TRANSFORMING THE WORLD
WITH SMALLER, LOWER COST, MORE EFFICIENT POWER ELECTRONICS

GaN Technologies For Electric Vehicles
NOVEMBER 2019
GaN Systems company overview

Market leader for GaN power transistors
- GaN-on-Silicon transistors for power conversion
- Industry’s broadest & highest-performing products
  - 100V & 650V devices; industry-best performance
  - Applications from 25W to 225,000W

Global reach with decades of experience in GaN
- Parts shipping to >2000 customers since 2014
- World-class fabless manufacturing and advanced packaging
- HQ in Ottawa, Canada
- Sales/App. Eng. in Germany, Japan, China, Taiwan, Korea, USA

CUSTOMERS ACHIEVE IMPROVED SYSTEMS
- Efficiency: 4x lower losses
- Size: 4x smaller
- Weight: 4x lighter
- Lower system cost: 10% to 20%
GaN’s Major Market Segments

**DATA CENTERS**
Inefficient and approaching 5% of global power usage

**RENEWABLE ENERGY**
Storage needed for Distributed Energy (ESS)

**INDUSTRIAL**
Inefficient and 30% of worldwide electricity usage

**ELECTRIC VEHICLES**
Government reduced CO2 & high MPG regulations

**CONSUMER**
Large, heavy, and Ecodesign directive for higher efficiency
Fast growing customer base

**Computer charger**
- 4x smaller
- 3x lighter
- 40 W/in$^3$

**AC/DC Converter**
- 2x smaller
- 3x more power
- 6x density increase

**Solar ESS**
- 2x smaller
- 3x lighter
- Eliminated fan

**Data Center server power supply**
- 50% higher power density
- 20% lower $P_{loss}$

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Market Leaders have bought into GaN

BMW i Ventures Leads Strategic Investment in GaN Systems

Delta becomes Strategic Investor in GaN Systems

ROHM and GaN Systems Join Forces for GaN Power Semiconductors

ON Semiconductor Expands GaN Ecosystem with GaN driver ICs
Market leaders confirm the value of GaN

#1 Worldwide in Energy Storage

#2 Worldwide in Automotive

#4 Worldwide in Data Center Servers

Advantage with GaN Systems

- GaN Systems’ technology gives us improved design freedom
- Higher Efficiencies: 4% round-trip efficiency increase
- Normalized Efficiencies: at low and high power
- Reduction in Material Cost: 8% BoM cost savings
- Reduction in Size: 30% smaller

- GaN provides an improved value-stack at a competitive cost position
- Extending the value of the battery usable capacity by improving directional efficiencies
- Allow us to design more integrated solutions

Source: APEC Conference 2019

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### Improved data center power efficiency

- Supermicro high-density, high-efficiency cost effective solutions save space, money and reduce our imprint on the environment.

- GaN-based power supplies provide the leap in efficiency and power density.

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Source: APEC Conference 2019
In Automotive, **EV & AV** are the driving forces

Electric Vehicle market drivers
- CO₂ emissions
- Renewable energy

Autonomous Vehicle market drivers
- Safety
- Convenience
- Productivity
- Accessibility
- Social Integration
- Resource Utilization
**EV Sales**
- 2M+ vehicles in 2018
- 10M vehicles in 2025
- 28M vehicles in 2030

**EV Electricity Demand**
- 60 TWh in 2018
- 2,333 TWh in 2040
- EVs add 7% to WW electricity usage

Source: BloombergNEF
## Aggressive EV performance targets

### On-Board Charger

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2025</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost, $/kW</td>
<td>50</td>
<td>35</td>
<td>30% cost reduction</td>
</tr>
<tr>
<td>Specific power, kW/kg</td>
<td>3</td>
<td>4</td>
<td>33% weight reduction</td>
</tr>
<tr>
<td>Power density, kW/L</td>
<td>3.5</td>
<td>4.6</td>
<td>24% volume reduction</td>
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<tr>
<td>Efficiency</td>
<td>97%</td>
<td>98%</td>
<td>33% loss reduction</td>
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### DC/DC Converter

<table>
<thead>
<tr>
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<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost, $/kW</td>
<td>&lt;50</td>
<td>30</td>
<td>40% cost reduction</td>
</tr>
<tr>
<td>Specific power, kW/kg</td>
<td>&gt;1.2</td>
<td>4</td>
<td>70% weight reduction</td>
</tr>
<tr>
<td>Power density, kW/L</td>
<td>&gt;3.0</td>
<td>4.6</td>
<td>50% volume reduction</td>
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<tr>
<td>Efficiency</td>
<td>&gt;94%</td>
<td>98%</td>
<td>60% loss reduction</td>
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</table>

### Traction Inverter

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2025</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost, $/kW</td>
<td>8</td>
<td>6</td>
<td>25% cost reduction</td>
</tr>
<tr>
<td>Power density, kW/L</td>
<td>4.0</td>
<td>33</td>
<td>88% volume reduction</td>
</tr>
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</table>

• Industry association for EV  
• Analysis on each key electronic system of the price/performance needed:  
  • For Consumers  
  • For Automobile makers  
  • Expressed as targets for the Tier 1’s
GaN in Automotive

- Wireless phone charging
- 48V P0-P4 (Mild Hybrid)
- LiDAR sensor
- On-Board Charger
- Wireless battery charging
- DC/DC Converter
- Traction Inverter
- V2G and ESS inverter battery reuse
- Datacenter Server
On-Board Charger (OBC)

- 5X size reduction
- >3X loss reduction
EV DC/DC and Inverter examples with GaN

**DC/DC Converter**
- 1 kW/L: 93% Efficient Water-cooled
- 2 kW/L: 98% Efficient Air-cooled Lower Cost

**Inverter**
- 93% Efficient Water-cooled
- 98% Efficient Air-cooled
- 8% Cost Reduction

100% better Power Density
GaN enables long range, high resolution LIDAR

10X better performance
- 4 channel laser for high resolution
- 480W of optical power for long range
- Nanosecond pulses for high accuracy
Advantages with high frequency wireless charging

• Multiple phones
• High power, fast charging
• Randomly positioned, stacked
• Foreign objects don’t interfere
All GaN Vehicle at the Tokyo Motor Show

Source: Toyota & Nagoya University, October 2019
GaN Systems solutions

Broadest line of Products

650 V GaN

- GS6502B: 7.5 A, 200 mΩ, 6.6 x 5.0 mm
- GS66504B: 15 A, 100 mΩ, 6.6 x 5.0 mm
- GS66506T: 22 A, 67 mΩ, 5.6 x 4.5 mm
- GS66508T: 30 A, 50 mΩ, 7.0 x 4.5 mm

Die used in power module for Traction Inverter

NEW

- GS65-080-1-D2: 80 A, 18 mΩ, 6.6 x 5.6 mm
- GS65-150-1-D2: 150 A, 10 mΩ, 12.7 x 5.6 mm

75 kW Traction Inverter module with GaN Systems 150 A devices

100 V GaN

- GS61004B: 45 A, 15 mΩ, 4.6 x 4.4 mm
- GS61008P: 90 A, 7 mΩ, 7.6 x 4.6 mm
- GS61008T: 90 A, 7 mΩ, 7.0 x 4.0 mm

Packaged devices used in On-Board Charger DC/DC Converter

Packaged devices used in 48V Mild Hybrid Inverter

Die used in power module for Traction Inverter
GaN Systems Today

#1 in GaN
- Highest current; broadest voltages
- Best electrical performance
- Best die & best package
- Most widely used by customers

Shipping since 2014
- Parts shipping to >2000 customers
- Worldwide distribution & direct sales

Customer Successes
- AC Adapters
- Wireless Power and Charging
- Datacenter Server and Rack Power
- Solar Inverter and ESS
- Motor Drives
- Automotive OBC & Traction Inverter

GaN Systems

[Image of consumer, datacenter, industrial, transportation applications]