Why GaN in Space?

Alex Lidow, Ph.D.

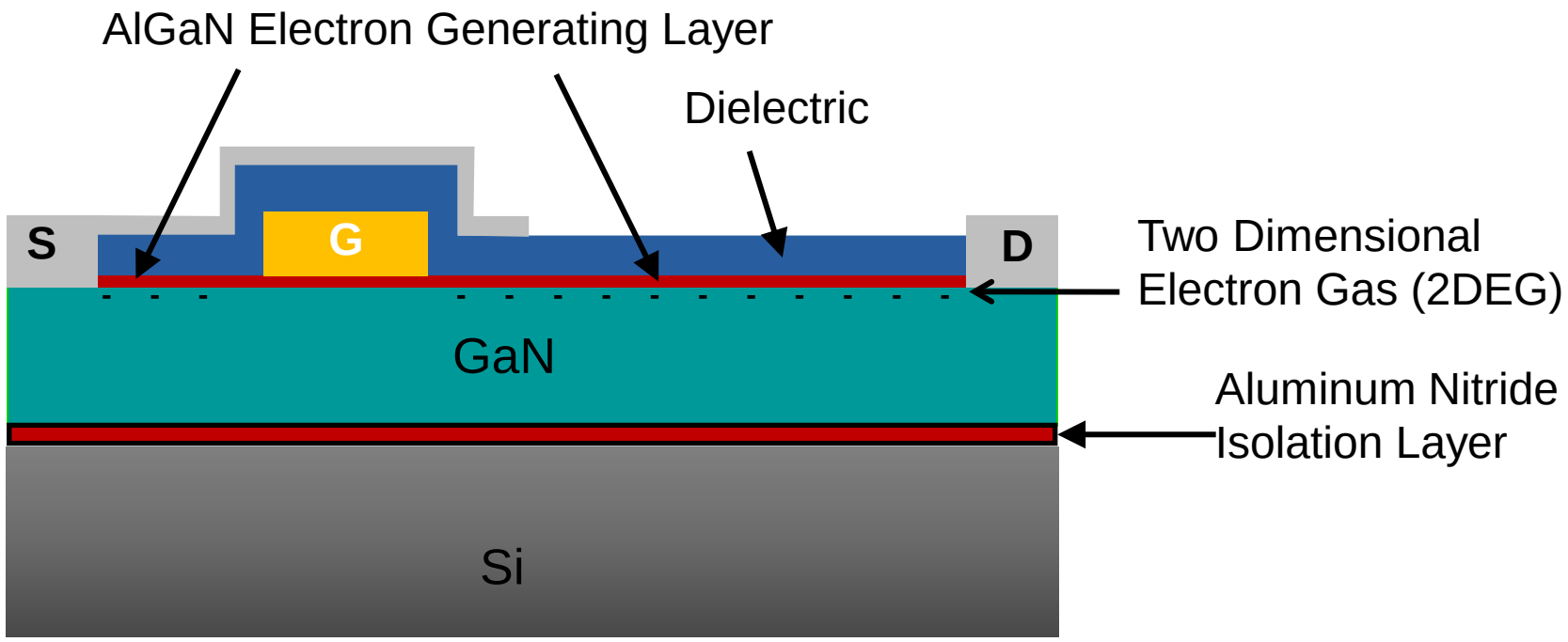
Agenda

- GaN overview
- GaN reliability
- Radiation tolerance of GaN vs. Silicon
- Failure mechanisms of GaN
- Superior electrical performance of GaN
- Space applications and solutions

What is GaN-on-Si technology?

- GaN-on-Si technology is the recognized displacement technology for Si power MOSFETs
- GaN-on-Si FETs are smaller, higher performance, more radiation hard, and more rugged than Si power MOSFETs
- eGaN technology, developed by EPC, is very Radiation Hard
- GaN-on-Si technology can be integrated while preserving extraordinary radiation hardness
- EPC is the largest producer of GaN-on-Si power devices in the < 400 V market

How is GaN Built?



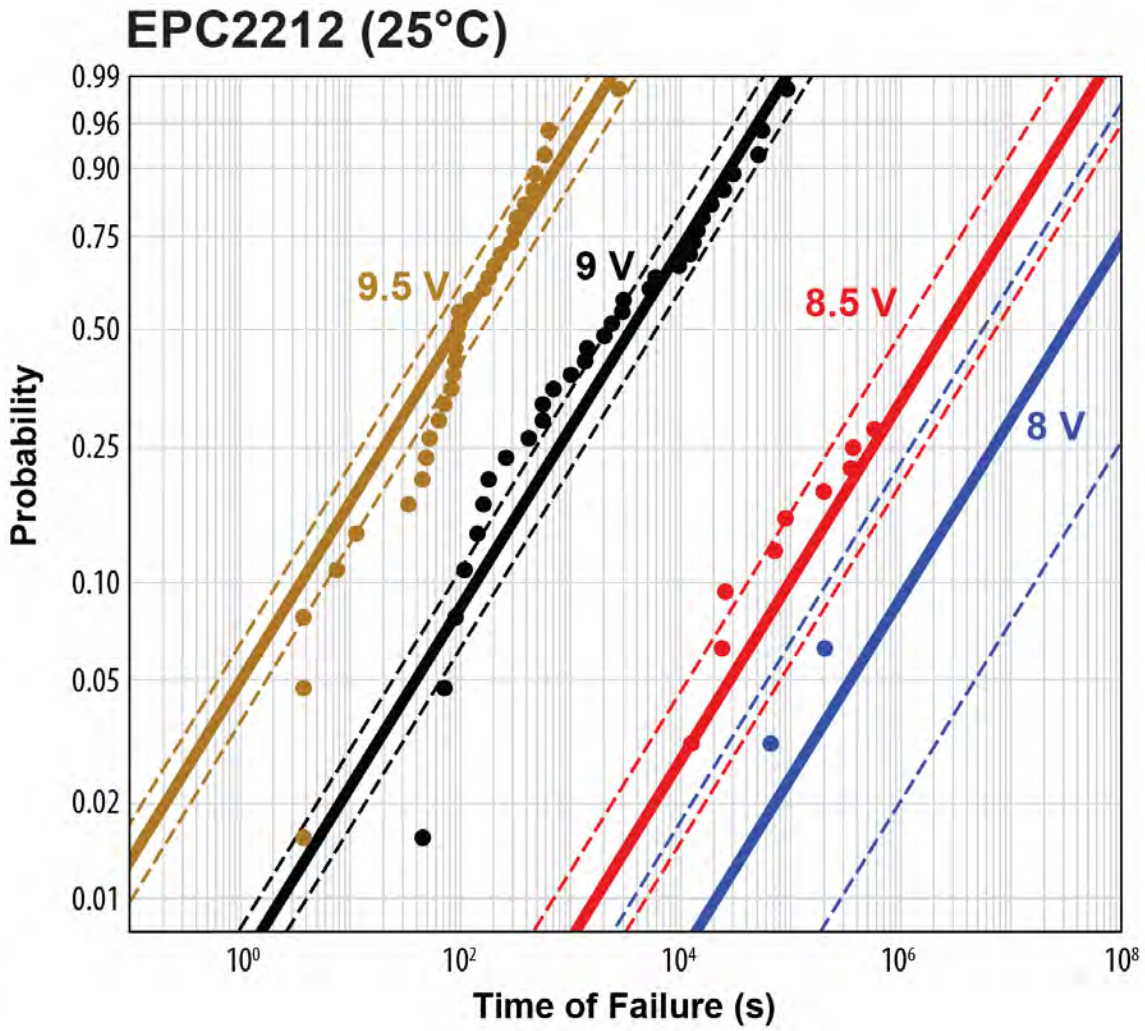
Die and Package Stress Tests

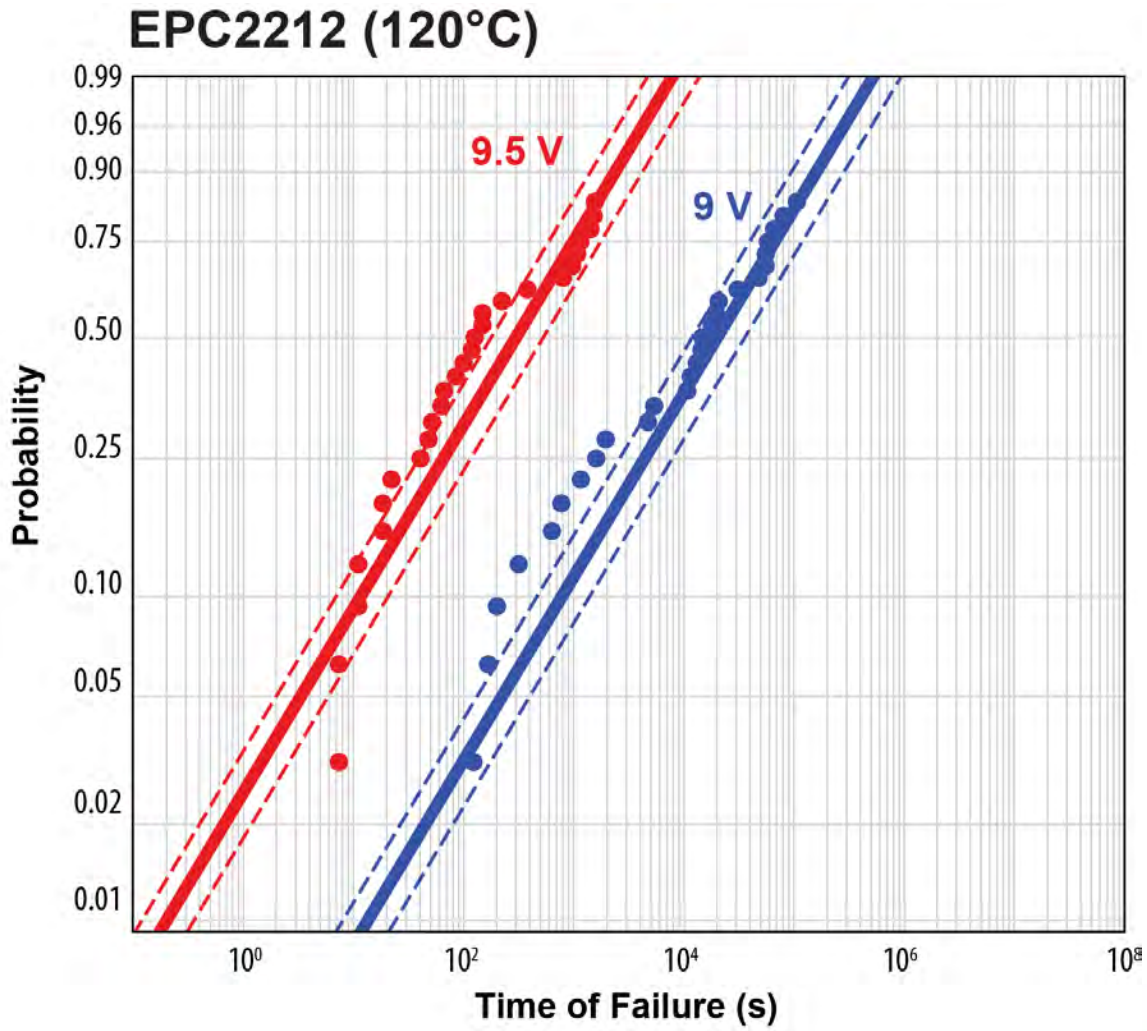
Stressor	Device/Package	Method	Intrinsic Failure Mechanism	Evidence
Voltage	Gate-Source	HTGB	Dielectric Failure (TDDB) Threshold Shift	Gate-Source Leakage Gate-Source Threshold
	Drain-Source	HTRB	$R_{DS(on)}$	$R_{DS(on)}$ Shift vs time
Current	Drain-Source	DC Current	Electromigration	$R_{DS(on)}$ Failure
			Thermomigration	$R_{DS(on)}$ Failure
			Thermal	DC SOA Failures
		Pulsed Current	Thermal Unknown Mechanism	Pulsed SOA Failure Hyper-fast high current pulses
dv/dt	Drain-Source	Super-Hard Switching Tests	$R_{DS(on)}$	$R_{DS(on)}$ Shift vs time
di/dt	Drain Source	High Current Narrow Pulse	Unknown Mechanism	Hyper-fast high current pulses
Temperature	Package	Storage Temperature	Unknown Mechanism	MSL1 Testing High Temp Storage
Chemical	Package	Humidity	Dendrite Formation/Corrosion	H3TRB Testing HAST Testing
Mechanical Strain	Package	Temperature Cycling	Solder Fatigue	Temperature Cycling Test
		IOL	Solder Fatigue	Temperature and Current Test
		Bending Force Test	Delamination	I_{DSS} Failures
		Die Shear	Solder Strength	Solder strength test
		Package Force	Device Breakage	Device Pressure Testing
Piezoelectric Strain	Drain-Source	Pulsed Current	Unknown Mechanism	Hyper-fast high current pulses
Radiation	Gate-Source	Gamma Radiation	Charge Trapping	V_{TH} shift vs RAD(Si)
	Drain Source	Single Event	Proprietary	I_{DSS} vs LET and dose

Stress – Voltage Gate-Source

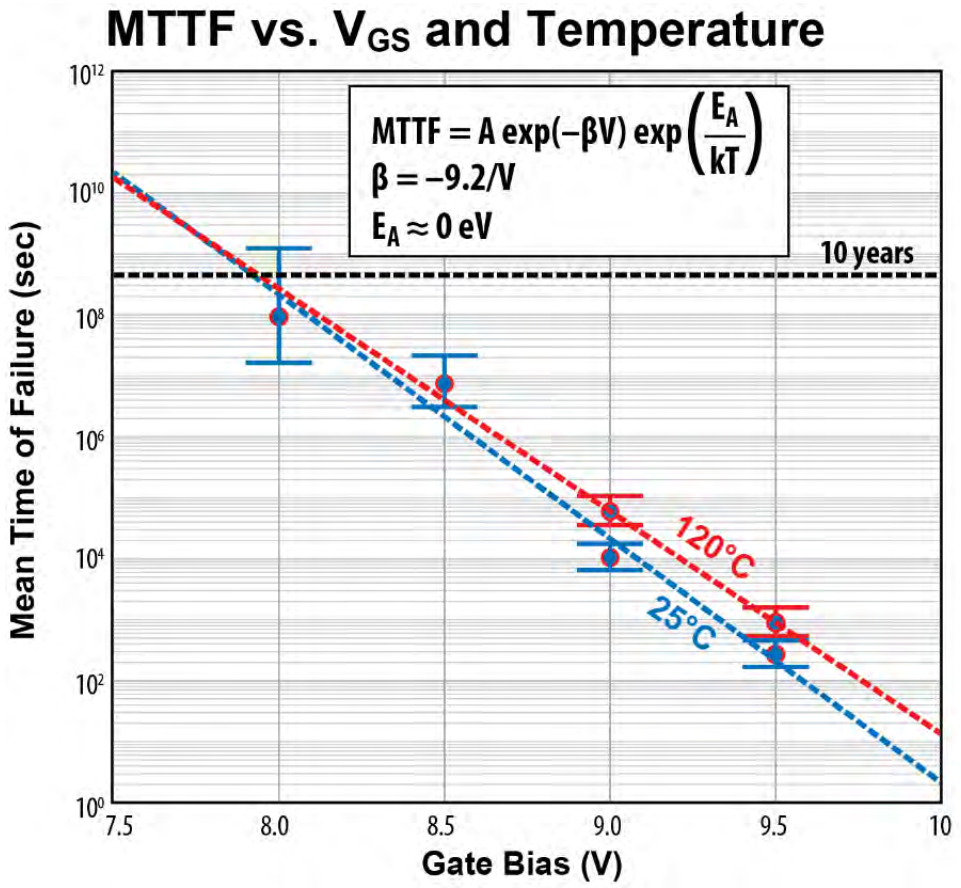
Gate Acceleration: Analysis

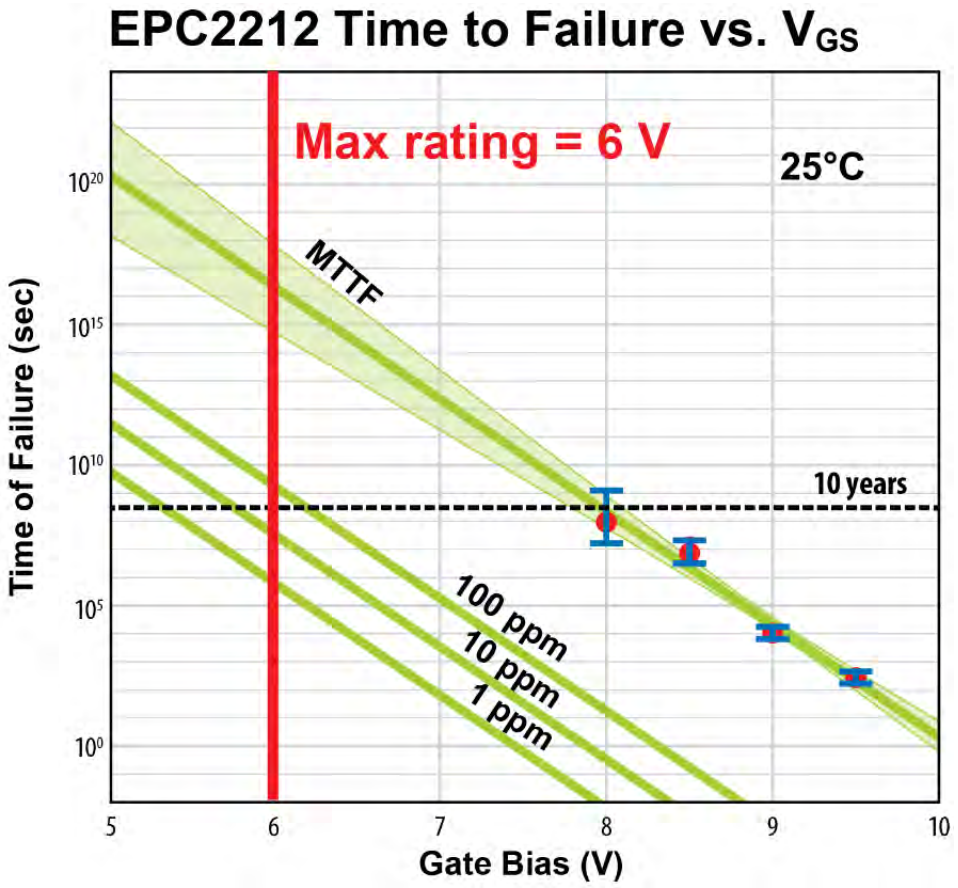
Data Sheet Maximum = 6 V_{GS}



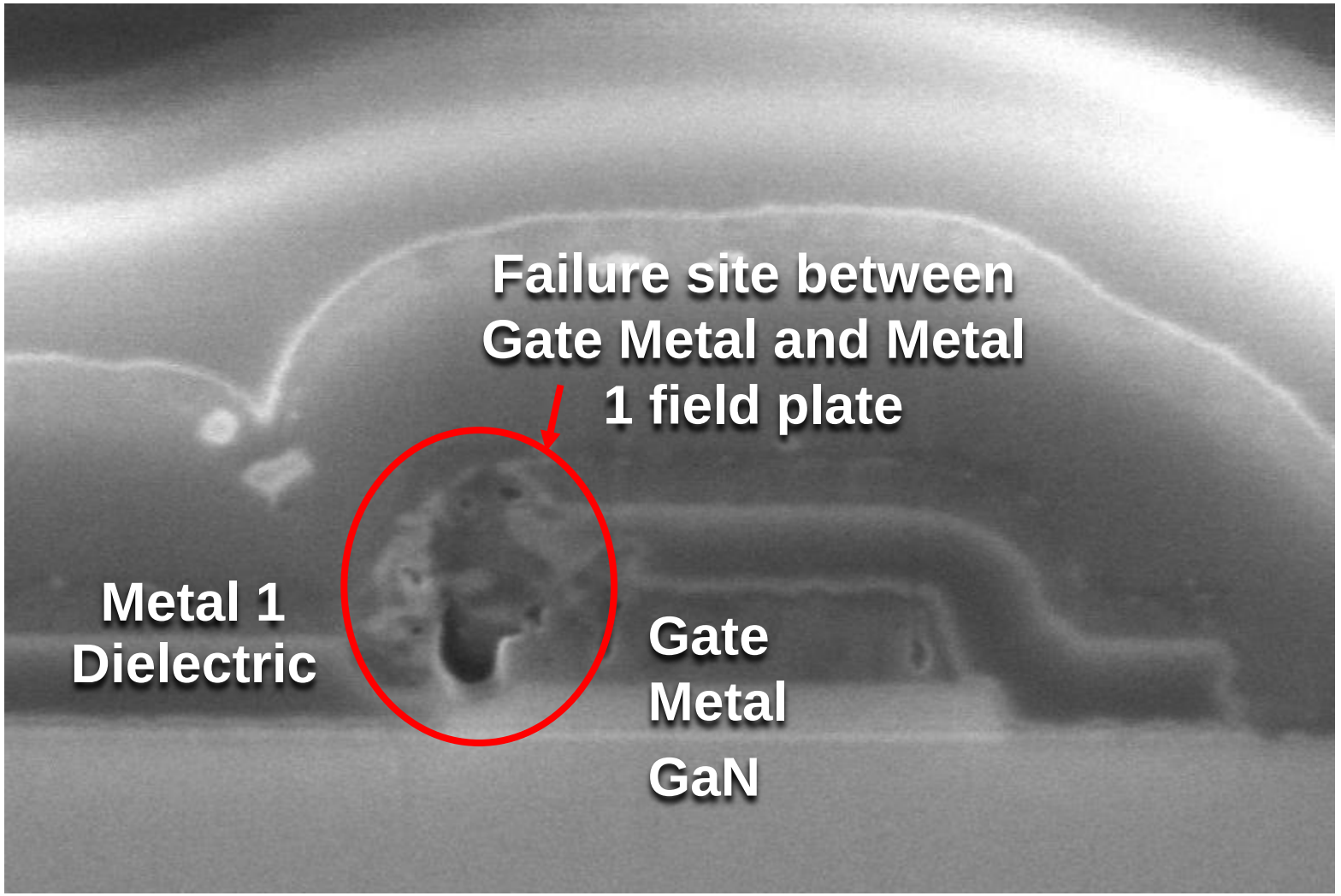


Gate Acceleration: Time to Failure





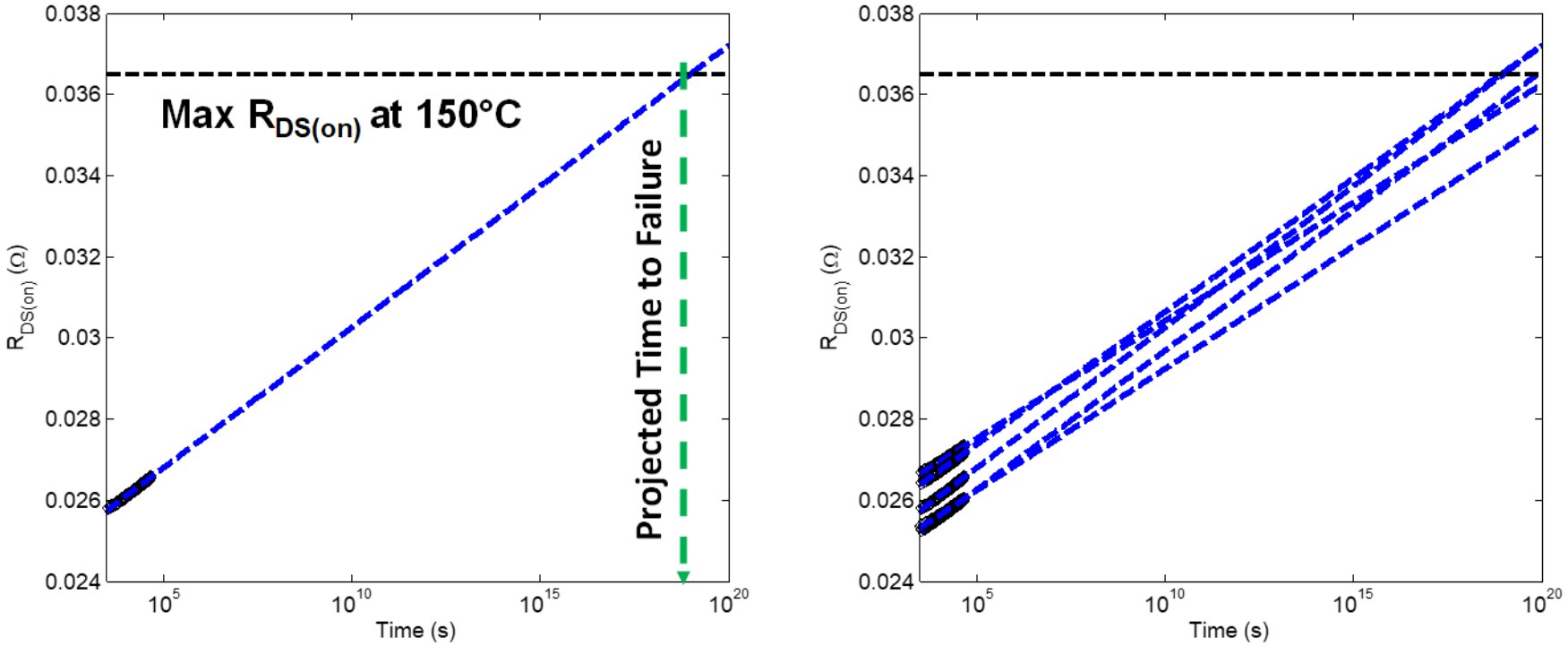
Gate Failures Not in GaN



Stress – Voltage Drain-Source

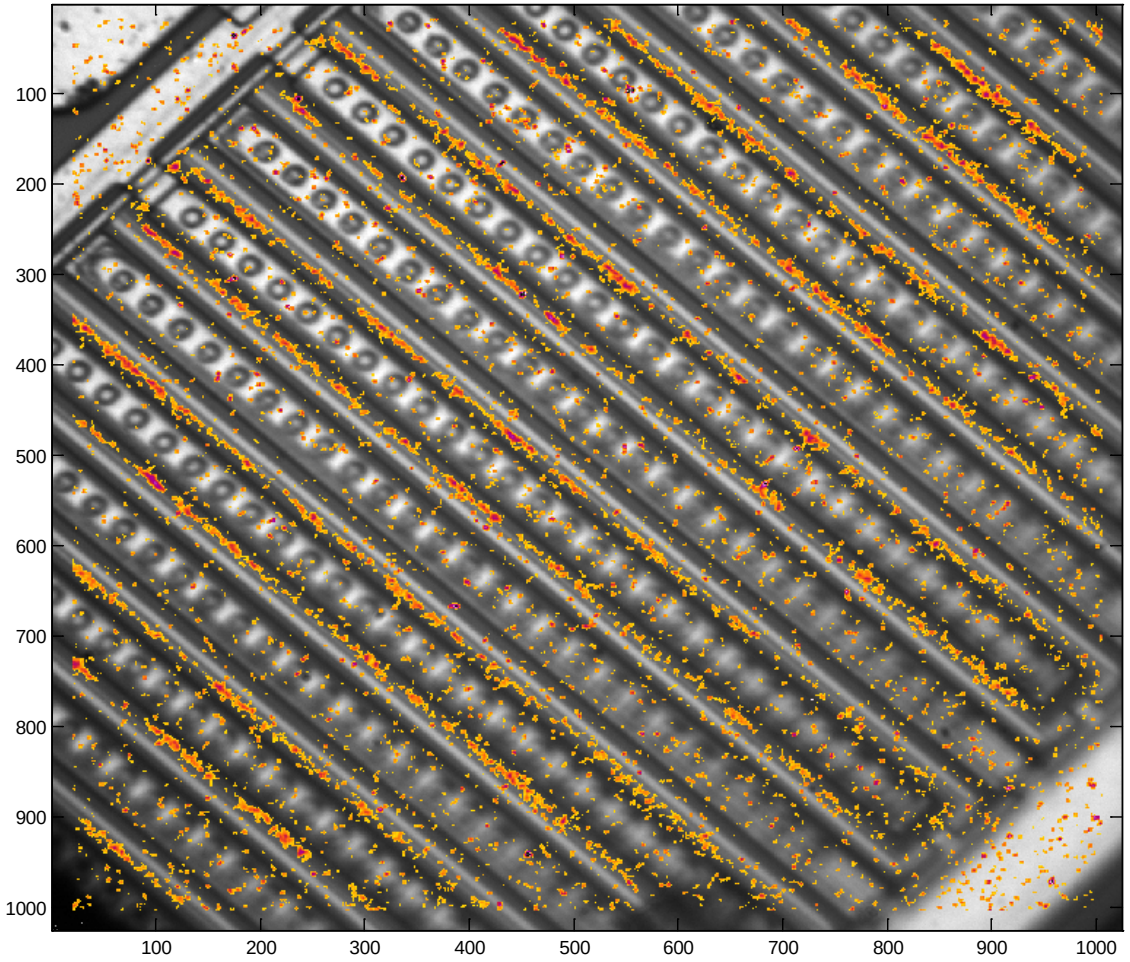
Characterizing $R_{DS(on)}$ Shift in Time

120 V overstress at 150 °C
(100 V Rated Device)

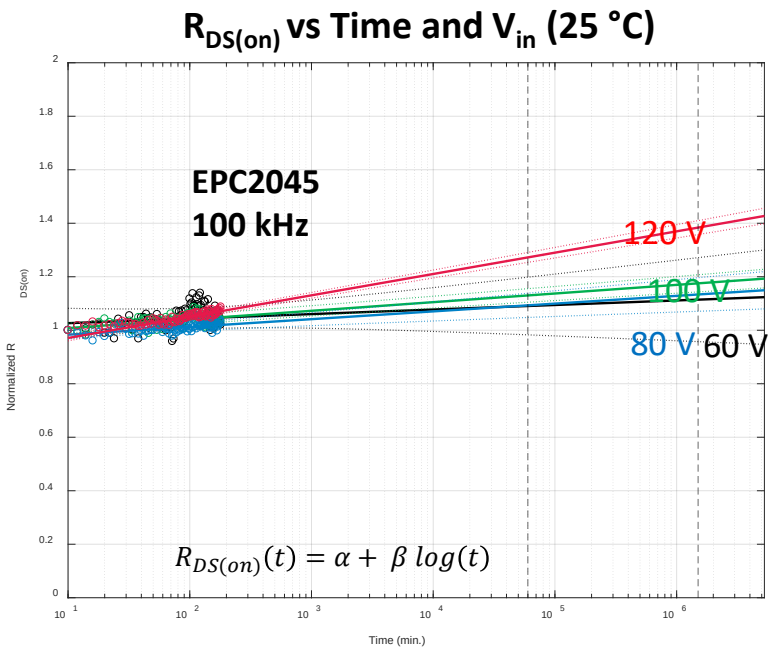


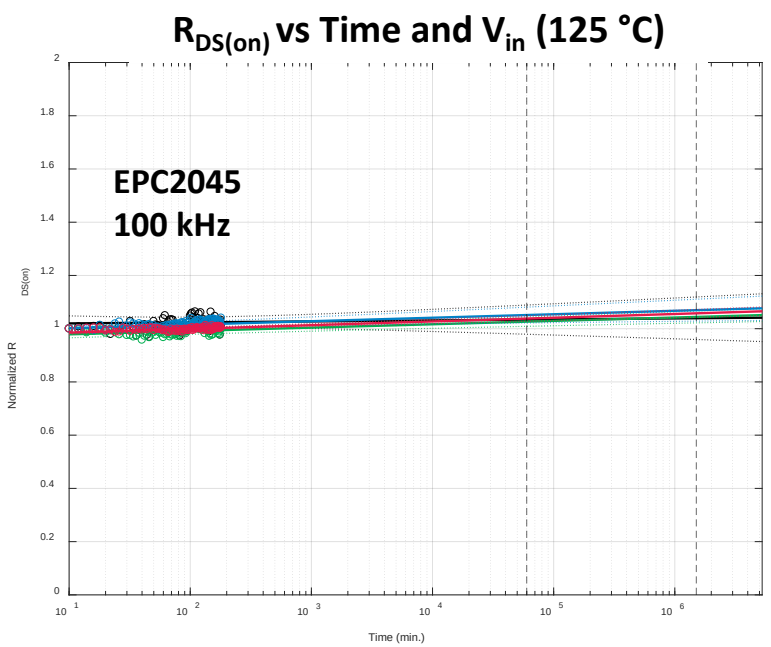
$$R(t) = R_0\left(\alpha + \beta \ln[t]\right)$$

Physics of $R_{DS(on)}$ Shift - Hot Carrier Emission

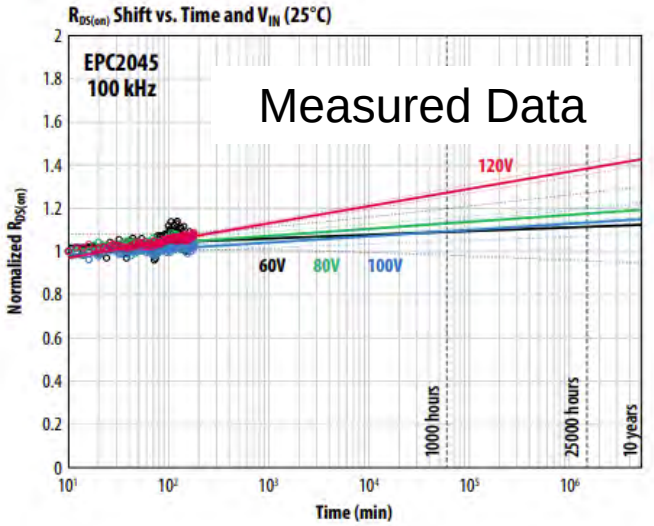


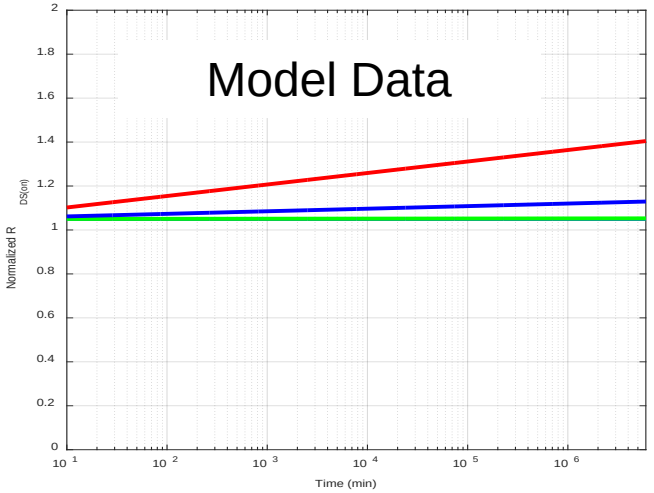
Hard-Switching: Effect of V_{IN} for 100 V Products

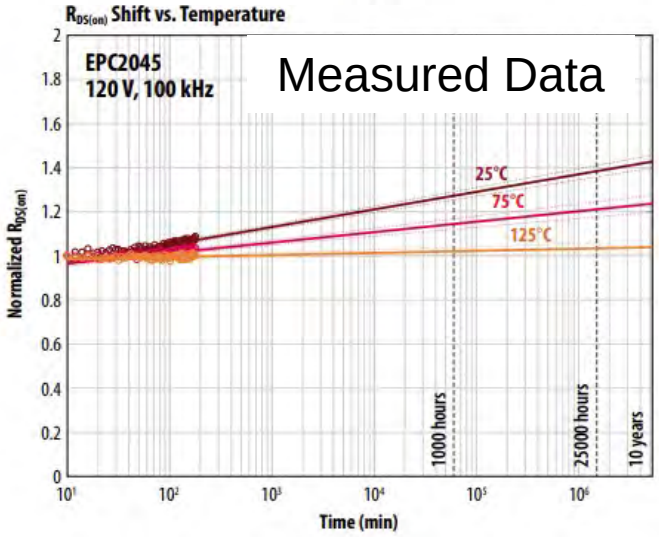


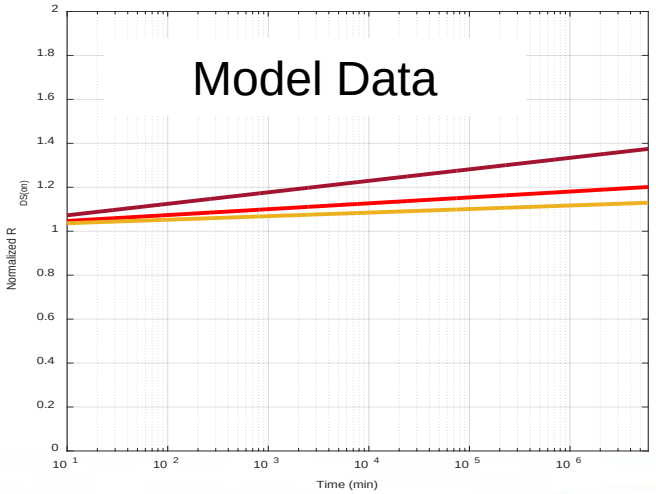


Model vs Measurement









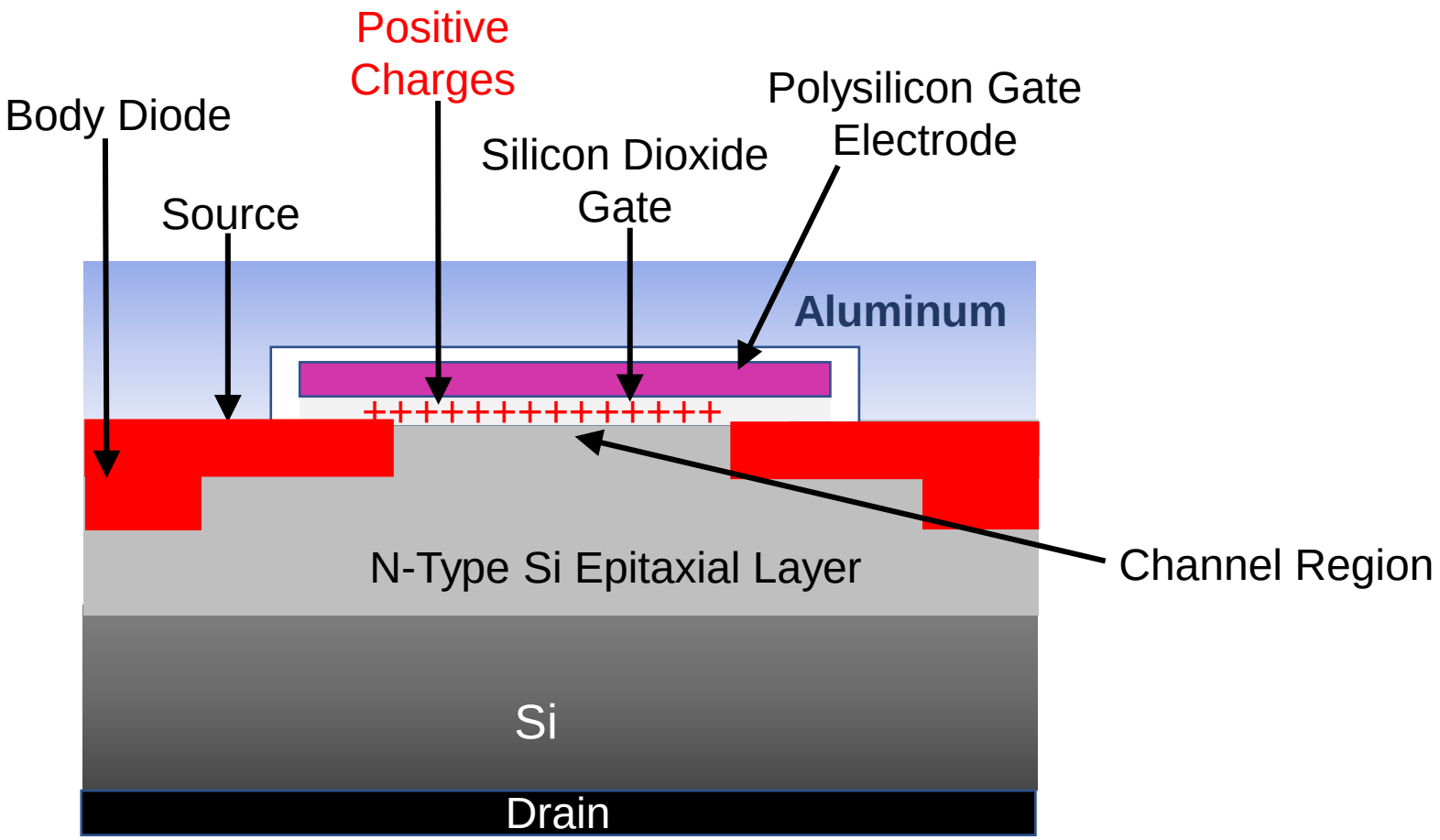
Radiation in Space

- Gamma radiation
- Neutron radiation
- Heavy ions

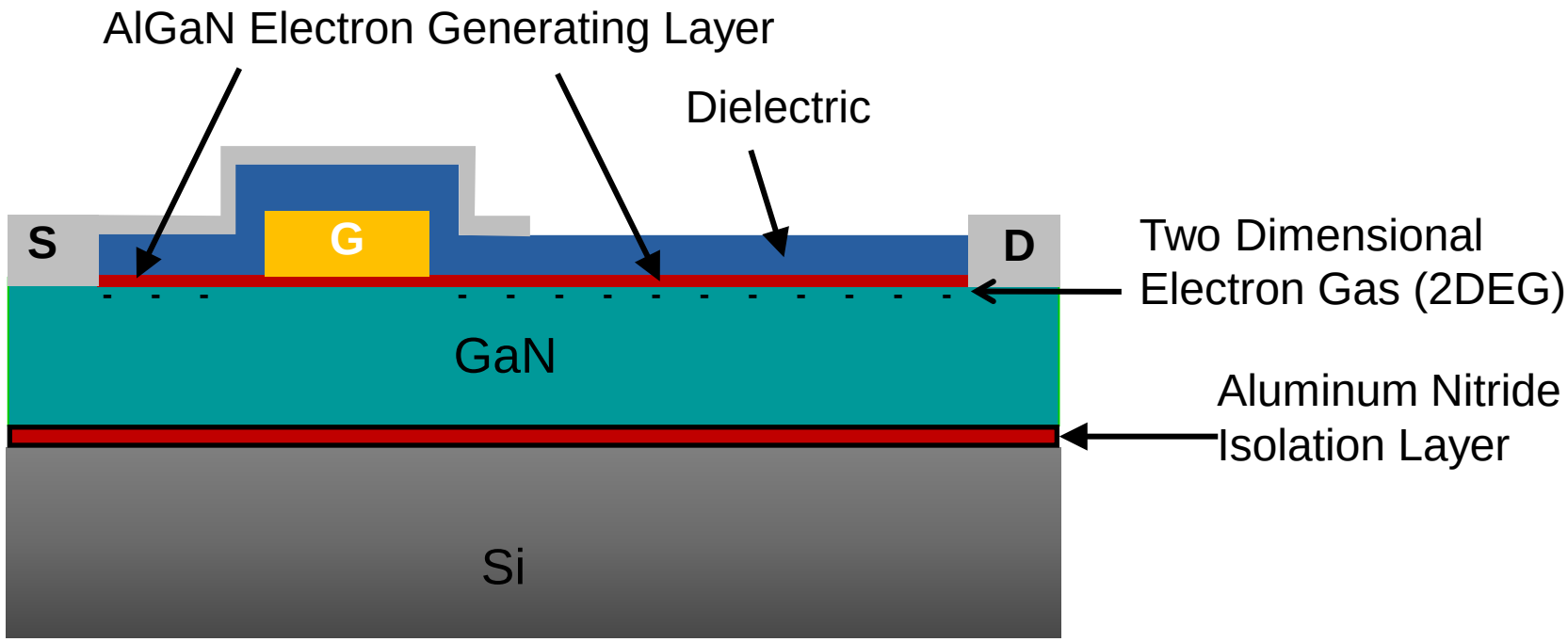
Failure Mechanisms

- Trapping
- Physical damage to the crystal
- Momentary short due to electron-hole cloud

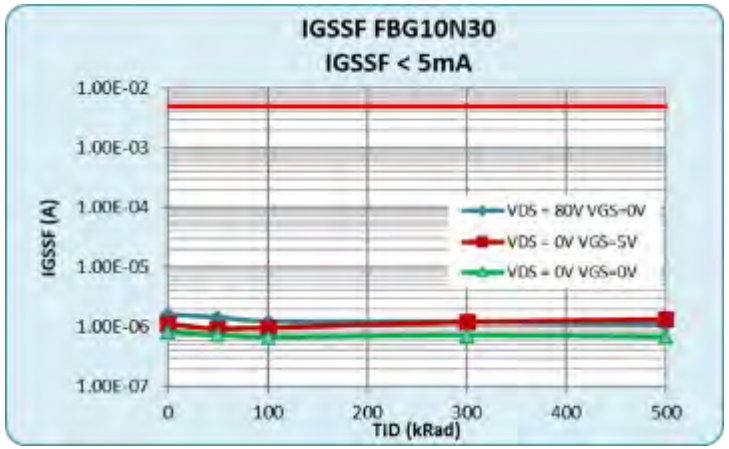
Gamma Radiation – Si MOSFETs

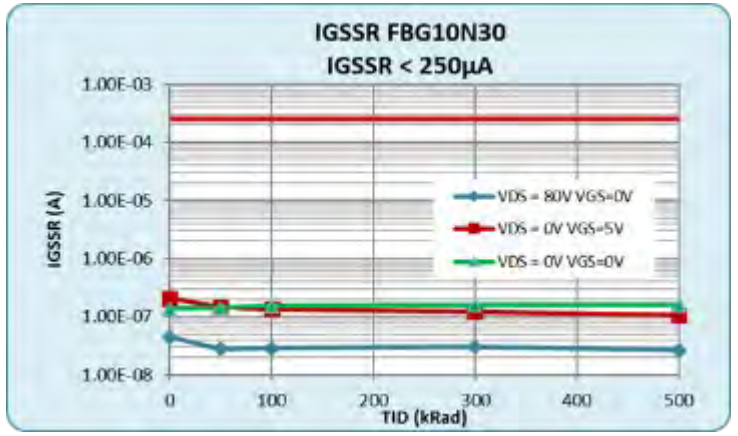


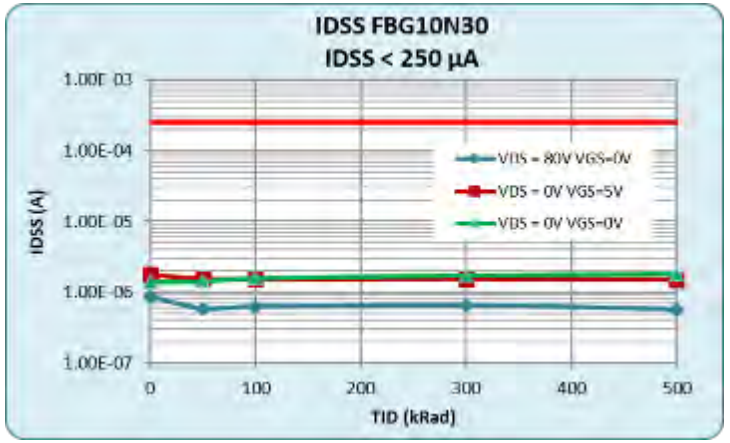
Gamma Radiation – eGaN® Transistors

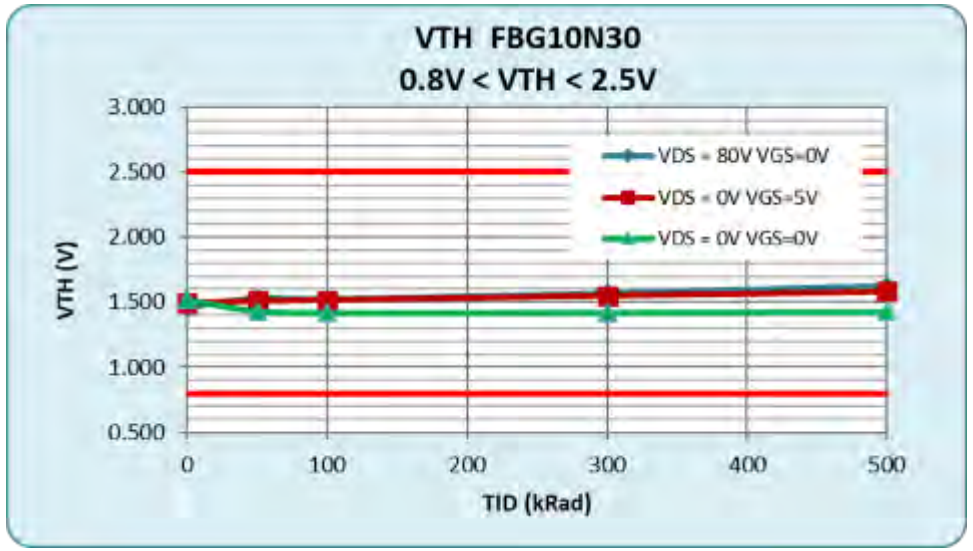


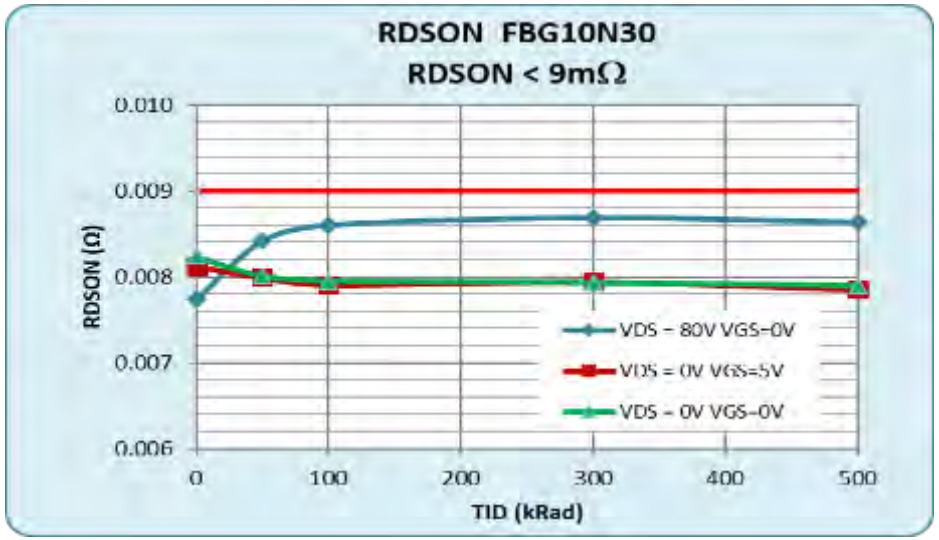
Gamma Radiation – eGaN Transistors







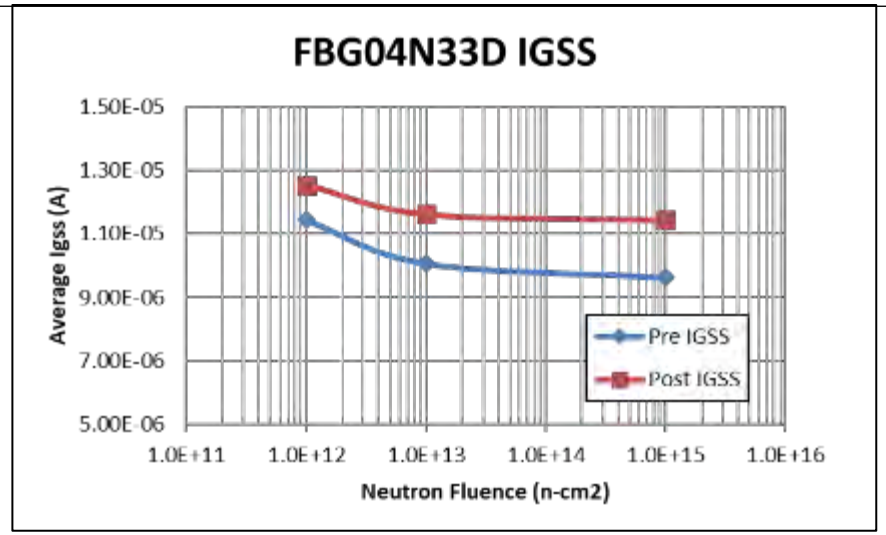


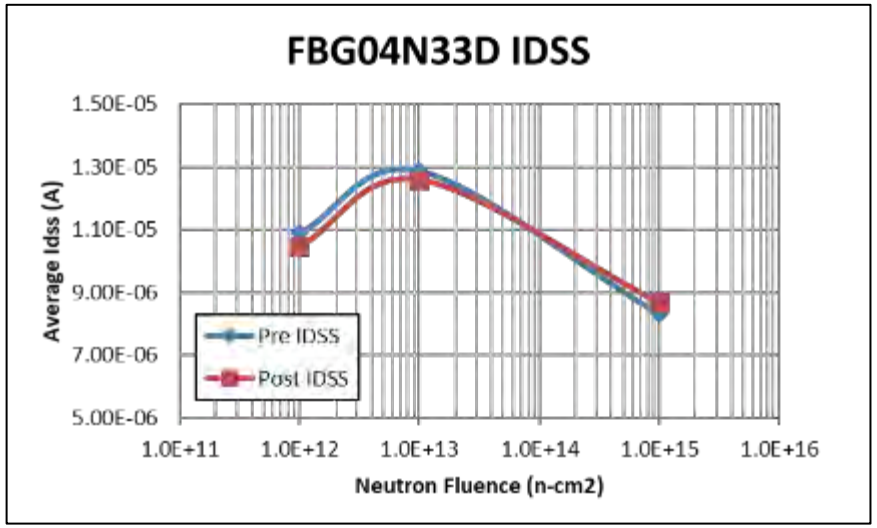


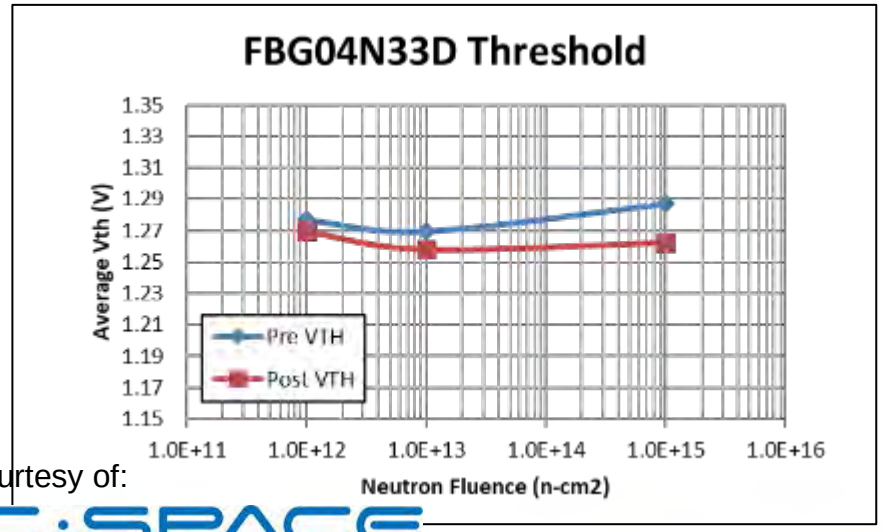
Results courtesy of:

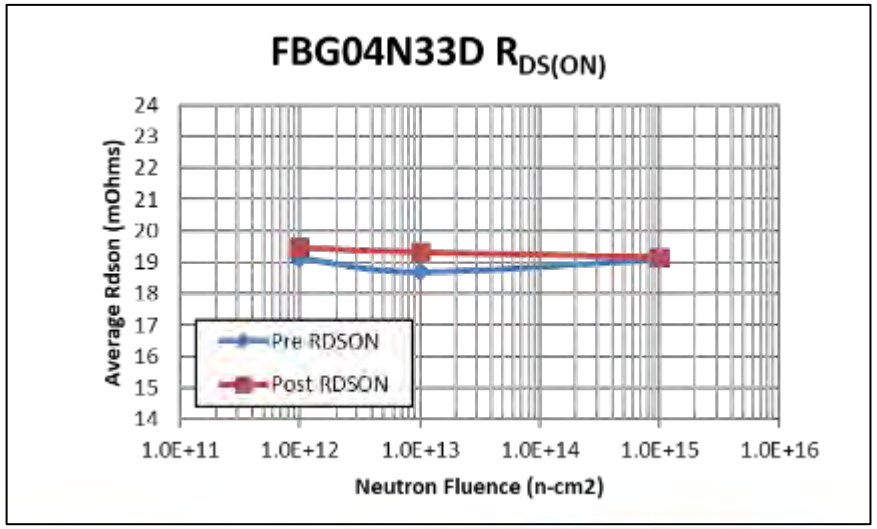
EPC·SPACE

Neutron Radiation









Results courtesy of:

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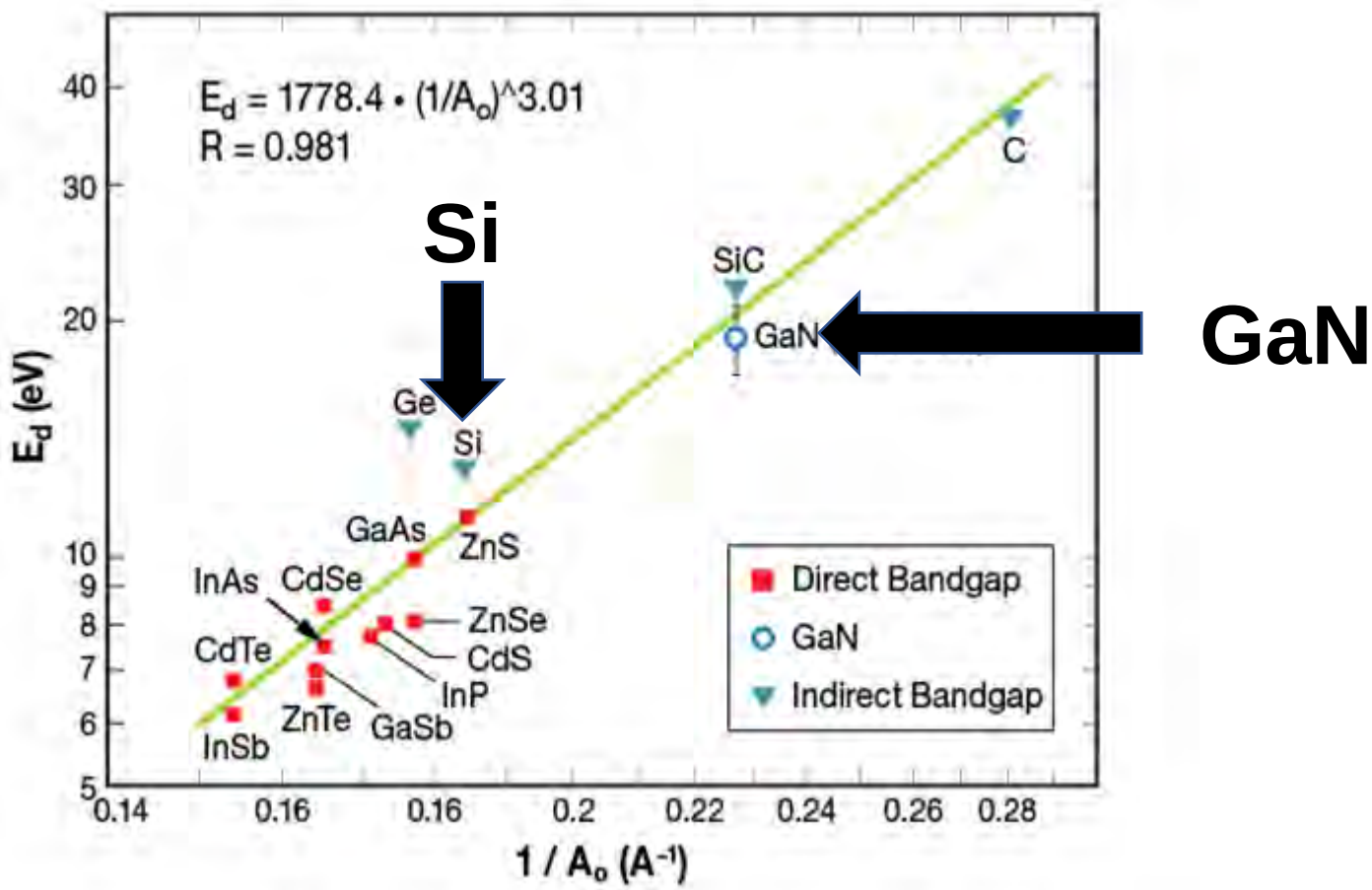
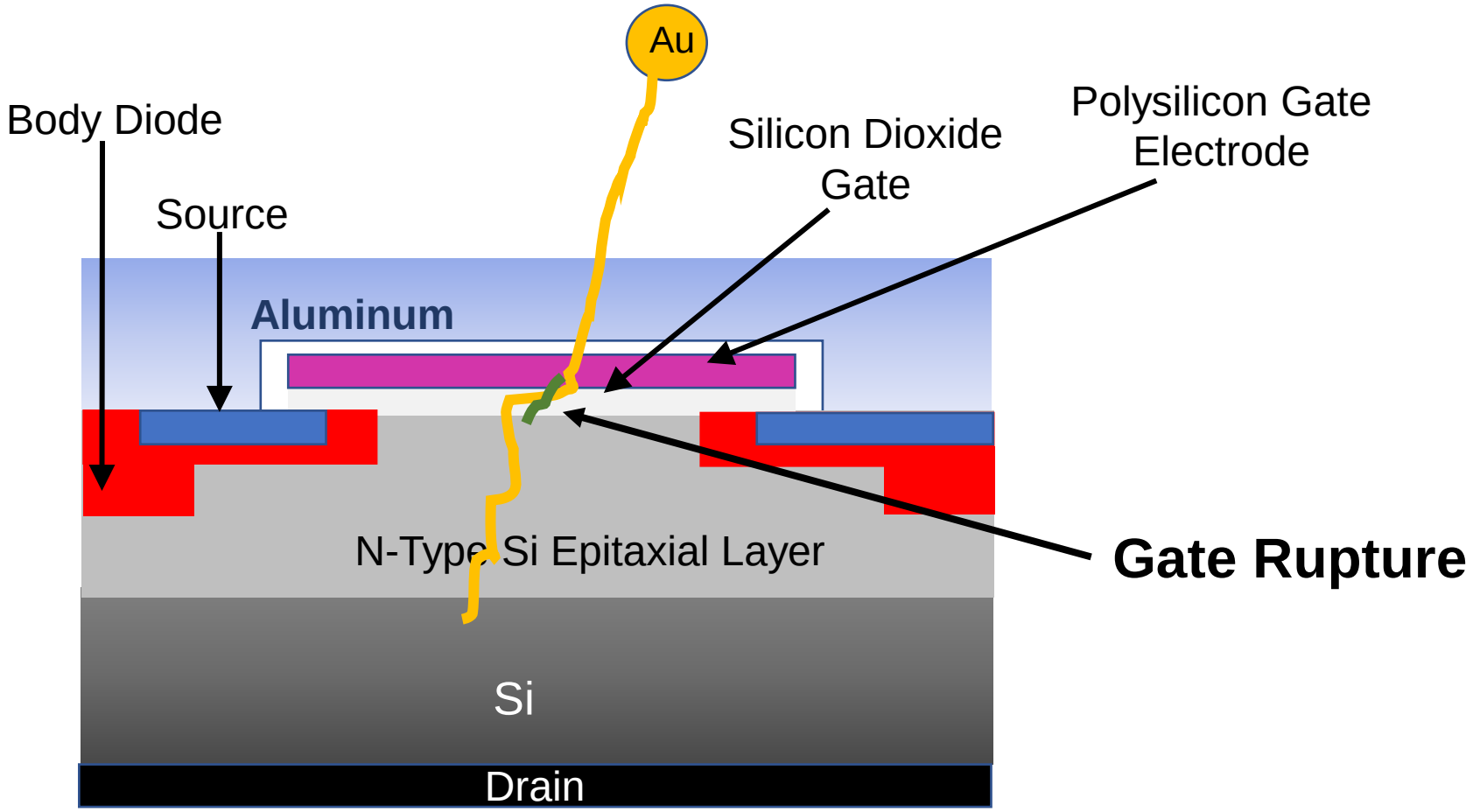
Displacement Damage



Single Event Effects – Si MOSFETs



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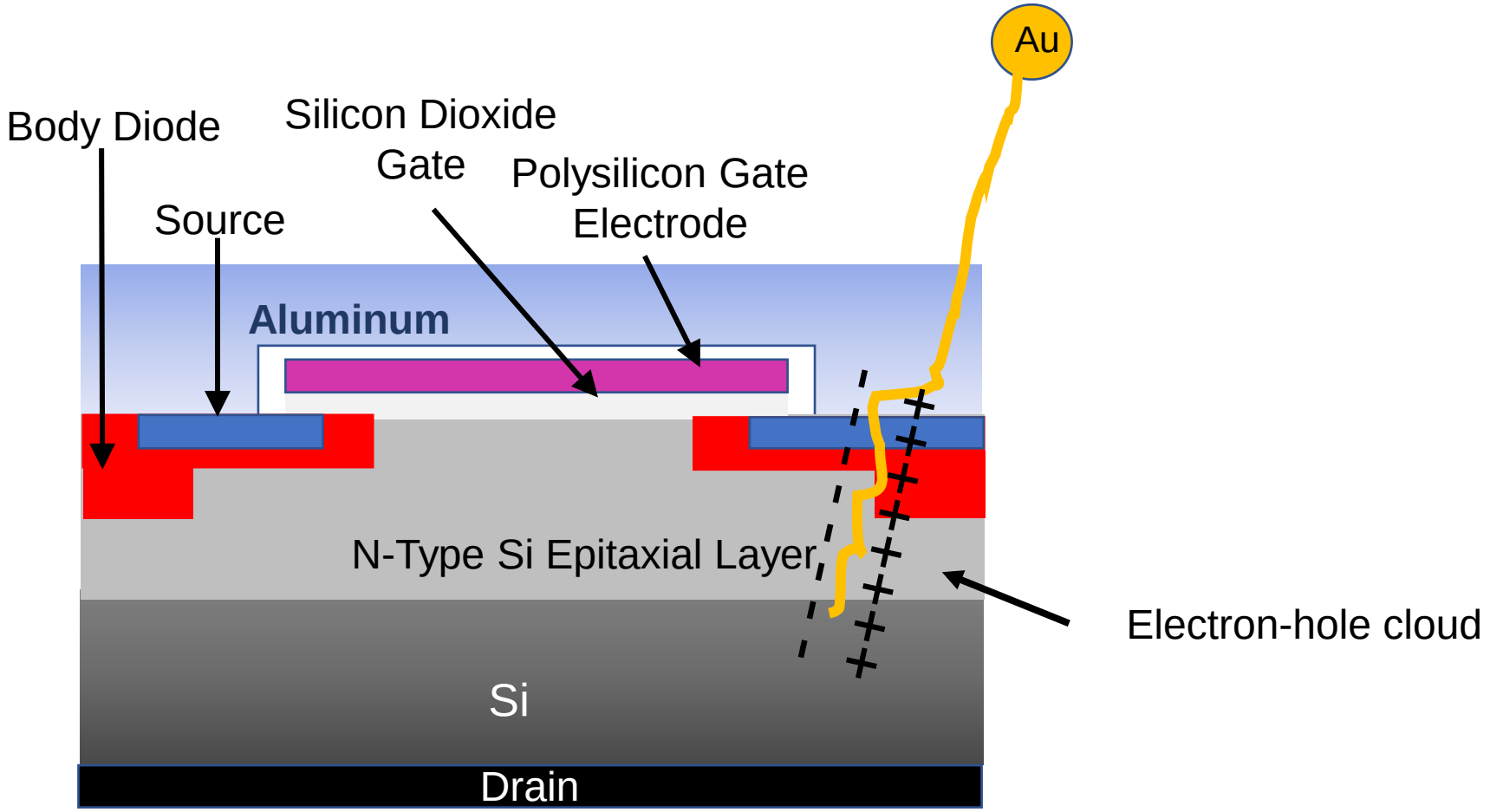
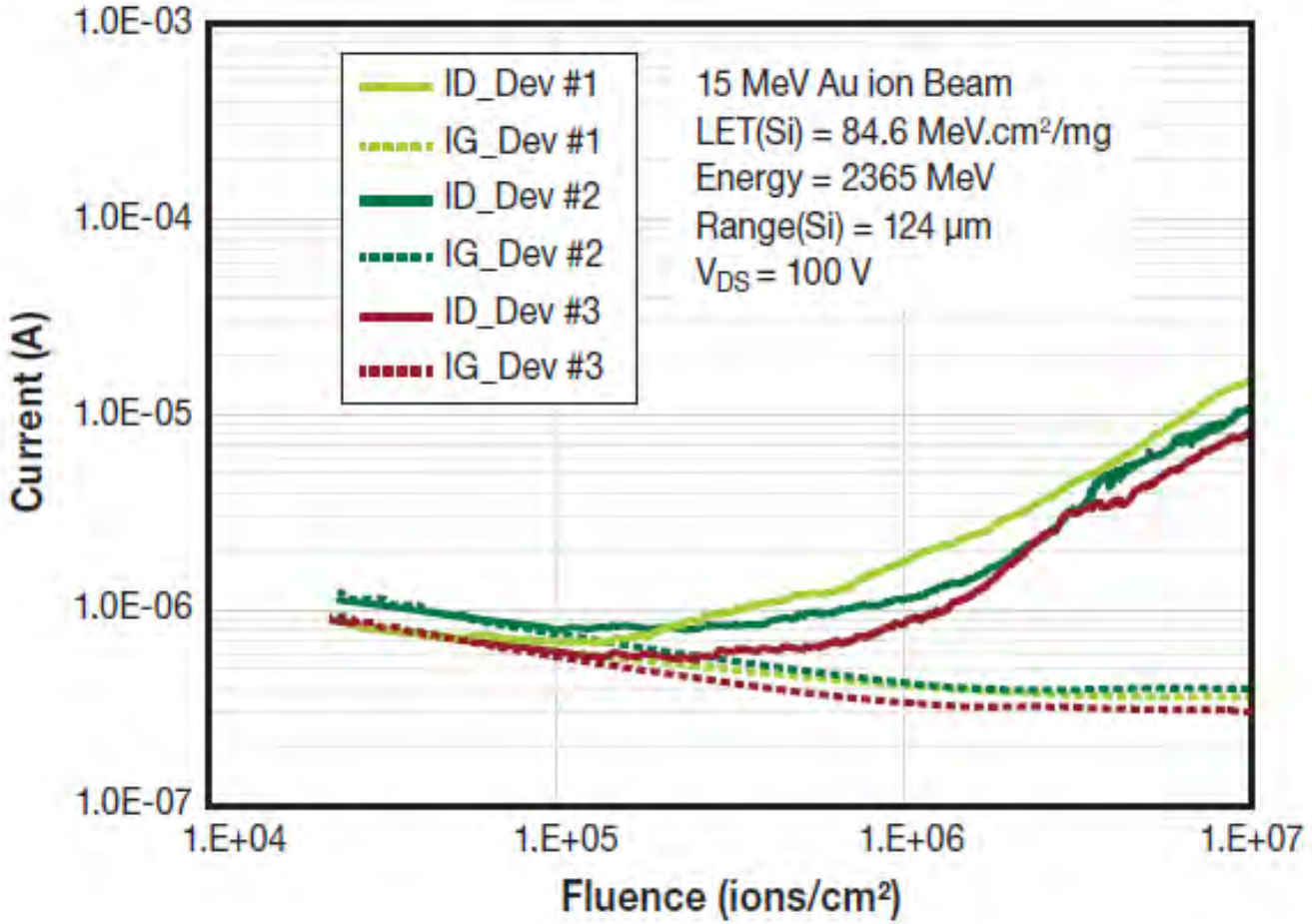


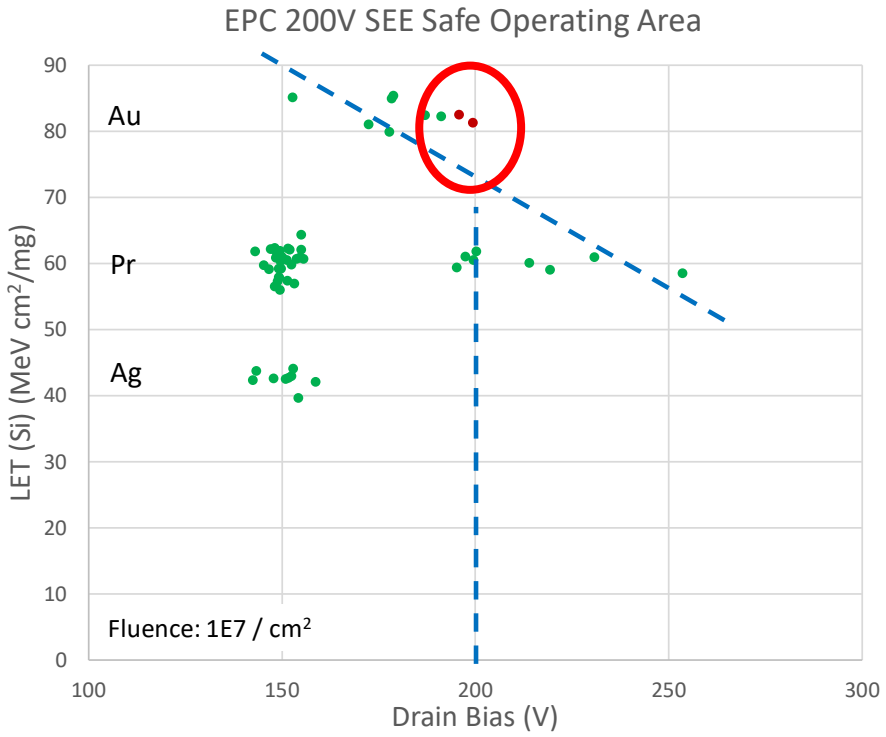
Single Event



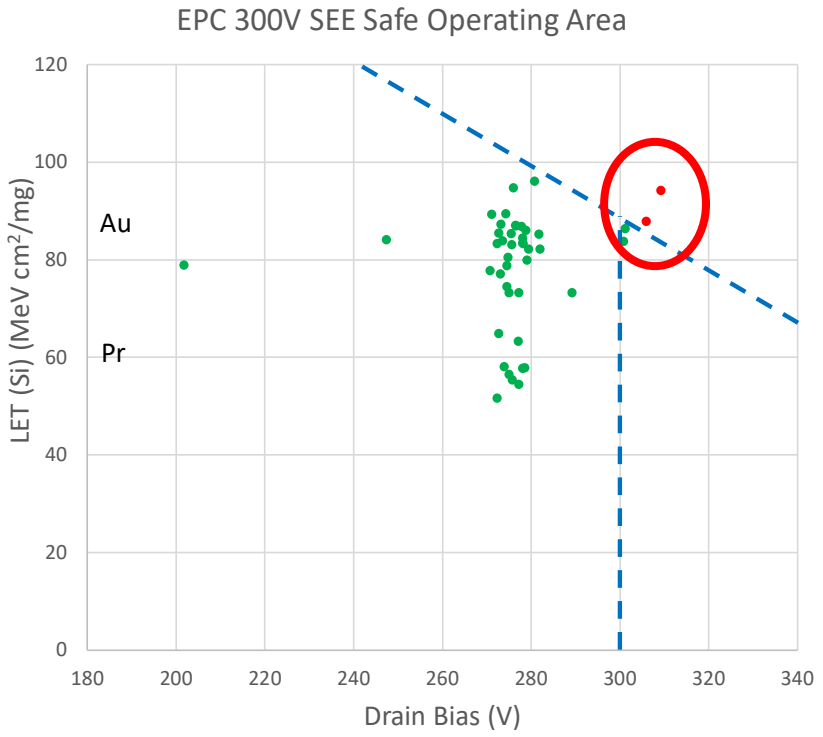
Results courtesy of:

EPC·SPACE

SEE Safe Operating Area



FBG20N18



FBG30N04

Results courtesy of:

EPC·SPACE

Electrical Performance Comparison at 60 V

60 V

	EPC7014	IRHLUB770Z4/JANS R2N7616UB	IRHLUB730Z4/JANS F2N7616UB
V_{DS}	60 V	60 V	60 V
I_d	2.4 A	0.8 A	0.8 A
$I_{d\ pulsed}$	4 A	3.2 A	3.2 A
R_{DSon}	340 mΩ	680 mΩ	680 mΩ
$Q_{g\ max}$	0.2 nC	3.6 nC	3.6 nC
Q_{gd}	0.03 nC	1.8 nC	1.8 nC
Size	0.8 mm2	9 mm2	9 mm2
SEE LET (MeV/(mg/cm^2))	85	85	85
Radiation Level	1 Mrad	100 kRads	300 kRads

EPC7014

Electrical Performance Comparison at 100 V

100V

Part Number	FBG10N30	IRHNA67160	Units
I_D	30	35	A
I_{DM}	120	140	A
BV_{DSS}	100	100	V
$R_{DS(on)}$	**9**	18	mΩ
Q_G	**9**	160	nC
Q_{GD}	**2**	65	nC
Q_{rr}	**0**	1.9	µC
$R_{\Theta JC}$	2.12	0.5	°C/W
Radiation Level	**> 10 M**	300 k	Rad(Si)
SEE @85 LET	100	100	V
Size	**21**	236	mm^2

Part Number	FBG10N05	IRHNJ67130	Units
I_D	5	22	A
I_{DM}	40	88	A
BV_{DSS}	100	100	V
$R_{DS(on)}$	**38**	42	mΩ
Q_G	**2.2**	50	nC
Q_{GD}	**0.6**	20	nC
Q_{rr}	**0**	3	µC
$R_{\Theta JC}$	3.6	1.67	°C/W
Radiation Level	**> 10 M**	300 k	Rad(Si)
SEE @85 LET	100	100	V
Size	**10**	78.5	mm^2

Electrical Performance Comparison at 200 V

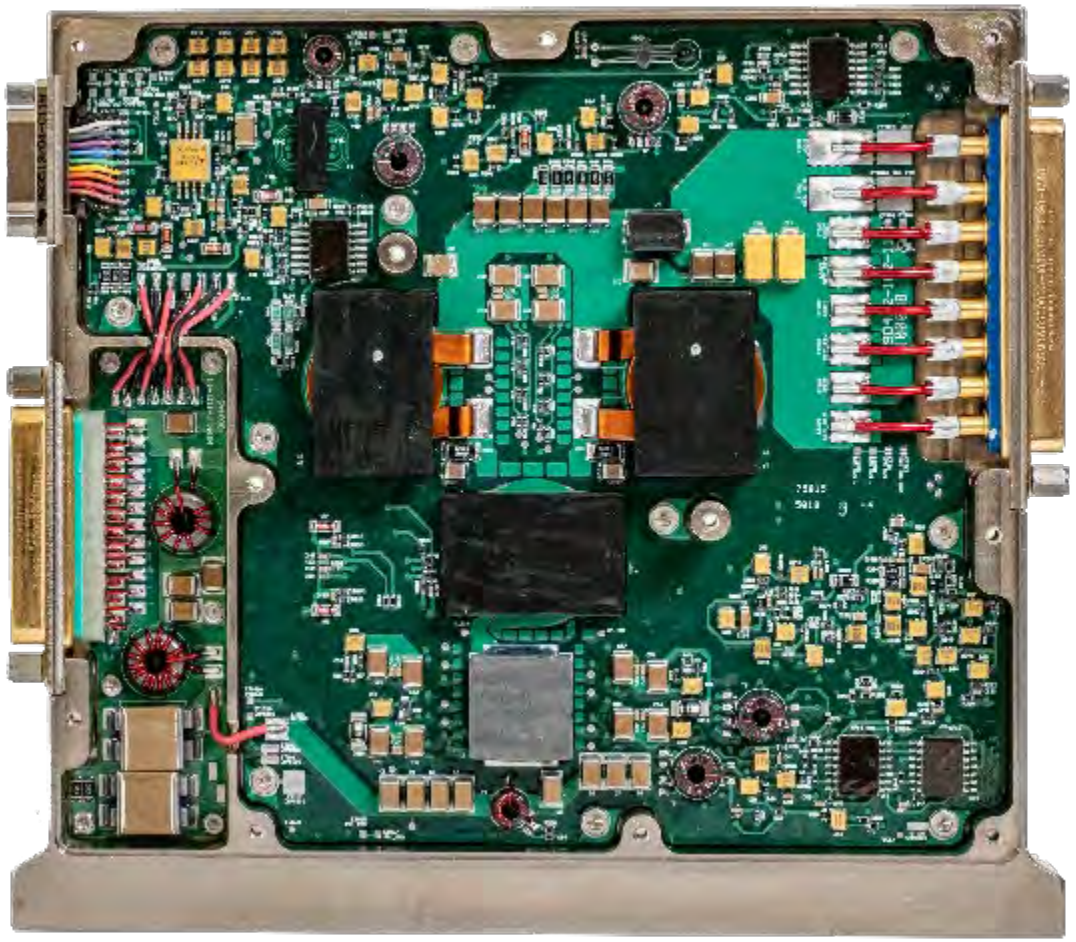
200V

Part Number	FBG20N18B	IRHNA67260	Units
I_D	18	56	A
I_{DM}	72	224	A
BV_{DSS}	200	200	V
$R_{DS(on)}$	26	28	mΩ
Q_G	**6**	240	nC
Q_{GD}	**1.95**	60	nC
Q_{rr}	**0**	11.7	µC
$R_{\Theta JC}$	2.12	0.5	°C/W
Radiation Level	**> 10 M**	300 k	Rad(Si)
SEE @85 LET	175	170	V
Size	**23**	236	mm^2

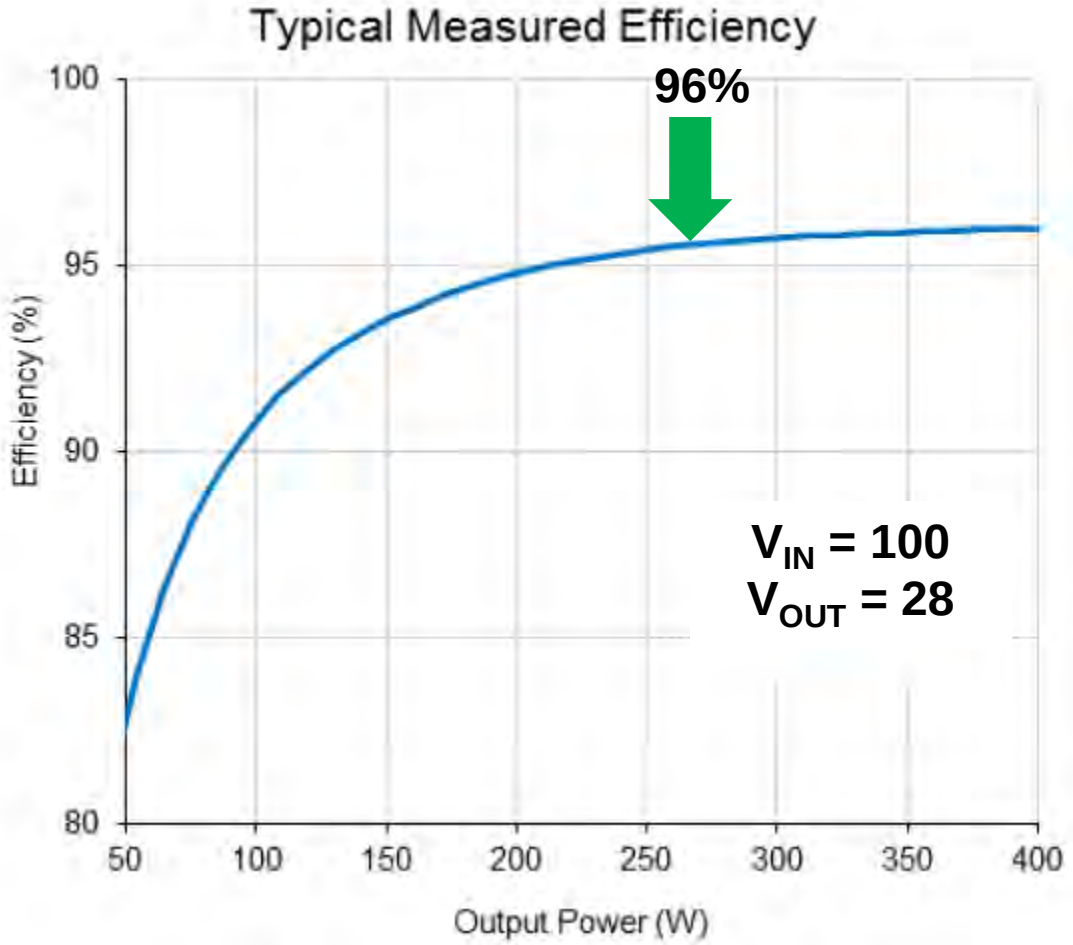
Part Number	FBG20N18B	IRHNJ67230	Units
I_D	**18**	16	A
I_{DM}	**72**	64	A
BV_{DSS}	200	200	V
$R_{DS(on)}$	**26**	130	mΩ
Q_G	**6**	50	nC
Q_{GD}	**1.95**	20	nC
Q_{rr}	**0**	3.6	µC
$R_{\Theta JC}$	2.12	1.67	°C/W
Radiation Level	**> 10 M**	300 k	Rad(Si)
SEE @85 LET	175	170	V
Size	**23**	76	mm^2

Applications

DC-DC Conversion



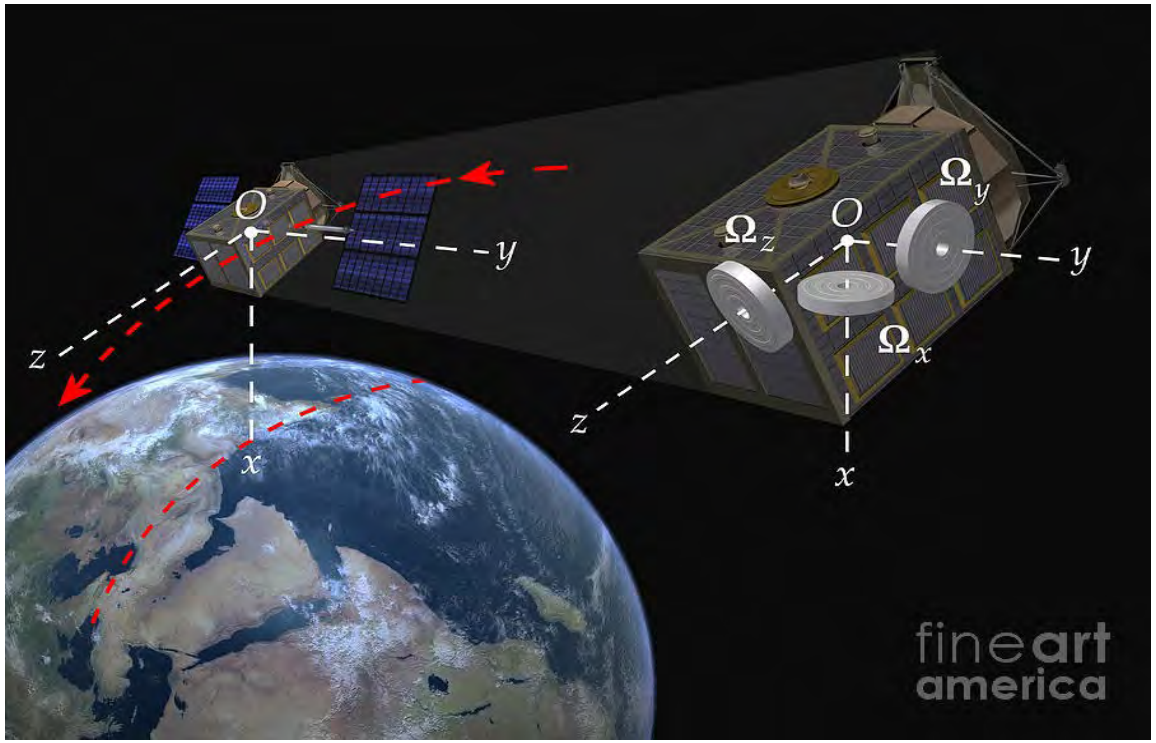
SGRB10028S Series Converter from VPT
EPC.SPACE



Satellites Reaction Wheel

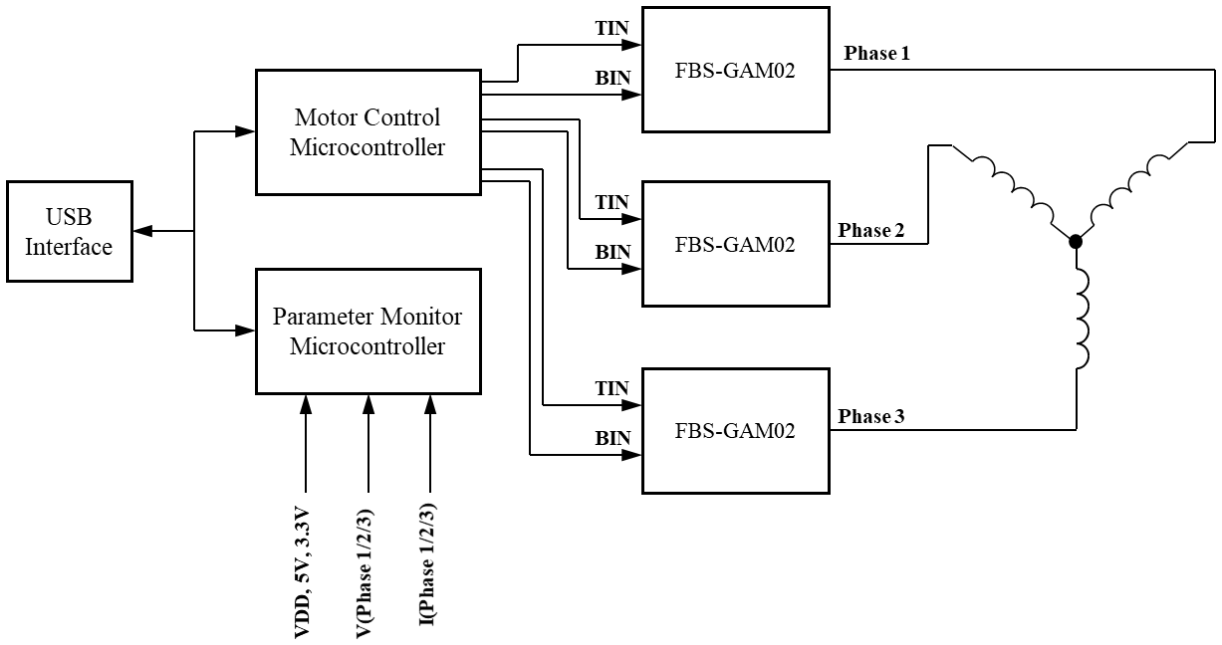
Why GaN?

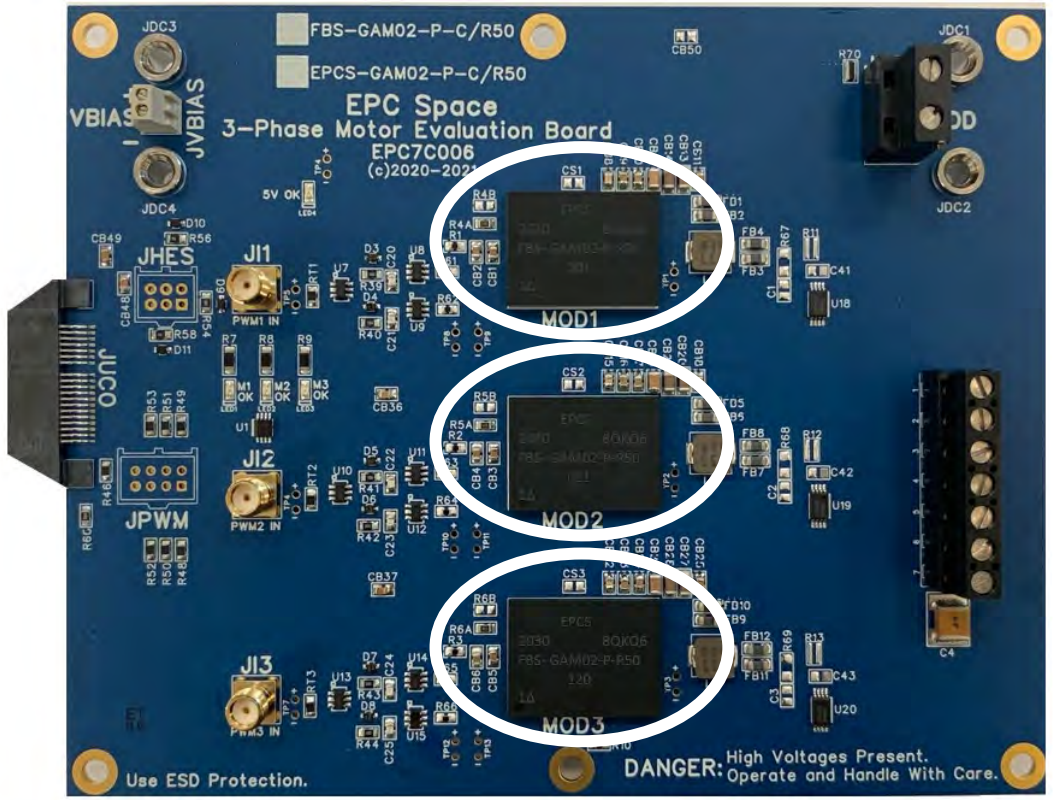
- Improve precision
- Smaller size/lower weight
- Faster response
- Lower EMI



The GAM02-P-R50 has been designed in many motor control applications such as reaction wheels and has over 42,048,000 GAM02-Hours in Low Earth Orbit.

Satellite Motor Drives





The EPC7C006 demo Board Allows customers to Evaluate FBS-GAM02 at Various VDD Levels and Over the Range of Motor Speeds and Accelerations AS A MOTOR CONTROLLER!

Lidar

Why GaN?

- Increase resolution
- Increase range
- Increase frame speed
- Smaller size/lower weight

Ion Thrusters

Why GaN?

- Higher efficiency
- Increased power delivery
- Smaller size/lower weight

eGaN Devices for Space

- Significantly different failure mechanisms compared to silicon MOSFETs
- When exposed to various forms of radiation, eGaN devices are more rugged than Rad Hard MOSFETs
- Superior electrical performance compared to aging Rad Hard power MOSFET
- Most efficient, smallest, most reliable solution for spaceborne systems

EPC Take-aways for Space

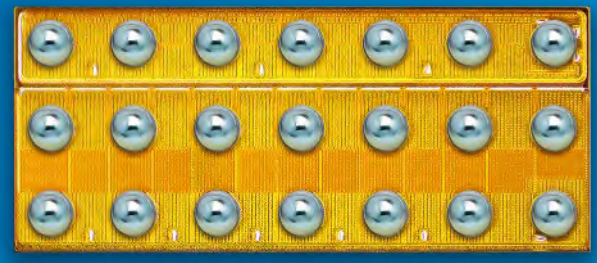
Smaller, Lighter, Reliable

- Superior radiation and electrical performance vs. Rad Hard MOSFETs
- **EPC** offers High Lead Rad Hard devices in WLCSP that meet all TID specs (> 1 Mkrad) & SEL/SEB LET level 85 MeV/(mg/cm^2).
- **EPC Space** offers packaged Rad Hard GaN devices
- Key applications: DC-DC power, motor drives, lidar, ion thrusters

EFFICIENT POWER CONVERSION

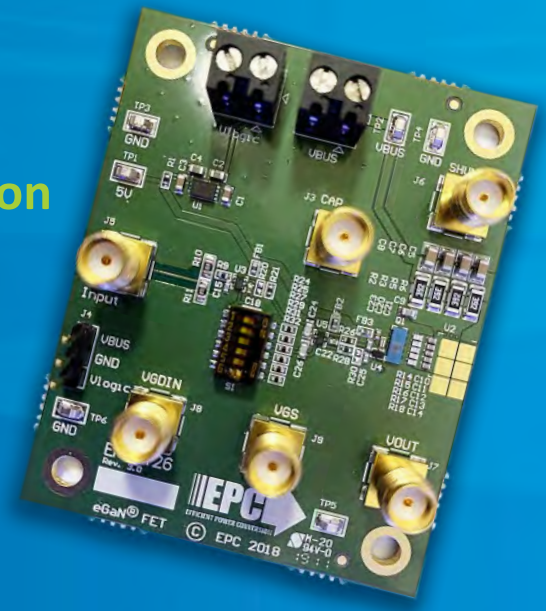
How To GaN Video Series

3rd Edition Textbook



eGaN® FETs and ICs

Evaluation Kits



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