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• Why is GaN interesting to fabricate power devices for PV solar power generation?

• What is GaN? What do we refer to as “GaN based power devices”?

• What are the barriers to commercialization of GaN based power devices?

• How does IR’s GaNpowIR technology platform overcome these barriers?

• What benefit does GaN based power conversion make available to solar power generation?

• What is current performance of GaN based Power conversion for solar power generation?

• Barriers to Realizing the benefits: Opportunity for ARPA-e
• Assuming a 3000€ cost per KW (total cost), and nominal power of 4KW, every 1% of efficiency improvement translates in 120€.

• Still better to spend more in power electronics than PV m²
Power Conversion Process

$V_{in} \rightarrow \text{Power Converter} \rightarrow V_{out}$

$I_{in} \rightarrow \text{Power Converter} \rightarrow I_{out}$

Waste Heat
Figure of Merit: Tradeoffs

\[
FOM = \text{Ron} \times Q_{\text{sw}} \times \text{Cost}
\]

\[
FOM = \frac{\text{efficiency} \times \text{density}}{\text{cost}}
\]
Dramatic Improvements in Power Device FOM

Comparison of $R_{on}$ for Si, SiC, and GaN

Measured data

Ecrit : Si = 20 V/μm , GaN = 300 V/μm

Ref: N. Ikeda et.al. ISPSD 2008 p.289
HEMT-FET Structure

Gate Dielectric

2D Electron Gas

Transition Layers

Silicon Substrate

Schottky/Al$_x$Ga$_{(1-x)}$N/GaN

2DEG Density ($10^{13}$/cm$^2$)

$X$ (Al fraction)

AlGaN Thickness (Å)

Measured$^a$

Calculated

$x=.35$

$\Phi_{\text{GaN}}$ = 1.0 eV

$\Phi_b$

$x=.25$

2DEG Density ($10^{13}$/cm$^2$)

$x=.15$

$0.0$ $0.1$ $0.2$ $0.3$ $0.4$

$100$ $200$ $300$ $400$

$0.0$ $0.5$ $1.0$ $1.5$ $2.0$ $2.5$

$0.0$ $0.5$ $1.0$ $1.5$ $2.0$

$100$ $200$ $300$ $400$

$2DEG$ Density ($10^{13}$/cm$^2$)

$X$ (Al fraction)

AlGaN Thickness (Å)

$a$ J. Van Hove, SVTA & J. Redwing, ATMI
Requirements for commercially viable GaN based power devices:

- \( \frac{P/C (GaN)}{P/C (Si)} > 2-3 \)
- Epi + substrate cost < $3/cm² (i.e. silicon)
- \( I_{\text{leak}} < 0.1 \mu A/\text{mm} \), \( I_{\text{on}} / I_{\text{off}} > 10^6 \)
- 2 DEG mobility > 1800 cm²/Vs
- Truly Crack Free epi (< 1 mm from edge) with low active defect density
- Yields >80% for 10mm²
- Stable electrical performance (eg: \( R_{DS(on)} \), \( R^*Qg \), Isat, \( Vp \), \( I_{\text{leak}} \))
- Large diameter (> 150 mm) substrates with < 50 µm bow after epi growth
- High Volume (> 10 k wafers/ wk) Si Wafer Fab Compatible
- Supply needed: >10⁶ 150 mm wafer equivalents (to support 10% total power semiconductor market at current utilization rates)
6” GaNpowIR Device Fabrication - > 2 um epitaxy – NO cracks
IR GaN Heteroepitaxy 2 µm epi on 150 mm Si wafers
Applications PFC Rectifier

• GaN Schottky diodes offer the same performance benefits as SiC diodes when used in Boost circuit topology (i.e PFC) but with much lower cost to be expected.

![Diode Diagram]

• Performance of GaN diodes as demonstrated by Velox in 2009 using GaN on Sapphire.

Novel 600 V GaN Schottky Diode Delivering SiC Performance Without the SiC Price

Authors: Isaac Cohen⁸, Ting Gang Zhu⁹, Linlin Liu⁹, Michael Murphy⁹, Milan Pophristic⁹, Marek Pabisz⁹, Mark Gottfried⁹, Bryan S. Shelton⁹, Boris Peres⁹, Alex Ceruzzi⁹, Rick A. Stall⁹

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⁹VELOX Semiconductor Corporation, 394 Elizabeth Avenue, Somerset, NJ 08873
⁸EMCORE Corporation, 145 Belmont Drive, Somerset, NJ 08873
• In 2008 Fraunhofer Institute demonstrated higher efficiency in PV Inverters using SiC JFet replacing traditional IGBTs and power Mosfets.

“98.5% Inverter Efficiency with SiC-MOSFETs”, Bruno Burger, Benriah Goeldi, Dirk Kranzer, Heribert Schmidt. 23rd EU PVSEC, 1st to 4th September 2008, Valencia, Spain
In 2009 Fraunhofer Institute demonstrated that, with SiC components, 99% efficiency in Single Phase PV Inverter efficiency (HERIC Topology) is feasible.

- Efficiency is no longer the problem
- Cost is the Problem
- GaN technology has the potential to deliver highest performance/cost benefit.

Ref: Fraunhofer Institute/ Prof.Bruno Burger
## Power Losses Comparison - Flyback Topology

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<th>Rdson</th>
<th>Qoss</th>
<th>Qgd</th>
<th>Qg</th>
<th>Qrr</th>
<th>BV</th>
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<tr>
<td>IRFS4321</td>
<td>12mΩ</td>
<td>36nC</td>
<td>16nC</td>
<td>71nC</td>
<td>150nC</td>
<td>150V</td>
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<tr>
<td>GaN MV05</td>
<td>5mΩ</td>
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<td>22nC</td>
<td>5nC</td>
<td>150V</td>
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<tr>
<td>GaN Gen1.1</td>
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<td>35nC</td>
<td>5nC</td>
<td>15nC</td>
<td>3nC</td>
<td>150V</td>
</tr>
</tbody>
</table>

### Total Losses - W

- **conduction**
- **gate drive**
- **switching**

95.9% Tested

96.4% Projection
(Model Simulation)
HV HEMT Reverse Blocking Characteristics

(Wg=100 mm, Lg=2um)

\[ \text{Ion/loff(600 V) > 10}^6 \]

\( V_g = -10V, \ BV = 0.1 \text{ uA/mm} \)
Switches:
GaN Eoff (Off switching loss) is 72% less than for IGBT.

Rectifiers:
GaN based device has 20x Lower Qrr compared to IGBT Copak and more than 200x less than Super Junction body diode.
Performance vs. Current Density (6A device):

Performance FOM: $V_{ds(on)} \times (E_{on} + E_{off})$

Current Density (A/mm$^2$)

Performance FOM: $V_{ds(on)} \times (E_{on} + E_{off})$
Barriers to benefits of GaN in Solar Power

• Must achieve Performance required:
  • Cover broad range of voltage (depends on conversion topology)
    – 20-1200V expected (30 -200 now, 650V CY2011)
    – Even Higher voltage GaN devices possible

• Integrate!

• Must define and meet reliability requirements:
  • 20 year useful life? At what allowable failure rate?
  • On the surface this is more demanding than automotive applications
  • Typical (Silicon) components used today not manufactured /designed to meet these requirements
Opportunities for ARPA-e:

- **Invest in reliability engineering of GaN based power devices for use in PV solar power**
  - Meet environmental requirements
  - Meet lifetime requirements
  - Meet FIT expectations

- **Invest in developing high density/frequency power conversion**:  
  - Realize smaller form factor (eg: for use in micro and nano inverter applications)
  - Higher frequency allows use of more reliable passives

- **Invest in system level integration to maximize cost effectiveness**
  - Lateral GaN HEMT technology is inherently integratable
  - Potential to monolithically integrate multiple power devices and drivers
Thank You
for
Your Kind Attention