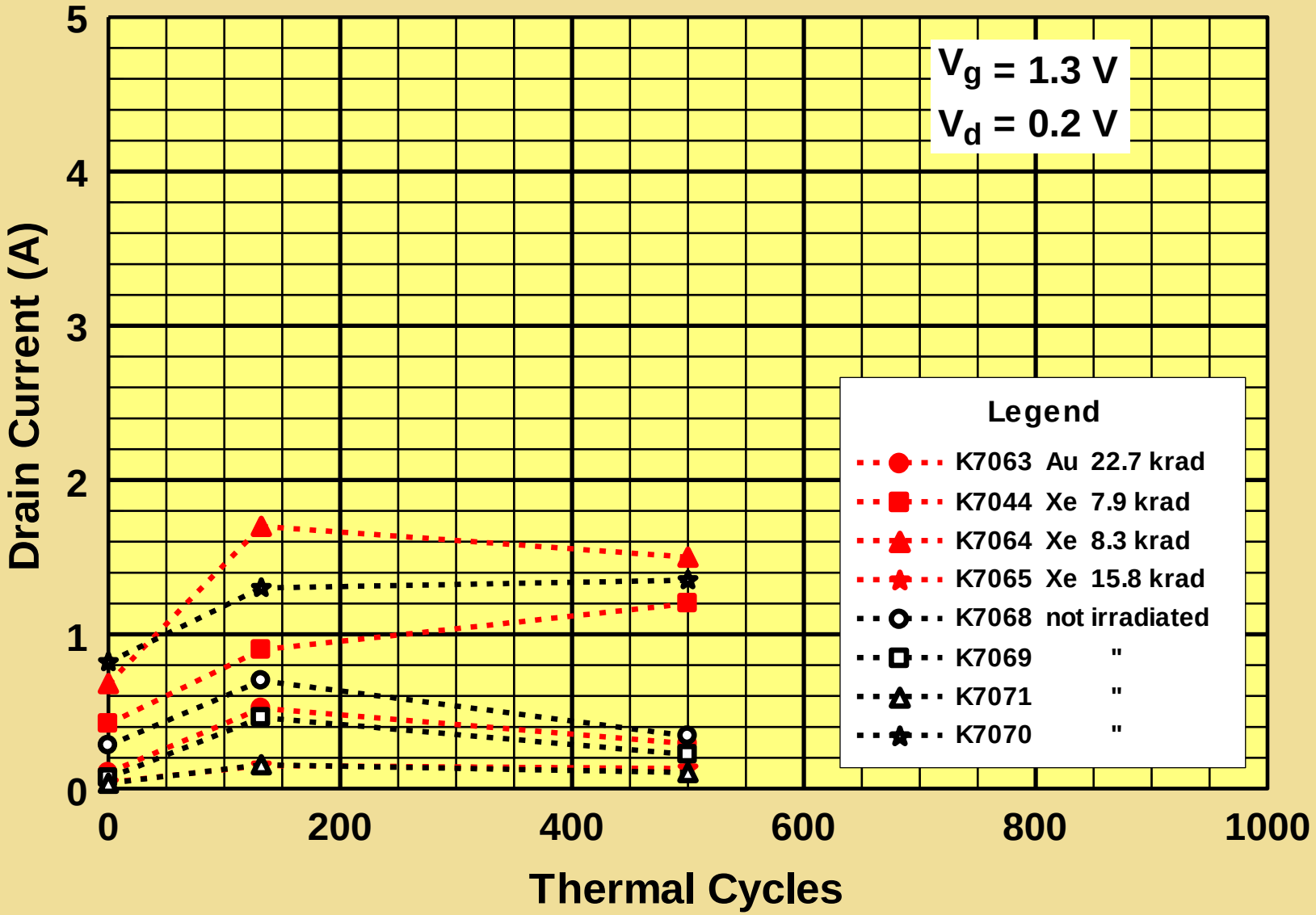
EPC1010 E- Mode GaN Power Transistor (200V, 12A), passivated die form						
# of Samples	Condition	Ion	Energy (MeV)	LET	Range (μm)	Dose (rads)
1	Irradiated	Xe	1569	50.9	124.5	8719.6
1	Irradiated	Au	2342	84.7	122.9	6634
4	Control					

GRC On-Going Work

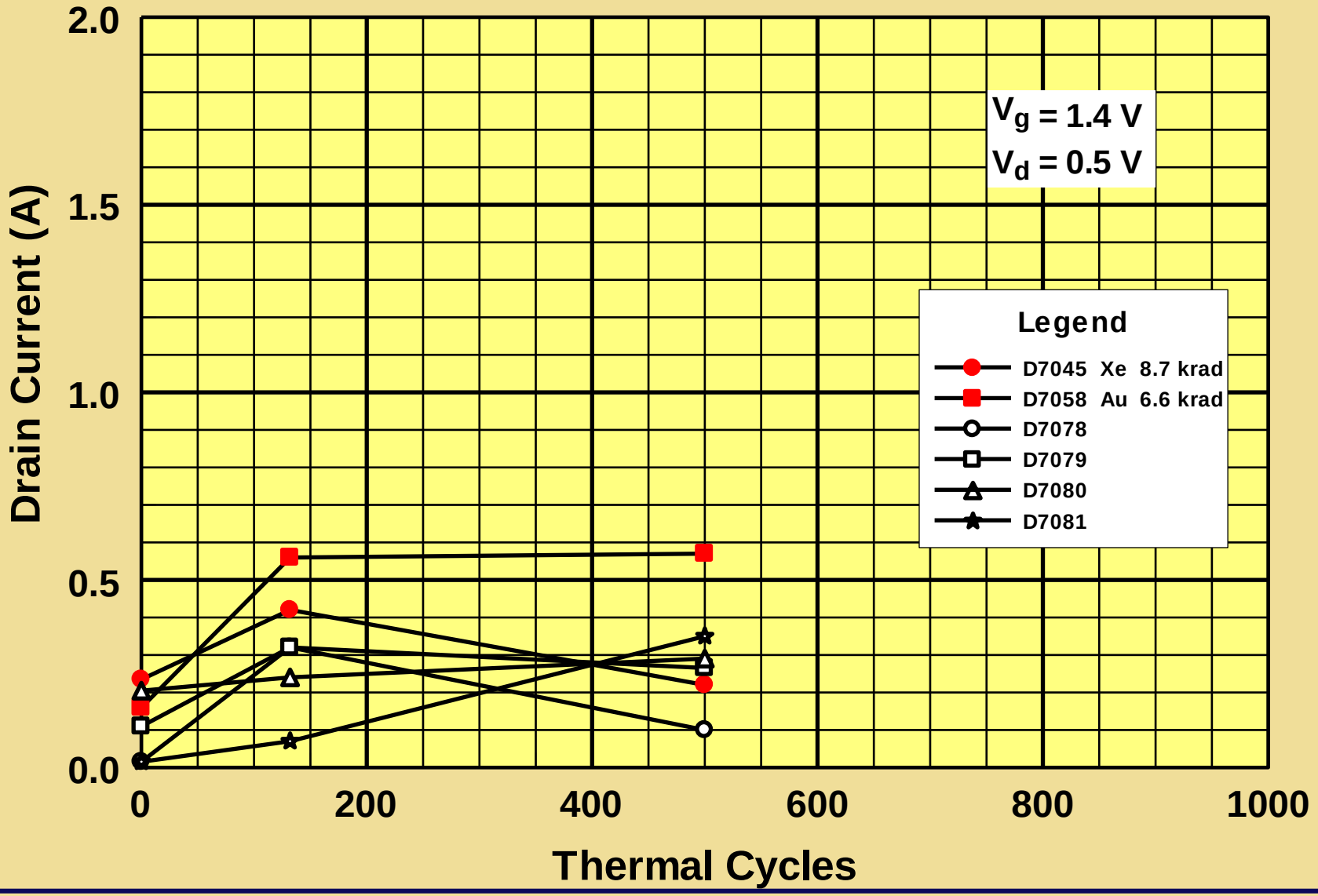
Devices presently undergoing thermal cycling

EPC1012 E- Mode GaN Power Transistor (200V, 3A), passivated die form						
# of Samples	Condition	Ion	Energy (MeV)	LET	Range (μm)	Dose (rads)
1	Irradiated	Xe	1569	50.9	124.5	6328.1
1	Irradiated	Xe	1569	98.8	124.5	6340
3	Control					

EPC1014 E- Mode GaN Power Transistor (40V, 10A), passivated die form						
# of Samples	Condition	Ion	Energy (MeV)	LET	Range (μm)	Dose (rads)
1	Irradiated	Xe	1569	98.8	124.5	6325
1	Irradiated	Xe	1569	50.9	124.5	3154.8
1	Irradiated	Au	2342	84.7	122.9	5337
4	Control					

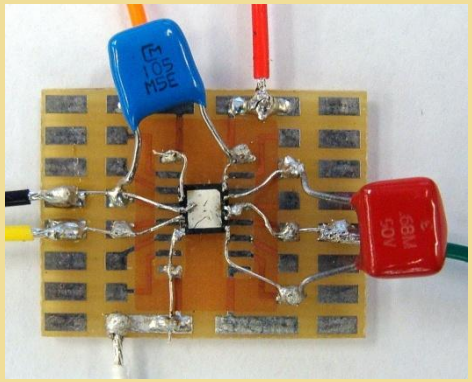

EPC1001 GaN FET, Enhancement Mode (Specs; Vds = 100 V, I d = 25 A)
Vg = 1.3 V
Vd = 0.2 V
Drain Current (A)
0
1
2
3
4
5
0
200
400
600
800
1000
Thermal Cycles
Legend
K7063 Au 22.7 krad
K7044 Xe 7.9 krad
K7064 Xe 8.3 krad
K7065 Xe 15.8 krad
K7068 not irradiated
K7069 "
K7071 "
K7070 "

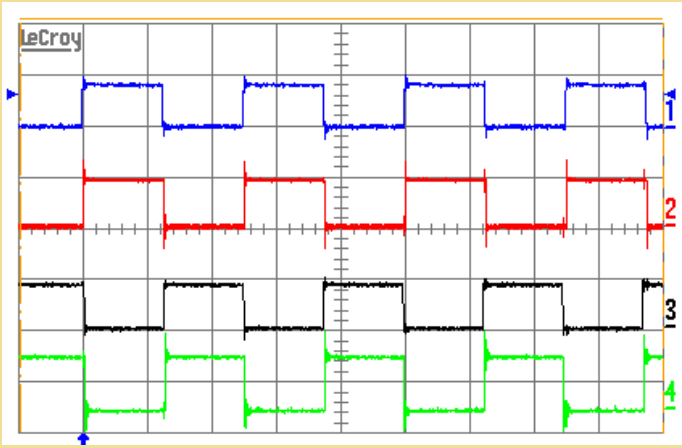
EPC1010 GaN FET (Specs: Vds = 200 V, Id = 12 A)



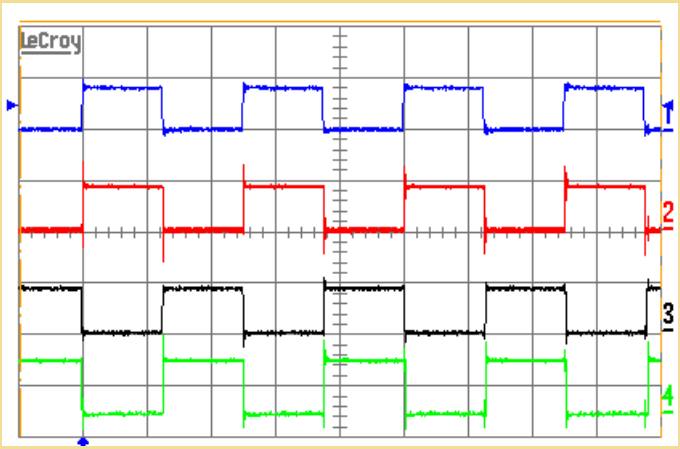
Supporting Electronics for GaN

New Half-Bridge Gate Driver for Enhancement-Mode GaN FETs, Type LM5113

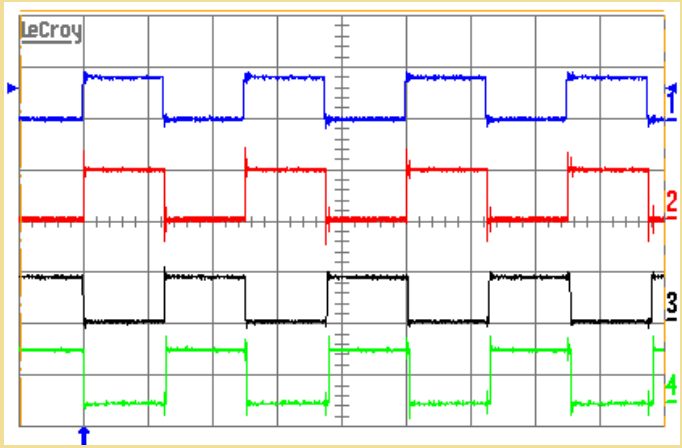




Waveforms of HI(1), HO(2), LI(3), and LO(4) signals @ +23°C



Waveforms of HI(1), HO(2), LI(3), and LO(4) signals @ -194°C



Waveforms of HI(1), HO(2), LI(3), and LO(4) signals @ +150°C

Planned Work:

- Finish thermal cycling of the EPC GaN FETs.
- Perform long-term thermal cycling on second generation of EPC GaN FETs.
- Investigate effects of thermal cycling on new (control and irradiated) SiC and GaN power devices as parts become available from GSFC and JPL.