Effects of Radiation and Long-Term Thermal Cycling on EPC 1001 Gallium Nitride Transistors

Richard L. Patterson, NASA GRC
Leif Scheick, JPL
Jean-Marie Lauenstein & Megan Casey, NASA GSFC
Ahmad Hammoud, Vantage Partners LLC

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, and thermal cycling, to name a few. Data obtained on long-term thermal cycling of new un-irradiated and irradiated samples of EPC1001 gallium nitride enhancement-mode transistors are presented. This work was done by a collaborative effort including GRC, GSFC, and JPL in support of the NASA Electronic Parts and Packaging (NEPP) Program.

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SCOPE OF WORK

- A NEPP (NASA Electronic Parts and Packaging) collaborative effort among NASA Centers to address performance and reliability of new COTS (Commercial-Off-The-Shelf) power devices based on wide bandgap semiconductor for use in space harsh environment

- Test and evaluate performance of emerging GaN (Gallium Nitride) & SiC (Silicon Carbide) power devices under the exposure to radiation and thermal cycling

- Document results and disseminate findings

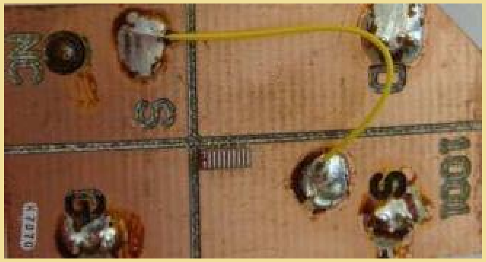
TECHNICAL APPROACH:

- Identify and acquire candidate power devices
- Perform parametric evaluation
- Subject devices to radiation exposure representative of mission environment
- Perform long-term thermal cycling on survived parts
- Determine effects of radiation and temperature cycling on performance of devices
- Address reliability, determine risk factors, and identify mitigation techniques for device use in space missions

TEST DEVICES

- **Efficient Power Conversion, EPC1001, GaN transistors grown on Si (Silicon) wafer; http://www.epc-co.com**
- **Passivated-die form with solder bumps**

Sample die mounted on test structure



# of Parts	Device Label	Condition	Ion	Energy (MeV)	LET (MeV•cm^2 /gm)	Range (µm)	Dose (rad)
1	K7063	Irradiated	Au	2342	84.7	122.9	22718
1	K7064	Irradiated	Xe	1569	98.8	124.5	8301
1	K7044	Irradiated	Xe	1569	50.9	124.5	7886
1	K7065	Irradiated	Xe	1569	98.8	124.5	15838
4	K7068-K7071	Control (un-irradiated)					

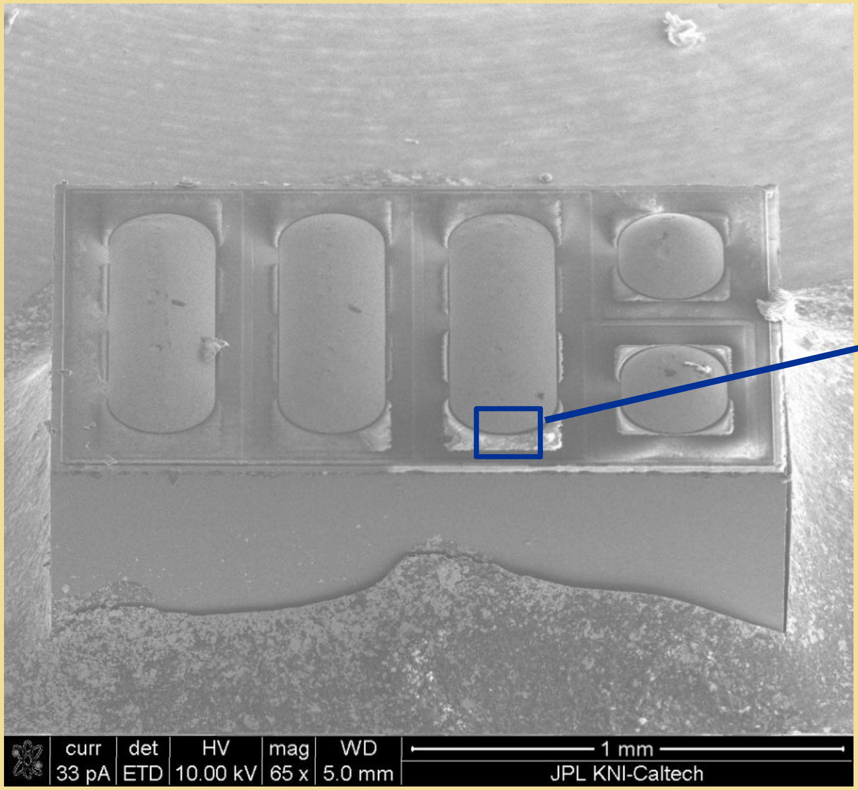
EPC1001 Enhancement-Mode GaN Power Transistor

Manufacturer’s Specifications

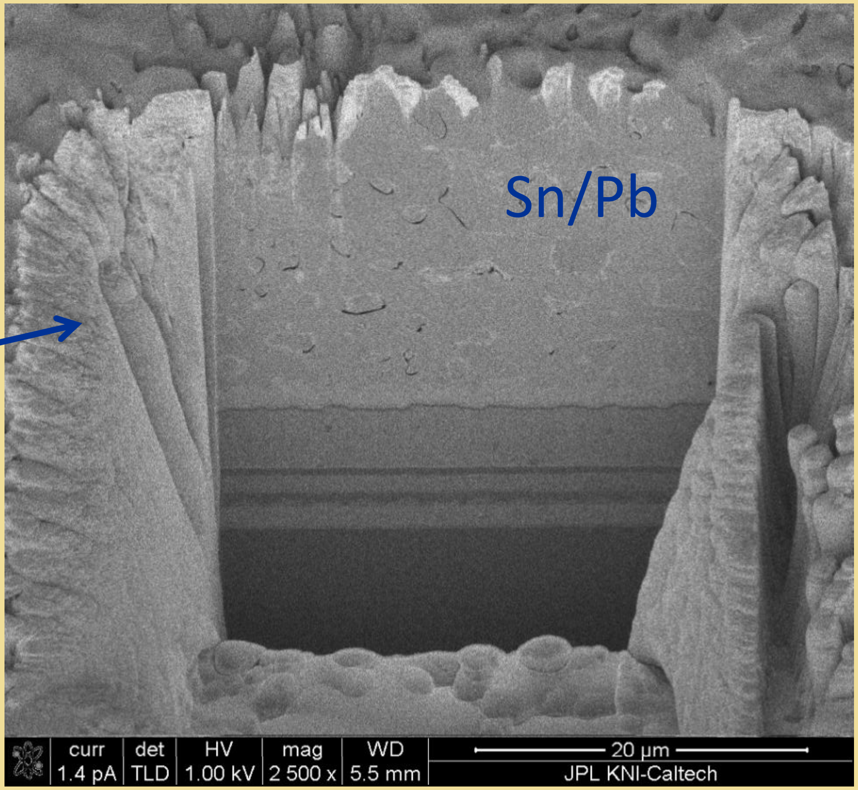
Part #	EPC1001
Drain-Source Voltage, V_{DS} (V)	100
Gate Threshold Voltage, V_{TH} (V)	1.4 @ $V_{DS} = V_{GS}$, I_D = 5 mA
Drain Current, I_D (A)	25
Drain-Source On Resistance, $R_{DS(ON)}$ (mΩ)	5.6 @ V_{GS} = 5V, I_D = 25 A
Operating Temperature, T_J (ºC)	-40 to +125
Package Type	Passivated-Die with Solder Bumps

Focused Ion Beam and SEM Cross-Section of EPC GaN Transistor

SEM Micrograph, 65X , 52 deg. Tilt



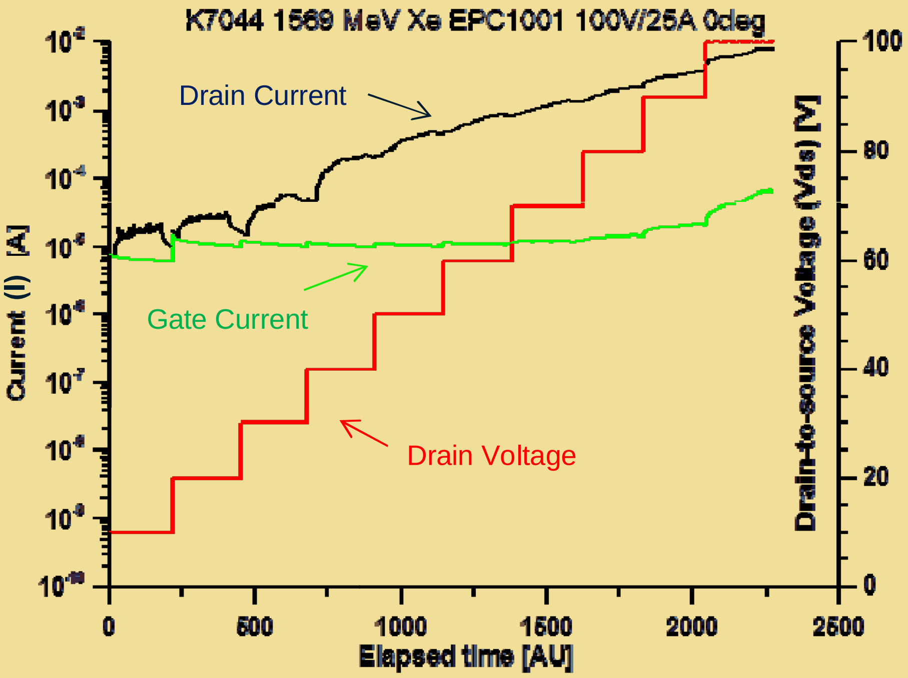
SEM Micrograph after FIB Cut, 2500X, 52 deg. Tilt

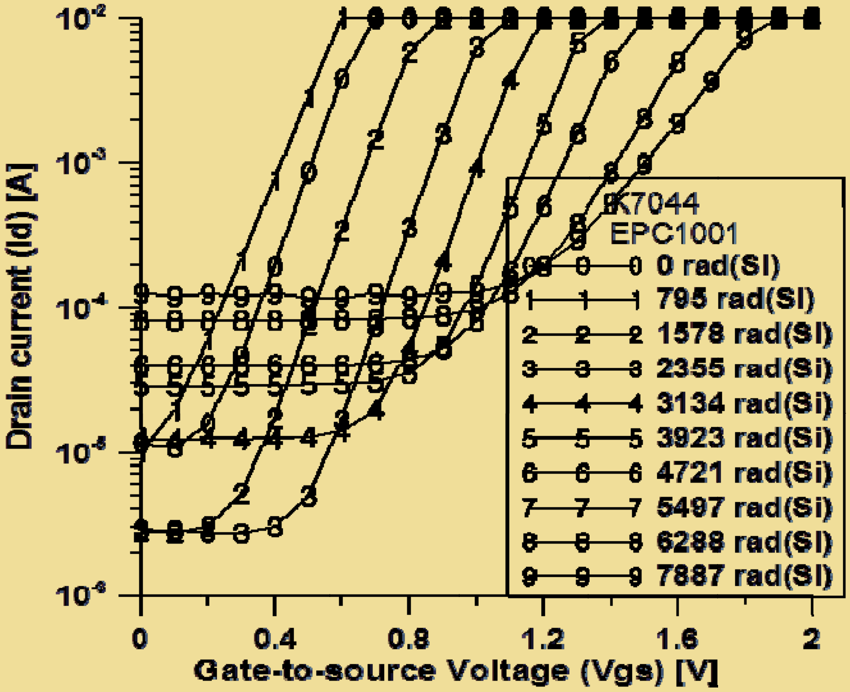


RADIATION DATA

- Devices were irradiated under bias at increasing drain biases
- Transfer curves were measured between irradiations
- Devices still functioned but were well out of spec after irradiation

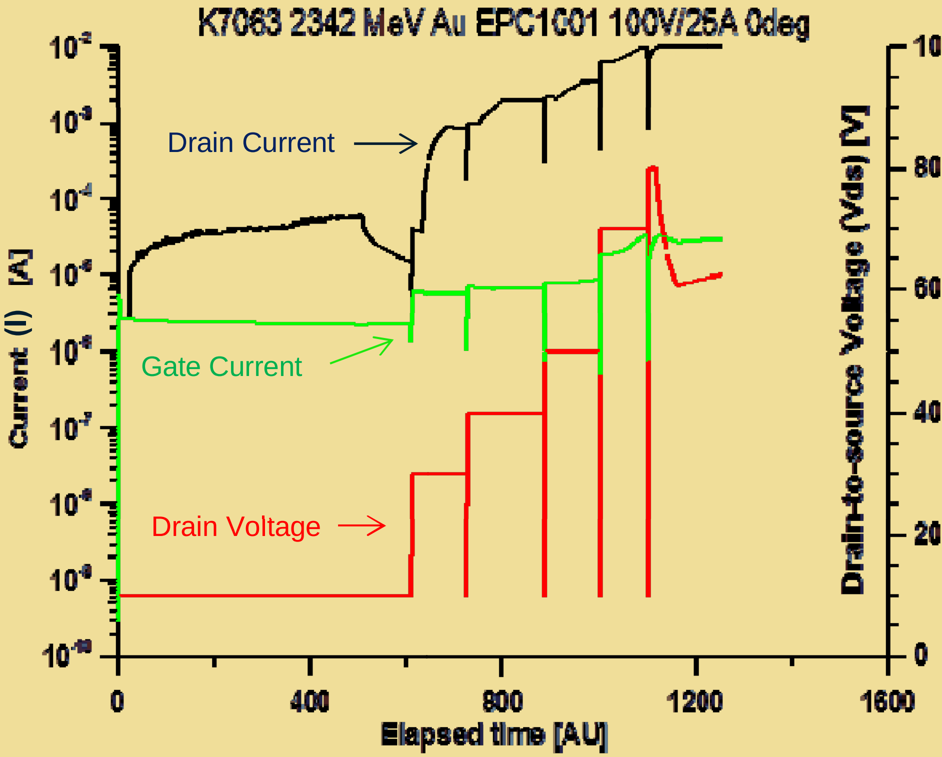
Device K7044

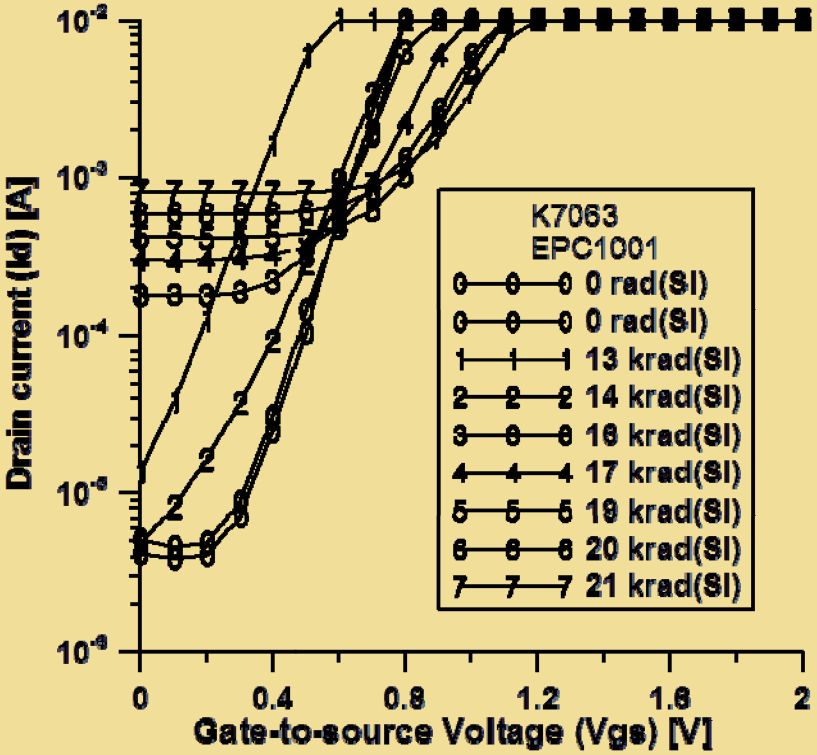




RADIATION DATA

Device K7063

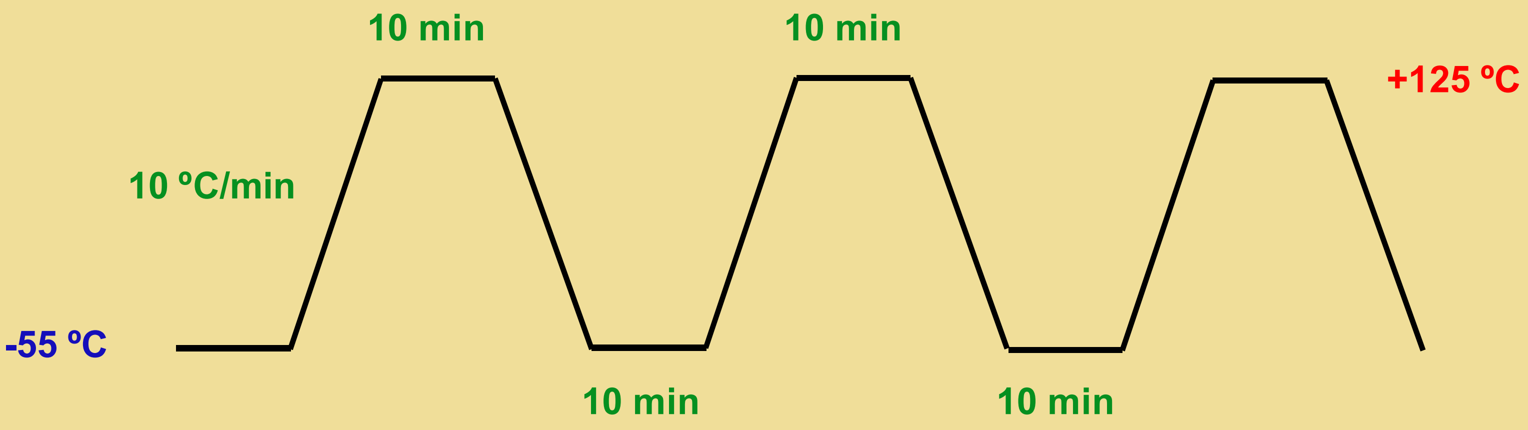




THERMAL CYCLING TEST

Cycling profile

- Total # of Cycles 1000
- Temperature rate of change: 10 ºC/min
- 18 min temp change time
- Temperature range: -55 ºC to +125 ºC
- Soak time at extreme temperatures: 10 min



THERMAL CYCLING SETUP & MEASUREMENT

Parameters

- I-V Output Characteristics
- Gate Threshold Voltage, V_{TH}
- Drain-Source On-Resistance, $R_{DS(on)}$

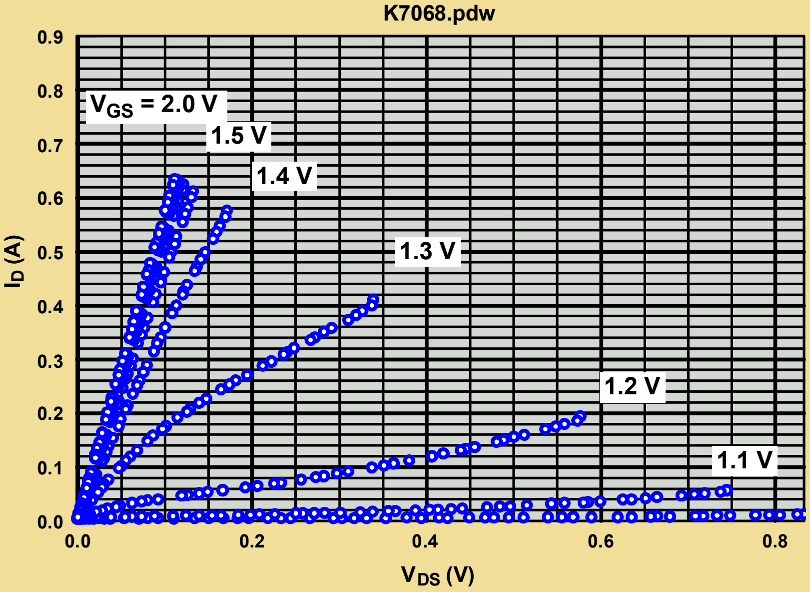
Equipment

- SONY/Tektronix 370A Curve Tracer
- Keithley 238 Source-Measure-Units
- Sun System Environmental Chamber

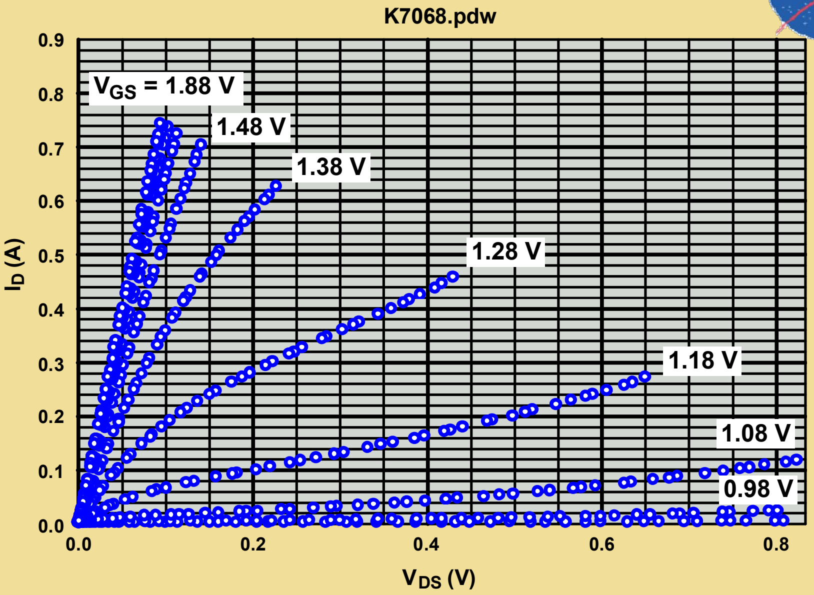
Measurements

- Pre, during, & post-cycling
- At room temperature

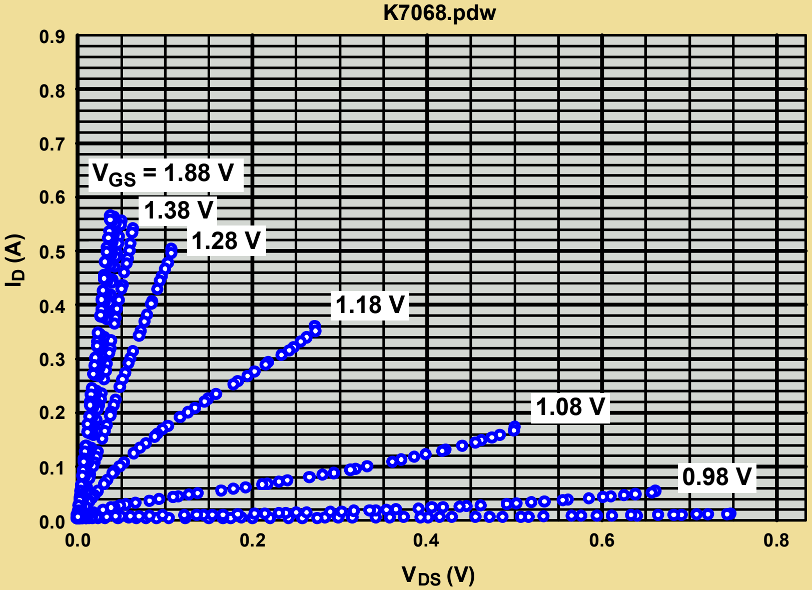
I-V Curves for K7068 (control)



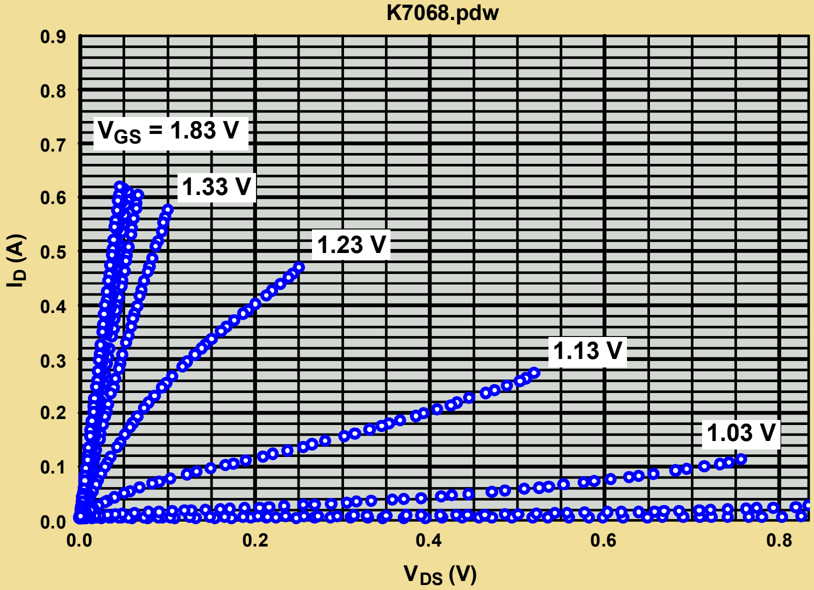
Pre-Cycling



After 500 Cycles

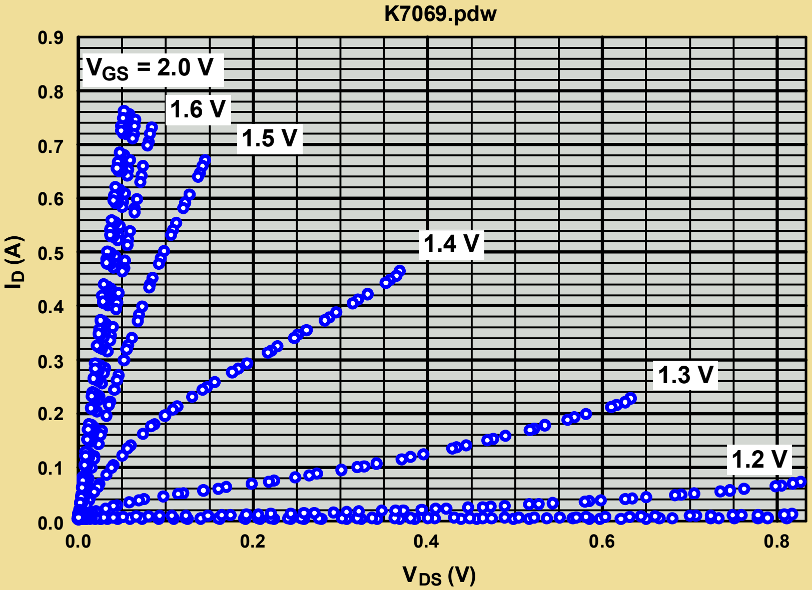


After 824 Cycles

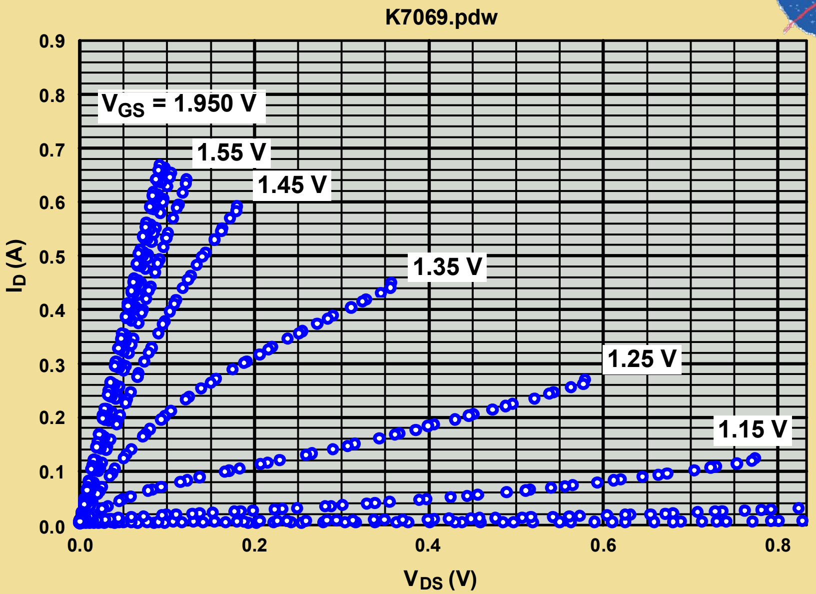


After 1000 Cycles

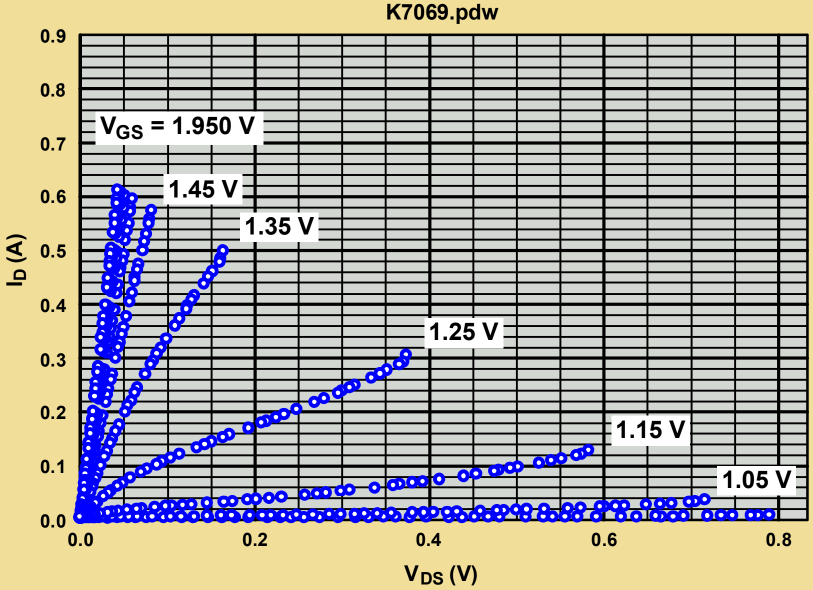
I-V Curves for K7069 (control)



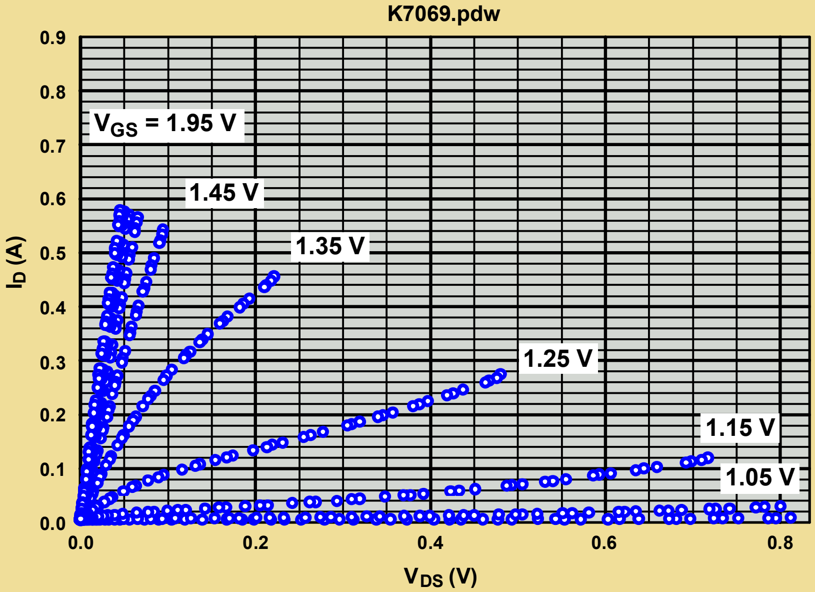
Pre-Cycling



After 500 Cycles

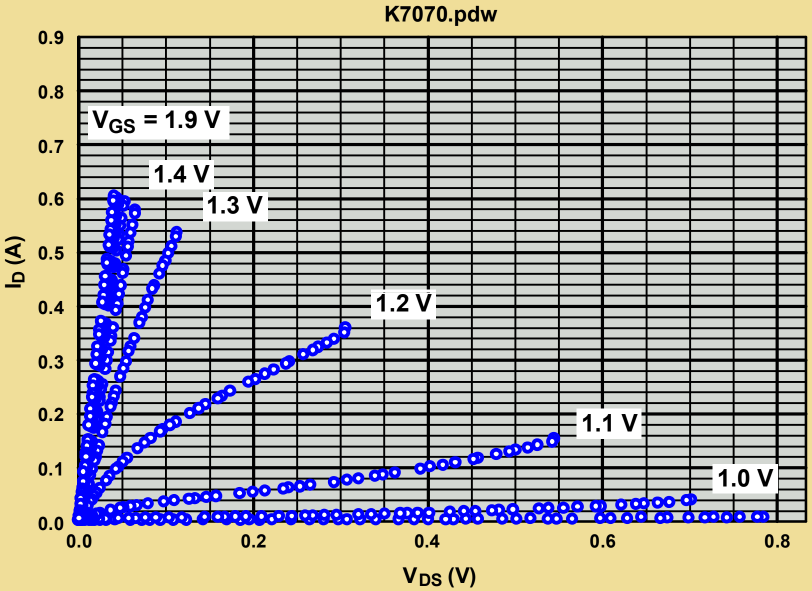


After 824 Cycles

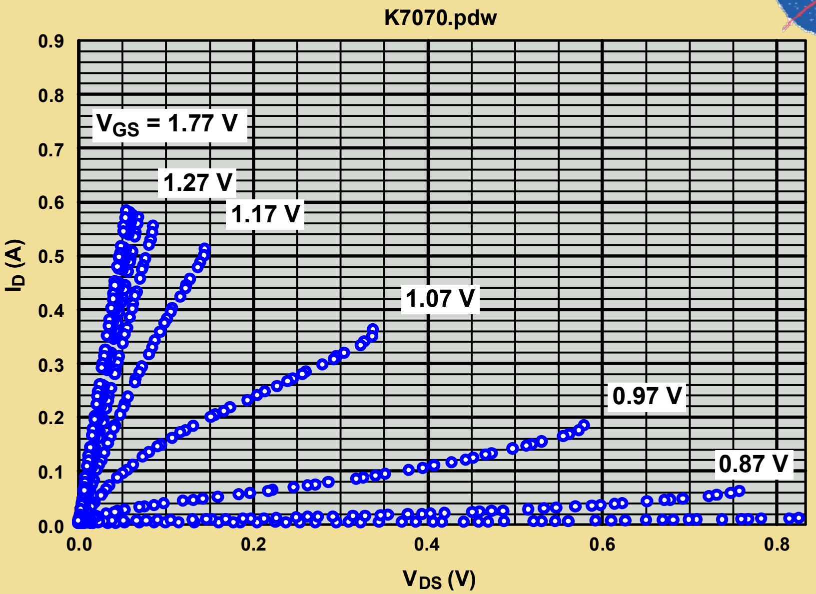


After 1000 Cycles

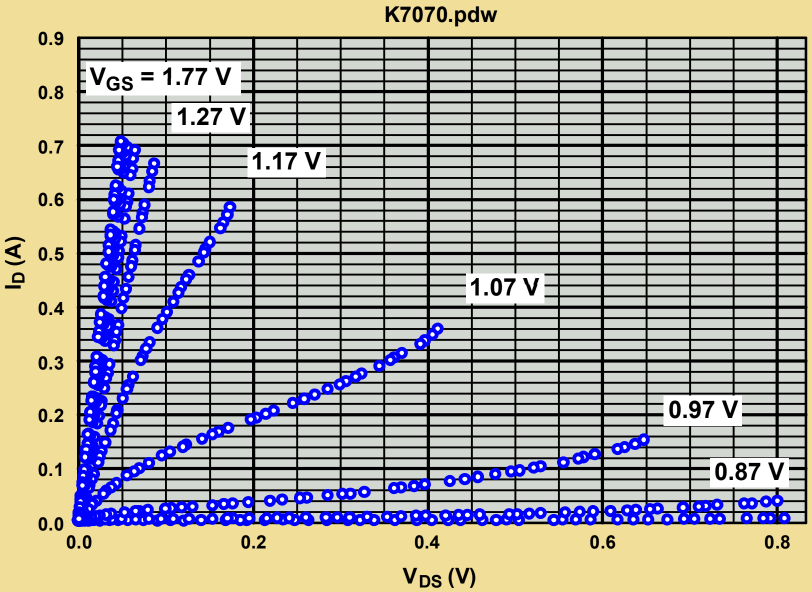
I-V Curves for K7070 (control)



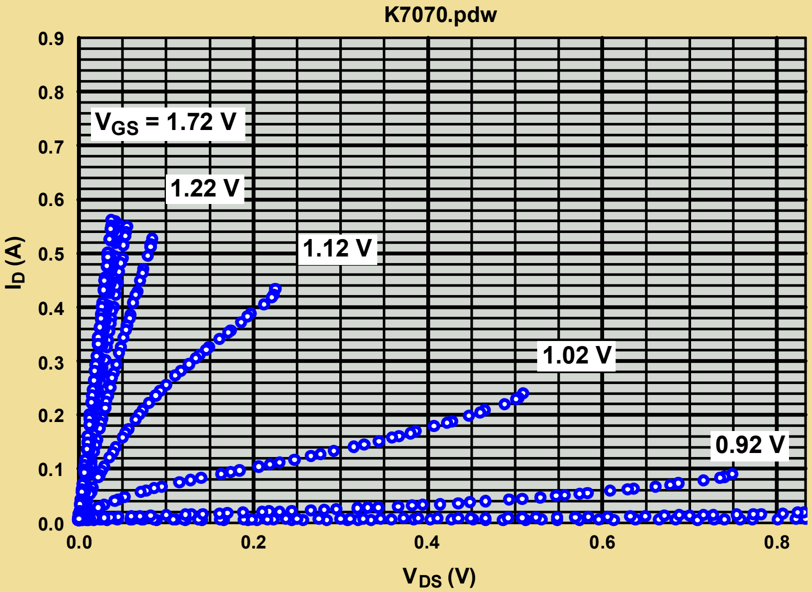
Pre-Cycling



After 500 Cycles

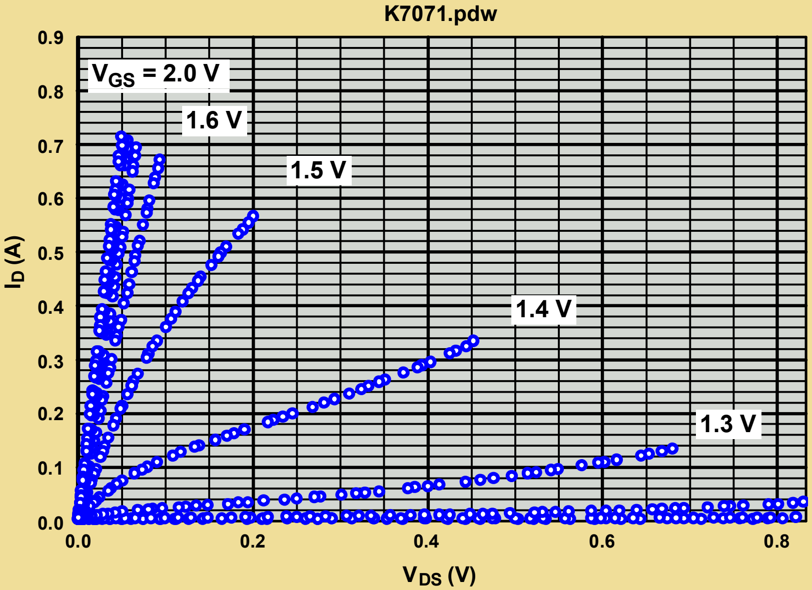


After 824 Cycles

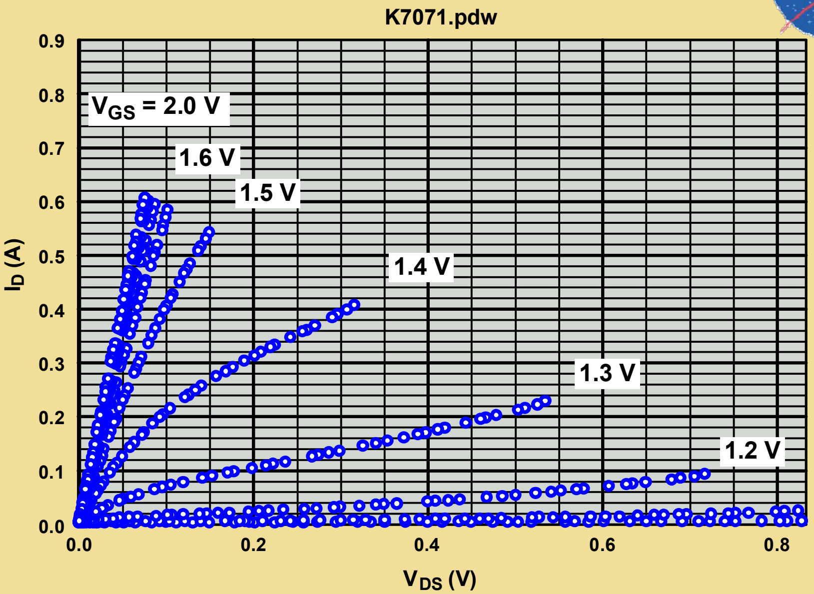


After 1000 Cycles

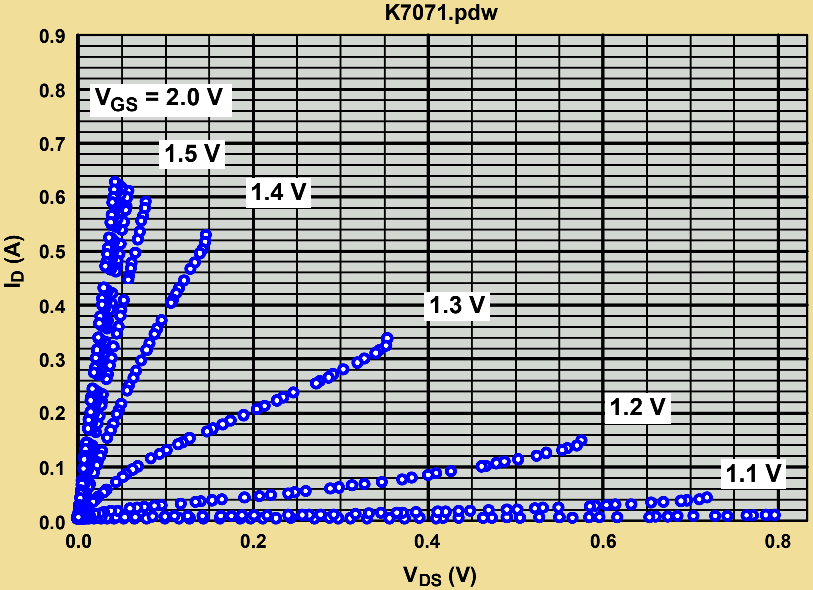
I-V Curves for K7071 (control)



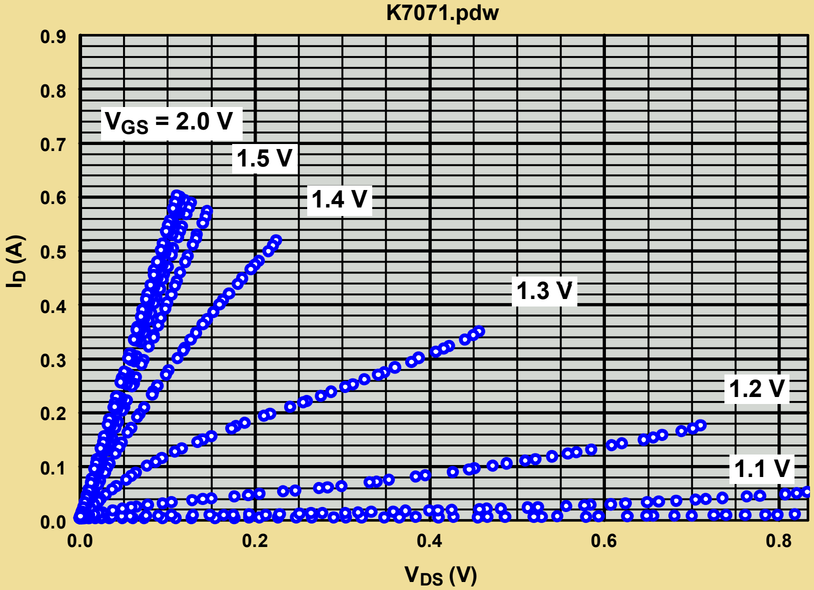
Pre-Cycling



After 500 Cycles

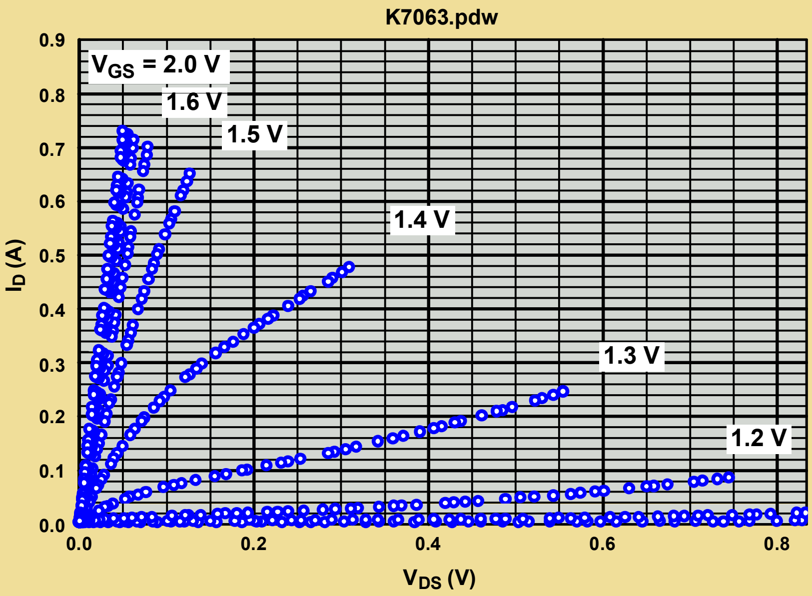


After 824 Cycles

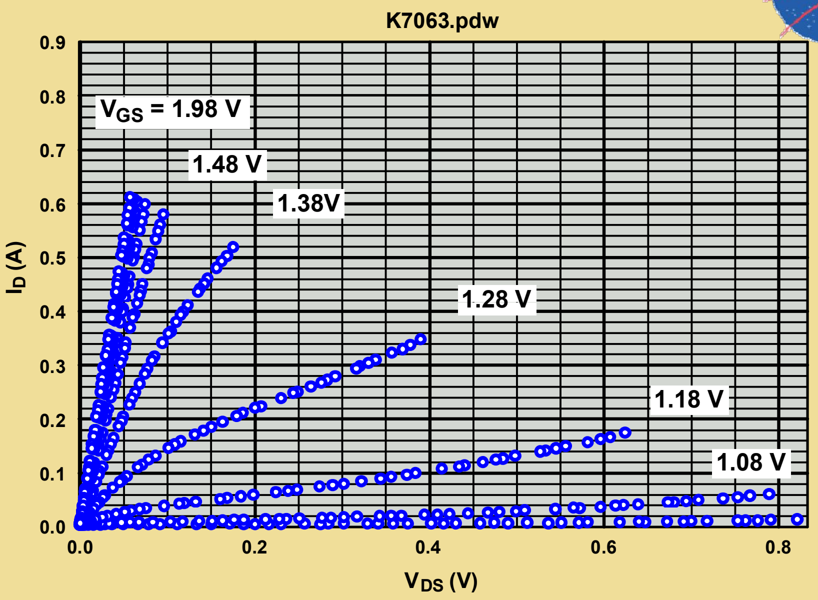


After 1000 Cycles

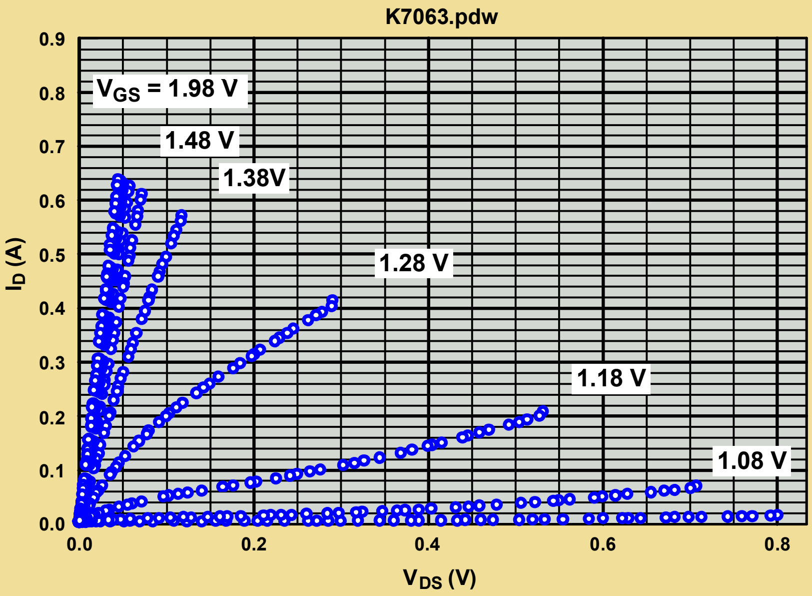
I-V Curves for K7063 (irradiated, Au ions, 22.7 krad)



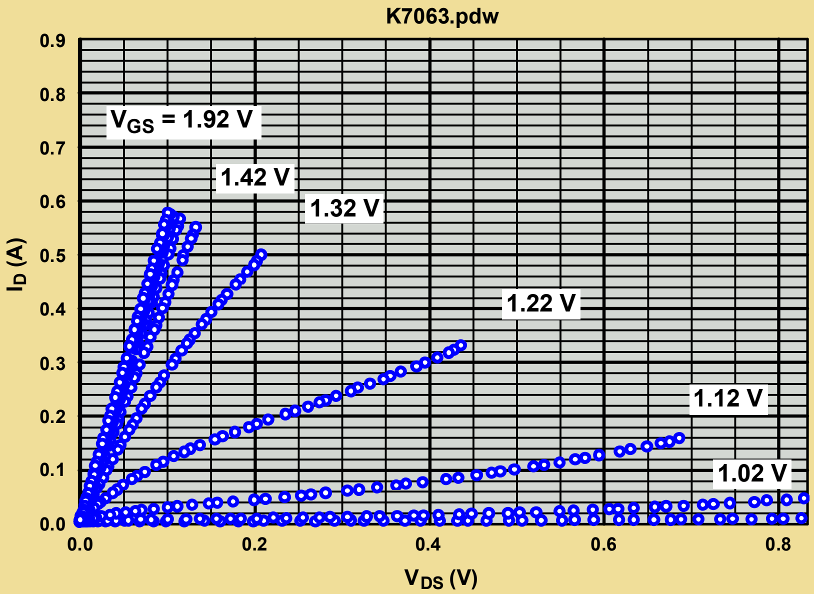
Pre-Cycling



After 500 Cycles

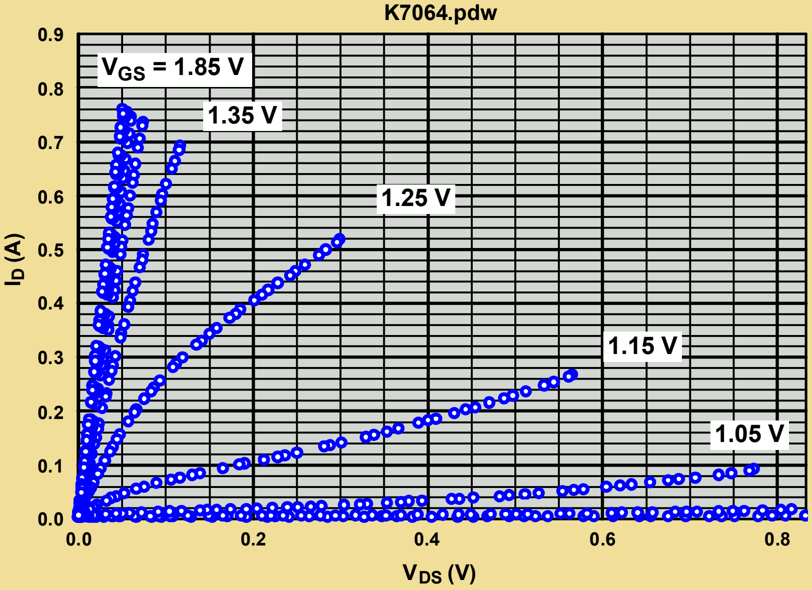


After 824 Cycles

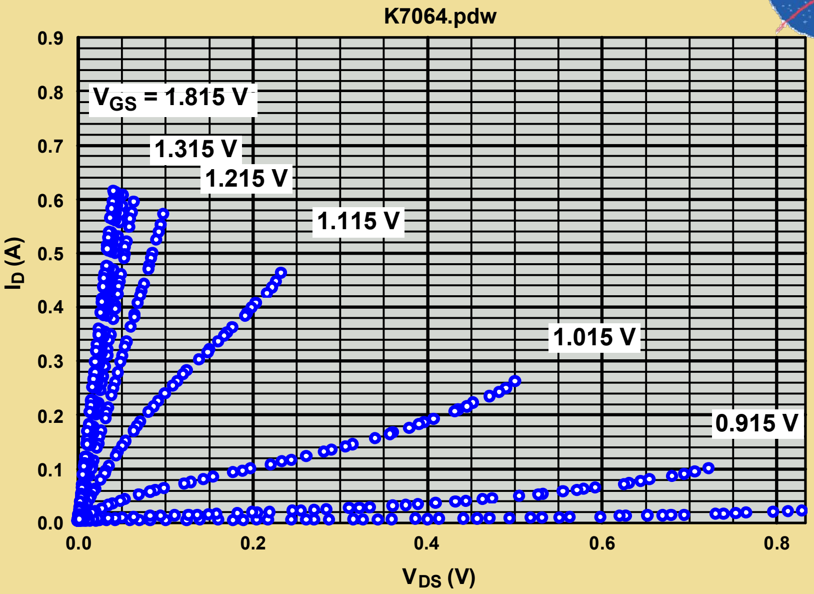


After 1000 Cycles

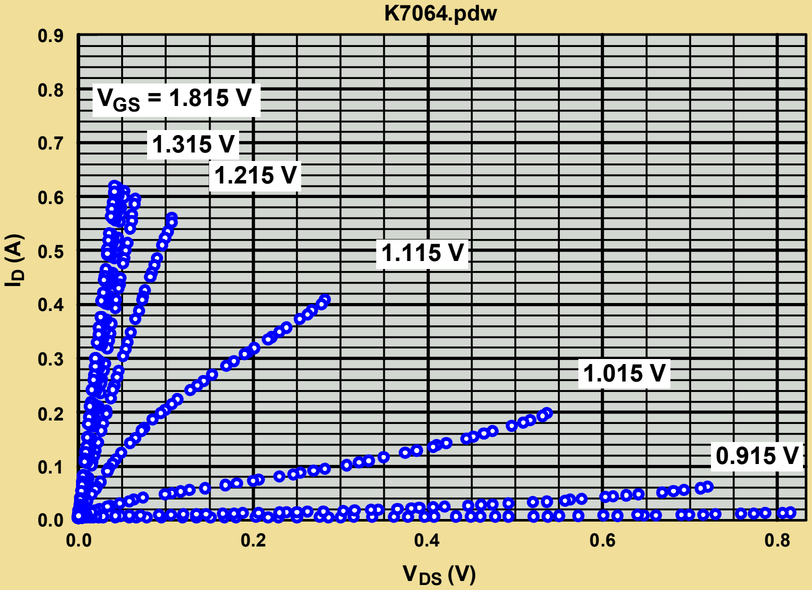
I-V Curves for K7064 (irradiated, Xe ions, 8.3 krad)



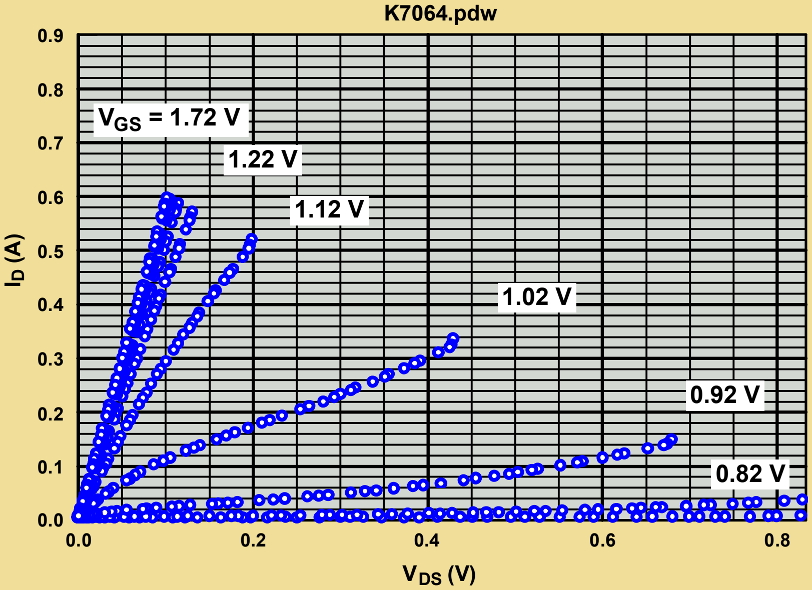
Pre-Cycling



After 500 Cycles

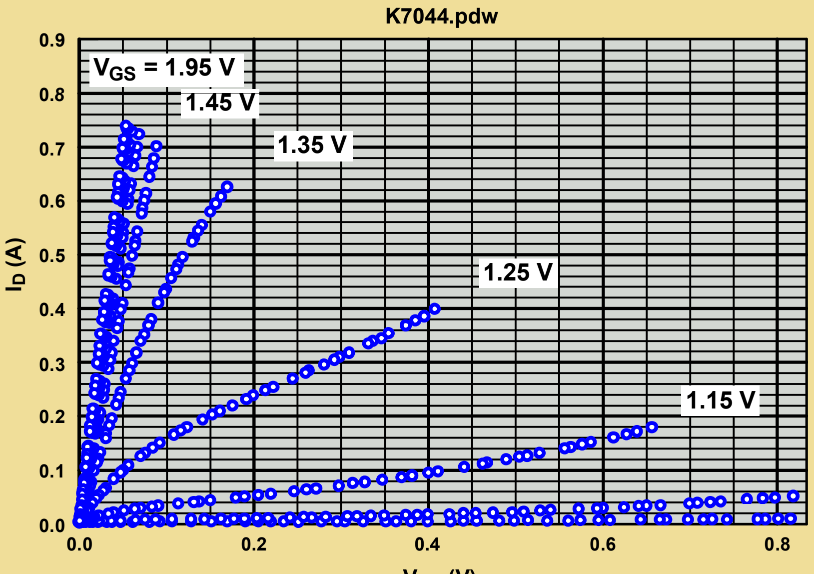


After 824 Cycles

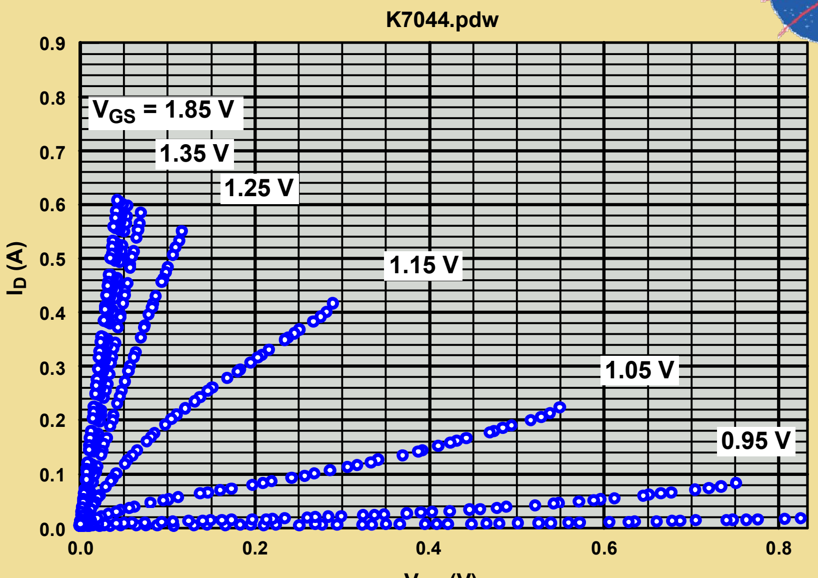


After 1000 Cycles

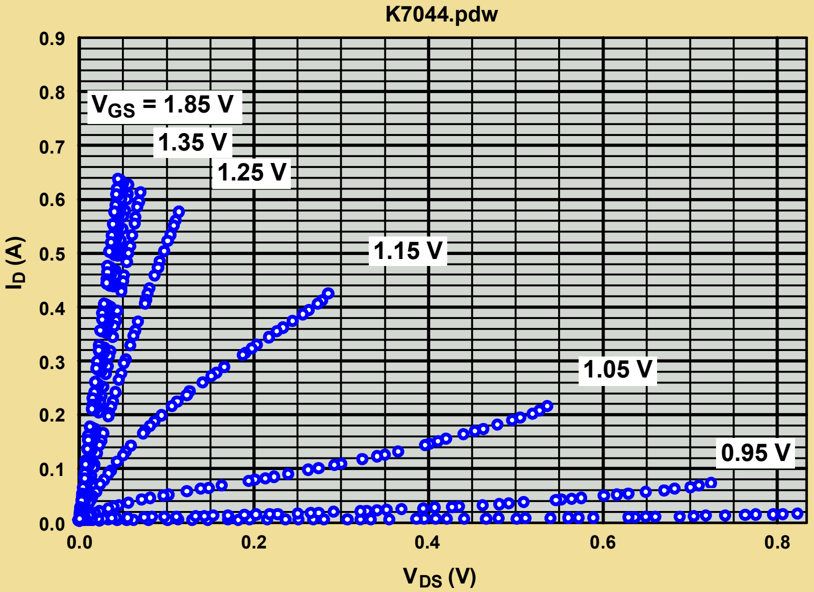
I-V Curves for K7044 (irradiated, Xe ions, 7.9 krad)



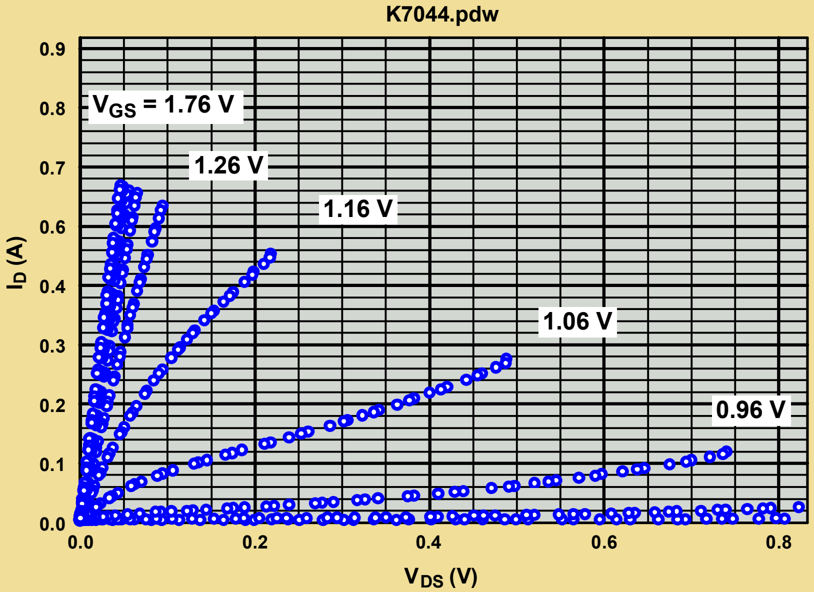
Pre-Cycling



After 500 Cycles

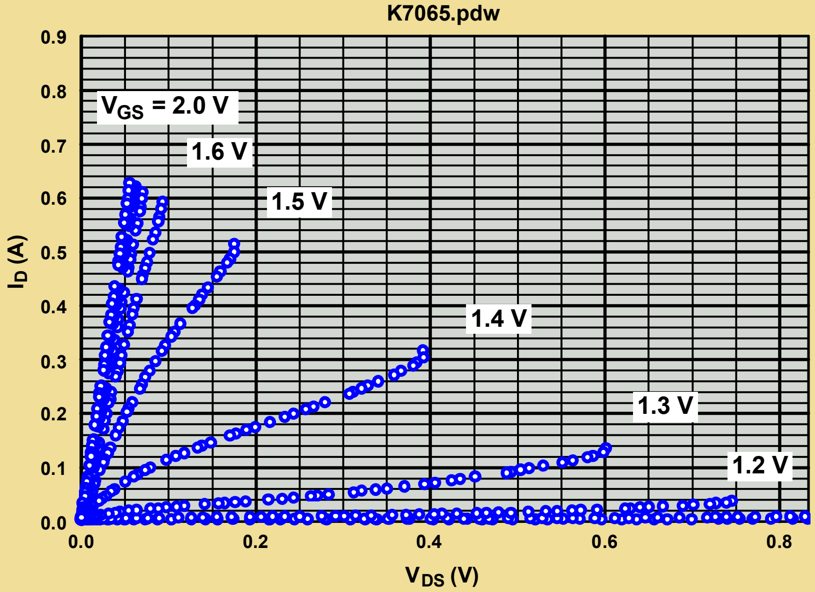


After 824 Cycles

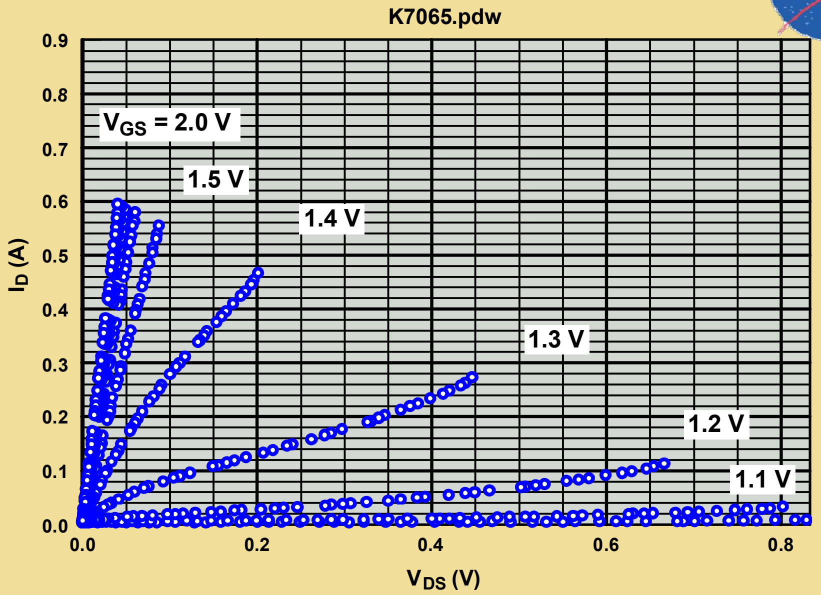


After 1000 Cycles

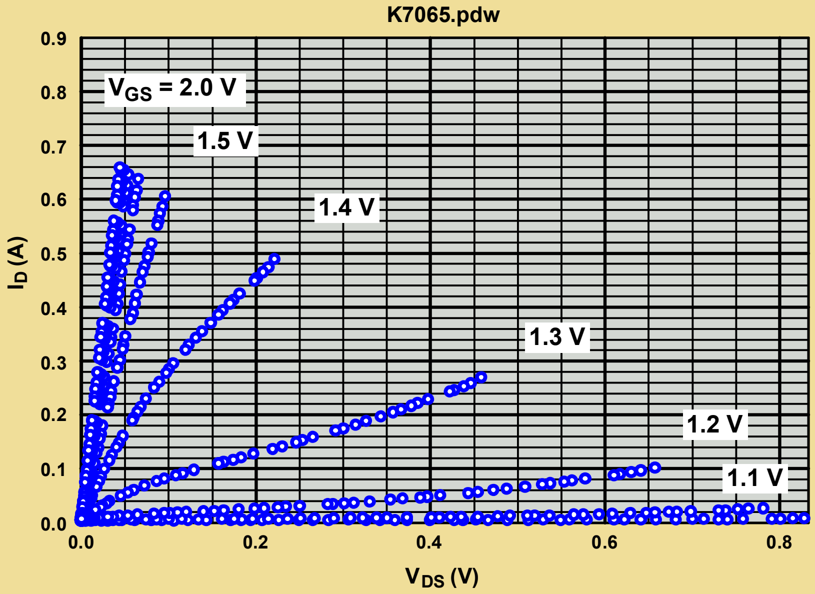
I-V Curves for K7065 (irradiated, Xe ions, 15.8 krad)



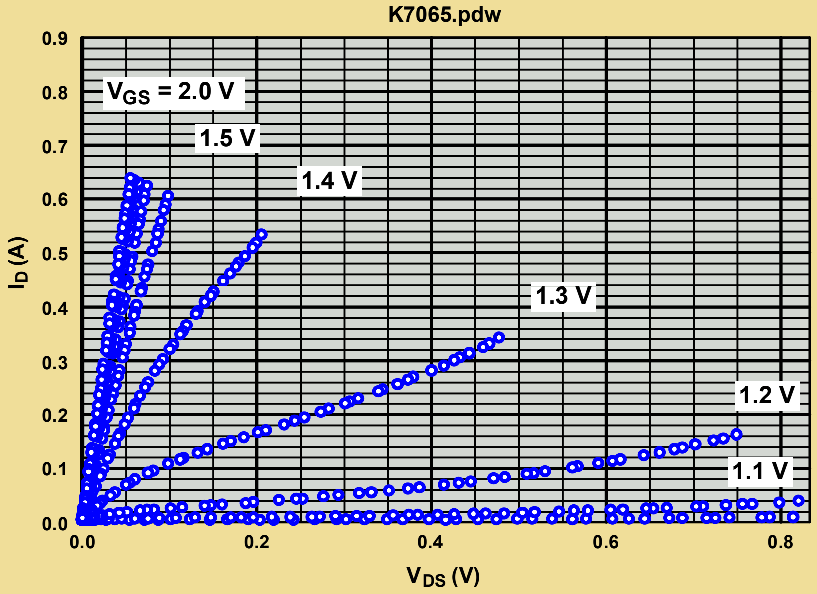
Pre-Cycling



After 500 Cycles

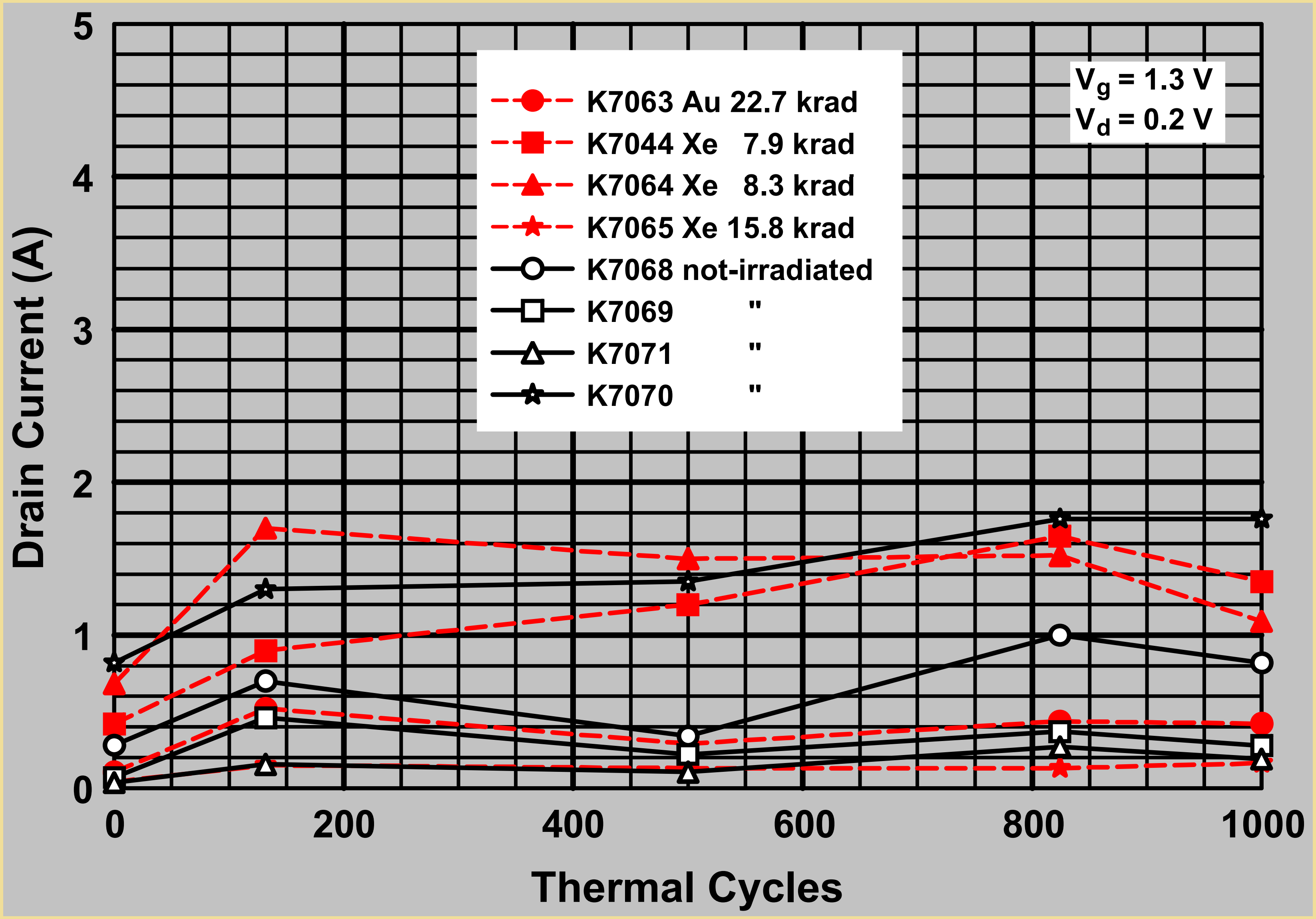


After 824 Cycles

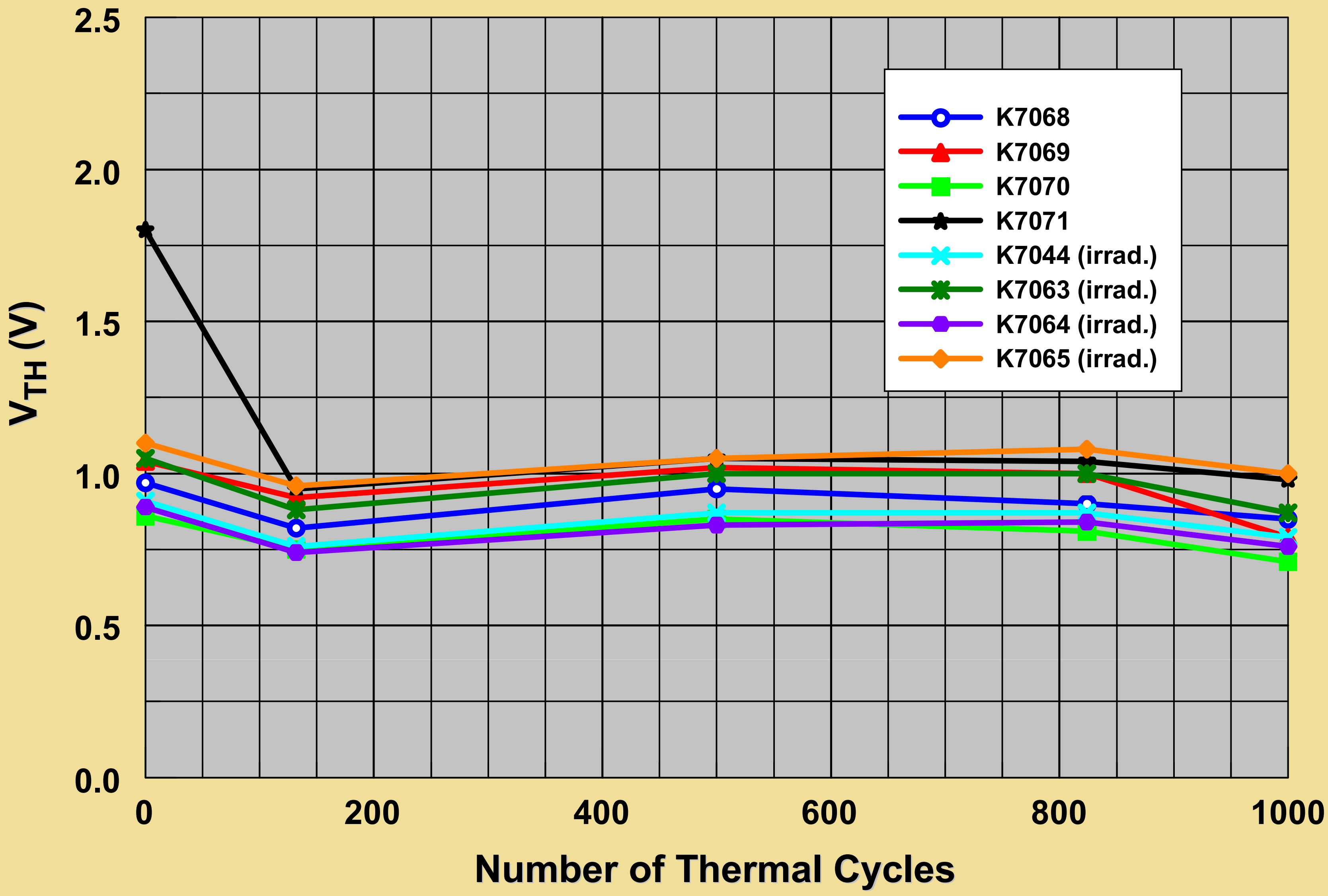


After 1000 Cycles

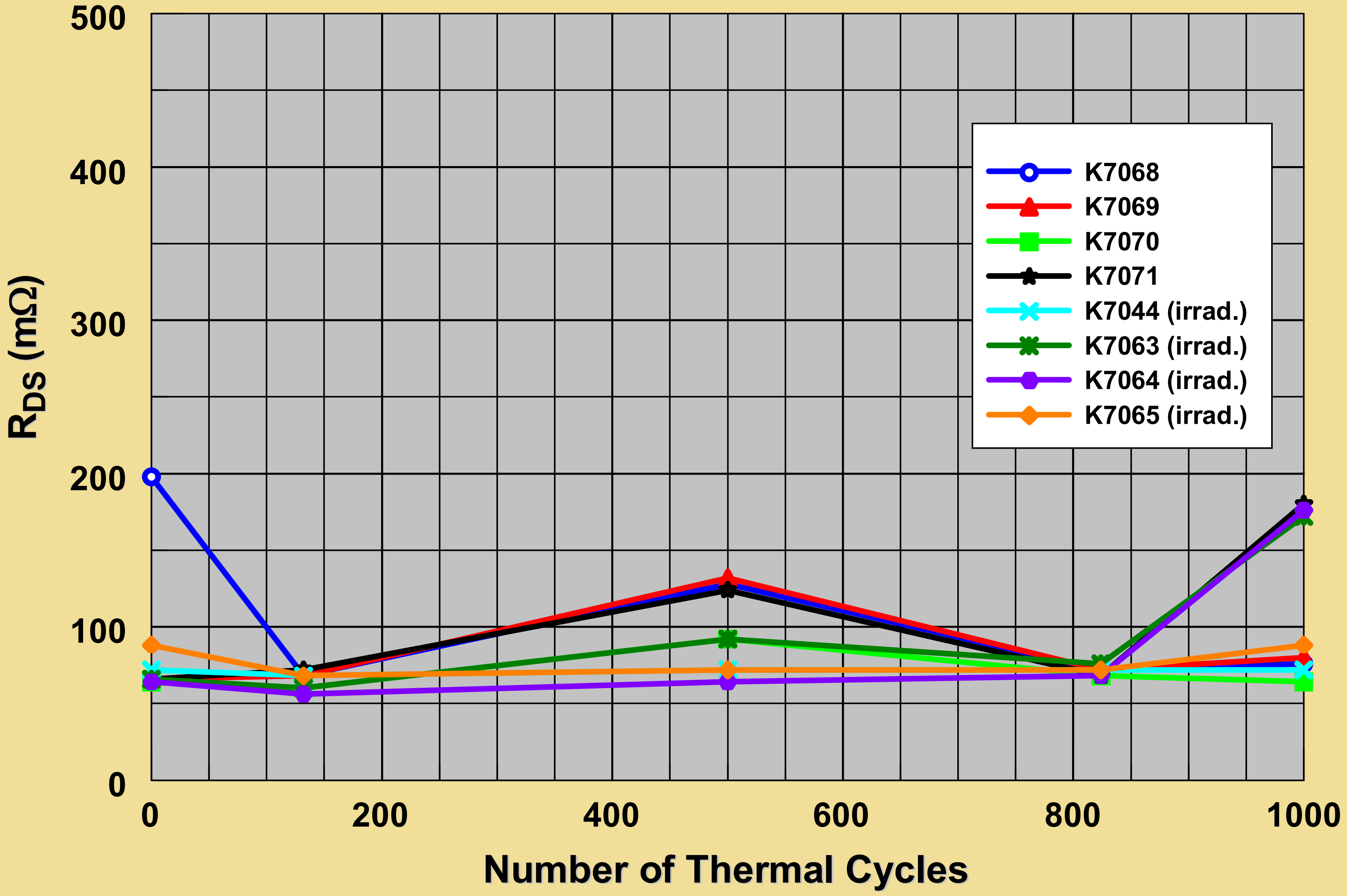
Drain Current of EPC1001 GaN Transistors to 1000 Thermal Cycles



GATE THRESHOLD VOLTAGE, V_{TH}



Drain-Source On Resistance, $R_{DS(ON)}$



OBSERVATIONS

- All eight GaN transistors remained functional after exposure to radiation followed by 1000 thermal cycles between -55 & +125 ^{0}C
- Main impact of radiation was increase in leakage current of devices
- Thermal cycling seemed to introduce inconsistent variation in I-V characteristic curves of the GaN transistors; notably in their transconductance
- V_{TH} of tested devices experienced an initial decrease with cycling but seemed to level off after exposure to about 130 cycles; possibly due to thermal conditioning
- For the $R_{DS(ON)}$ data, at 1000 thermal cycles the values of $R_{DS(ON)}$ occurred in two distinct clusters. A two-sample t-test ($p<0.005$) showed that the means of the clusters were different. The cause of the two distinct clusters is not known, but further investigation should probably wait until the second generation of the devices is tested.

PROPOSED FOLLOW-UP

- Conduct multi-stress tests (electrical/thermal) on these control and irradiated GaN FETs (Field Effect Transistors).
- Perform overstress tests to determine failure mechanisms
- Evaluate and assess performance of second generation of these devices
- Repeat work on newly-developed GaN and SiC COTS power devices in support of NEPP Program

ACKNOWLEDGMENT

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