GaNFast Power ICs: Beyond Chargers

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GaN Expected To Replace Silicon In Power Applications

Note: Statistical data is based on Navitas estimate of GaN-based systems compared to Si-based in the 2024-2025 timeframe. Based on Navitas measurements of select GaN-based mobile wall chargers compared to Si-based chargers with similar output power.

(1) Relative to silicon, GaN has 10x stronger electrical fields and 2x greater electron mobility, enabling high voltages in fast chips and fast switching with high energy savings.
Power GaN Technologies

High Performance Semiconductor

- High voltage operation
- High current density
- High frequency switching
- High efficiency

- Energy gap (eV)
- Electron velocity (x10^6 cm/s)
- Melting point (x10^6 °C)
- Thermal Conductivity (W/cm°C)
- Electric Field (MV/cm)

- Si
- SiC
- GaN

eMode FET (normally off)

- GaN Discrete
  - Complex gate drive

dMode FET (normally on)

- Extra Si FET in ‘cascode’ configuration

- Si controller/driver
  + Si FET cascode
  + GaN dMode FET

Integration

GaN Power IC
- GaN Power (FET), Drive, Control, Protection
- 120+ Patents
**Speed and Efficiency Drive Value**

GaN power ICs enable up to 3x smaller, lighter  

(1) Based on Navitas measurements of GaN-based chargers compared to Si-based chargers with the same output power.

GaN ICs save 40% energy (2), 100x more reliable (3)

(2) Navitas estimate of GaN-based power systems compared to Si-based systems in the 2024-2025 timeframe, Navitas measurements of select GaN-based chargers vs. Si-based chargers with similar power.

(3) $V_{GSf}$ failure distribution based on Navitas internal characterization of Discrete GaN Transistors compared to GaN power ICs.
## GaN Integration is Critical

<table>
<thead>
<tr>
<th>Driver</th>
<th>Parasitics</th>
<th>Power Device</th>
<th>Speed</th>
<th>Power Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive, control &amp; protection</td>
<td>Limit speed &amp; efficiency</td>
<td>Si or GaN</td>
<td>Switching Frequency</td>
<td>Faster Charging, Smaller Size</td>
</tr>
<tr>
<td>Silicon Discrete</td>
<td><img src="image1" alt="Parasitics Diagram" /></td>
<td><img src="image2" alt="Power Device Diagram" /></td>
<td>&lt; 100 kHz</td>
<td>&lt;0.5 W/cc</td>
</tr>
<tr>
<td>(in system controller)</td>
<td>$L_G R_G$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GaN Discrete, MCM</td>
<td><img src="image3" alt="Parasitics Diagram" /></td>
<td><img src="image4" alt="Power Device Diagram" /></td>
<td>&lt; 200 kHz</td>
<td>&lt;1 W/cc</td>
</tr>
<tr>
<td>(complex circuit)</td>
<td>$L_G R_G$</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Navitas GaN IC</td>
<td><img src="image5" alt="Parasitics Diagram" /></td>
<td><img src="image6" alt="Power Device Diagram" /></td>
<td>Up to 2 MHz (3-10x faster)</td>
<td>&gt;&gt;1 W/cc</td>
</tr>
</tbody>
</table>

Note: Based on Navitas lab evaluations of 65W chargers
Integration Drives Performance

NV6128

Integrated Gate Driver + Integrated GaN gate = Zero Gate-Source Loop Impedance
Only GaNFast is Fast... and Safe

- Exposed gate
- Faulty switching
- Dangerous ringing & glitching!

- Integrated gate
- Clean switching
- Safe, smooth performance

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### Industry-Leading IP Position

130+ Patents

**Issued / Pending**

Applications across mobile, consumer, EV, enterprise and renewables

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### Mature and Comprehensive GaN Integrated Circuit Process Design Kit (PDK)

#### Device Development / Library
- 650 eMode power FET
- 12-40V eMode power FET
- 650V dMode power FET
- 12-40V dMode power FET
- 2-DEG & SiCr resistors
- Gate capacitors
- MIM / hybrid capacitors
- Over 20 devices developed

#### Circuit Development / Library
- Logic gates and latch
- Linear regulators
- Comparators
- Voltage sensors
- Charge pump
- Bootstrap circuits
- Level-shifters
- Protection circuits
- Over 200 circuits developed

#### Characterization and Verification
- Dedicated and automated characterization stations (wafer level, package)
- Safe Operating Area (SOA)
- Layout Design Rule Checker (DRC)
- Layout Versus Schematic (LVS)
- Layout Parasitic Extraction and simulation tool (LPE)
- Over 1Mu characterized

#### Models and Simulation
- Device and circuit models with <5% accuracy
- Ultra-fast system simulations (Simplis)
- Accurate and fast device, circuit and system models cut design time from weeks to days and reduce design cycles by 50-75%

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Navitas’ 20+ years of GaN experience

*Solved complex issues with:*
- Manufacturing
- Reliability
- Materials
- Capacity
- Cost

**GaN Epi Layer**
- Multi-sourced reactors, scalable, low CapEx

**Low-cost, Si wafer**
- “GaN-on-Si” technology

**Tier-1, Low-Cost Foundry**
- TSMC Fab 2 (6", 0.35μm CMOS)
  - Old, available, under-utilized, low-cost fabs available

**Finished Wafer**

**Tier-1, Low-Cost Packaging**
- Standard, high-capacity
  - Low-cost, available

- 90%+ yields
- 24M+ shipped
- 0 GaN field-failures
- Committed capacity, with significant upside
- Only 12-week lead-times

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(1) Based on Navitas cumulative production shipments through July 1st, 2021.
(2) Based on no customer-reported consumer failures for production shipments through July 22nd, 2021.
System-Cost Tipping Point

Mobile served as a pioneer and other markets are expected to reap the benefits at lower cost points

Navitas GaN vs Silicon – $ Dollar Per Watt

Navitas GaN $ / W

Si $ / W

2010 2015 2020 2025 2030

How Navitas Enables Lower Cost

Early Mover Advantage
High yields and low manufacturing cost

New GaN Generations Every Year
Cost and performance improvements each generation

Increasing Levels of GaN Integration Every Year
Lower customer implementation costs

Faster GaN Performance Every Year
Smaller and lower cost external components every year

Navitas is Positioned to Drive Mainstream Adoption

(1) Navitas estimate comparing cost of GaN-based vs Si-based wall charger bill-of-materials cost (high-voltage power device, driver/controller, magnetics, PCB and case) for typical 65W mobile charger.

(2) Based on Navitas production release of 650V GaN power IC in Q3 '18.
**GaN is the Future of Mobile Charging**

- **Fast**
  - Up to 3x more power
  - Up to 3x faster charging

- **Mobile**
  - Half the size and weight of traditional chargers

- **Universal**
  - One charger for ALL your devices
  - *One and Done!!*

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**$2.5B/yr GaN IC Opportunity**

- 2.5B mobile chargers / year
- ~$1 GaN per charger

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**3 Silicon Chargers + 1 GaN Charger**

- 3x smaller, 3x lighter, and less expensive

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(1) Based on Navitas measurements of select GaN-based mobile wall chargers compared to Si-based chargers with similar output power.

(2) Based on estimates from IDC PC Tracker, USB-C research, Yole Research and Navitas estimates.
Power-Hungry Smartphones Use GaN

Bigger screens, bigger batteries

More power, go GaN!
Navitas has 8 of 11 GaN chargers

Silicon  GaN  TBD

(1) Navitas survey of public information, including gsmarena.com, Nov 2nd 2021
# Leading Customers Adopting Navitas GaN

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<th>Tier 1 OEMs</th>
<th>Aftermarket Examples</th>
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140+ GaN Chargers In Mass Production

150+ GaN Chargers In Development (MP 2021-2022)

90%+ Mobile OEMs Designing With Navitas GaN ICs

30M+ GaN ICs Shipped

Zero GaN Field-Failures(1)

Note: #chargers as of July 7th 2021, #shipped as of October 31st, 2021.

(1) Based on no customer-reported consumer failures for production shipments through July 22nd 2021.
Navitas GaN Chargers from 20W to 300W

- **30W C+A**: 67 cc, 82 g
- **Pro 65W C+A**: 76 cc, 106 g
- **Omnia 90W 2C+A**: 131 cc, 190 g
- **100W 3C+A**: 149 cc, 220 g
- **120W 2C+A**: 154 cc, 216 g
- **200W 2C+2A**: 203 cc, 220 g
- **20W C**: 67 cc, 82 g

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Navitas GaN Applied in High-Speed Topologies
Consumer: More Power, Smaller Size, $2B/yr Opportunity

- Need more power in smaller, slimmer sizes
  - Ultra-thin TVs, gaming, all-in-one PCs, smart home = 600M/yr
  - TV screens upgrade from UHD to 8K = 4x more power
  - $3/unit potential GaN
  - = $2B+/yr opportunity\(^{(3)}\)

- GaN ICs make it possible
  - Up to 3x smaller and lighter, low-profile form factors
  - Up to 40% energy savings

\(^{(1)}\) Based on Navitas measurements comparing typical 150W 65 kHz Si-based AC/DC power adapter to 150W 1MHz GaN-based power adapter prototype.

\(^{(2)}\) Based on information provided to management by potential customers.

\(^{(3)}\) Based on estimates from Gartner, Pulsenews, WitsView, Statista and Navitas estimates.
Data Centers: Save $1.9B/yr (1)

- 44% of Data Center costs related to power (electricity, power & cooling)(3)
- Estimate GaN ICs can reduce electricity use by up to 10%(2)
- Worldwide, could save >15 TWh or $1.9B in annual electricity costs (1-year ROI of 6x)(1)

(1) Navitas estimate based on a) Navitas server/datacom forecast & AAAS data, b) 50.12/kWhr, c) Si vs. GaN $/W and d) data center loading profile.
(2) Navitas estimated based on known existing Si-based solutions to deliver >500A next-generation data processors to Navitas targets for new GaN-based AC/DC and DC/DC for these same next-generation data processors.
(3) Schneider Electric. White Paper – Determining Total Cost of Ownership for Data Center and Network Room Infrastructure.
(4) Navitas measurements based on existing Si-based 3.2kW AC/DC server power supply to a 1 MHz GaN-based 3.2kW AC/DC prototype.

“GaN is a breakthrough new technology that is enabling dramatic reductions in size, energy savings and power density”
“Navitas is an excellent partner with industry-leading GaN ICs”

Robin Cheng, VP R&D

“GaNFast” AC-48V 97% 48V-3V 96% 99% Data Processing

“Navifast” AC-48V 97% 48V-3V 96% 99% Data Processing
Shrink microinverter size, weight & cost
  • 25% cost reduction of solar inverters
  • Up to 40% energy savings
  • Improve solar payback by 10%+ (vs. typical 8 years)

Total residential solar GaN IC opportunity > $1B/yr
  • $3M GaN IC sales potential per GW solar installation

Leading player expected to adopt GaN IC in next-gen
  • >$500M GaN IC revenue opportunity between 2023-2030

“It’s the end of the road for silicon.”

“GaN offers >10x frequency and significant cost advantages.”
**EV / eMobility: Accelerating Adoption by 3 Years**

**Longer Range, Lower Costs**

- 3x faster charging\(^{(4)}\)
- Extended range
  - 70% energy savings enables
    - 5% extended driving range, or 5% lower battery costs\(^{(3)}\)
- >$2.5B/yr GaN opportunity in 2025\(^{(2)}\)
  - ~$50 GaN in OBC, ~$15 DC-DC, ~$200 traction = **$250+ GaN TAM per Pure-EV**
  - >50Mu/yr EVs projected by 2030
  - $400M opportunity with 1st EV customer (2025-30)

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**Our current OBC product line up is Si & SiC. GaN will enable us to *further improve.*”**

“Navitas advantages are *simplicity of driving, high-speed, reliability & compact form factor.*”

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Note: Assumes 150 kW traction inverter, 100 kWh battery, $100/kWh battery cost and typical 230 mile range.

(1) Based on DNV and Navitas analysis
(2) Based on BCG Research, Yole Research and Navitas analysis.
(3) Navitas estimate based on discussions with major suppliers of power electronics to the electric vehicle industry.
(4) 6.6 kW Si OBC vs. 21 kW GaN OBC assuming a 90 kWh battery and 80A wall charge limit.
Power Market Grows, GaN Market Grows Faster!

GaN Opportunity Within Total Power Semiconductor TAM\(^{(1,2)}\)

- **2020**: $9.0B
- **2026**: $13.1B

GaN Power Semiconductor TAM\(^{(2)}\)

- **2026**: $2.1B\(^{(3)}\)
  - **Other**: $724M
  - **EV / eMobility**: $189M
  - **Renewables / Solar**: $139M
  - **Enterprise**: $293M
  - **Consumer**: $575M
  - **Mobile**: $293M

\(^{(1)}\) GaN IC potential market based on voltage rating of 80V – 1,000V derived from Yole Développement, Status of the Power Electronic Industry 2020.


\(^{(3)}\) Reflects midpoint of forecasted 2026 market size range of $1.6 billion to $2.6 billion.

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GaNFast is ‘Green’

GaN Power ICs Reduce CO₂ Emissions

4x-10x lower component CO₂ footprint than silicon

28% lower lifetime CO₂ footprint for chargers / adapters

Accelerate transition from ICE to EV by 3 years, saving 20%/yr of road sector emissions by 2050

GaN addresses 2.6 Gton / year by 2050

Every GaNFast™ power IC shipped saves 4 kg CO₂

(1) Navitas and Earth-Shift Global analysis. 4x lower for 2021, 10x lower by 2022 per life-cycle analysis
(2) Navitas and Earth-Shift Global estimated based on 65W charger per life-cycle analysis
(3) Navitas estimate based on GaN vs Si total life-cycle analysis.
(4) DNV estimate for 75%-adoption milestone pull-in, total road sector benefit
(5) Company information, DNV GL, EPA, IEA, International Renewable Energy Agency (IRENA). See 5-7-21 Investor presentation for details (filed with SEC) Derived from demand and energy efficiency CO₂ reduction of 1.4 Gt; assumes a $0.12 / kWh cost of electricity and a carbon to energy ratio of 0.00071 tons / kWh, aligned with the EPA’s marginal emission rate.
GaN: A Big Opportunity

GaN (Lateral) vs. SiC (Vertical)

- **Device Structure**
  - GaN: Lateral
  - SiC: Vertical

- **Circuit Integration**
  - GaN: Yes (Power + Analog)
  - SiC: No

- **Switching Frequency**
  - GaN: Highest (200 kHz – 2 MHz)
  - SiC: Medium (100 – 300 kHz)

- **Cost**
  - GaN: Si substrate (very low cost)
  - SiC: Si substrate (10x cost vs Si)

- **Thermal Performance**
  - GaN: Same as Silicon (1.3 W/cmK)
  - SiC: Highest (3.8 W/cmK)

- **Market Opportunity**
  - GaN: $13.1B+
  - SiC: $13.1B+

**Application Power**

- **EV On-board Chargers & DC/DC Converters**
- **Solar Inverters**
- **TV, Game System**
- **5G Base Station**
- **Solar Microinverters**
- **Indirect Motors, Welders, UPS**
- **Utility**
- **Wind Turbines**
- **Traction**

**Device Voltage (V)**

- **30V**
- **100V**
- **300V**
- **600V**
- **>1,200V**

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(1) GaN IC potential market based on voltage rating of 80V – 1,000V derived from Yole Développement. Status of the Power Electronic Industry 2020. Reflects estimated GaN market opportunity for power semiconductors by 2026.
Thank You

Navitas
Energy • Efficiency • Sustainability