Maximizing application benefits with GaN: a comparison of commercial technologies

Dario Pagnano, Senior GaN Device Manager, Nexperia
Marco Scilio, EMEA FAE Team Leader – Analog & Power, Nexperia

Bodo's
Wide Bandgap
Event 2024

Making WBG Designs Happen

GaN

Our portfolio of essential semiconductors

15.000
parts in total

800
new types
added each year

Benchmarks in efficiency

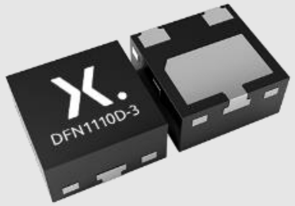
Process

Power

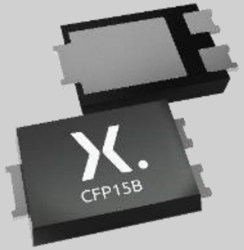
Performance

Industry-leading
small packages

Bipolar transistors



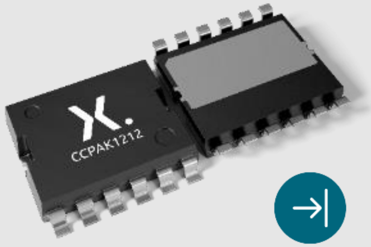
Diodes



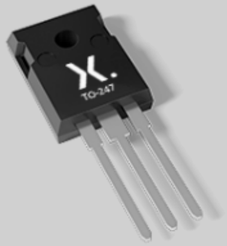
ESD protection, TVS, signal conditioning

MOSFETs

GaN FETs

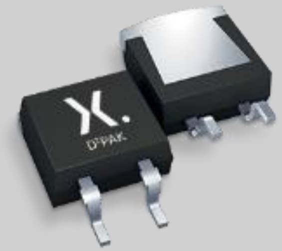


IGBTs

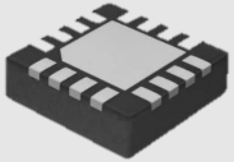


Analog Logic ICs

New Product Portfolio Investments

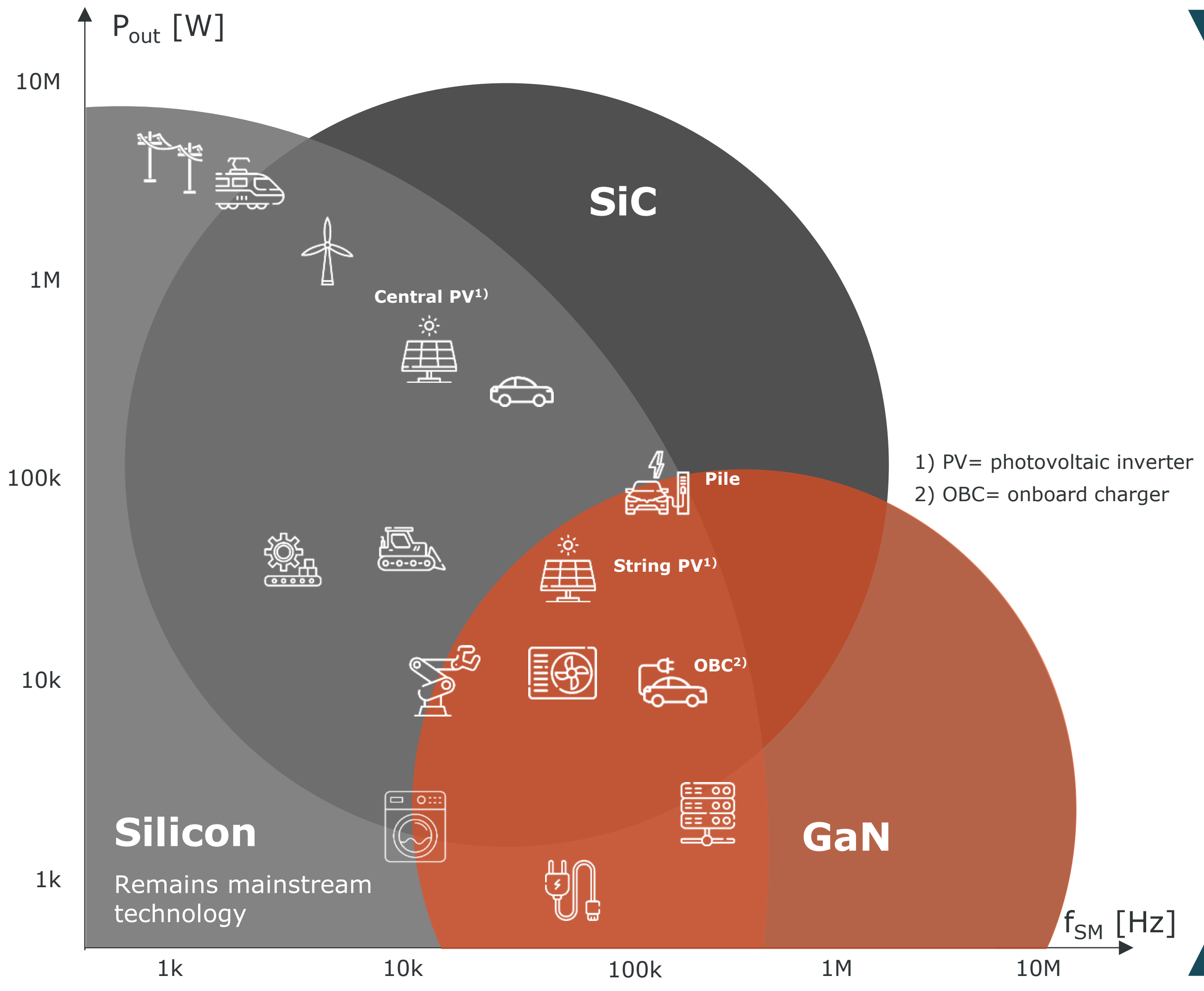


SiC Rectifiers and FETs



Analog & Power Management ICs

Co-existence of power technologies addressing different applications



Silicon power devices

Si remains mainstream technology

Targeting up to 6.5kV

Low to high power

Silicon carbide MOSFET/diodes

Targeting voltage ranges from 650V – 3.3 kV

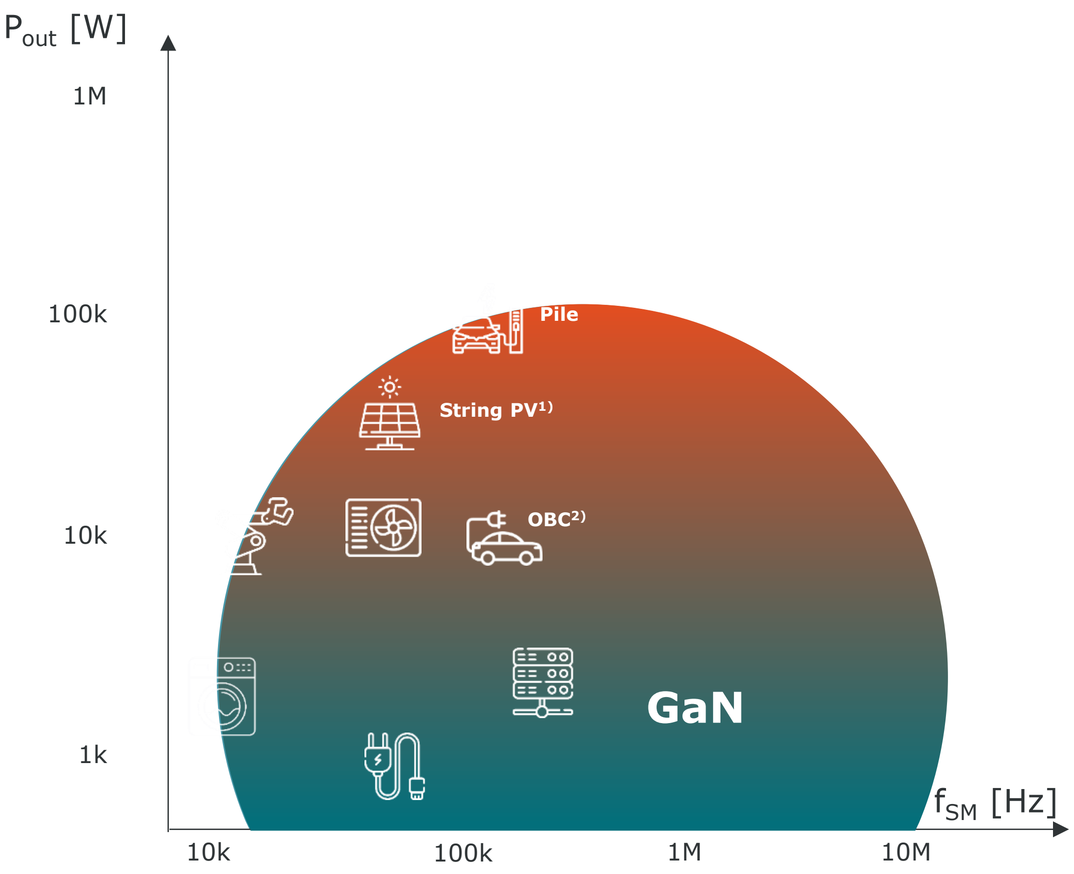
Medium/High power from moderate to high switching frequency

Gallium Nitride FET

Targeting voltage ranges from 40V – 650V

Low/Medium power at highest switching frequency

Co-existence of power technologies addressing different applications



Cascode
High voltage, medium to high-power

Industry 4.0
- Servo motor drives/ frequency inverters
- Telecom power supplies
- Class-D Audio amplifiers
- Welding machines

The path to Net Zero CO_2
- Solar (PV) inverters
- Server Titanium grade power supplies
- Battery storage/ UPS inverters
- Heat pumps

E-mode
Low & high voltage, Low to Medium power

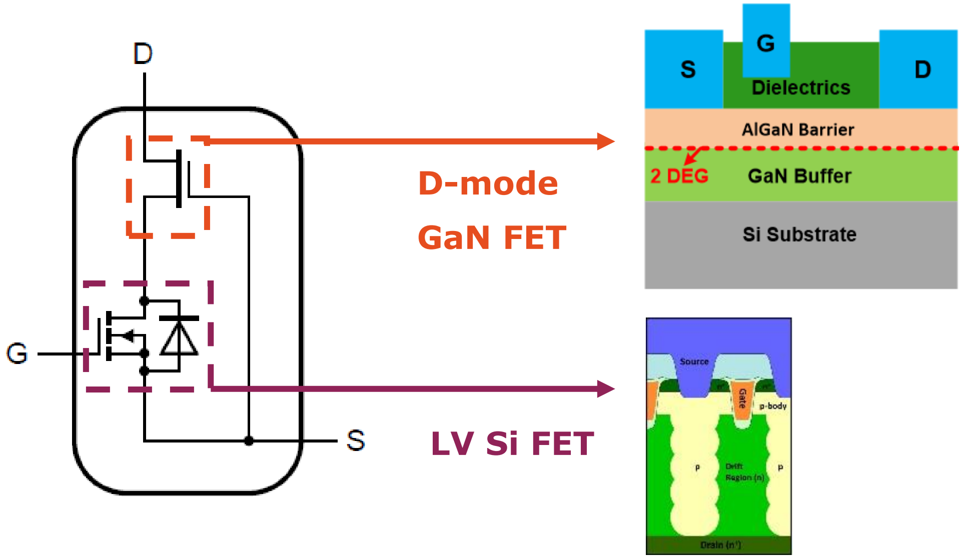
100/150 V applications
- 400V-48V LLC converter for datacenters
- 48V to POL direct conversion
- Power supply (AC/DC) fast charging for e-mobility
- USB-C power delivery fast charging for portables
- LiDAR (non-automotive)

650 V applications
- Datacom and Telecom (AC/DC and DC/DC)
- Photovoltaic (PV) micro inverter (DC/AC)
- Industrial (DC/AC)
- BLDC / micro servo motor drives
- TV power supply unit (PSU)

GaN technologies compared

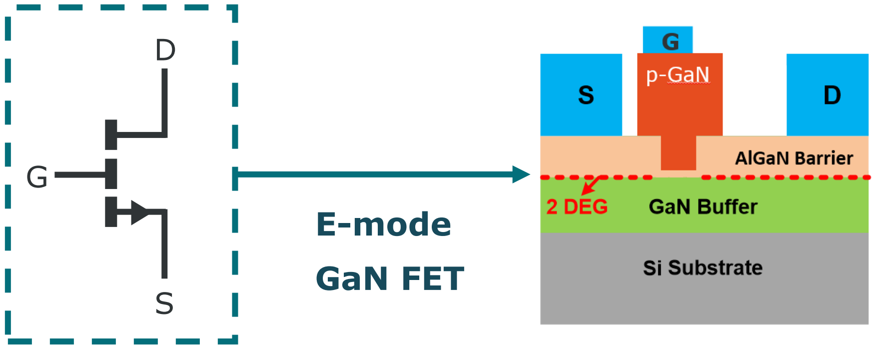
GaN cascode (d-mode)

- Two die solution
- Uncompromised 2DEG
  → highest electron mobility
  → best channel conductivity full temperature range
- Robust gate (V_{th}=4 V, V_{GS}=±20 V)
  → high margin against noise
- Easy to drive (no negative drive)

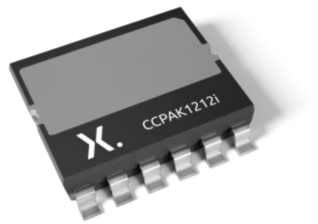


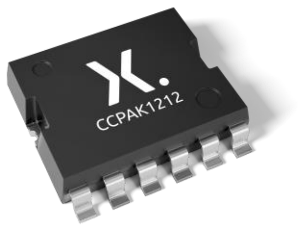
GaN E-mode

- Single die: HEMT
  → easier package, manufacturing, SCM
- Gate voltage (V_{th} ~1.5-2V), devices fully turned-on at 5-6V
- Pure GaN die, able to work at very high frequency
- Excellent FOM vs others compounds (5x better than LV 100V Si MOSFET)



Complementing products to maximize system benefit





CCPAK1212(i)

Copper clip package with flexible leads for best board level reliability and possibility of automatic optical inspection. In top-side and bottom-side cooled designs.

- **Robust gate**
- **Easy to drive**
- **Very low R_{th} ≤0.5K/W**
- **Ultra-low inductance <1.3nH**
- **JEDEC**
- **Higher saturation current**
- **Very low losses in reverse conduction mode**
- **Extremely low switching losses**

- **Very low Q_G**
- **Fully enhanced at 5…6V**
- **Very fast rise and fall time**
- **Low package inductance**
- **Direct slew rate control**
- **Reverse conduction without body diode**
- **Very low *Qoss* and *Eoss***
- **Extremely low switching losses**

DFN5060

Dual Flat No Leads package with 5mm x 6mm form factor for compact and high-performance designs

WLCSP8

Wafer-Level Chip Scale Package to minimize device size and RLC parasitics while offering excellent thermal dissipation

650V E-mode vs. Cascode Datasheet Comparison

	Cascode Nexperia	E-mode Competitor
V_{DS} max.	650V	650V
$R_{DS(on)}$ typ. @ 25°C	50mΩ	50mΩ
$R_{DS(on)}$ typ. @ 150°C	103mΩ	129mΩ
I_{DS} Pulse	150A	60A
V_{SD} @ 150°C	2.6V	6V
$V_{GS(th)}$ min.	3.4V	1.1V
V_{GS} on	10V	6V
V_{GS} max.	20V	7V
Q_{GD}/Q_{GS1}	0.9	2.3
Q_{OSS}	125nC	64nC
Q_G	15nC	6.1nC

For low power applications with higher $R_{DS(on)}$ parts, the benefits of the Cascode become less decisive.

Cascode Benefits

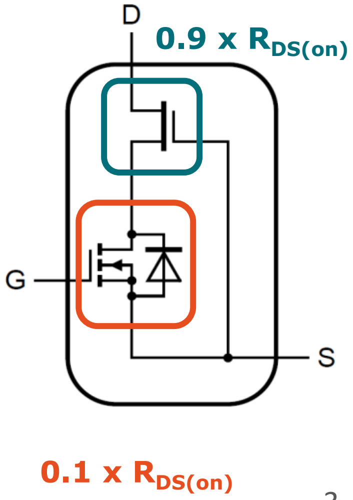
- Cascode for high-power applications
  - $R_{DS(on)}$ more stable over temperature
  - Higher saturation current
  - Lower reverse conduction losses
- Robust gate drive
  - High $V_{GS(th)}$ (inherently safe against parasitic turn-on)
  - High dv/dt immunity (low Miller ratio)

E-mode Benefits

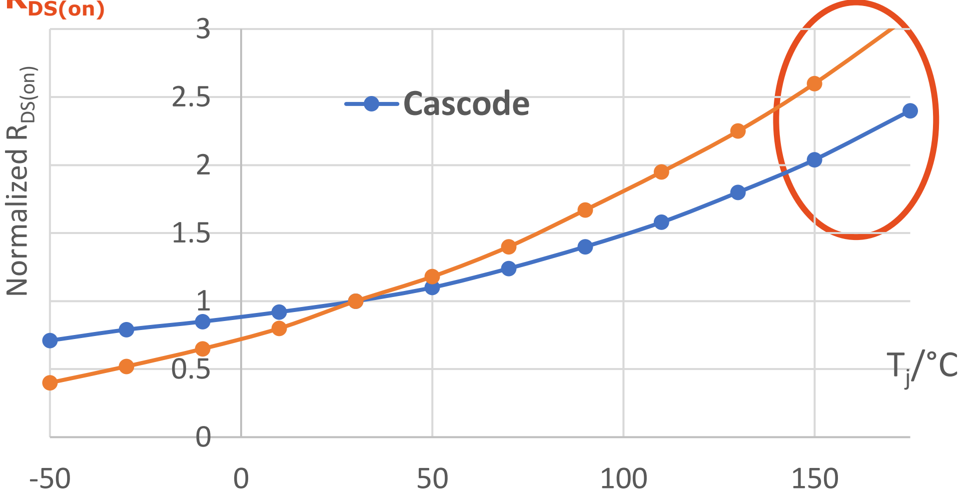
- E-Mode for higher switching frequencies
  - Lower switching losses
  - Lower gate drive losses

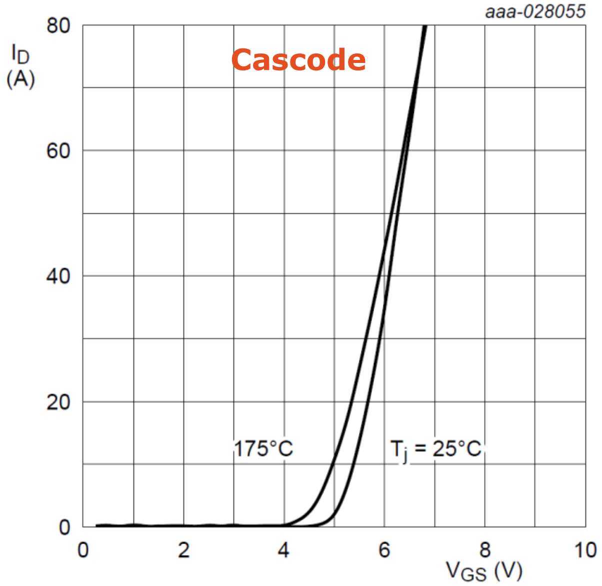
$R_{DS(on)}$ and Saturation Current

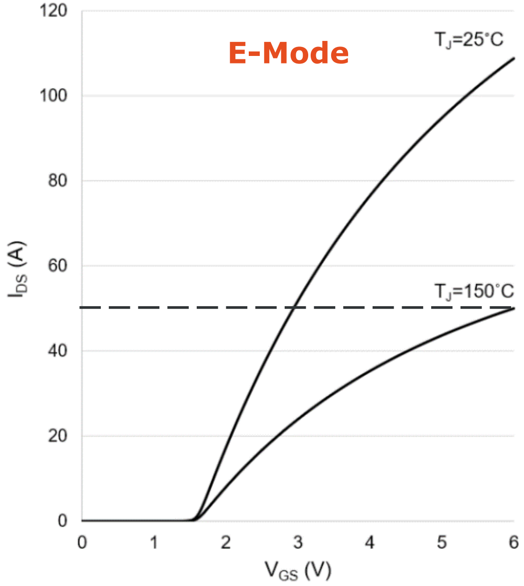
Cascode better for high power applications



- Si MOSFET $R_{DS(on)}$ typ. less than 10% of GaN HEMT $R_{DS(on)}$
- Cascode $R_{DS(on)}$ compared to E-mode is more stable over temperature:
  - 2.0 vs. 2.6 (@ 150°C)
  - 2.4 vs. 3.3 (@ 175°C)



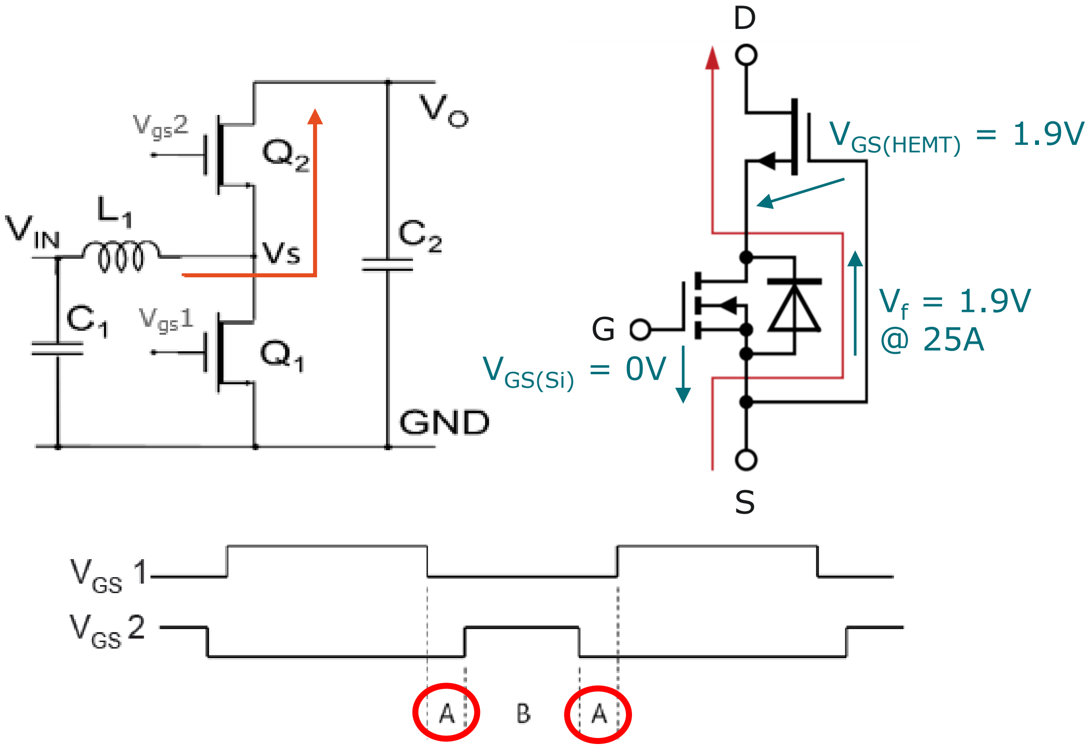




- Cascode high temperature saturation is well beyond rated I_D and I_D is not limited by saturation
- E-mode shows drop in I_{Sat} with temperature

V_{SD} in Reverse Conduction

Very low V_f voltage drop of SI MOSFET body diode



- Body diode with **low V_f** enables Si-like freewheeling current capability with **low V_{SD}**

Technology	V_{SD} @ 25°C	V_{SD} @ 150°C
Cascode GaN (V_{GS} = 0V)	1.9V	2.6V
E-mode GaN (V_{GS} = 0V)	3.7V	6V

I_D = 25A, recommended V_{GS} as per datasheet

- Negative V_{GS} ensures safe operation for E-mode or SiC but increases reverse conduction loss

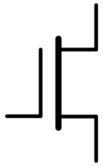
The Si MOSFET body diode allows the HEMT to completely turn on with a small positive V_{GS}

Cascode GaN in CCPAK1212

Leveraging 20 years of LFPAK experience to maximize the potential of the GaN technology

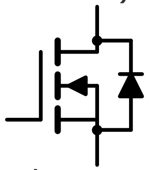
650V D-mode GaN HEMT

- **Normally-on;** requires negative V_{GS}
- Simplest structure made with GaN
- Highest electron mobility for a wide bandgap FET
- Low $R_{DS(on)}$, low C_{OSS}
- Fast turn on/off → Low E_{on}/E_{off}
- High V_{DS} transient capability (800V)



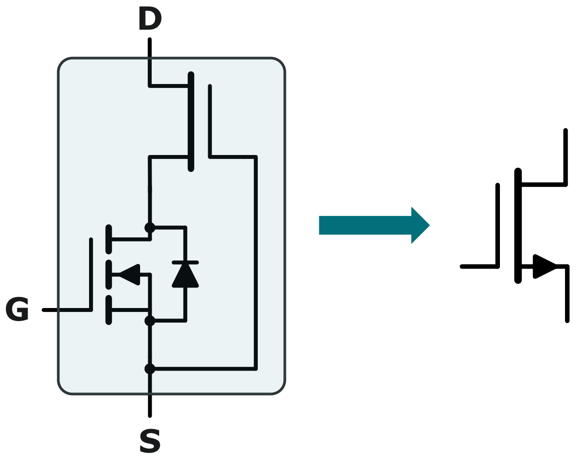
30V Si MOSFET

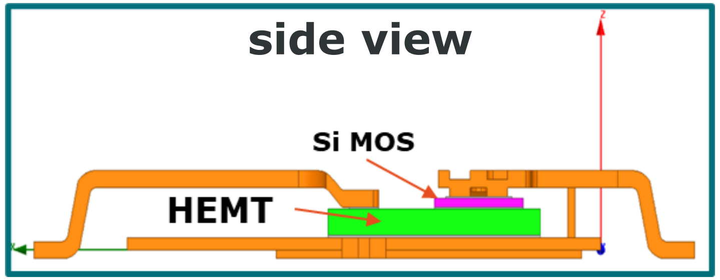
- **Normally-off**
- Robust and reliable gate structure (V_{GS} = ±20V)
- High threshold voltage (V_{th} = 4V)
- Low Q_G & low Q_{rr}
- Very low V_f body diode
- Nexperia's latest Trench 9 MOSFET technology

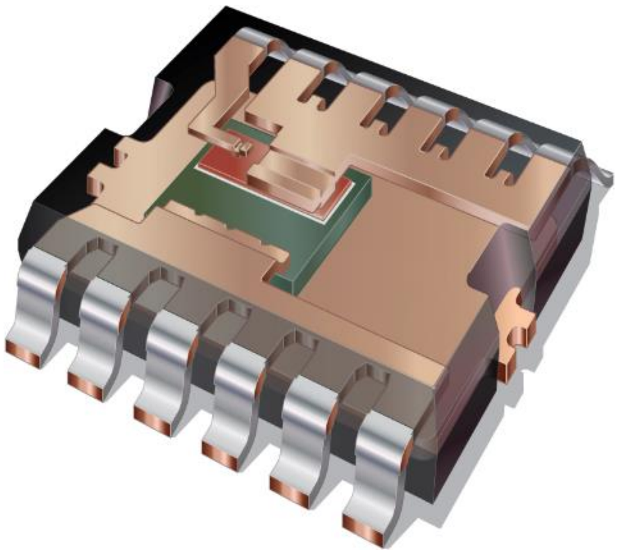


650V GaN cascode

- **Normally-off**
- Two-die structure
- D-Mode GaN + Si-FET
- T_j = -55 to +175°C

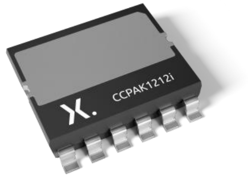






Stacked die and copper clip minimize parasitics – Very low R_{th}

Cascode and e-mode qualified to JEDEC standards



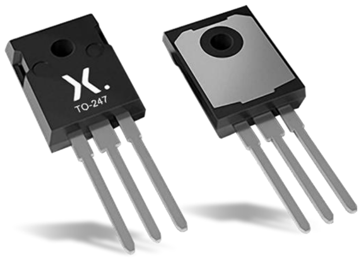
GAN039-650NTB

Tests	Sample size	Results	Status
High Temperature Negative Gate Bias (HTNGB) T_j = 175 °C, V_{GS}= -20 V, V_{DS}=0 V, 1000 hours	240	**PASS**	**Completed**
High Temperature Positive Gate Bias (HTPGB) T_j = 175 °C, V_{GS}= +20 V, V_{DS}=0 V, 1000 hours	240	**PASS**	**Completed**
High Humidity High Temperature and Reverse Bias (H3TRB) TA = 85 °C / 85 %RH, V_{DS} = 100 V, V_{GS}= 0 V	240	**PASS**	**Completed**
Unbiased Highly Accelerated Stress Test (UHAST) TA = 130 °C / 85 %RH	240	**PASS**	**Completed**
Intermittent Operating Life (TFAT) dT_j = 80 °C, 10 k cycles	240	**PASS**	**Completed**
Thermal cycling TA = -55 °C to 150 °C, 1000 cycles	240	**PASS**	**Completed**
High Temperature Reverse Bias (HTRB) Tj = 150 °C, V_{DS}= 520 V, V_{GS}=0 V, 1000 Hrs	240	**PASS**	**Completed**

GAN3R2-100CBE

Tests	Sample size	Results	Status
High Temperature Gate Bias (HTGB) T_j = 150 °C, VGS= 5.5V, 1000 hours	231	**PASS**	**Completed**
High Humidity High Temperature and Reverse Bias (H3TRB) T = 85°C, RH = 85%, V_{DS} = 80 V, 1000 hours	231	**PASS**	**Completed**
Highly Accelerated Stress Test (HAST) T = 130 ºC, RH = 85%, V_{DS} = 42 V, 96 hours	231	**PASS**	**Completed**
High Accelerated Stress Test (HTOL) LLC, V_{in} = 60 V, FFSW = 1 MHz, T_j>125 °C, 1000 hours	231	**PASS**	**Completed**
Thermal cycling -40 ºC to 125 ºC @ rate of 15 °C / min, 1000 cycles	231	**PASS**	**Completed**
High Temperature Reverse Bias (HTRB) T = 150 °C, V_{DS} = 80 V, 1000 hours	231	**PASS**	**Completed**

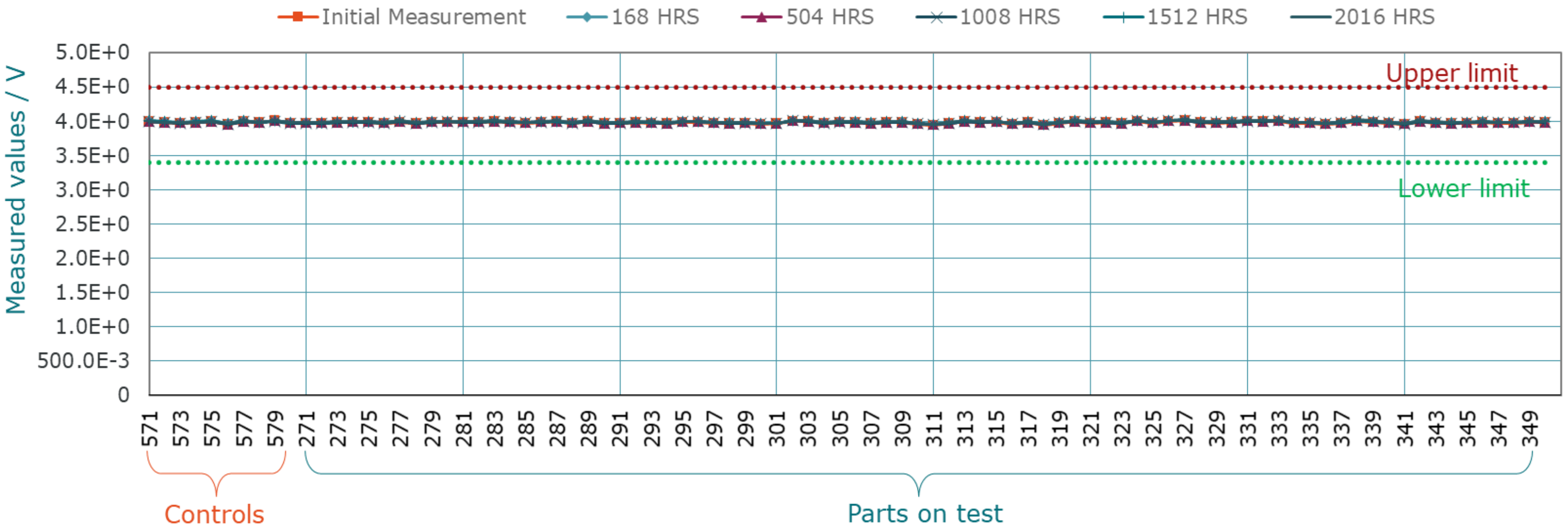
GAN041-650WSB - Qualification beyond standard



Tests	Sample size	Results	Nexperia Extended Results		Current Status
High Temperature Negative Gate Bias (HTNGB) T_j = 175 °C, V_{GS}= -20 V, V_{DS}=0 V, 1000 hours	240	PASS	2000 hrs	**2x**	Completed
High Temperature Positive Gate Bias (HTPGB) T_j = 175 °C, V_{GS}= +20 V, V_{DS}=0 V, 1000 hours	240	PASS	2000 hrs	**2x**	Completed
High Humidity High Temperature and Reverse Bias (H3TRB) TA = 85 °C / 85 %RH, V_{DS} = 100 V, V_{GS}= 0 V	240	PASS	2000 hrs	**2x**	Completed
Unbiased Highly Accelerated Stress Test (UHAST) TA = 130 °C / 85%RH	240	PASS	198 hrs	**2x**	Completed
Intermittent Operating Life (TFAT) dT_j = 80 °C, 10 k cycles	240	PASS	20,000 cyc	**2x**	Completed
Thermal cycling TA = -55 °C to 150 °C, 1000 cycles	240	PASS	2000 cyc	**2x**	Completed
High Temperature Reverse Bias (HTRB) T_j = 175 °C, V_{DS}= 520 V, V_{GS}=0 V, 1000 Hrs	240	PASS	2000 hrs	**2x**	Completed

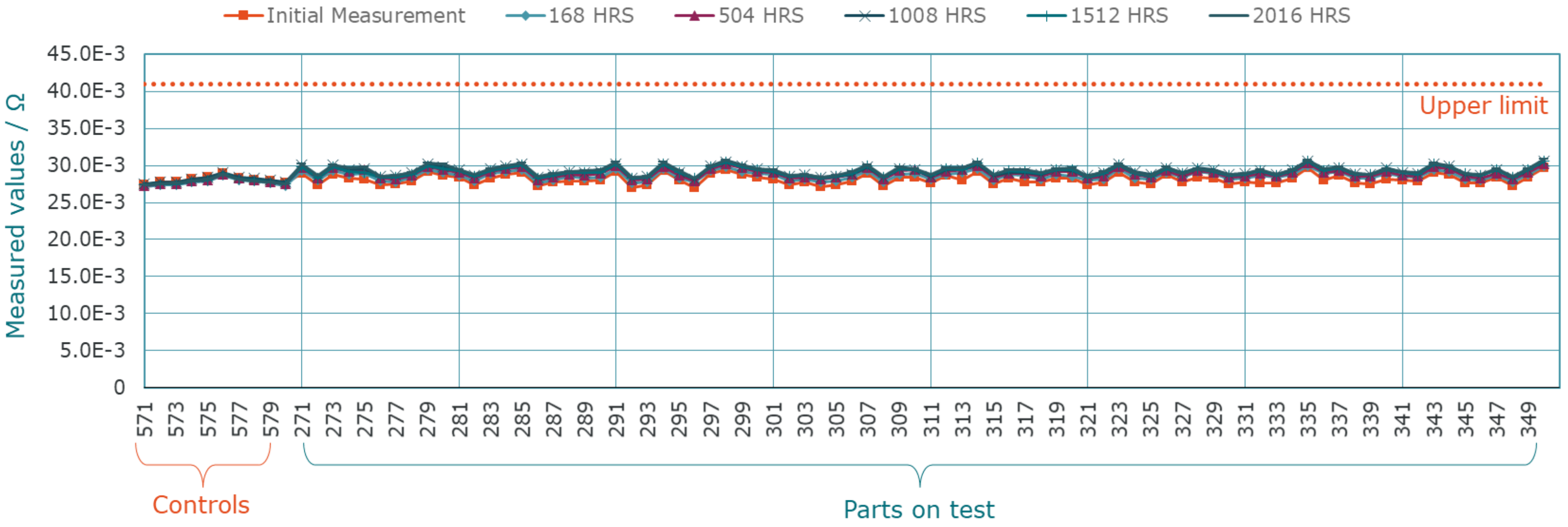
GAN041-650WSB - Qualification beyond standard

V_{th} plot: HTRB at 520 V, 175 °C

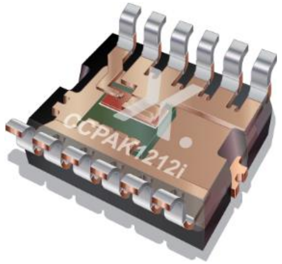


$R_{DS(on)}$ plot: HTRB at 520 V, 175 °C

- Less than 5% delta shift after 2000 hours

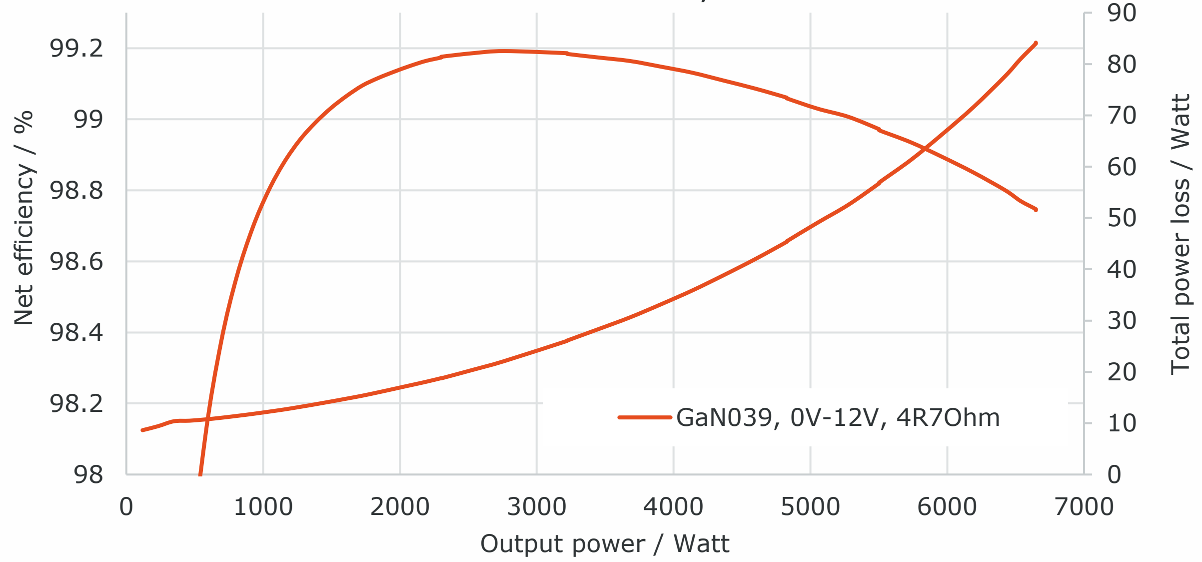


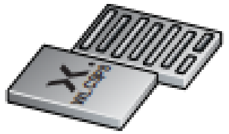
Complemeting technologies delivering highest efficiencies



GAN039-650NTB

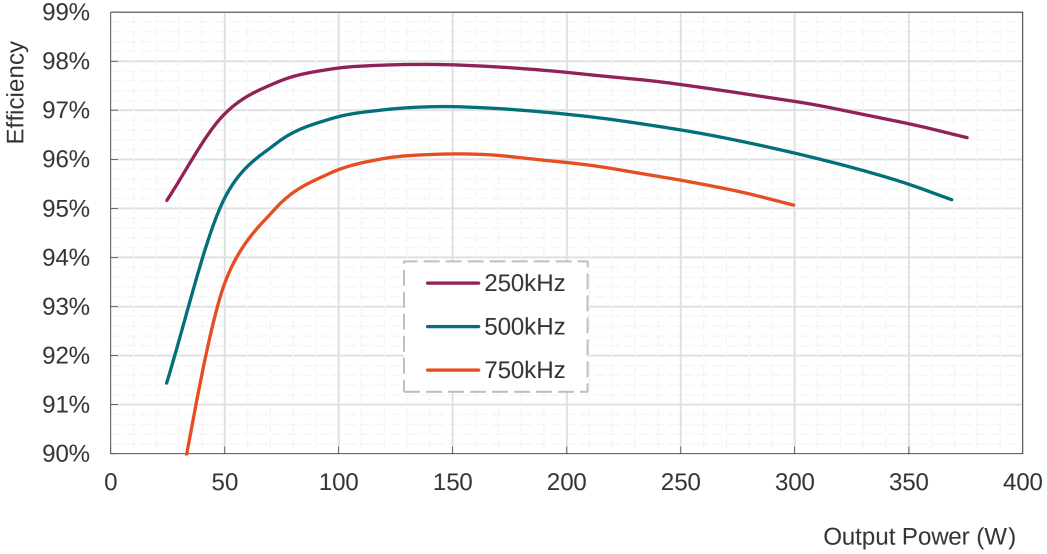
Buck converter 400V to 230V;
25°C water cooled; 100kHz





GAN3R2-100CBE

Efficiency for a buck converter 48V to 12V
(fSW = 250kHz, 500kHz, 750kHz)



For more information visit:
nexperia.com/gan-fets

E-mode and D-mode GaN technologies have complementing strengths

Both technologies have specific application areas where they fit best

The right package and product concept maximizes the benefit coming from the technological strengths

Both technologies have proven reliability and deliver high efficiencies

Nexperia provides the solution that fits best to the customer!