GaN monolithic integration levels: a journey from discrete devices to power ICs with complex functionality

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Dr. Giorgia Longobardi

Founder and CEO

- Graduated from University of Naples Federico II
- PhD from Cambridge University
- Founded Cambridge GaN Devices in 2016
- Former **leader** at the Engineering Department of the **University of Cambridge**
- **12 years' experience** in reliable Gallium Nitride power devices
- Collaborated with major semiconductor companies

Outline

1. GaN market and megatrend
2. Application requirements
3. From discrete to monolithically integrated solutions
4. Efficiency curves and thermal performance
5. Conclusions

4 megatrends driving the growth of energy Consumption

Unprecedented Levels of CO_2 Emissions Caused by Human Activity

Climate Change

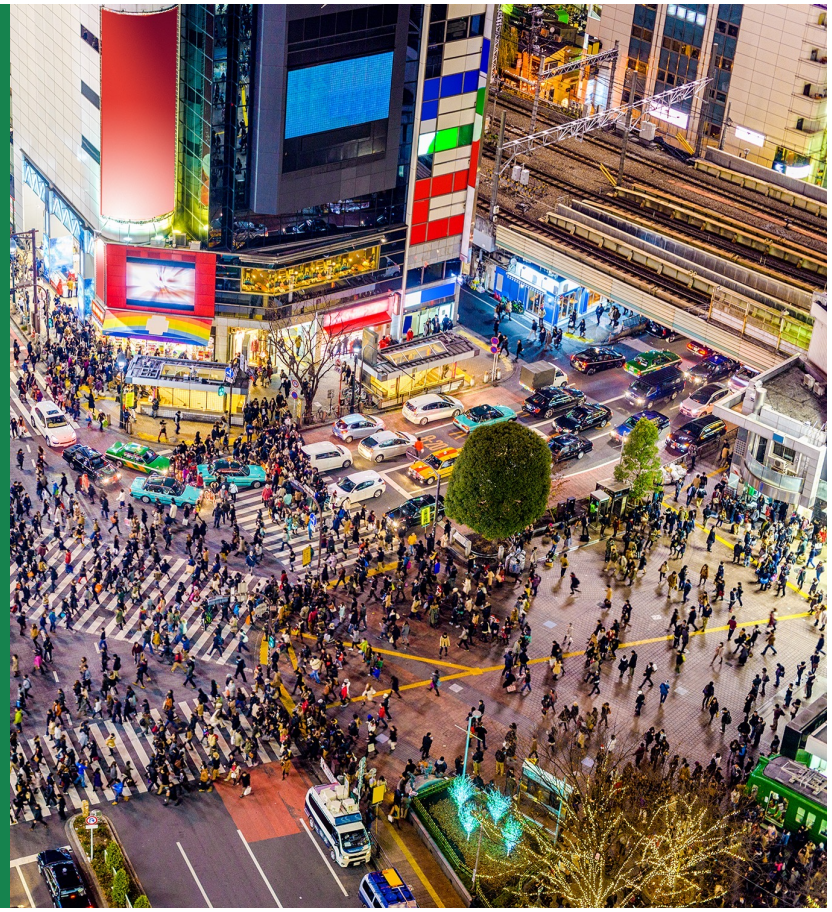
Population Growth

Urbanisation

Digital Transformation

36,7Gt of CO_2 emissions

22,848 TWh consumed electricity

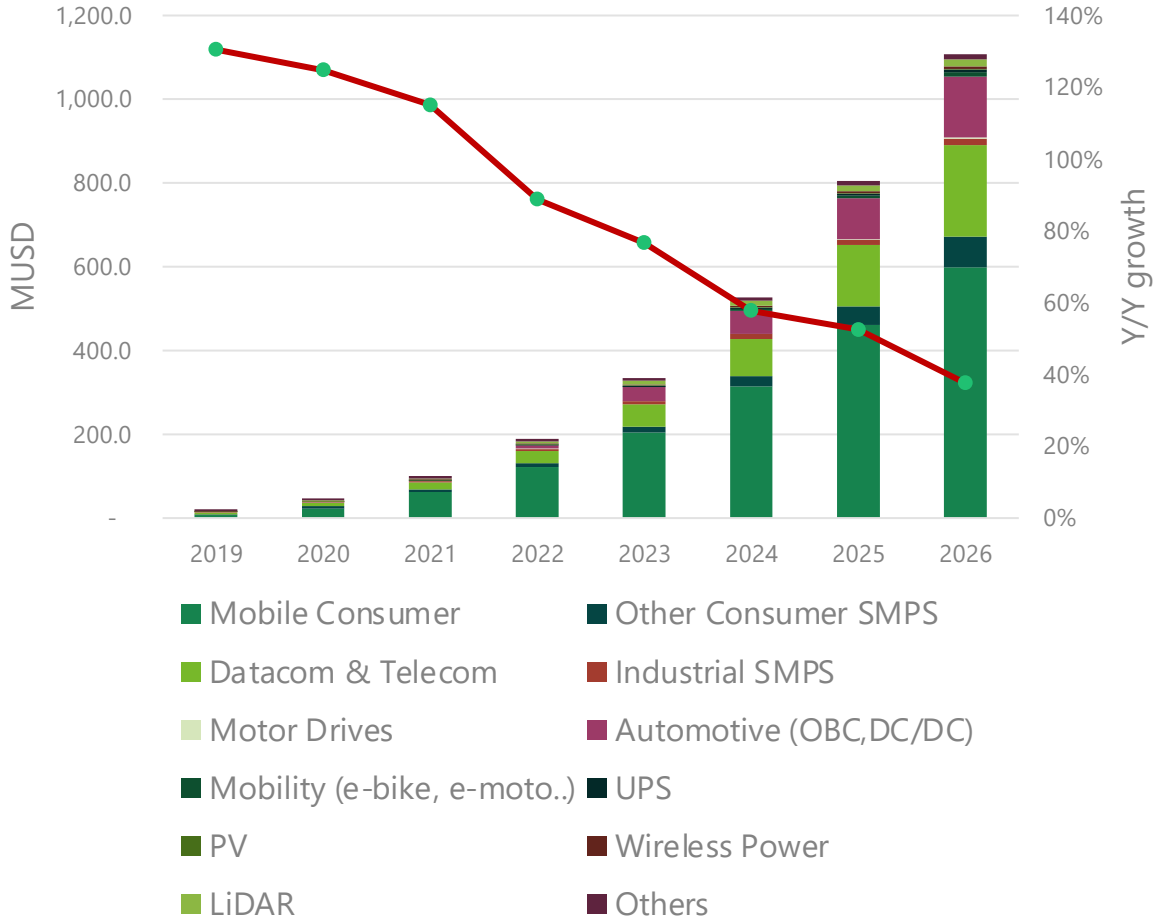




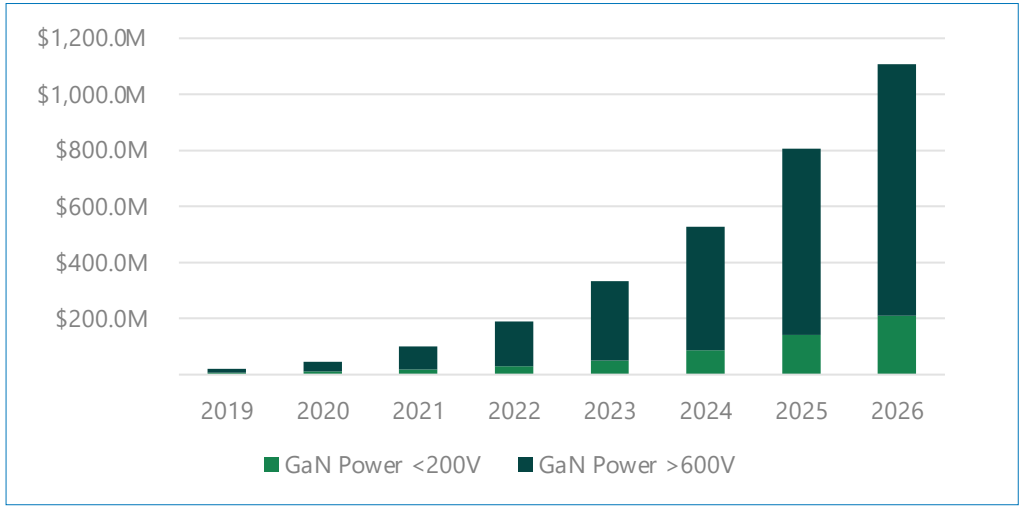

Demographics, Social Change and the Climate Crisis Urge for **Energy-efficient Power Electronics** and **semiconductors**

GaN market

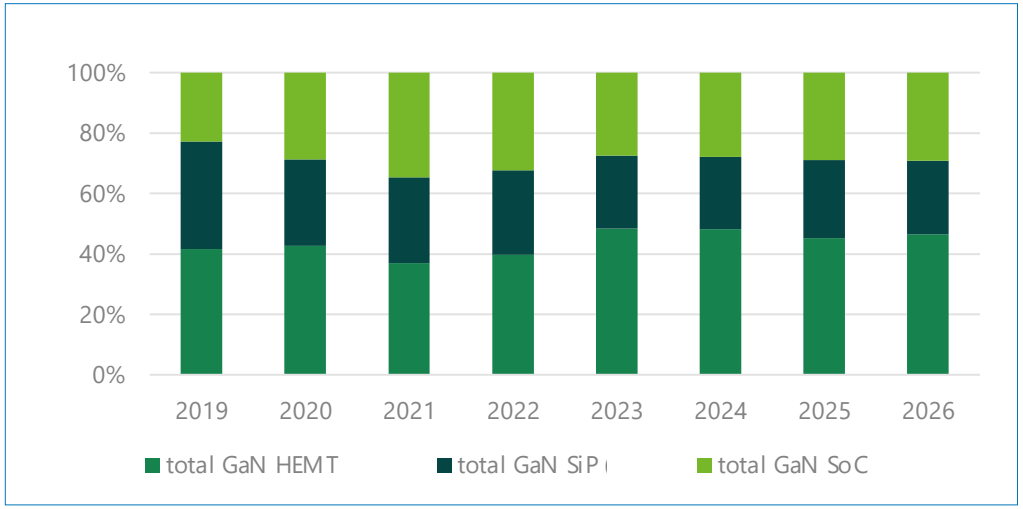
Power GaN Market



Power GaN Market LV and HV

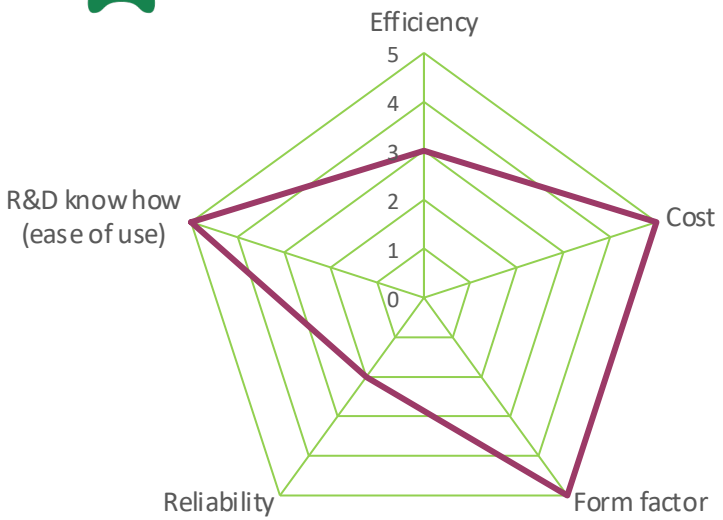


Normalised GaN market split by technology

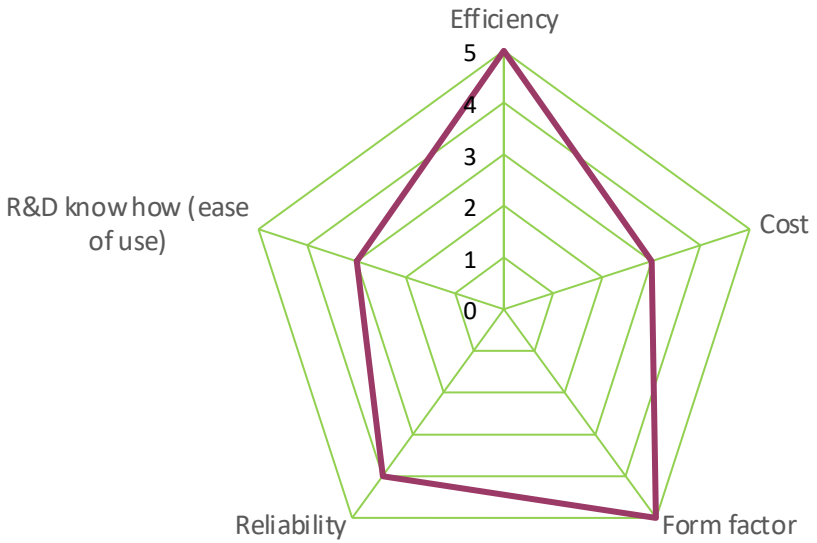


Technology drivers based on application

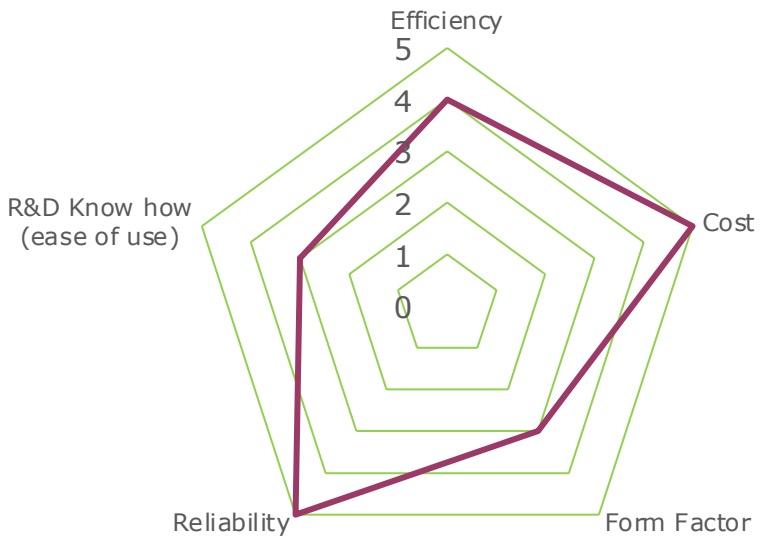
Consumer electronics



Data centres



Automotive



Efficiency, ease-of-use and form factor are key drivers for the adoption of GaN technology

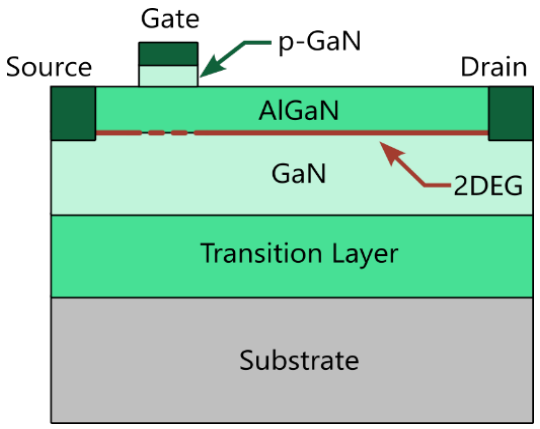
Lateral GaN technology – 650 V

Advantages of lateral technology versus vertical technology

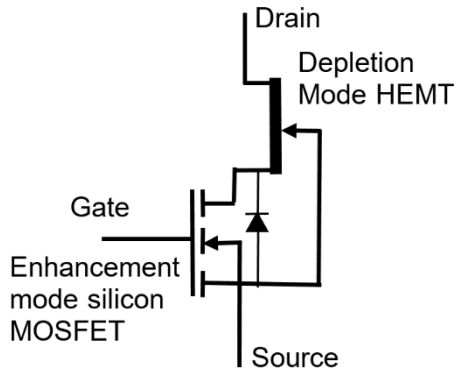
- It allows **monolithic integration** of sensing, protection and drive circuits with relatively simple isolation
- It allows easy **access to all terminals** (including the high voltage terminal)
- It allows integration of **half bridge** devices and multiple power devices operating on a common substrate
- It allows the **connection of the substrate** to the ground and its physical contact to a heat sink
- It allows **simpler and cheaper packaging**
- It allows devices to be **self-terminated** (i.e. do not require an additional termination region to shape the electric field at the edge of the device as in the case of vertical structures)

From discrete to hybrid and monolithically integrated solutions

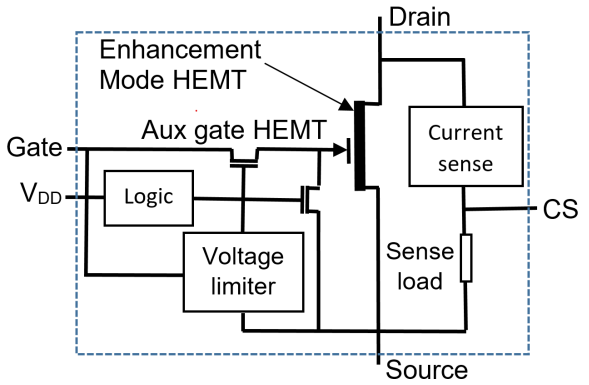
Discrete HEMT



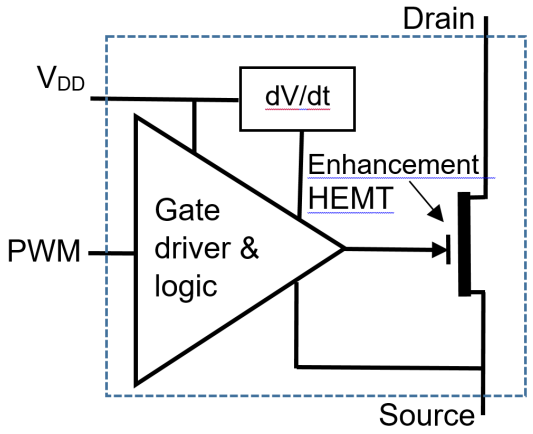
Cascode Si MOSFET + HEMT



Smart HEMT - ICeGaN™ HEMT



Power IC with HEMT and integrated drive



Discrete

P-GaN Enhancement HEMT

Hybrid

Schottky gate depletion mode HEMT in series with a silicon low-voltage MOSFET

Power IC – Level 1 monolithic integration

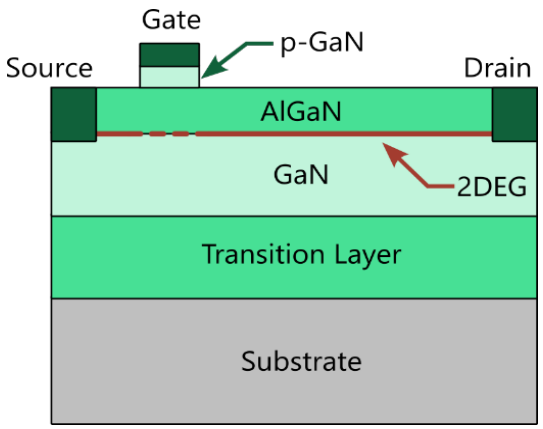
- Enhancement mode HEMT
- Smart interface for higher threshold voltage and higher reliability of the gate
- Gate voltage protection
- Current sensing

Power IC – Level 2 monolithic integration

- Enhancement mode HEMT
- Gate driver integrated
- dV/dt slew rate adjustment

From discrete to hybrid and monolithically integrated solutions

Discrete HEMT



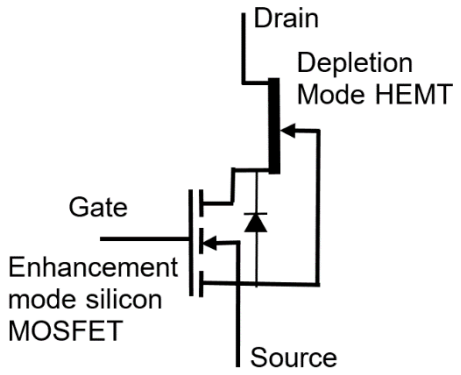
Features:

- normally off operation
- p-GaN gate using Mg doping
- choice of gate Ohmic or Schottky contact

Challenges:

- low threshold voltage Vth ~ 1.5 V
- fragility of the gate with max voltage ~7 V
- requires negative voltages for a safe and reliable turn-off

Hybrid integration



Features:

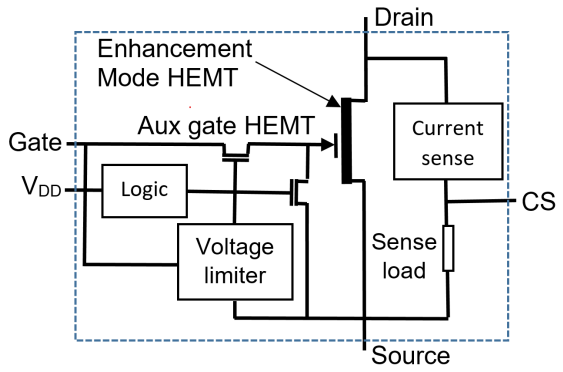
- stable, reliable and easy to use drive provided by the silicon MOS gate
- good reliability
- low on-state forward drop in the reverse conduction (diode) mode

Challenges:

- co-packaging of two or multiple components
- voltage sharing
- reverse recovery losses due to the anti-parallel bipolar diode
- no possibility of adjustment of slew rate on the HEMT gate
- relatively high output charge

From discrete to hybrid and monolithically integrated solutions

Power IC – Level 1 monolithic integration



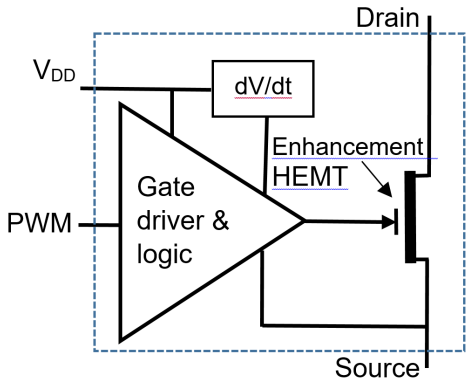
Advantages:

- stable, reliable and easy to use drive attached to the gate
- high Vth ~ 3V
- extended voltage range, up to 20 V
- no negative voltage requirement
- current sensing
- Miller clamp for safe turn-off and gate protection
- integrated ESD

Challenges:

extra GaN area for the smart interface.

Power IC – Level 2 monolithic integration



Features:

- stable & reliable operation
- low parasitic inductances
- compact solution

Challenges:

- extra GaN area for the drive circuit
- thermal consideration, as the drive & logic circuits can get hot during HEMT operation
- limited performance of the drive and logic circuits - availability of only n-channel low-voltage GaN transistors

Technology characteristics comparison

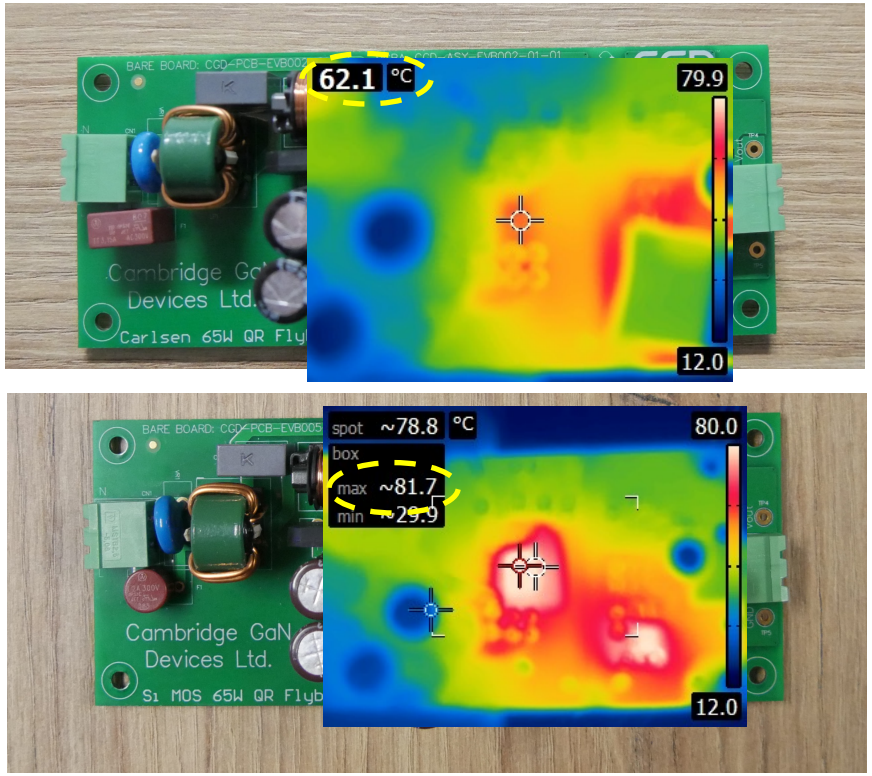
	Silicon Super-junction	GaN Cascode	p-GaN gate Schottky HEMT	ICeGaN™
Specific on-resistance Ron.Area [mΩ.mm^2]	8	2.8	3.2	3.2
Threshold voltage [V]	3.5	2.1	1.7	**3**
Maximum gate Voltage [V]	20	20	7	20
Ron.Qg [mΩ.µC]	3.5	0.15	0.28	**0.3**
Ron.Qoss [mΩ.µC]	22.5	5.5	3	3
Ron.Qrr [mΩ.µC]	32	6.5	0	**0**
Negative voltage drive requirement	no	no	yes	**no**
Current Sensing	no	no	no	**yes**
Typical Packaging	TO-247	TO-247	DFN	DFN

ICeGaN™ improves the thermals

By keeping the gate driver outside and enabling Source-to-Ground connection

CGD 65W QR Flyback Evaluation Board

Thermal Test @ V_{IN} 230 V, V_{OUT} 20 V, I_{OUT} 3.25 A

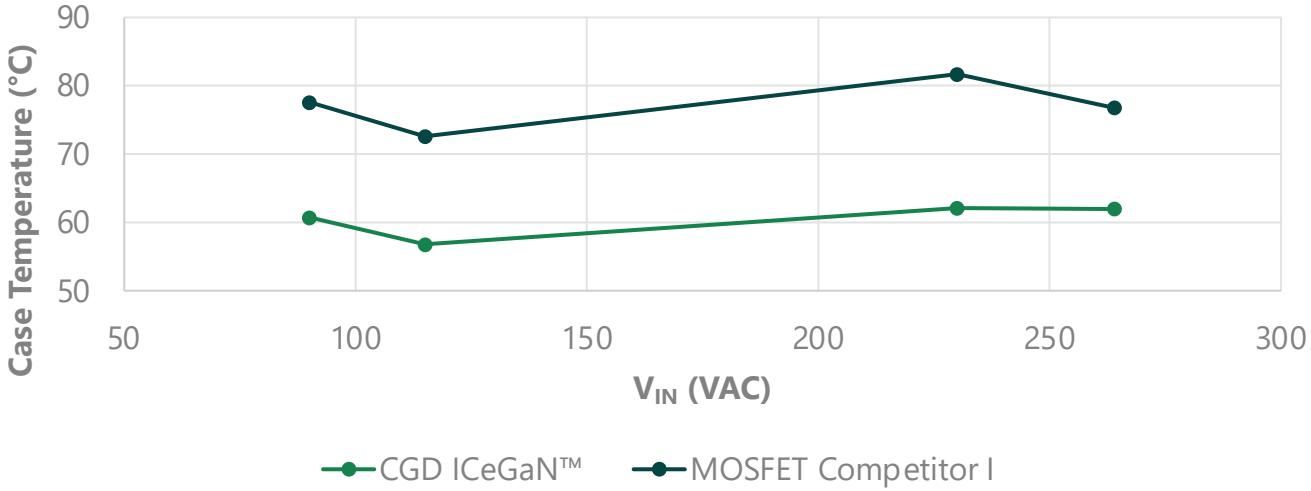


A real-world example.

ICeGaN™ compared with a MOSFET in an otherwise identical QR Flyback Application.

ICeGaN™s integrated current sense allows for a direct 'Source' to ground connection and removal of external sense resistors.

Thermal Test @ V_{OUT} 20V, I_{OUT} 3.25A



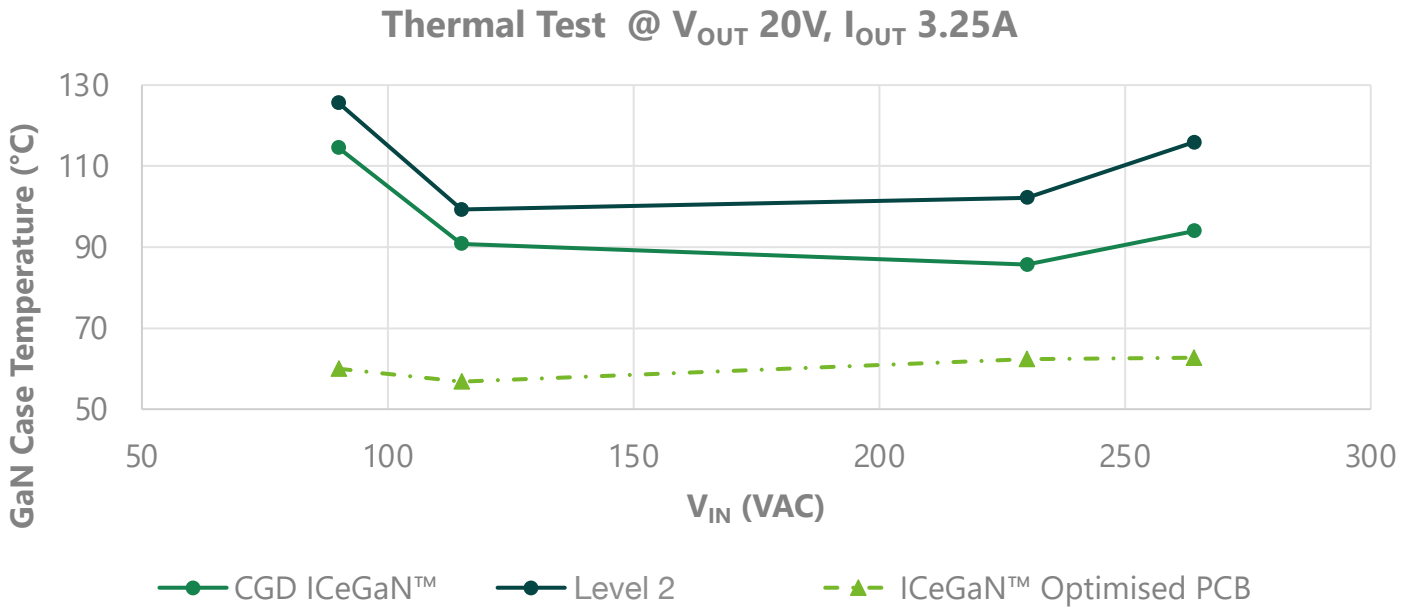
Implementation of ICeGaN™ has demonstrated an average temperature reduction of 16.5°C over line voltage - reducing device temperature by 30%.

ICeGaN™ improves the thermals

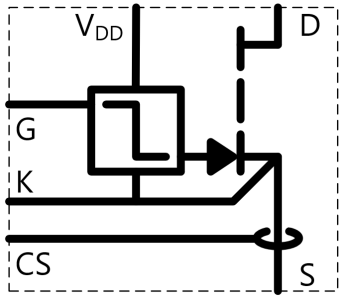
By keeping the gate driver outside and enabling Source-to-Ground connection

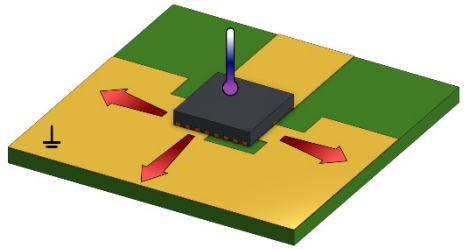
65W 2C1A USB – PD Adaptor

- 18W/in³
- QR Flyback
- Dual Type-C ports and one Type-A port with smart power distribution



ICeGaN™ enables easy connection to drivers/controllers without additional components. The Integrated current sense allows for direct source-to-ground connection, while also saving on external sense resistors



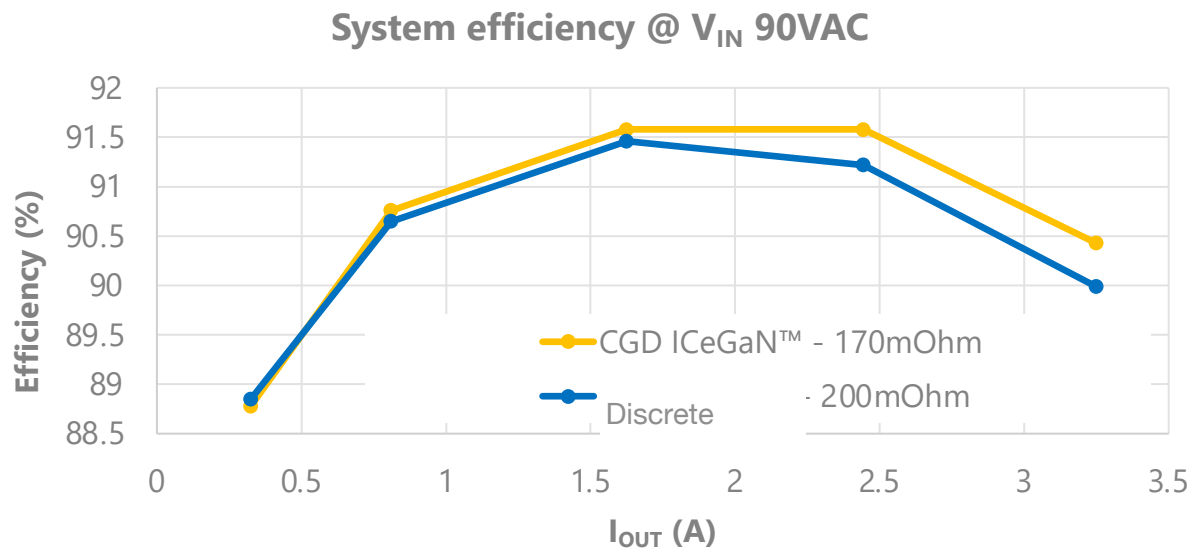


ICeGaN™ reduces the number of components

With same or better efficiency over full load range

65W 2C1A USB – PD Adaptor

- 18W/in^3
- QR Flyback
- Dual Type-C ports and one Type-A port with smart power distribution



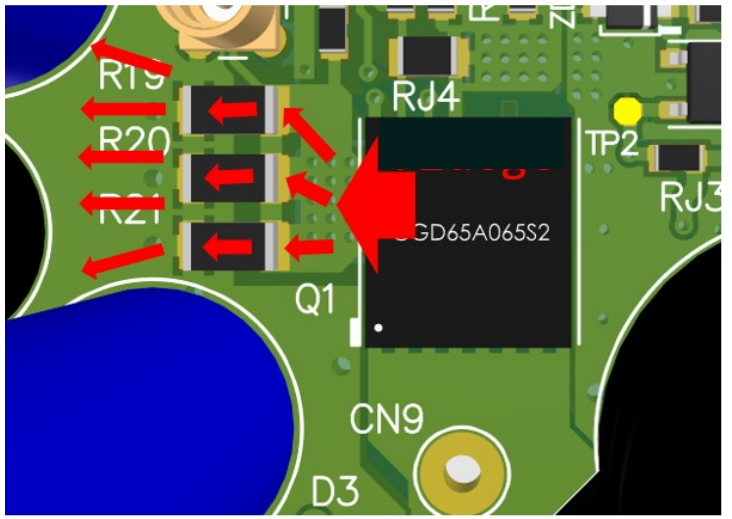
Function	CGD ICeGaN™		Discrete	
Control turn ON speed	**Same**		**1x Resistor**	**5-10 Ω / 1% 200mW**
Keep the driving voltage	**Not needed**		**1x Resistor**	**~ 10 kΩ /5%**
Hold negative voltage for turning off	**Not needed**		**1x Capacitor**	**~ 47 nF / 30V**
Zener Clamp, positive gate voltage	**Not needed**		**1x Zener diode**	**5V6 200mW**
Zener Clamp, negative gate voltage	**Not needed**		**1x Zener diode**	**9V1 200mW**
VDD Voltage Supply	**1x Capacitor**	**1uF / 40V**	**Not needed**	

* According to the company guidelines for low side driving circuit

ICeGaN™ Thermal performance in a QR Flyback Application

Standard flyback topologies

- use sense-resistors to sense I_d
  - Sense resistors increase the thermal path from device to ambient, restricting the flow of heat energy
    => Switching devices run hotter.
  - Power will also be dissipated within the sense resistors.
    => Flyback efficiency reduces

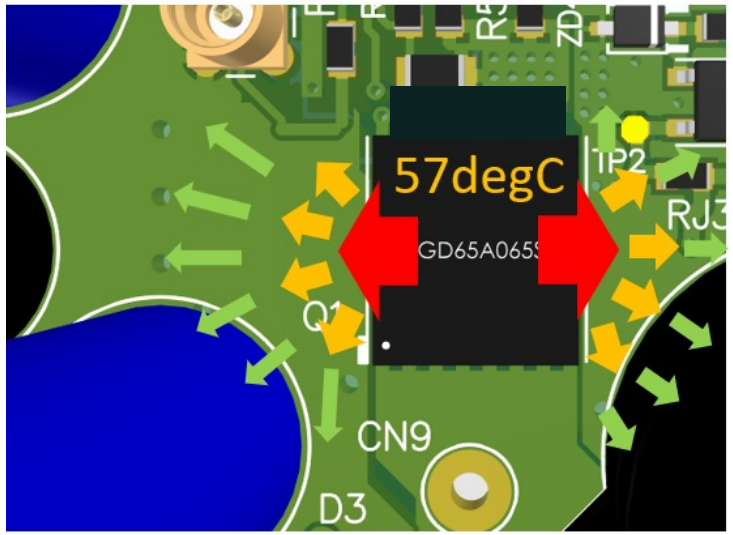


Thermal Path

MOSFET junction
↓
Source Copper
↓
Resistors
↓
Ground Plane
↓
Ambient
↓

ICeGaN™ flyback topologies

- do not use sense-resistors to sense I_d
  - The thermal path from device to ambient does not restrict the flow of heat energy
    => ICeGaN devices run cooler.
  - No additional local power dissipation.
    => Flyback efficiency Increases

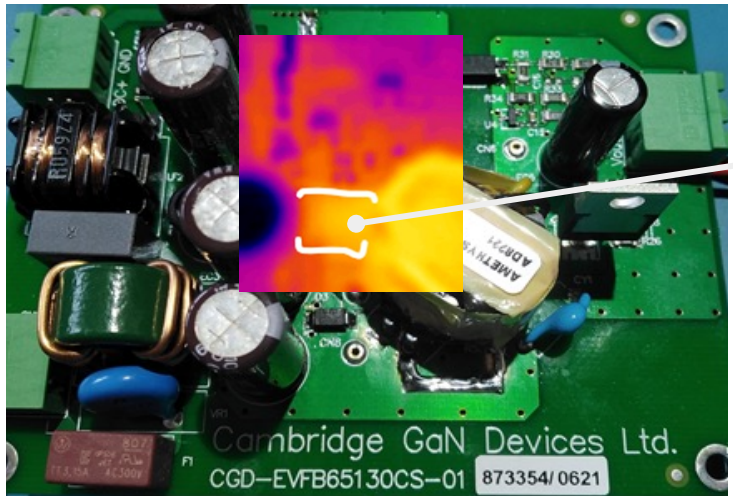


Thermal Path

MOSFET junction
↓
Ground Plane
↓
Ambient
↓

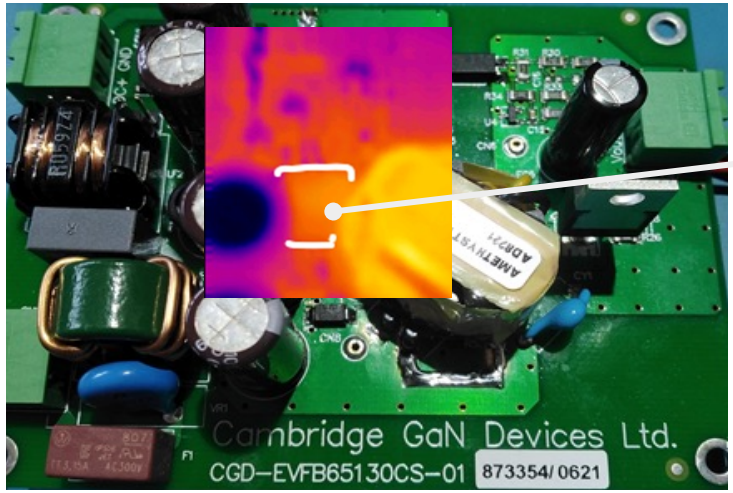
ICeGaN ™ Thermal performance in a QR Flyback Application

Standard flyback topologies



Temperature measurement 72°C

ICeGaN™ flyback topologies



Temperature measurement 57°C

Conclusions

- Besides Silicon, GaN is the first material in power electronics to be employed in a lateral configuration, allowing hybrid or monolithic integration with different levels of complexity.

- There are three types of integration (i) **hybrid**, where a silicon chip is adjacent to a high power GaN device (e.g. Cascode), (ii) **Level 1 monolithic integration**- smart GaN based on an intelligent interface with sensing and protection features (iii) **Level 3 monolithic integration** which additionally incorporates the driver to cut the parasitic inductances.

- ICeGaN™ features an optimal level of integration based on a smart interface for reliable, safe and ease of use of the enhancement mode HEMT with additional sensing protection capabilities

- When compared to best Silicon solutions, ICeGaN™ can achieve much higher power densities in the system (18W/cm^3 operating at higher frequencies > 500 KHz)

- When compared to other GaN solutions, ICeGaN™ can operate cooler, allow for a reduced BOM and for a more flexible and versatile driving solution.

Thank you for your interest.

Dr. Giorgia Longobardi
CEO, Cambridge GaN Devices

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Integration in WBG Semiconductors: Increased Power Density and Advanced Functionalities at Application Level