Intelligent GaN Power Solutions

200-mm GaN-On-Silicon
From Switches to Intelligent Power Solutions to Boost Performance of a New Generation of Power Converters

Eric Moreau – Product & Application Director
Exagan

- Spin off SOITEC & CEA-LETI
- Created in 2014 - 35 employees
- 2 sites in France – 1 in Taiwan
- 3 Industrial partnerships (MFG, Sales, Quality)
- Focus on GaN 650..1200 V Power Switch Solutions
- Unique 200 mm GaN/Si technology
- Fab-light industrial model, in-house epitaxy

Grenoble

Toulouse

Taipei

Global go-to-market strategy coupled with regional sales deployment

Joint Dev. Collaboration

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Exagan’s Fab-light Model with Established 200 mm Supply Chain

- Delivers robust & cost competitive manufacturing, for high volume production with limited CAPEX on materials using standard CMOS manufacturing.

**STEP 1**
Exagan direct manufacturing & volume shipment

**STEP 2**
Process transfer to partner (exclusive)

**STEP 3**
Test transfer to partner (exclusive)

- Exagan MFG fab in France
- Standard & automated equipment
- Process = 1 equipment

- Fabs in Germany and France
- Standard CMOS 200mm
- No specific CAPEX
- High capacity available

- Standard packaging lines
- Very high-volume production
- Automated testing
- Turnkey service: direct shipment to customers

**Fab light**
- Volume scalability
- Cost competitiveness
- Full technology control

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Exagan’s Unique G-Stack™ Technology
200-mm GaN-Si: Silicon Scalability, High Quality and Competitive Cost

G-Stack™: Enabling **Ultimate balance** between GaN thickness, quality & flatness on Si 200 mm
Designing Products for Outstanding Standards
From JEDEC JC70-1 to AECQ100/101

Design for the most demanding application in terms of quality and reliability

Automotive

eV/pHeV on board and fast charging

Consumer

Integrated power supply USB-PD

Server

Compact & energy efficient server

Energy

Solar inverter & micro-inverter

Industrial

UPS motor drive

Aerospace

Aircraft electrification

Military

Integrated supply
Material & Device Based Rel. Testing

Critical parameters

2DEG & contact reliability

Elementary test structure

Metal 3
VIA 2
Metal 2
VIA 1
Metal 1
Contact
GaN (2DEG)

Continuous resistance monitoring

180°C

R shift

15%
10%
5%
0%
-5%

Time (h)

0 200 400 600 800 1000 1200 1400

GaN-On-Si EPI Lifetime

DC EPI leakage measurements

Critical parameters drifts on wafer level

210°C / 1000 Hrs

Ex: Rdson

Thermionic emission

\[ I_{sub} = \gamma^2 e^{-\frac{2.9 \times 10^{-10}}{kT}} * e^{\left(\frac{1.8 \times 10^{-22}}{kT}\right) V_{sub}} \]

Today : 45 Years less than 1 ppm  400 V/ 85°C

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**Product Use Case(s) Rel. Testing**

Critical testing

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**Repetitive HV Spikes**

- **Silicon** → avalanche
- **GaN** → No avalanche

<table>
<thead>
<tr>
<th>Voltage (Vds)</th>
<th>Current (Id)</th>
<th>Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>700 V</td>
<td>100 µA</td>
<td>85°C</td>
</tr>
<tr>
<td>900 V</td>
<td>0</td>
<td>25°C &amp; 150°C</td>
</tr>
</tbody>
</table>

Leakage monitoring (Cp/Cpk) >> 10M spikes

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**Repetitive hard switching**

- **22µH**
- **DUT**

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Current (Id)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 V</td>
<td>100 µA</td>
</tr>
<tr>
<td>650 V</td>
<td>0</td>
</tr>
</tbody>
</table>

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**Buck/Boost Converter**

- **Switching/Locus modes**

- Different magnetizing energies
- Monitoring Tcase switches/Efficiencies

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**Device:** EXA06C190LDS0
Exagan’s Product Portfolio,
Servicing the Most Demanding Applications

**Easy to Use**

**G-FET™**
650V Transistor
Safe and Powerful Switching

**G-DRIVE™**
650 V Transistor + Driver
Intelligent and Fast Switching

**Technology**
- GaN MIS Transistor
- Standard analog gate control

**Features**
- < 500 kHz switching
- <10 up to 75 A capability
- Standard Silicon driver (external)
- Implementation in existing and new designs

**Applications**
- Consumer power supply (Cost competitiveness, < 100 W)
- Automotive Charger (On/Off board) (High Reliability, 3-20 KW)

**Integration**

**Technology**
- Based on G-FET with embedded intelligent driver
- Digital Control (MCU)

**Features**
- Up to 3 MHz switching
- Integrated protection & diagnostic
- High speed current monitoring capability

**Applications**
- High end consumer power supply (> 100 W)
- Datacenter power supply (KW)
- Industrial motor control
- Automotive DC/DC (1.5 KW)

**Product roadmap**

- 2019: Generic product portfolio
- 2020: Application specific standardized products
- 2021: Automotive qualified products
GaN Discrete to Smart Power Integration Solution

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Power

- Power Discrete
  - G-FET™
- Discretes Integrated
  - Switches
- Smart HV Power Integration
  - G-Drive™
  - Driver+ Switch(es) + Protections, Diag. + Syst. Features+

System Integration

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**G-FET™ Series**  
A Robust Family of Products to Meet all Power Range Needs

**Product features**

<table>
<thead>
<tr>
<th>System design</th>
<th>Analog power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving</td>
<td>+/- 20V analog</td>
</tr>
</tbody>
</table>

Benefits for power-conversion designers include:

- Compatibility with standard silicon drivers
  - 10-volt analog signal to control the gate
  - Robust gate with a maximum rating of ±20 V
  - No gate leakage
  - No negative voltage to force in off-state
- Gate return pin to reduce the switching inductance loop

**650 V products portfolio**

<table>
<thead>
<tr>
<th>Part number</th>
<th>$R_{DS(on)} \text{ (mΩ)}$</th>
<th>$I_{DSS} \text{ (A)}$</th>
<th>$I_{DM} \text{ (A)}$</th>
<th>$C_{oss} \text{ (pF)}$</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXA06C190LDS0</td>
<td>190</td>
<td>10</td>
<td>30</td>
<td>45</td>
<td>PQFN8x8</td>
</tr>
<tr>
<td>EXA06C135LDS0</td>
<td>135</td>
<td>25</td>
<td>75</td>
<td>65</td>
<td>PQFN8x8</td>
</tr>
<tr>
<td>EXA06C075LDS0</td>
<td>75</td>
<td>30</td>
<td>90</td>
<td>110</td>
<td>PQFN8x8</td>
</tr>
<tr>
<td>EXA06C050XDS0</td>
<td>50</td>
<td>40</td>
<td>120</td>
<td>145</td>
<td>TO247-4L</td>
</tr>
<tr>
<td>EXA06C030HSS0</td>
<td>30</td>
<td>75</td>
<td>225</td>
<td>240</td>
<td>PQFN15x15</td>
</tr>
</tbody>
</table>

**G-FET™**

Safe and Powerful

- Broad power range
- Easy system implementation
- Rugged gate

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Exagan GaN technology
650 V device specification (135 mOhm as an example)

650 V Optimized soft breakdown
< 100 µA @ 900 V

Repetitive Pulse > 750 V
(Per JEDEC JC-70-1)

100 nA @ 650 V
G-FET™ 650 V / 75 mOhm
Exa06C075LDS0

Eon+Eoff ~ 65 µJ @ 20 A @ 25°C

Eon+Eoff ~ 54 µJ @ 20 A @ 25°C
**G-DRIVE™ Series**
An intelligent and safe power-switching solution

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**G-DRIVE™**
Intelligent and fast

- Embedded GaN gate driver
- Fast switching capability (MHz)
- Integrated protection and diagnostic
- Slew rate control capability
- Peak current monitoring

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### Product features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System design</strong></td>
<td>Digital power</td>
</tr>
<tr>
<td><strong>Driving</strong></td>
<td>3.3V to 5V CMOS</td>
</tr>
<tr>
<td><strong>Diagnostics</strong></td>
<td>UVLO, OCP, TSD²</td>
</tr>
<tr>
<td><strong>Self protected</strong></td>
<td>State machine</td>
</tr>
<tr>
<td><strong>Current sensing</strong></td>
<td>Adjustable, SFB²</td>
</tr>
<tr>
<td><strong>EMI</strong></td>
<td>Slew rate control</td>
</tr>
</tbody>
</table>


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**Benefits for power-conversion designers include:**

- Control of the load current without complex software
  - CMOS digital control and diagnostics
  - Current loop regulation using Sense Feedback (SFB)
  - Embedded state machine for protection
- Self protection thanks to an embedded state machine
- EMI optimization using slew rate adjustment

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### 650 V product portfolio

<table>
<thead>
<tr>
<th>Part number</th>
<th>( R_{DS(on)} ) (mΩ)²</th>
<th>( I_{oss} ) (A)²</th>
<th>( I_{SM} ) (A)²</th>
<th>( C_{oss} ) (pF)²</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXA06D190MS50</td>
<td>190</td>
<td>10</td>
<td>30</td>
<td>30</td>
<td>PQFN8x8</td>
</tr>
<tr>
<td>EXA06D115MS50</td>
<td>115</td>
<td>25</td>
<td>75</td>
<td>35</td>
<td>PQFN8x8</td>
</tr>
<tr>
<td>EXA06D065MS50</td>
<td>65</td>
<td>35</td>
<td>100</td>
<td>80</td>
<td>PQFN8x8</td>
</tr>
</tbody>
</table>

3: 25°C typical values
G-DRIVE™ GaN Solutions
Integration

- GaN-Si Power
- Dedicated Driver
- Built-In Protected (Current, Temp,..)
- Current sensing (Loss less)
- Very fast resp. time (SC < 40 ns)
- Very fast switching time (< 5ns)
**G-DRIVE™ Series**

Easy Regulation Software Loop

**Simplified Application Diagram:**

- **MCU**: Computes Current Targeted
- **G-DRIVE**: Reports Peak Current Detected
- **G-DRIVE** generates PWM (« IN » signal)
- **MCU** generates PWM (« IN » signal)
- **MCU** sets current peak (« IPKCTRL »)
- **MCU** adapts PWM output (« IN » signal)

**Current Regulation Loop**

Cycle by Cycle

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G-Drive EXA06D190LDS0

400 Volts

Fall < 7ns

~ 25V ripple

~ 3 Amps
G-DRIVE™ Series
Performances at a Glance

Up to 3 Mhz

Propagation Time (10 to 20 ns)

Switching Time (< 5 ns)

Peak Current Accuracy < 5% @ 250 mA (0 to 150°C)

Slew Rate Control

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Current Peak & Over Current Detections (EXA06D190MSS0)

- Current Threshold set @ 10 A
- Over Current Protection set @ 12 A

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**Peak Current Threshold detected**

**Ipk digital signal** (Blanking ~ 200ns, prog. fuse)

**Over Current Protection (OCP) detected** (Prog. fuse)

**OCP digital signal** (Resp. time < 40ns)
G-FET™ & G-DRIVE™ Evaluation Modules

HS 400 V / 12 A ➔ 25 V Ripple

4 layers PCBs
Switching node capacitance & Power loop Inductance optimized
**GaN-ification (GaN Adoption)**

**Trends, Opportunities**

<table>
<thead>
<tr>
<th>Penetration of existing markets</th>
<th>Expansion into new markets</th>
<th>Substitution by alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Datacenter, Consumer</em></td>
<td><em>Industrial, Automotive, Aero.</em></td>
<td><em>Challenging Others</em></td>
</tr>
<tr>
<td>Improving Value proposition</td>
<td>Providing performances</td>
<td>- High Voltage (900/1200 V)</td>
</tr>
<tr>
<td>- Better figures of merits</td>
<td>- High reliability</td>
<td></td>
</tr>
<tr>
<td>- Lower system cost</td>
<td>- High current</td>
<td></td>
</tr>
<tr>
<td>- More functionalities in ICs</td>
<td>- Robust (SC, Overload,..)</td>
<td></td>
</tr>
<tr>
<td>- Dies Integration (PM, IPM)</td>
<td>- Auto On/Off Board Charger</td>
<td></td>
</tr>
<tr>
<td>- 15~65 W..100W adapter</td>
<td>- Higher efficiency</td>
<td></td>
</tr>
<tr>
<td>- Tiny USB Power Delivery</td>
<td>- Lower BOM cost</td>
<td></td>
</tr>
<tr>
<td>- Led lighting</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- PSU DataServer
  - Hard switching Apps
  - Bridgeless Totem Pole
  - Dc-dc LLC

- 2020
- 2023
- 2025..
USB-PD Type C using G-FET™ 190 mΩ device

PowerTrain (~ 93.5% Eff.)

GFET™ 650V/190 mΩ PQFN8*8
ACF Ctrlr UCC27880
Xfer RM8 6:1
SynRec 120V/9mΩ

USB PD 2D board – Back side:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>230V/50Hz</td>
</tr>
<tr>
<td>Output</td>
<td>20V/3A (60W*)</td>
</tr>
<tr>
<td>Highside GaN Temperature</td>
<td>65.2°C</td>
</tr>
<tr>
<td>Lowside GaN Temperature</td>
<td>70.1°C</td>
</tr>
</tbody>
</table>

* Limited by the PD controller
G_FET™ Solutions for PFC Totem Pole

GaNDalf

• Specifications:-  
  • 85Vac to 265Vac input  
  • 400Vdc out  
  • <10% THD, >0.98 PF  
  • 99% efficiency target

650 V/ 30m  
PQFN 15*15

650 V/ 190m  
PQFN 8*8

650 V/ 50m  
TO247-4L

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CCM PFC (AN4163 STM)
Case study

- Standard PFC CCM Ref. Design
- Well Established Controller L4984
- 70 Khz Switching frequency
- 2 * STF21N65M5 SJ (650V/150 mΩ)

Wide Range 350 W PFC CCM

Replace by 1* GaN G-FET™ 135 mΩ (PQFN 8*8)
CCM PFC GaN-ification with G-FET™
Case study

One G-FET™ 650 V /135 mΩ

CCM PFC GaN based

- Power Density* > 35X
- Weight ~ (Heatsink Less)
- Lower cost *

same Fsw*
In low load efficiency differences are more than 5% @ 120V.

Average improvements are above 3%.

Improvements are based on the fact that MOS FET is still conducting due to gate charges which cannot be removed as fast as the controller wants to close.

GaN switches faster.
CCM PFC GaN-ification
Thermal Comparison @ 100W

<table>
<thead>
<tr>
<th>GaN</th>
<th>MOSFET</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Bridge Rectifier 55.7C</td>
<td>▪ Bridge Rectifier 56.2C</td>
</tr>
<tr>
<td>▪ PFC Diode 58.3C</td>
<td>▪ PFC Diode 69.6C</td>
</tr>
<tr>
<td>▪ GaN FET 54.4.2C</td>
<td>▪ MOSFET 67.2C/68.9C</td>
</tr>
</tbody>
</table>

Δ ~ – 11°C

Δ ~ – 14°C

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With mosfet’s original EMI filter

Mosfet

G-FET™

150K....30Mhz
GaN Revolutionizing Power Electronics

10x
Better Figures Of Merits vs Si

10x
Faster power switch than Silicon devices

3-10x
Higher frequency & size reduction for converters

- Lower losses
- Higher switching frequencies
- Higher operating temperature
- Robust, reliable & radiation-hard
- High breakdown voltage
- Price nearer to Si
- No body diode
- Device integration on Si

→ Enables smaller systems, size, weight and cost reduction
The GaN specialists

- Team of industry experts - 100% focused on GaN
- Pioneer in GaN with 20 years legacy
- Owning material - full control to optimize application

Extensive product portfolio

- Focused product strategy on chargers
- Larger power range capability - 10’s to 10’s KW
- From power switches to system solutions

Large-scale 8” manufacturing & global deployment

- Excellent cost structure and quality
- Global access and 1st class support