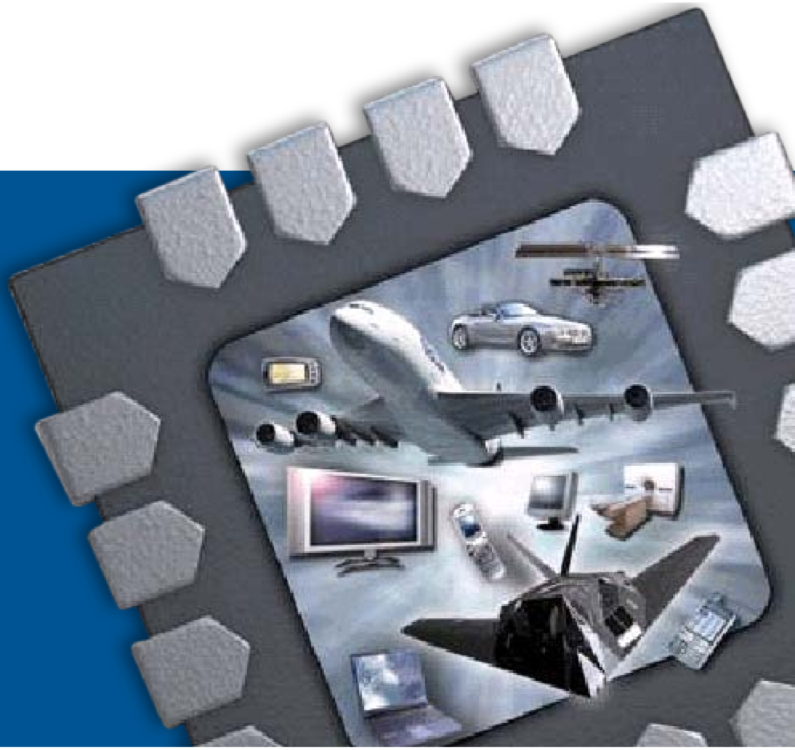
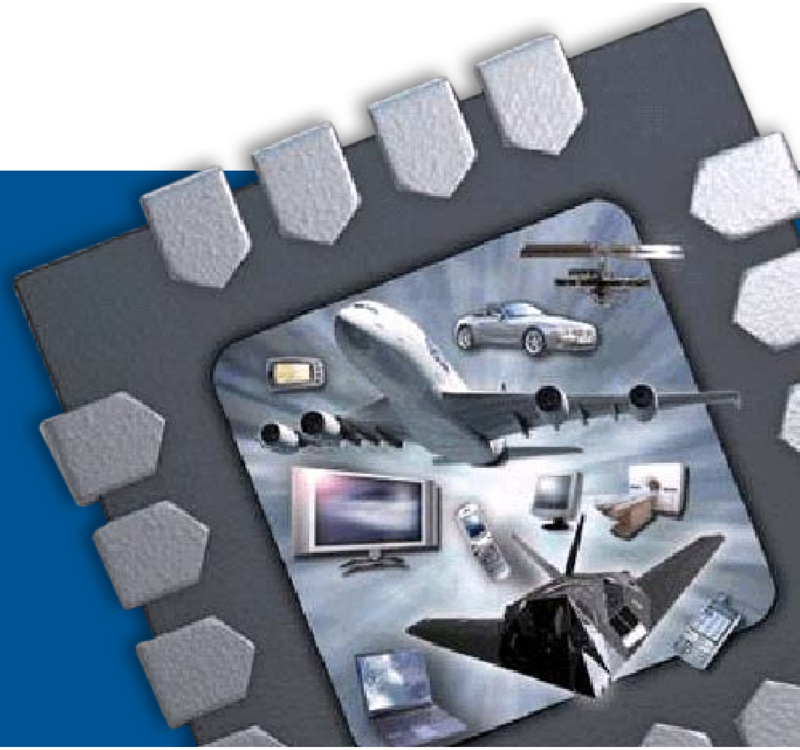
Experiences with Non-Silicon Based Enhancement Mode Semiconductors, GaN and SiC



Alan Tasker
Rad-Hard Engineering
Hybrid Products Group
Microsemi Corp.

V5

Enhancement Mode GaN Power



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Material Properties

Comparisons of Si vs SiC-4H vs GaN Semiconductors

Materials Property	Si	SiC-4H	GaN
Band Gap (eV)	1.1	3.2	3.4
Critical Field V/µm	30	300	350
Electron Mobility (cm^2/V-sec)	1450	900	2000
Electron Saturation Velocity (10^6 cm/sec)	10	22	25
Minimum Structure to Support 1200V Full Depletion (µm)	80	8	6.9
Minority Electron Transit Time for 1200V Structure (ns)	1356	22	7.3
Majority Electron Transit Time for 1200V Structure (ps)	800	36	28
1200V Rds(on) Compared to 600V Si CoolMOS	1	0.2	0.09
Thermal Conductivity (Watts/cm^2 K)	1.5	5	1.3

= Key Features

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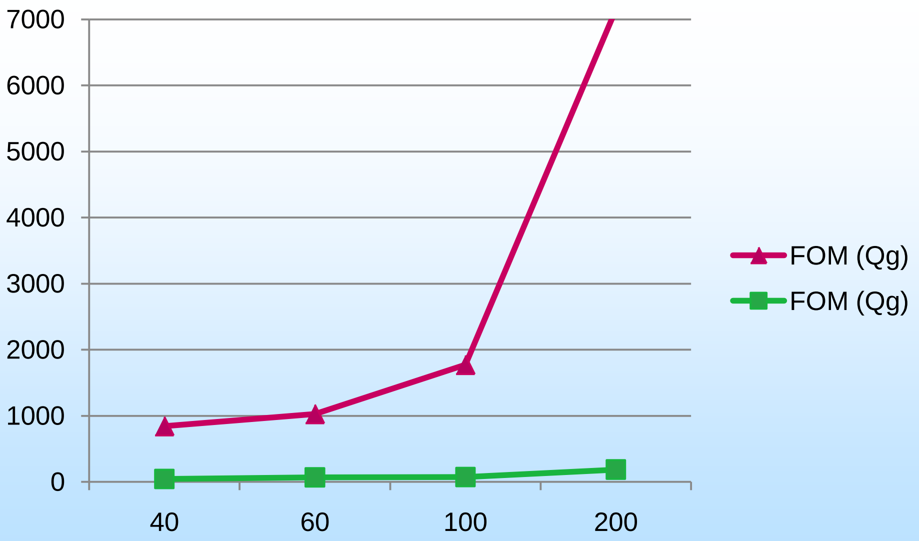
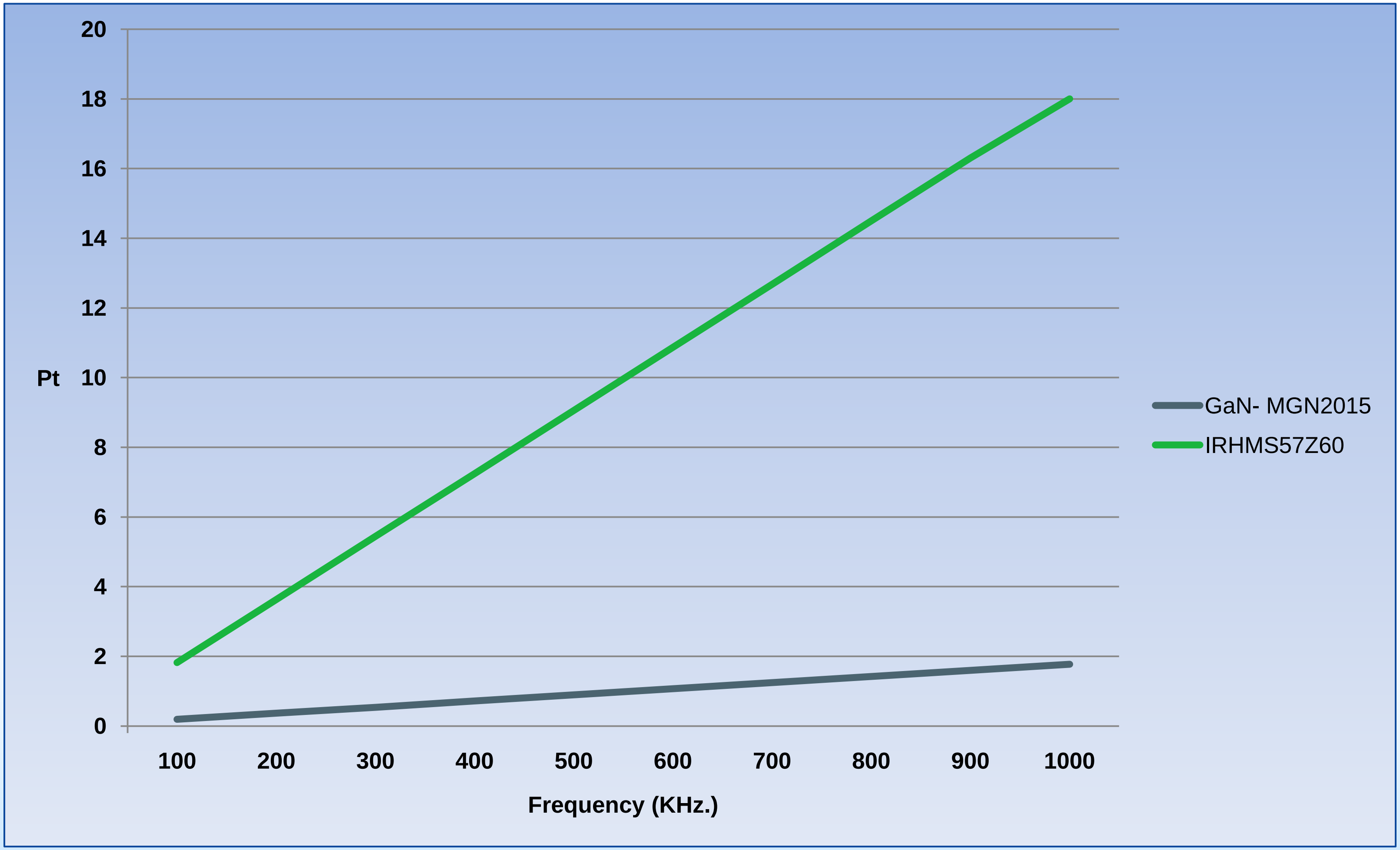
Performance of GaN vs. RH Si

PART NO.	VOLTAGE Vds	CURRENT	PEAK	RDS(ON) (mΩ)	Qg	FOM-(QgxRds(on))	DIM (mils)	EST Size
MGN1015	40V	33A	150A	4	11.6	46.4	162x65	2
IRHNA57Z60	30V	45	300	4	200	800	.257 sq.	6
MGN1005	60V	25A	100A	7	10	70	162x65	2
IRHNA57064	60V	75	300	6	160	960	.257 sq.	6
MGN1001	100V	25A	100A	7	10.5	73.5	162x65	2
IRHNA67160	100V	56	224	10	170	1700	.257 sq.	6
MGN1010	200V	12A	40A	25	7.5	187.5	141x65	1.5
IRHNA67260	200V	56	224	29	240	6960	.257 sq.	6

Dramatic improvement in Qg & FOM vs. Vds!



GaN vs. Silicon



Nearly a 10:1 difference in power dissipated

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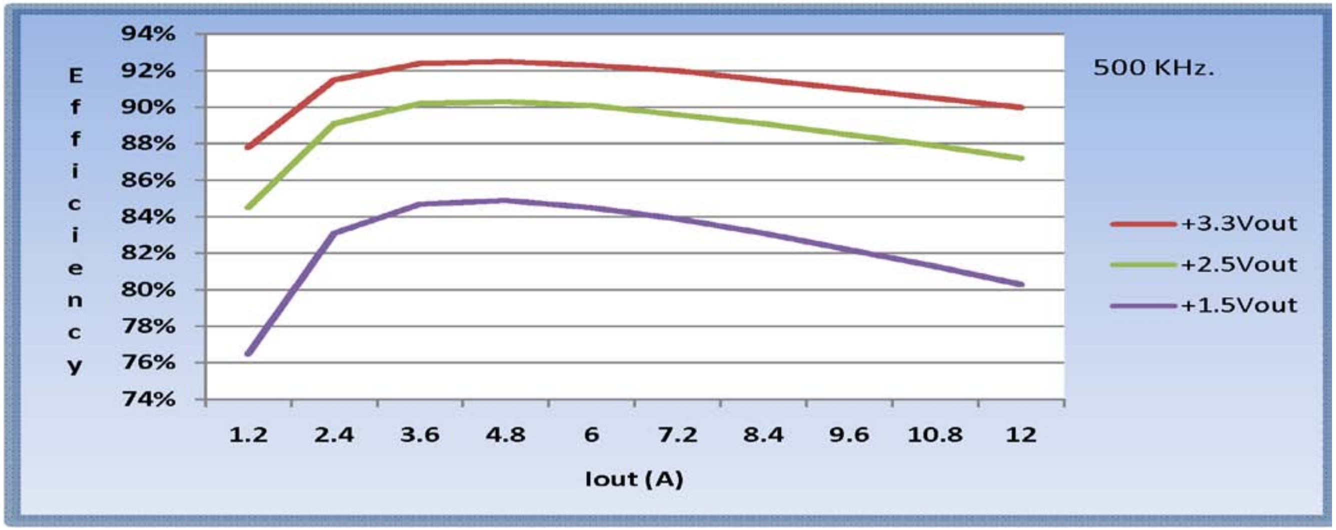
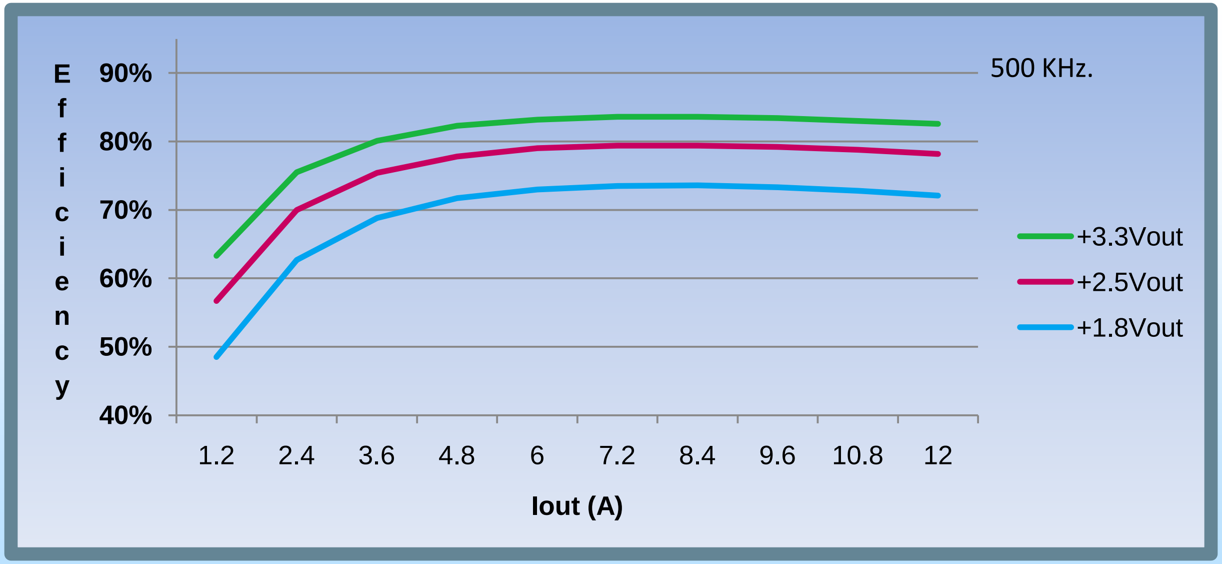
RH, 40W POL Efficiency Comparison

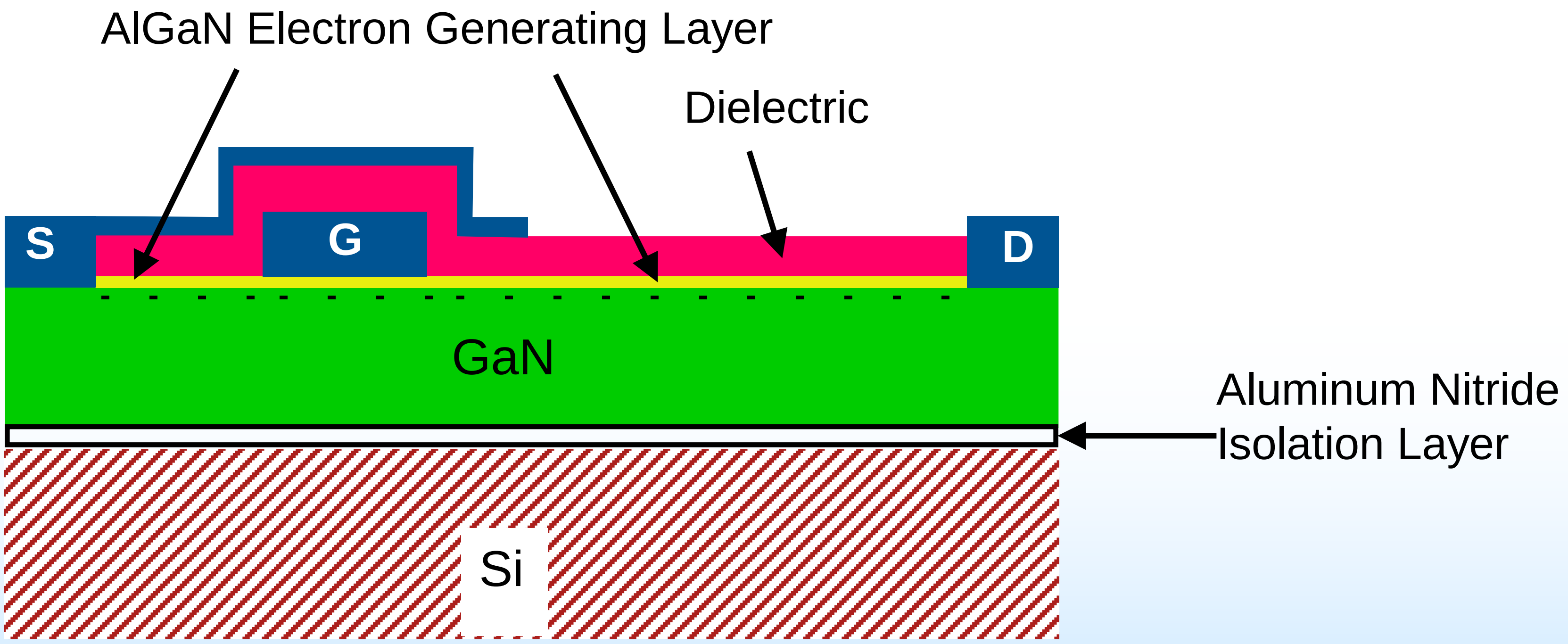


GaN POL
Rad-Hard
92.5% @
3.3 V out

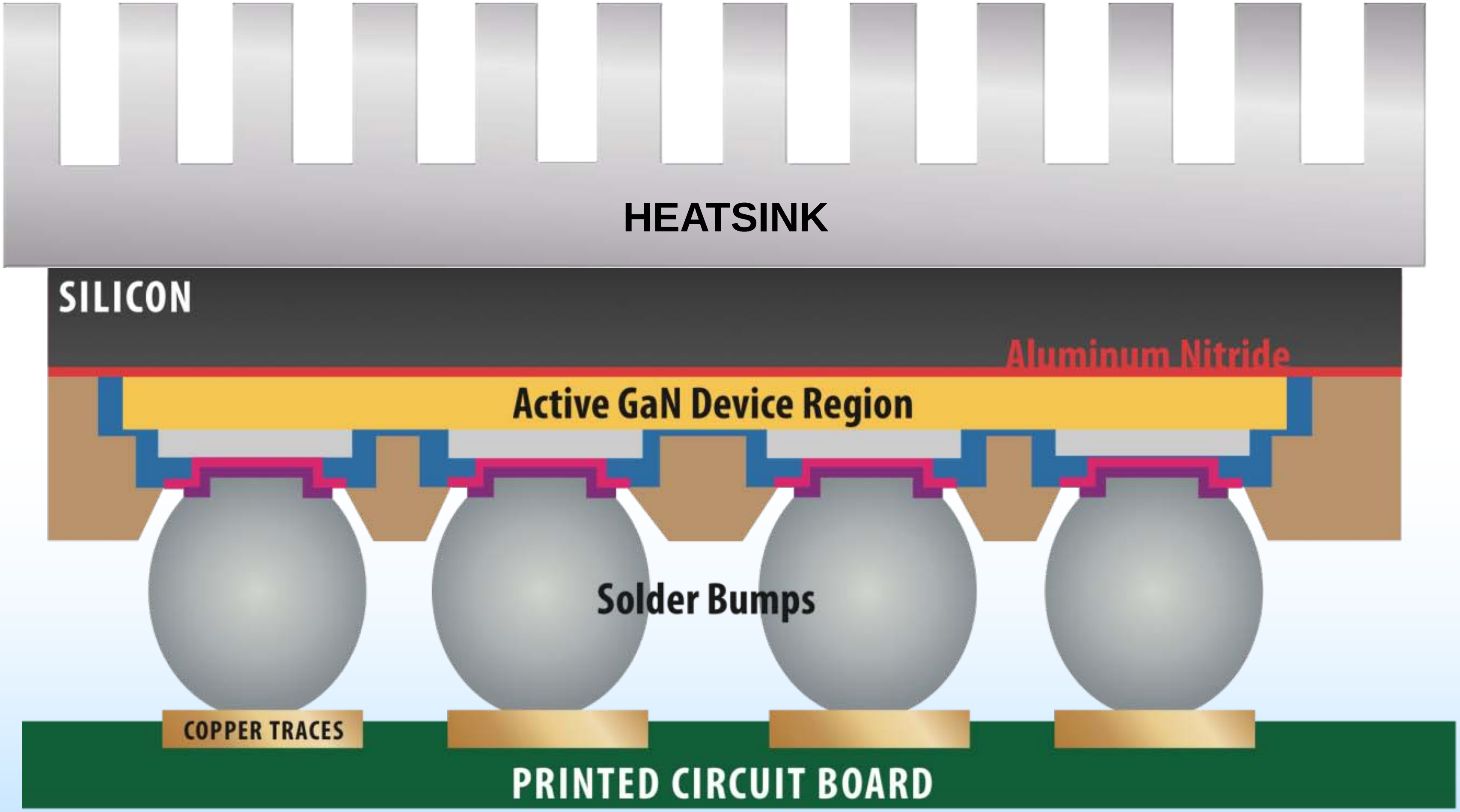
Si POL
Rad-Hard
84% @
3.3 V out



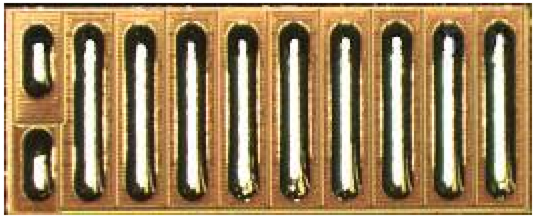
eGaN FET Structure



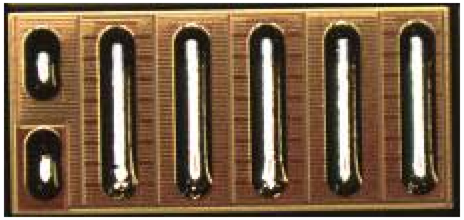
Flip Chip Assembly



GaN MOSFET Topography



LGA 4.1x1.6 x0.8



LGA 3.6x1.6 x0.8

LGA 1.7x1.1x0.8

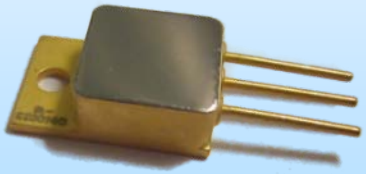
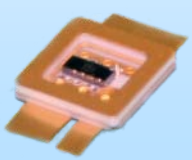
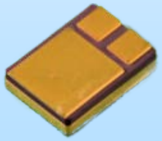
LGA 1.7x0.9x0.8

Part Number Structure

Part Number	Market	Substrate	Solder	Electricals
EPC1014	Commercial	Floating	RoHS	14
EPC**2**014	Commercial	**Connected**	RoHS	14
MGN2**9**14	**HiRel** (With Traceability)	Connected	**90/10 Lead/tin**	14

GaN Product line
with Non RoHS Solder (90/10)

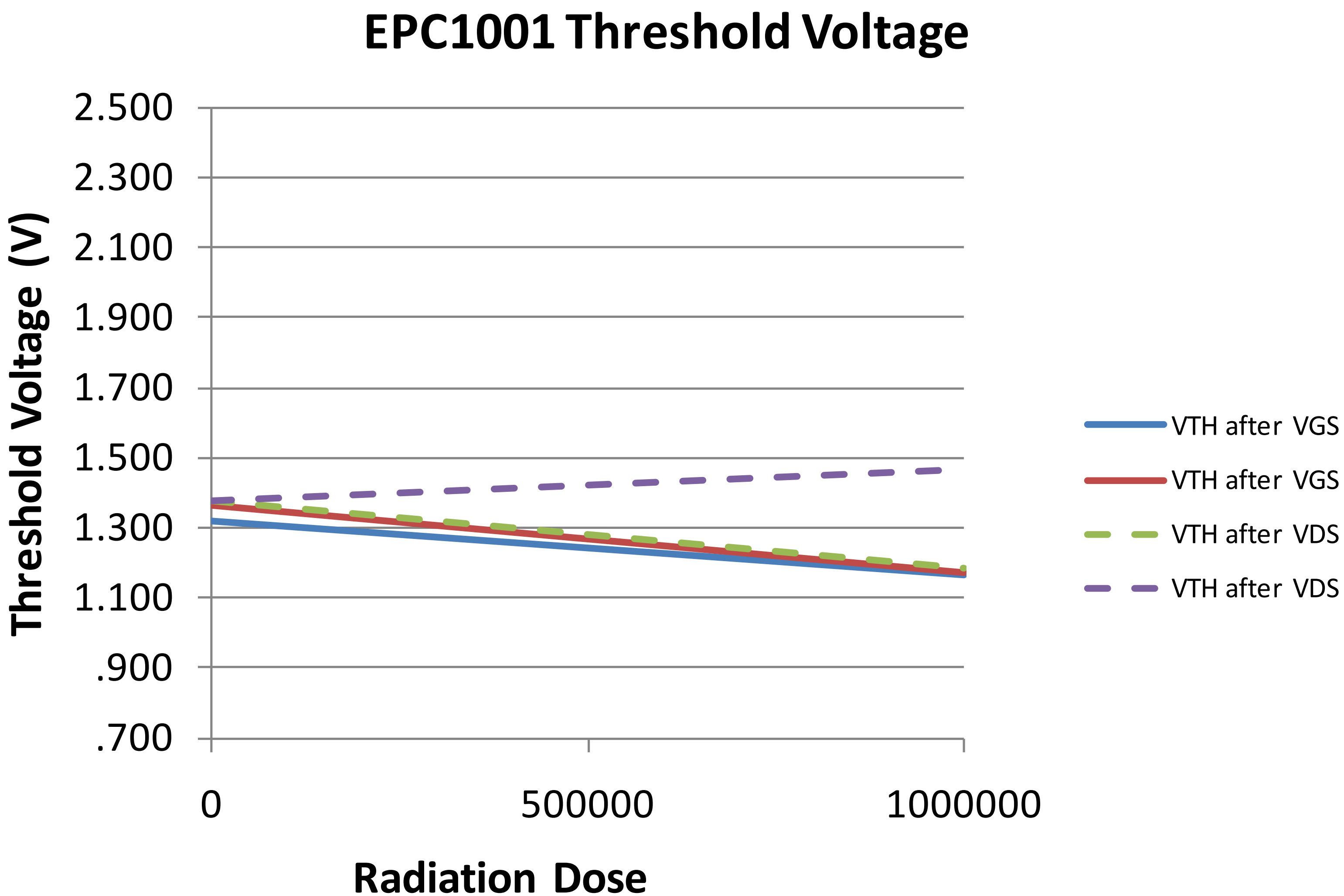
PART NO.	DIE SIZE (mm)	VOLTAGE	CURRENT	PEAK	RDS(ON) (mΩ)	Qg	FOM- Qg
MGN2914	1.1x1.7	40V	10A	40A	16	3	48
MGN2915	1.6x4.1	40V	33A	150A	4	11.6	46.4
MGN2909	1.1x1.7	60V	6A	25A	30	2.4	72
MGN2907	1.1x1.7	100V	6A	25A	30	2.7	81
MGN2905	1.6x4.1	60V	25A	100A	7	10	70
MGN2901	1.6x4.1	100V	25A	100A	7	10.5	73.5
MGN2913	0.9x1.7	150V	3A	12A	100	1.7	170
MGN2912	0.9x1.7	200V	3A	12A	100	1.9	190
MGN2911	1.6x3.6	150V	12A	40A	25	6.7	167.5
MGN2910	1.6x3.6	200V	12A	40A	25	7.5	187.5

The Three Biggest Differences, GaN vs. Silicon MOSFETs

- Gate Drive Voltage is 5 Volts, but do not exceed 6 Volts.
  - Watch inductance.
  - Drive at 5 V max.
- Layout Considerations (keep noise down)
  - Place driver close to eGaN FET
  - Reduce stray inductance
  - Use good bypass capacitor techniques
  - Use power planes where possible
  - Employ a single point ground
- In reverse direction, does act like it has a body diode w/o minority carriers.

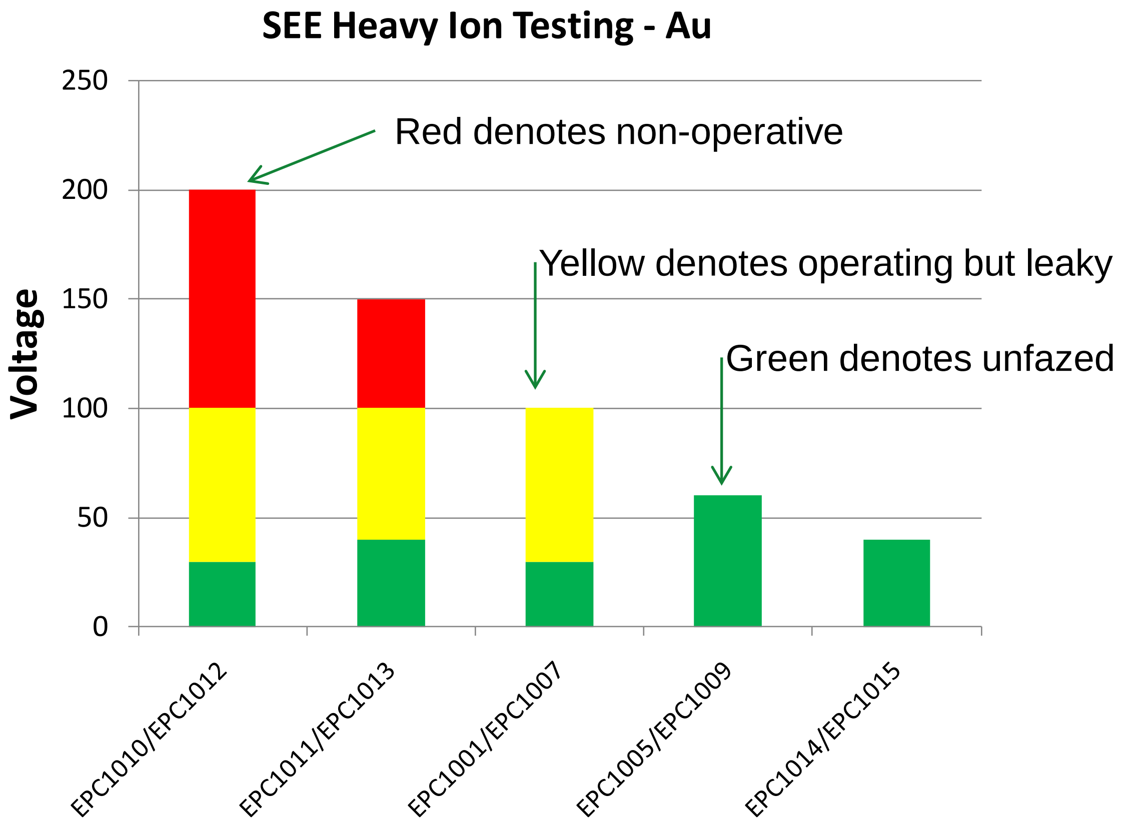
TID Radiation Performance



MIL-STD-750E, METHOD 1019

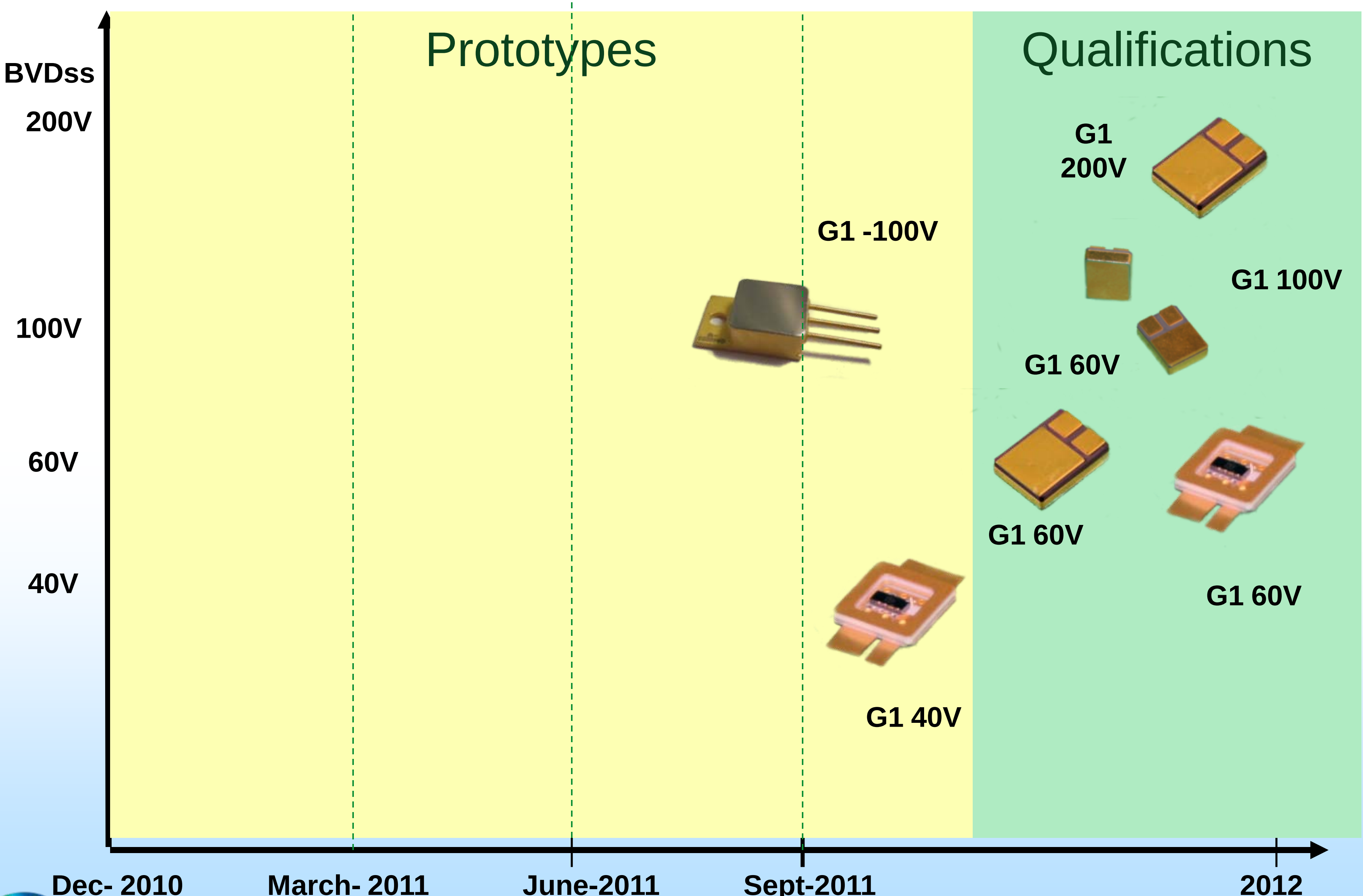
SEE Radiation Performance

SEE Results



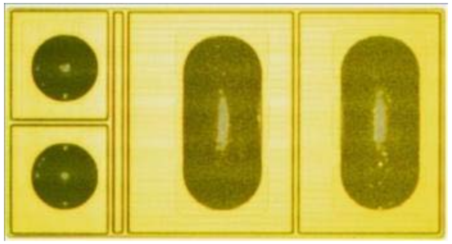
MIL-STD-750E, METHOD 1080

HiRel GaN Product Roadmap

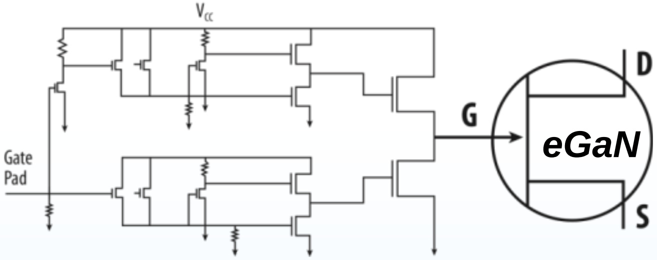


Future GaN Technology

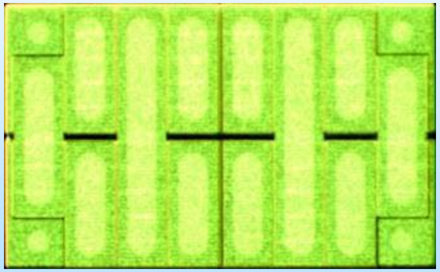
Discrete eGaN FET



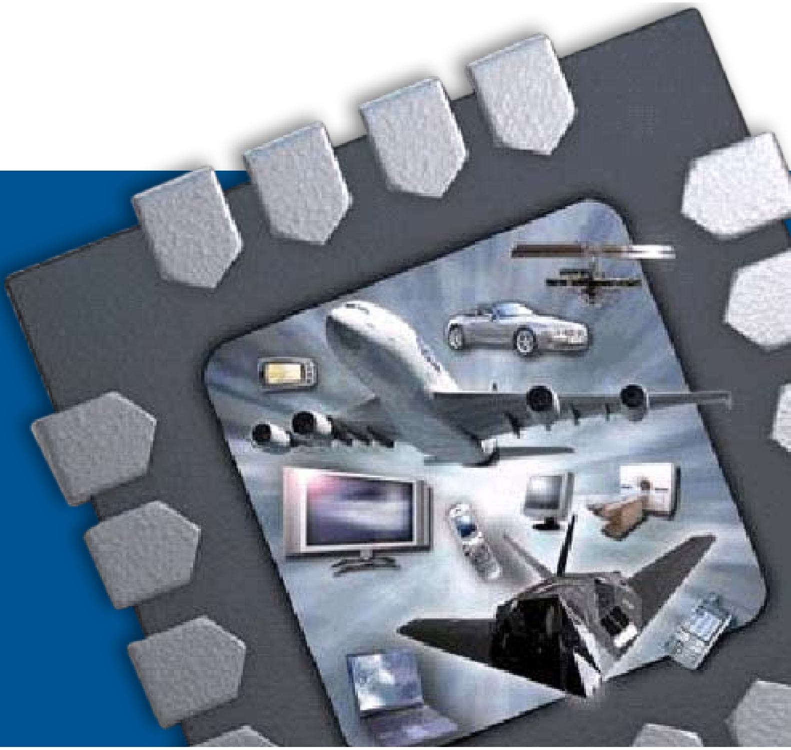
Driver On Board



Full-Bridge with Driver and Level Shift



Enhancement Mode SiC Power JFETs



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Enhancement Mode SiC JFETs

- SemiSouth Laboratories, Inc. (Starkville, MS) offers a line of SiC Power Products, including the following.
  - Power Diodes
  - **Enhancement mode Power JFETs.**
  - Depletion mode Power JFETs.
- Enhancement mode JFETs have excellent radiation withstand capabilities.
  - Total Dose performance is >1 Meg rad (Si)[1].
  - SE easily withstands gold (V_{DS}=200 V, gate shorted to Source)[1].
- There are notable Differences between a Silicon MOSFET and a SiC enhancement Mode JFET.
  - Enhancement Mode SiC JFETs want to have 10 to 100 mA or more of gate current to reach its lowest on resistance.
  - Drain leakage current is higher than Silicon types.
  - A very high percentage of the input capacitance is gate-to-drain.
  - There is no body diode.

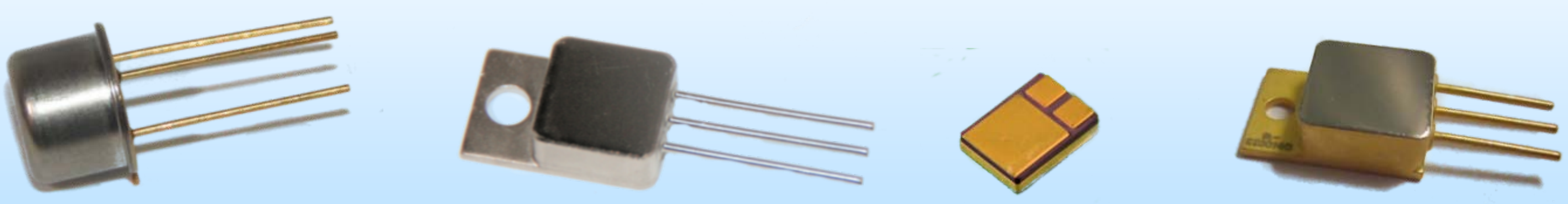
1.-Courtesy of tests accomplished by Sandia Labs

Available SiC JFETs from SemiSouth

P/N	Type	Breakdown Voltage	I_{MAX} @ 100^0 C (A)	$R_{DS(ON)}$ mΩ	Die LxW (mils)
SJEC170R550	**Enh**	**1700**	**3**	**550**	**40x57**
SJEC120R100	**Enh**	**1200**	**17**	**100**	**79x89**
SJEC120R050	**Enh**	**1200**	**29**	**50**	**158x89**
SJDC120R085	**Depl**	**1200**	**17**	**85**	**79x89**
SJDC120R045	**Depl**	**1200**	**30**	**45**	**158x89**
Cree CMF20120D MOSFET	Enh	1200	17	80	?

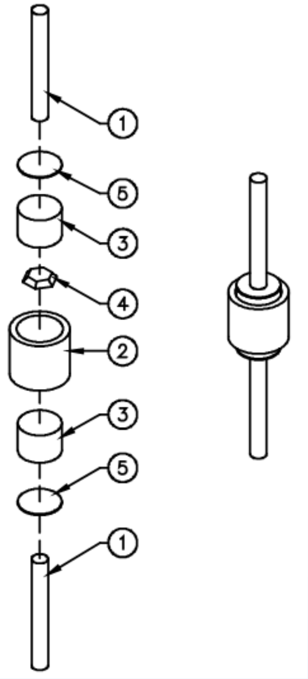
Product Roadmap: Silicon Carbide in Traditional Hermetic packages

- Single and Dual Schottky Diode configurations:
    - T0-39, T0-257, T0-254, and SMD packages
- Preliminary Datasheets are being finalized.
- Die sourced from CREE & Microsemi PPG
    - 10A 600V, 5A 1200V, 10A 1200V, 50A 1200V
- We have completed our HTRB evaluations and will initially offer these devices with a Tj rating of 225°C.



Silicon Carbide Glass Rectifier Diode

- **64 X 64 mil die size, 600-1200V, 1-3 A**
- **Zero Recovery SiC Glass Rectifier Diode**
  - **V_R = 600V, then 1200V**
  - **Vacuum collapsed glass seal**
  - **Low Leakage at Very High temp**
  - **V_F < 1.8 V**
  - **Q_C < 5 nC at 400V/1A**
- **Down Hole Operation to 300C**
- **From Bend SiC Fab**



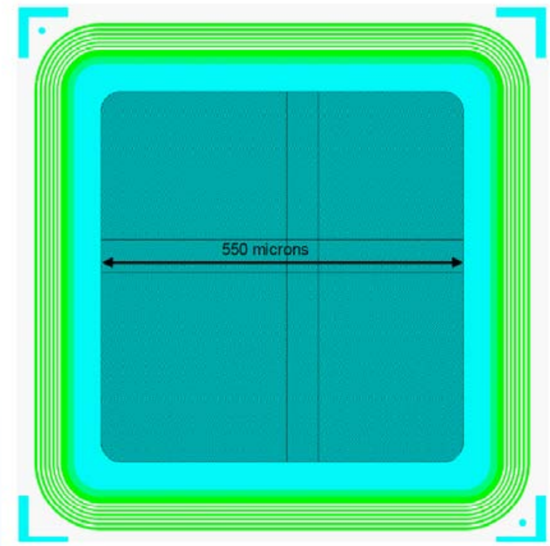


Figure 1: SBD die layout

Die size: 800 µm square
Top metal: Ti / Ni / Ag
Back metal: Ti / Ni / Ag

Summary

- New Semiconductor Materials are coming on stream.
- Testing will show which materials have a chance of yielding radiation hardened behavior.
- SE performance is tougher to obtain than TID performance.
- GaN transistors show “in spec” performance when exposed to Gold ions at Drain Voltages up to 40 V, and reduced spec performance (higher leakage) at drain Voltages up to 100 V.
- Development continues on finding a more SE robust GaN transistor.
- SiC transistors also show promise of yielding rad hard SE performance, and are useful at higher Voltages than other types.
- Every material type has its differences.

Microsemi

Power Matters


Microsemi…Keeping the Heat On