GaN Transistor Comparison 2018

Structural, Process and Costing Report

POWER report by Elena BARBARINI
April 2018 – sample
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  - Transphorm
    - TPH3002PS
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  - GaN Systems
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      - LMG5200
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Executive Summary

GaN HEMT’s market is very appealing and more and more players are entering; the lowering of prices can make GaN devices a good competitor of the currently used Si-based power switching transistors such as MOSFET and IGBT.

Nevertheless, the technical panorama has still to be structured, and every manufacturer presents its solution on die design and packaging integration. This brings to a strong competition which will accelerate technical innovations and lower the prices. Moreover, GaN business models are still very different, and in the future, we will see a restructuration of the supply chain driven by the main cost factors.

Manufacturers propose different approaches for epitaxy, gate structure, device design, and packaging, all focused on solving the problems linked to GaN’s intrinsic properties and its integration with silicon.

In this report, System Plus Consulting presents an overview of the state of the art of GaN on Si HEMT to highlights the differences in design and manufacturing processes, and their impact on device size and production cost.

Different devices at low and medium voltage from EPC, Texas Instruments, Panasonic, GaN Systems and Transphorm have been analyses. The report proposes detailed optical, SEM and TEM pictures of the packaging, the transistor structure and the epitaxy.

This report also provides an estimated production cost for the IC gate driver, FET, and package. Moreover, this report proposes a comparison between the different components available on the market.
Main Players Roadmap

- **EPC**: First commercial product
- **Fujitsu**: Start production
- **Fujitsu + transphorm**: First commercial product
- **GaN Systems**: First commercial product
- **Navitas**: GaN IC
- **Dialog**: GaN IC
- **Texas Instruments**: 600V power stage
- **System Plus Consulting**: First GaN Power device
- **transphorm**: 80V power stage
- **Panasonic**: First commercial product
- **FAB + ExAGAN**: First commercial product
- **System Plus Consulting**: 600V power stage
- **Texas Instruments**: 600V power stage
- **System Plus Consulting**: First GaN Power device
- **FAB + ExAGAN**: First commercial product

**Timeline:**
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
Availables GaN devices

Values based on Datasheet
Medium Voltage SJMOSFETs Vs GaN HEMT FOM Comparison

SJ MOSFETs are still able to compete with the early GaN devices; but further optimization seems hard to obtain.

@ Vds 600/650 V

FOM: Rdson * Qg

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# GaN HEMT Analyzed

## High Voltage GaN on Si HEMT

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Year</th>
<th>Device Code</th>
<th>Technology</th>
<th>Packaging</th>
<th>Vds (V)</th>
<th>Id (A) @ 25°C</th>
<th>Rdson (Ohm)</th>
<th>Qg (nC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transphorm</td>
<td>2012</td>
<td>TPH3002PS</td>
<td>cascode gen 0</td>
<td>TO-220 (Source Tab)</td>
<td>600</td>
<td>9</td>
<td>0.29</td>
<td>6.2</td>
</tr>
<tr>
<td>Transphorm</td>
<td>2015</td>
<td>TPH3206PS</td>
<td>cascode gen 1</td>
<td>TO-220 (Source Tab)</td>
<td>600</td>
<td>17</td>
<td>0.15</td>
<td>6.2</td>
</tr>
<tr>
<td>Transphorm</td>
<td>2017</td>
<td>TPH3208PS</td>
<td>cascode gen 2</td>
<td>TO-220 (Source Tab)</td>
<td>650</td>
<td>20</td>
<td>0.11</td>
<td>6.2</td>
</tr>
<tr>
<td>GaN System</td>
<td>2014</td>
<td>GS66508P</td>
<td>p-GaN gate</td>
<td>bottom side cooling</td>
<td>650</td>
<td>30</td>
<td>0.055</td>
<td>5.8</td>
</tr>
<tr>
<td>GaN System</td>
<td>2015</td>
<td>GS66506T</td>
<td>p-GaN gate</td>
<td>top side cooling</td>
<td>650</td>
<td>22.5</td>
<td>0.07</td>
<td>4.4</td>
</tr>
<tr>
<td>GaN System</td>
<td>2015</td>
<td>GS66504B</td>
<td>p-GaN gate</td>
<td>top side cooling</td>
<td>650</td>
<td>15</td>
<td>0.11</td>
<td>3</td>
</tr>
<tr>
<td>Panasonic</td>
<td>2017</td>
<td>PGA26E19BA</td>
<td>GIT</td>
<td>TO220</td>
<td>600</td>
<td>10</td>
<td>0.12</td>
<td>2.6</td>
</tr>
<tr>
<td>TI</td>
<td>2016</td>
<td>LMG3410</td>
<td>thin p-AlGaN barrier</td>
<td>QFN + driver</td>
<td>600</td>
<td>12</td>
<td>0.09</td>
<td>2.6</td>
</tr>
</tbody>
</table>

## Overview / Introduction
- Technology & Market
- Company Profile & Supply Chain
- Physical Analysis
- Manufacturing Process Flow
- Cost & Price Analysis
- Feedbacks
- About System Plus
Power Devices Rdson Evolution – Medium Voltage

- Transphorm has drastically improved its quality in only two years!
GaN Technical Challenges & Potential

AlGaN/GaN HEMTs showed their potential as candidates to substitute Si devices for high frequency applications with high power and low noise.

But.....it faces several technical challenges:

- Epitaxy: lattice mismatch problems between GaN and Si
- Normally ON: the 2DEG (2 dimentional electrons gas) technology is normally ON
- Packaging & Integration:
  - Gate Driver: external vs integrated in the packaging?
  - Assembling: bare die vs packaging protection?
### Device design technologies

In order to have normally off, different approaches have been proposed:

- **Enhanced mode**: modify the gate to shift the threshold voltage positively
- **Cascode**: co-packaging of a normally off device with a low voltage normally on MOSFET

<table>
<thead>
<tr>
<th>Cascode</th>
<th>Enhanced mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>• Compatible with standard gate drivers</td>
<td>• Easier to integrate at chip and package level</td>
</tr>
<tr>
<td>• Low Vf body diode for reverse operations</td>
<td>• Switching speed controlled by Rg</td>
</tr>
<tr>
<td><strong>Applications</strong></td>
<td><strong>Applications</strong></td>
</tr>
<tr>
<td>Low/medium switching frequencies</td>
<td>• Hard switching applications (eg. Totem Pole)</td>
</tr>
<tr>
<td>Medium power applications</td>
<td>• Low voltage applications</td>
</tr>
<tr>
<td></td>
<td>• Multi chip applications</td>
</tr>
<tr>
<td></td>
<td>• High power applications</td>
</tr>
</tbody>
</table>

**Players**

- transphorm
- ON Semiconductor
- PANASONIC
- Navitas
- Infineon
- Texas Instruments
- Exagan

---

Because of the 2DEG, GaN technology is normally off: this is the major challenge for GaN devices.
Packaging is becoming a particular issue for GaN devices.

Different packaging have been proposed to optimise:

- Less Parasitic inductance and resistance
- Smaller footprint
- Higher thermal efficiency

The higher the device frequency, the more important the consequences of parasitics.
In March 2015 Texas Instruments introduced its integrated GaNFET power stage prototype, including a high-frequency driver and GaNFETs in a QFN package.
EPC Analysed Devices

<table>
<thead>
<tr>
<th>HEMT</th>
<th>Voltage</th>
<th>Current at 25°C</th>
<th>Die area</th>
<th>Current density</th>
<th>Rdson</th>
<th>Qg</th>
<th>FOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPC1010</td>
<td>200V</td>
<td>12 A</td>
<td>5.76 mm² (1.6x3.6)</td>
<td>2.08 A/mm²</td>
<td>0.027 ohm</td>
<td>7.5 nC</td>
<td>0.2 ohm*nC</td>
</tr>
<tr>
<td>EPC2010C</td>
<td>200V</td>
<td>12 A</td>
<td>5.76 mm² (1.6x3.6)</td>
<td>2.08 A/mm²</td>
<td>0.018 ohm</td>
<td>5.2 nC</td>
<td>0.09 ohm*nC</td>
</tr>
<tr>
<td>EPC2045</td>
<td>100V</td>
<td>16 A</td>
<td>3.75 mm² (1.5x2.5)</td>
<td>4.27 A/mm²</td>
<td>0.007 ohm</td>
<td>5.2 nC</td>
<td>0.036 ohm*nC</td>
</tr>
<tr>
<td>EPC2040</td>
<td>15V</td>
<td>3.4 A</td>
<td>1.06 mm² (0.85x1.2)</td>
<td>3.2 A/mm²</td>
<td>0.03 ohm</td>
<td>0.745 nC</td>
<td>0.022 ohm*nC</td>
</tr>
</tbody>
</table>
EPC1010

- The package type is a WLP
- Package size: 1.6mm x 3.6mm x 0.73mm
- The package markings include the following markings:

  1010
  9B25
  2891
LMG5200 Package characteristics

- The package type is a QFM
- Package size: 6mm x 8mm x 2mm
- The package markings include the following markings:
  - TI logo
  - Year Month: 2017 May
  - Pb free

Physical Analysis
- Low Voltage
  - EPC
    - EPC1010
    - EPC2010C
    - EPC2045
    - EPC2040
  - TI
    - LMG5200

- Medium Voltage
  - Transphorm
    - TPH1002PS
    - TPH206PS
    - TPH208PS
  - GaN Systems
    - GS66508P
    - GS66506T
    - GS66504B
  - Panasonic
    - PGA26E19BA
  - TI
    - LMG3410

Manufacturing Process Flow

Cost & Price Analysis

Feedbacks

About System Plus

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TPH3002PS

- The epitaxy structure is realized with different layer:
  - Total thickness: 5.1 µm
  - Gate width: 1.66 µm

Die cross section
MOSFET die Dimensions

- Die dimensions: 1.6 mm² (1.7mm x 0.95mm)

Die Overview

Die – Cross section

Die Overview

Die – Cross section
## Devices Supply chain

<table>
<thead>
<tr>
<th>HEMT die</th>
<th>Packaging</th>
<th>Vendor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design</strong></td>
<td><strong>Front End</strong></td>
<td><strong>Back end</strong></td>
</tr>
<tr>
<td>EPC (USA)</td>
<td>Episil (Taiwan)</td>
<td></td>
</tr>
<tr>
<td>TI (USA)</td>
<td>Episil (Taiwan)</td>
<td></td>
</tr>
<tr>
<td>Transphorm (USA)</td>
<td>Fujitsu (JP)</td>
<td></td>
</tr>
<tr>
<td>GaN Systems (Ca)</td>
<td>TSMC (Tw)</td>
<td></td>
</tr>
<tr>
<td>Panasonic (Japan)</td>
<td>Panasonic (JP)</td>
<td></td>
</tr>
</tbody>
</table>

*Power Device value chain*
A thin layer of AlN is deposited on the silicon substrate. The silicon substrate is a carrier substrate and has no function in the transistor.

The AlN insulates the GaN layers from the silicon substrate and is the nucleation layer for the next layer.

A template layer in AlGaN is deposited. It is composed of two layers of AlGaN

Epitaxy of the GaN layer.

A thin layer of AlGaN is deposited. This layer provides the 2D electron gas.

A layer of GaN is deposited.

Annealing
EPC GaN Transistor - Process Flow

Implantation:
- Implantation in the AlGaN layer
- Implantation in the gate GaN layer

Gate:
- Pattern and GaN etching

Gate:
- TiN deposition
- Pattern Gate Metal

Drawing not to Scale

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EPC GaN Transistor - Process Flow

Metal 2 and 3

- Tungsten plug
- Metal2
- IMD 2

Passivation

- Silicon contact
- Metal 3
- Passivation deposition and pattern

Contact between the metal 3 and the silicon substrate
In our simulation, we assume a development and a production ramp up without important technical problem.
### GaN Systems Wafer Cost

#### Front-End Cost Breakdown

<table>
<thead>
<tr>
<th></th>
<th>GS66508P</th>
<th>GS66506T</th>
<th>GS66504B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw wafer Cost (Si)</strong></td>
<td>$60.00</td>
<td>$60.00</td>
<td>$60.00</td>
</tr>
<tr>
<td><strong>Epitaxy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Front + Back End Cost</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Yield losses Cost</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>HEMT Front-End Cost</strong></td>
<td>$575.65</td>
<td>$575.65</td>
<td>$575.65</td>
</tr>
</tbody>
</table>

#### Yield Losses Cost Breakdown

- **Raw wafer Cost (Si)**: 10%
- **Epitaxy**: 37%
- **Front + Back End Cost**: 32%
- **Yield losses Cost**: 21%
## Panasonic Wafer & Die cost

<table>
<thead>
<tr>
<th>Front-End</th>
<th>PGA26E19BA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw wafer Cost (Si)</td>
<td>$60.00</td>
</tr>
<tr>
<td>Epitaxy</td>
<td>$240.57</td>
</tr>
<tr>
<td>Front + Back End Cost</td>
<td></td>
</tr>
<tr>
<td>Yield losses Cost</td>
<td></td>
</tr>
<tr>
<td><strong>HEMT Front-End Cost</strong></td>
<td>$809.90</td>
</tr>
</tbody>
</table>

### Cost & Price Analysis

- **Low Voltage**
  - EPC
    - EPC1010
    - EPC2010C
    - EPC2045
    - EPC2040
  - TI
  - LM65200
- **Medium Voltage**
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    - TPH3208PS
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    - GS66506T
    - GS66504B
  - Panasonic
    - PGA26E19BA
  - TI
    - LMG3410

### Feedbacks

- Panasonic Wafer & Die cost
## Panasonic Component cost & price

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEMT Die cost</td>
<td>$0.286</td>
<td>16.1%</td>
</tr>
<tr>
<td>Packaging cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final test &amp; Calibration cost</td>
<td>$0.01</td>
<td>0.5%</td>
</tr>
<tr>
<td>Yield losses cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Component Cost</strong></td>
<td>$0.459</td>
<td>26%</td>
</tr>
<tr>
<td><strong>Ampere Cost</strong></td>
<td>$0.05</td>
<td></td>
</tr>
</tbody>
</table>

### Panasonic Component cost breakdown

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Component cost</strong></td>
<td>$0.459</td>
<td></td>
</tr>
<tr>
<td>Gross Profit</td>
<td>$0.247</td>
<td>+35%</td>
</tr>
<tr>
<td><strong>Component price</strong></td>
<td>$0.705</td>
<td></td>
</tr>
<tr>
<td><strong>Panasonic</strong></td>
<td></td>
<td>35.0%</td>
</tr>
</tbody>
</table>

**Gross Margin**

- Low Voltage
  - EPC
    - EPC1010
    - EPC2010C
    - EPC2045
    - EPC2040
  - TI
  - LM65200
- Medium Voltage
  - Transphorm
    - TPH3002PS
    - TPH3206PS
    - TPH3208PS
  - GaN Systems
    - GS66508P
    - GS66506T
    - GS66504B
  - Panasonic
    - PGA26E19BA
    - TI
      - LMG3410
Wafer & Die Structure and Cost Comparison

GaN Systems (650V, 15A) 6.5 mm²
Transphorm (600V, 17A) 7.12 mm²
Panasonic (600V, 10A) 4.6 mm²
TI (600V, 12A) 12.6 mm²

P-GaN Gate
Normally ON
Gate Injection Transistor
Thin p-AlGaN barrier

Wafer Cost Structure Comparison

Sample
**Complementary Report**

**Power GaN 2017: Epitaxy, Devices, Applications, and Technology Trends** – by Yole Développement

The GaN power device supply chain is acting to support market growth.

**KEY FEATURES OF THE REPORT**

- In-depth analysis of GaN’s penetration in different applications including power supplies, PV, EV/HEV, UPS, lidar, wireless power and electrical transmission
- State-of-the-art GaN power devices, including product charts and device descriptions
- Description of the GaN power industrial landscape, from epitaxy and device design to device processing
- Discussion of GaN power market dynamics
- State-of-the-art for power GaN packaging
- Reliability overview on GaN
- Market projection for the GaN epitaxy market through 2021 by value and volume

**Bundle offer possible with the GaN-on-Silicon Transistor Comparison 2018 Report by System Plus Consulting, contact us for more information.**
Related Reports

Power Semiconductors & Compound
- Transphorm GaN-on-Silicon HEMT TPH3206PS
- Efficient Power Conversion EPC2040
- GaN Systems GaNpx Top Cooled – AT&S ECP® Embedded Power Die Package
- Transphorm TPH3002PS 600V GaN on Silicon HEMT
- GaN Systems – 650V GaN on Silicon HEMT AT&S ECP® Embedded Power Die Package
- EPC2010 GaN 200V power transistor
- Infineon – IPB60R280C6 600V CoolMOS C6 MOSFET
- Toshiba – TK31E60W 4thgen DTMOS 600V Super-Junction MOSFET
- Texas Instruments LMG3410 600V GaN FET Power Stage

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44200 Nantes – France

Contact:
EMAIL: sales@systemplus.fr
TEL: +33 2 40 18 09 16

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Our services:
TECHNOLOGY ANALYSIS - COSTING SERVICES - COSTING TOOLS - TRAININGS

www.systemplus.fr - sales@systemplus.fr
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The quoted prices already include the rebates and discounts that System Plus Consulting could have granted according to the number of orders placed by the Buyer, or other specific conditions. No discount is granted in case of early payment.

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System Plus Consulting remains sole owner of the delivered services until total payment of the invoice.

6. DELIVERIES
The delivery schedule on the purchase order is given for information only and cannot be strictly guaranteed. Consequently any reasonable delay in the delivery of services will not allow the buyer to claim for damages or to cancel the order.

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The transport costs and risks are fully born by the Buyer. Should the customer wish to ensure the goods against lost or damage on the base of their real value, he must imperatively point it out to System Plus Consulting when the shipment takes place. Without any specific requirement, insurance terms for the return of goods will be the carrier current ones (reimbursement based on good weight instead of the real value).

8. FORC MAVEU
System Plus Consulting responsibility will not be involved in non execution or late delivery of one of its duties described in the current terms and conditions if these are the result of a force majeure case. Therefore, the force majeure includes all external event unpredictable and irresistibile as defined by the article 1148 of the French Code Civil?

9. CONFIDENTIALITY
As a rule, all information handed by customers to system Plus Consulting are considered as strictly confidential. A non-disclosure agreement can be signed on demand.

10. RESPONSABILIT LIMITATION
The Buyer is responsible for the use and interpretations he makes of the reports delivered by System Plus Consulting. Consequently, System Plus Consulting responsibility can in no case be called into question for any direct or indirect damage, financial or otherwise, that may result from the use of the results of our analysis or results obtained using one of our costing tools.

11. APPLICABLE LAW
Any dispute that may arise about the interpretation or execution of the current terms and conditions shall be resolved applying the French law.
It the dispute cannot be settled out-of-court, the competent Court will be the Tribunal de Commerce de Nantes.
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