Power Converters with
GaN HEMT (High Electron Mobility Transistor) FETs

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Materials Journey Se .. Ge…Si…GaN
Why Gallium Nitride. Better FOM = $R_{DS(ON)} \times Q_G$
Enable new Capabilities ?
High Electron Mobility
High Frequency – 10 GHz
X10 higher dielectric strength
Higher Thermal Conductivity
Majority Carrier Device – No reverse recovery
Cost ?
Is it easy to use? Learning curve
End of the Silicon near?
DC-DC Converters 48V- 1V, 400V- 48V Radiation ?
Development 600V,1200,5000V
LHC CONVERTERS VS RADIATION [2010]

- Rad Tolerant Design or standard Design with low Rad sensitivity (safe components)
- Standard Design and Rad sensitivity unknown (too many components, sub-assemblies...)

### LHC120A-10V
- FGC: 1
- 2 DCCTs: 191

### LHC600A-10V
- FGC: 1
- 2 DCCTs: 272

### LHC600A-40V
- FGC: 1
- 2 DCCTs: 25

### LHC4..8kA-08V
- FGC: 1
- 2 DCCTs: 066

### LHC13kA-18V
- FGC: 1
- 2 DCCTs: 16

### LHC13kA-180V
- FGC: 1
- 2 DCCTs: 8

### LHC60A-08V
- FGC: 1
- 2 DCCTs: 752

**Radiation Risk**

60 A @ 8 V 752 units

Is it possible to do this Power Train in GaN? Investigate??
First commercial GaN devices for Power Switching (DC-DC Converters)

Tests done using EPC (Efficient Power Conversion Corp, El Segundo, CA) Demo Boards

Plot conversion efficiency vs output current
  40V Devices: Input 12 / 24 /36 Volts Output ~ 1.2V
  100V Devices: Input 24 /36 /48 Volts Output ~ 1.2 -1.8V

Radiations Tests Schedule

- BNL: Gammas July 28, 2010
- TRIUMF (Organized by Sandia National Laboratories): Protons September 13-17, 2010

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New GaN Devices for Power Switching

Converter Efficiency Inputs = 12, 24 & 36 volts
output ~ 1.2 V

EPC9001 #2 Efficiency vs Output Current
Constant Frequency = 566 KHz: Pulse width = 124 - 240 ns:
Vout = 0.95 - 1.34V: L = 3.9 µH, 4.8 mΩ

EPC9001 #2 Efficiency vs Output Current
Constant twd = 240 ns: Frequency = 164 - 568 kHz
Vout ~ 1.2V: L = 3.9 µH, 4.8 mΩ
Converter Efficiency Inputs = 24, 36 & 48 volts
output ~ 1.8 v

Longer On Time improves efficiency (Lower Frequency)
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May 16, 2010

Set up with Resistor Load (Alternate is Active Load)
Figure 8: GaN on silicon can be used as a “flip chip”. The active device is isolated from the silicon substrate and can be completely encapsulated prior to singulation.

Figure 1: GaN on silicon devices have a very simple structure similar to a lateral DMOS device and can be built in a standard CMOS foundry.
Device Construction

![Diagram of device construction](image)
Flip Chip Assembly
## Status of GaN player

<table>
<thead>
<tr>
<th>Company</th>
<th>Detail of Target or status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fujitsu Laboratory</td>
<td>Mass-production level in 2011(fiscal)~2012 in the medium Vb over 600V using Si or SiC substrate (representative by Fujitsu Micro-elect.)</td>
</tr>
<tr>
<td>Furukawa and Fuji Electric</td>
<td>Commercial use at 2011(fiscal)</td>
</tr>
<tr>
<td>International Rectifiers</td>
<td>Commercial use from 2010&lt;br&gt;Beginning of product is lower Vb such several tens of voltage</td>
</tr>
<tr>
<td>NEC (Renesus)</td>
<td>Deliver Sample at 2011(fiscal)</td>
</tr>
<tr>
<td>Panasonic</td>
<td>Commercial use at 2011(fiscal)</td>
</tr>
<tr>
<td>Rohm</td>
<td>Deliver Sample at 2011(fiscal), also developing GaN native substrate</td>
</tr>
<tr>
<td>Sanken Electric</td>
<td>Trial manufacture of Vb over 800 V</td>
</tr>
</tbody>
</table>

**Timeline**

2006 2007 2008 2009 2010 2011 2012

- Velox (Developing SBD with STMicro)
- IR (Announcement of establish 6in-line)
- EPC announced GaN devices on Si
- Fujitsu (At DRC2009, massproduction at 2011 using 6in-line)
- NEC (paper at IEDM2009)
- Advanced power device research association (Furukawa & Fuji)
- Sanken-electric or Panasonic have been developing the GaN devices going to massproduction at 2012

*Prepared by Dr. Nariaki Ikeda of Advanced Power Device Research Association for Yale University*
Satish Dhawan, Yale University

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FET Setup for Proton Radiation Exposure
200 Mrads of Protons had no effect – switching 20 V 0.1 Amp
Parts still activated after 7 months
Proton Test

Proton Fluence = $1 \times 10^{15}$p/cm² over a period of about 24 hours.

Biased = 65 volts   switching @ 1MHz

Average current = 65 mA limited by Load resistor. No change in current.

Our next IEEE TNS Paper shall summarize work to date.
EPC 9001 Demo Board Connections for Rad Testing

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Brandon: Your connections ???

50 Ω Cable 20 feet?

5 V Drive see slide 36

1 Ω Shunt to 36 V power supply see slide 36

50 Ω Cable 20 feet?