TRANSFORMING THE WORLD

WITH SMALLER, LOWER COST, MORE EFFICIENT POWER ELECTRONICS

Bodo WBG Conference 2018

Market leader for GaN power transistors
• GaN-on-Silicon transistors for the power conversion market
• Industry’s most extensive & highest-performance products
  - Enhancement mode devices
  - 100V & 650V devices; industry-best performance

Global company with decades of experience in GaN
• Parts shipping overnight from Mouser since 2014
• World-class fabless manufacturing and advanced packaging
• HQ and R&D in Ottawa, Canada
• Sales & App. Eng. in Germany, Japan, China, Taiwan, Korea, USA
GaN LEADS THE SHIFT IN POWER ELECTRONICS

GaN SYSTEMS OUT-PERFORMS OTHER TRANSISTORS

- 13X better than best silicon
- 6X better than best SiC
- 3X better than the best GaN

ACHIEVE IMPROVED POWER DESIGNS

- More efficient 1/4 the losses
- Smaller 1/4 the size
- Lighter 1/4 the weight
- Lower system cost
A COMPLETE PRODUCT PORTFOLIO

Product Characteristics
- Low resistance
- Very high current
- 100V and 650V product families

GaN Systems device on a traditional T0-247 package
INDUSTRIES WHERE TRANSFORMATION IS REQUIRED

DATA CENTERS
- Inefficient & approaching 5% of global power usage

ELECTRIC VEHICLES
- Government reduced CO2 & high MPG regulations

RENEWABLE ENERGY
- Storage needed for Distributed Energy (ESS)

MOTORS
- Inefficient & 30% of global electricity usage

CHARGERS
- Big, bulky, clumsy
DATA CENTER
MORE SERVERS AND STORAGE PER RACK

Resonant tank

Silicon
• 33% power loss reduction
• 40% size reduction

AC/DC Inverter Loss Analysis

- Inductor Loss
- Conduction Loss
- Switching Loss

Loss (W)

IGBT 20kHz

GaN 40kHz

PV panel
Inverter
Bidirectional
Converter
Inverter

AC/DC Inverter Loss Analysis

Residential Load

Dryer
Washer
TV
Computer
Range
Microwave
Water Heater
A/C Unit
Lighting
AC ADAPTERS, TV POWER, LED LIGHTING
ELIMINATE THE DRIVER WITH AN EZDRIVE\textsuperscript{SM} CIRCUIT

- Leverage the driver in the controller

<table>
<thead>
<tr>
<th>Control</th>
<th>Driver</th>
<th>Transistor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller</td>
<td>Si MOSFET</td>
<td></td>
</tr>
</tbody>
</table>

Silicon MOSFET
- Inexpensive
- Efficient
- Big

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<td>SiC MOSFET</td>
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Other GaN
- Expensive
- Efficient
- Small

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<tr>
<th>Control</th>
<th>Driver</th>
<th>Transistor</th>
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<tbody>
<tr>
<td>Controller</td>
<td>GaN transistor with integrated driver</td>
<td></td>
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<th>Control</th>
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<tr>
<td>Controller</td>
<td>GaN Systems transistor</td>
<td></td>
</tr>
</tbody>
</table>

GaN Systems
- Inexpensive
- Efficient
- Small

Controller 12V\text{OUT} to GaN transistor 6V\text{IN} with EZDrive circuit
WIRELESS POWER TRANSFER/CHARGING

CUT THE CORD WITH 50W TO 300W POWER AMPLIFIERS

• >90% efficiency
LiDAR

PRECISE DETECTION AT MORE THAN 200m RANGE

Requirements

- >200m range
- <1ns switching
- 200Amps

GaN is the only power transistor technology that provides the speed, switching frequency and current to meet the long range requirements of LiDAR.
CUSTOMERS IN PRODUCTION

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

**EV inverter**
- 5x smaller
- 3x lighter
- 50% lower $P_{\text{loss}}$

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

**Datacenter server power supply**
- 50% higher power density
- 20% lower $P_{\text{loss}}$
ONBOARD CHARGER EXAMPLE

EV On-Board Charger (OBC)

5X size reduction

>3X loss reduction
EV TRACTION INVERTER

Motivation:
• IGBTs – offer lowest cost solution, but are lossy
• Part-load efficiency is dominant for traction inverter

GaN Advantages:
• Combine GaN with IGBT to reduce losses for 90% of mission profile
• Higher weighted efficiency than IGBT or SiC
• Battery system cost savings or longer vehicle range

Conventional inverter
IGBTs, SiC or GaN devices and anti-diodes

GaN Hybrid T-type inverter
IGBTs and anti-diodes

800V System
Efficiency Analysis
• 50kW/phase
• 800V/400VAC
• 10kHz

400V System
Efficiency Analysis
• 33kW/phase
• 400V/160VAC
• 10kHz

City + Highway + Top Speed = 90% of mission profile
GaN SYSTEMS

GaN MATERIAL PERFORMANCE ADVANTAGES

- **Figure of Merit (FOM)**
  - 30x better than the best IGBTs
  - 13x the best SJ MOSFET
  - 6x the best SiC

- **GaN PX package**
  - Faster switching, in use up to 100MHz
  - More current
  - Small size

- **Gate drive**
  - Similar to MOSFET
  - Easier than SiC

- **GaN is easy to parallel**
  - SiC is very difficult to parallel consistently

- **GaN-on-Si will reach cost parity with Silicon**
  - SiC has many high cost challenges

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Units</th>
<th>650V MOSFET</th>
<th>600V IGBT</th>
<th>900V SiC</th>
<th>650V GaN Systems GS66508T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching Energy</td>
<td>$E_{ON}/E_{OFF}$</td>
<td>µJ</td>
<td>Not avail..</td>
<td>940/440</td>
<td>47/17</td>
<td>29/8</td>
</tr>
<tr>
<td>FOM</td>
<td>$Q_g*R_{DS(on)}$</td>
<td>nC*mΩ</td>
<td>4480</td>
<td>10725</td>
<td>1976</td>
<td>358</td>
</tr>
<tr>
<td>Inductance</td>
<td>$L_{SOURCE}$</td>
<td>nH</td>
<td>2</td>
<td>12</td>
<td>5</td>
<td>0.2</td>
</tr>
<tr>
<td>Reverse Recovery</td>
<td>$Q_{RR}$</td>
<td>nC</td>
<td>10000</td>
<td>320</td>
<td>135</td>
<td>Zero</td>
</tr>
</tbody>
</table>

*GaN Systems’ E-HEMT delivers highest performance and lowest cost*
**GaN SYSTEMS**

**SUPERIOR PERFORMANCE FEATURES**

**CONVENTIONAL FINGERS**

**ISLAND TECHNOLOGY®**

- Island Technology enables smaller die, faster switching
- Isolated Islands enable >50A

**TRADITIONAL PQFN**

**GaNPX™ PACKAGING**

GaNPX enables faster switching, more current
ROHM and GaN Systems Join Forces for GaN Power Semiconductors

....to give customers more choices for GaN
MARKET LEADERS ARE BOUGHT INTO GaN

GAN IN AUTOMOTIVE

BMW i Ventures Leads Strategic Investment in GaN Systems
JULY 2017

GAN IN POWER SUPPLIES

Delta becomes Strategic Investor in GaN Systems
DECEMBER 2017
GaN CHANGES THE GAME

**DATACENTERS**
- More revenue / rack
- $Billions in energy savings
- Delayed DC build-outs

**ELECTRIC VEHICLES**
- Enable the ubiquitous EV
- Exceed CO2 & MPG regulations

**RENEWABLE ENERGY**
- $Billions in energy savings

**MOTORS**
- $Billions in material & efficiency savings

**CHARGERS**
- Cut-the-cord
- Eliminate wires
WHAT’S NEW FROM GaN SYSTEMS
CONTINUOUS INNOVATION

**NEW**

**650V**
- Highest current ever
- Lowest $R_{ds}$ ever
- Wire-bondable
- Die for power modules

**GS-065-120-1-D1**
120 A, 12 mΩ
12.7 x 5.6 mm

**650V**
- Low inductance
- Thermally efficient
- 3 parts, same footprint
- High power density

**GS-065-004-1-L**
4 A, 8 A and 11 A
500 mΩ to 150 mΩ
5 x 6 mm PQFN

**NEW**

**650V**
- High power GaN module
- Includes source sense pin
- Lower losses, cooler oper. temp.
- Simplifies high power design

**GSM-065-120-1-N-0**
120 A and 240 A
12.5 mΩ and 6.3 mΩ
32 x 22 mm

**NEW**

**100V**
- Highest current
- Lowest $R_{ds}$
- Even better $R_{sp}$
- Even better FOM
- Same package footprint

**GS-010-120-1-P**
120 A, 5 mΩ
7.0 x 4.0 mm
JOIN THE WAVE
TRANSFORM YOUR POWER ELECTRONICS WITH GaN

**Broaddest-line of Products**

### 650 V GaN power transistors

<table>
<thead>
<tr>
<th>Transistor</th>
<th>Current (A)</th>
<th>Resistance (mΩ)</th>
<th>Package Dimensions (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS66502B</td>
<td>7.5 A</td>
<td>200 mΩ</td>
<td>6.6 x 5.0</td>
</tr>
<tr>
<td>GS66504B</td>
<td>15 A</td>
<td>100 mΩ</td>
<td>6.6 x 5.0</td>
</tr>
<tr>
<td>GS66506T</td>
<td>22 A, 67 mΩ</td>
<td>5.6 x 4.5</td>
<td></td>
</tr>
<tr>
<td>GS66508T</td>
<td>30 A, 50 mΩ</td>
<td>7.0 x 4.5</td>
<td></td>
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</tbody>
</table>

### 100 V GaN power transistors

<table>
<thead>
<tr>
<th>Transistor</th>
<th>Current (A)</th>
<th>Resistance (mΩ)</th>
<th>Package Dimensions (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS61004B</td>
<td>45 A, 15 mΩ</td>
<td>90 A, 7 mΩ</td>
<td>7.6 x 4.6</td>
</tr>
<tr>
<td>GS61008P</td>
<td>90 A, 7 mΩ</td>
<td>90 A, 7 mΩ</td>
<td>7.0 x 4.0</td>
</tr>
<tr>
<td>GS61008T</td>
<td>120 A, 5 mΩ</td>
<td>120 A, 5 mΩ</td>
<td>7.0 x 4.0</td>
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**Lots of Eval Kits & Reference Designs**

- **Half bridge power stage**
- **High power Paralleling**
- **High density PFC/LLC**
- **3 kW bridgeless totem pole PFC**
- **650 V test kit**
- **300 W wireless power transfer**