A new era in power electronics with Infineon’s CoolGaN™

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Power management and multimarket division
Infineon will complement each of its leading edge silicon solutions with a wide bandgap technology!

**TrenchStop™ to CoolSiC™**

- **Si** IGBT
- **SiC** MOSFET

**CoolMOS™ to CoolGaN™**

- **Si** Superjunction
- **GaN** HV e-mode lateral HEMT

**OptiMOS™ to CoolGaN™**

- **Si** Fieldplate
- **GaN** MV e-mode lateral HEMT
Agenda

1. Infineon’s wide bandgap strategy
2. Why GaN? Key characteristics of the technology
3. Device characteristics of CoolGaN
4. Reliability first
5. Benefits in selected applications
6. Summary
GaN HEMTs are just at the begin of their technology roadmap...

Unipolar limit: \[ R_{on} = \frac{4BV^2}{\mu\varepsilon E_C^3} \]

Superjunction limit: \[ R_{on} = \frac{cpBV}{2\varepsilon\mu_n E_C^2} \]


Today’s devices are around one order of magnitude away from theoretical limits; lots of improvement potential is still ahead...
Comparing $Q_{rr}$ of GaN versus Superjunction

- Virtually zero reverse recovery charge
- Internal body diode of SJ can be made rugged; $Q_{rr}$ can be reduced by factor 5; snappiness will remain forever...
Wide bandgap power devices enable seamless shifts between hard and soft switching

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CoolGaN™: eMode-GaN-HEMT on Silicon substrate with p-gate injection technology

- Forward characteristic of gate electrode
- Threshold Vth and 2DEG concentration (RDSon*A) can be adjusted independently
Rdson vs Ids characteristic: CoolGaN™ 190 mΩ

TC = 25°C

TC = 125°C

No significant current saturation effects: specified RDSon is reachable up to rated pulsed drain currents
Specific GaN EiceDRIVER™ addresses safety and ease-of-use concerns

**Classic RC-driver**

- True three-state driver, stable negative supply voltage
- Safe operation of CoolGaN™ switches

**New 1EDx-G1 GaN Driver**

- 2x shorter propagation delay and accuracy
- Better efficiency

**1EDx-G1 benefits**

- Integrated galvanic isolation, only 1 positive voltage needed
- Superior BOM and power density
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Infineon's CoolGaN™ is normally-off with an intrinsically rugged gate structure.
As implicated by its name dynamic $R_{DS(on)}$ testing is strongly dependent on timing as trapped charges relax with time.

Competition is typically giving dyn. $R_{DS(on)}$ data measured $2.5\mu$s after turn-on for 400 V.

For hundreds of kHz up to MHz operation this is not enough.

E.g. 40% dyn. $R_{DS(on)}$ turns a 35mΩ device into a 50mΩ one.

Infineon’s CoolGaN™ has been characterized down to 100 ns for a full 600 V blocking with no dyn. $R_{DS(on)}$ increase.

We have 100% test coverage with 600 V / 700 ns.
CoolGaN™ 600 V technology reliability
dynamic R\textsubscript{DS(on)} - Application level test example

**Dyn. R\textsubscript{DS(on)} measured real time during hard switching! At full rate.**

- **Infineon measurement:** some competitor parts show increase in dyn. R\textsubscript{DS(on)} above 400V
- Published data for Competitor listed as 0% up to 400V (no data > 400V)

Data taken at 25°C, with 700 ns delay after device turns on

- Negligible shift at full rated voltage

True application measurements taken a few hundreds ns after hard switching device turn on! No impacts on datasheet!
HTRB modelling shows superior intrinsic quality of CoolGaN™!

The acceleration model is developed for voltage and temperature

- The predicted lifetime is \( \sim 55 \text{ years} \) @ 480 V and 125°C, which exceeds typical use cases by factor 3
- 3 times higher safety margin from Infineon's criteria
From application-related reliability testing to testing reliability in the real application

- According to **IPC9592 Rev.B** (Requirements for power conversion devices for the computer and telecommunications industries)
- Standard duration 1000 h at maximum allowed ambient temperature of 50°C
- The GaN PFC stage is stressed at high input voltage, 264 V\textsubscript{AC} and at low input voltage, 200 V\textsubscript{AC}
- HTOB testing was done on **150 rectifiers**
- **2000 h extended test passed without failures!**

HTOB system of our customer for up to 48 rectifiers/converters, up to 144 kW
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# CoolGaN™ 600 V + GaN EiceDRIVER™

## Featured applications

<table>
<thead>
<tr>
<th>Category</th>
<th>Benefits</th>
</tr>
</thead>
</table>
| Server Datacenters | - Highest efficiency > 97.5%  
                       - Cost savings (OPEX, CAPEX, BOM)                                   |
| Telecom            | - Highest efficiency > 97.5%  
                       - Cost savings (OPEX, CAPEX, BOM)                                   |
| Charger Adapter    | - Breakthrough in power density for small and lightweight, highly efficient solutions |
| Wireless charging  | - CoolGaN™ 600 V - low $Q_G$ and $C_{OSS}$ enable high efficiency at higher power levels  
                       - GaN enables optimal tuning in class E designs especially for solutions > 30W |

- CoolGaN™ can be used in many other applications and as a general switch*

* For more information, please visit [www.infineon.com/gan](http://www.infineon.com/gan).
Optimization of a high-density 3 kW/12V server power supply

- System: 1-Φ, 12V, 3kW, Server power supply
- Topology: Totem-Pole PFC & Half-bridge LLC
- PFC Modulation: CCM for GaN; TCM for TP Si
- Optimization point: 50% load, 230Vrms, 12Vout
GaN High-Density Optimization Results

- Optimization Results for 50% Load, 230V\textsubscript{in}, 12V\textsubscript{out}
- The Results include Control Losses, Cooling System, 20% Air between Components, Casing, Connectors, PCB, Manufacturing Cost

![Graph showing Efficiency vs. Power Density]
Topology Selection for 3kW/12V Server Supply

- GaN „Totem-Pole“ PFC with CCM and Large Current Ripple provides Natural ZVS over a Large Part of the Mains Period
- Low $R_{DS,\text{on}}$ Si Superjunction in Return Path
- GaN Half-Bridge LLC with Matrix Transformer to Share Output Current Among Multiple Si Sync. Rect. Stages
Selected Converter Design (80W/inch³)

Main Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC/DC Stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>( f_{\text{sw,ACDC}} )</td>
<td>135 kHz</td>
</tr>
<tr>
<td>Nr. of HF legs</td>
<td>( N_{\text{HF}} )</td>
<td>1</td>
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<tr>
<td>On-state Res. of HF GaN HEMTS</td>
<td>( R_{\text{DS,on}} )</td>
<td>35 mΩ</td>
</tr>
<tr>
<td>On-state Res. of LF Si SJ MOSFETs</td>
<td>( R_{\text{DS,on}} )</td>
<td>17 mΩ</td>
</tr>
<tr>
<td>Boost Inductance</td>
<td>( L_{\text{boost}} )</td>
<td>48.5 µH</td>
</tr>
<tr>
<td>DC-Link Capacitance</td>
<td>( C_{\text{DC}} )</td>
<td>2 \cdot 680 µF</td>
</tr>
</tbody>
</table>

DC/DC Stage

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nr. of Transformers (Matrix)</td>
<td>( N_{\text{TX}} )</td>
<td>4</td>
</tr>
<tr>
<td>Turns Ratio of each Trans.</td>
<td>( n_{\text{tV}} )</td>
<td>4</td>
</tr>
<tr>
<td>Resonant frequency</td>
<td>( f_{\text{res}} )</td>
<td>250 kHz</td>
</tr>
<tr>
<td>Magnetizing inductance</td>
<td>( L_{\text{mag}} )</td>
<td>18.8 µH</td>
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<tr>
<td>Resonant inductance</td>
<td>( L_{\text{res}} )</td>
<td>1.2 µH</td>
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<tr>
<td>Resonant capacitance</td>
<td>( C_{\text{res}} )</td>
<td>338 nF</td>
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<tr>
<td>On-state Res. of GaN HEMTS</td>
<td>( R_{\text{DS,on}} )</td>
<td>35 mΩ</td>
</tr>
<tr>
<td>On-state Res. of Sync. Rect. MOSFETs</td>
<td>( R_{\text{DS,on}} )</td>
<td>0.5 mΩ</td>
</tr>
</tbody>
</table>

Calculated Efficiencies

- Optimized Power Supply
- Typ. Platinum Power Supply

Topography

35mOhm 600V GaN eMode

17mOhm SJ

3D CAD Layout

W=68mm
L=210mm
H=44mm
Outlook on Advanced DC/DC Converters

- Collaboration with ETH Zürich to develop High Density GaN DC/DC Converter
- PCB Integrated „Snake“ Matrix Transformer for Smallest Volume and Lowest Manufacturing Cost without Circulating Output Currents
- Advanced Phase-Shift and Frequency Control dep. on DC-Link Voltage and Output Power

Infineon GaN
Our differentiating core competencies

Benchmark in manufacturing

› GaN manufacturing embedded into high volume Si lines in Villach
› Typical Infineon quality standards are applied
› Dual source offering with partner Panasonic

Application-dedicated products

› GaN product portfolio optimized for specific application requirements
› Application specific reliability testing
› GaN products are offered in SMD packages

Unique power technology portfolio

› Expertise in all leading power technologies (Si, SiC, GaN)
› Extensive GaN knowhow from both Infineon and International Rectifier
› Large GaN patent portfolio

Extensive system expertise

› Extensive application / system understanding
› Global design support
› Focus on system performance /cost ratio
Part of your life. Part of tomorrow.