Wide Band-Gap Semiconductors
GaN & SiC

Your 2015 APEC Rap Session

17 of March 2015 – Charlotte, NC
Schedule

• Panelists introduction
• Introduction with presentations
  1. *Market, players and trends quick update*
     • By Alex AVRÓN from Point The Gap
  2. *GaN vs. Silicon*
     • By Ionel Dan Jitaru from Rompower

3. Questions and discussion time!!!
Panel?

Bob White
Alex Lidow
JJ Wilkerson
Eric Persson
Dan Jitaro
Ron Vinsant
Larry Spaziani

Embedded Power Labs
Excelsys
Infineon
Rompower
VISHAY
GAN Systems
GaN & SiC
Technology & Market knowledge update
by Alex Avron – alex@pointthegap.com
The content

What has been going on recently in:

- Market
- Applications
- Players, Capital & investment
- Technologies

1% Knowledge update starting…
Gallium Nitride

2% Knowledge update on going…
Announced products with GaN Devices

Max 100W – 240V

5-30kW – 600V

3-30kW – 240V

30W – 240V

US DoE project

Zolt
FINSIIX
Yaskawa
Delta
Toshiba
Gallium Nitride power devices market estimation

GaN power market to 2020 draft estimation

$ 100M  $ 200M  $ 300M  $ 400M  $ 500M  $ 600M  $ 700M

GaN power devices start-ups & heavy players

Heavy players

Start-ups

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GaN power devices leaders and their finance ‘sources’

- **FURUKAWA ELECTRIC**
- **FUJITSU**
- **CREE**
- **transphorm**
- **GaN Systems**
- **infineon**
- **Panasonic**
- **EPC**

**Capital investment in…**

**Staff**

**Company acquired by…**

2nd source agreement
**GaN power devices players: What and how?**

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Substrate</th>
<th>Rated Voltage</th>
<th>Device</th>
<th>Planned</th>
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<tbody>
<tr>
<td>Cascode</td>
<td>Si</td>
<td>650V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cascode</td>
<td>GaN</td>
<td>600V</td>
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<tr>
<td>Enhancement mode</td>
<td>GaN</td>
<td>600V</td>
<td></td>
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<tr>
<td>Enhancement mode</td>
<td>Si</td>
<td>600V</td>
<td></td>
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</tr>
<tr>
<td>Enhancement mode</td>
<td>Si</td>
<td>450V</td>
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<tr>
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<td>Si</td>
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<td>Si</td>
<td>600V</td>
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</tr>
</tbody>
</table>

**GaN Systems International**

**Infineon**

**EPC**

**Avogy**

**Point the Gap**

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Silicon Carbide

50% Knowledge update on going…
Actual to Future products with SiC Switching devices

- **5-500kW – 600-1200V**
- **0.5-5MW - 1200V**  
  *Auxiliary in test*
- **30-90kW – 900V**  
  *In test*
Silicon Carbide power devices* market forecast

*Including switches and diodes

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European SiC players: Foundry, Device, Consulting…

SiCify
ascatron
FAIRCHILD
SEMICONDUCTOR®

Raytheon
Scotland, UK

Infineon
Erlangen, Germany

Fraunhofer IISB

CISSOID
Belgium (Packaging)

STI

CALY TECHNOLOGIES

IBS

VISHAY

Point the Gap
US SiC players: Foundry, Device, Consulting…
Japan SiC players: Foundry, Device, Consulting…
Silicon carbide switches availability

R&D

Limited availability

Claimed public availability

MOSFE

BOSCH

SUMITOMO ELECTRIC

MITSUBISHI ELECTRIC

ROHM SEMICONDUCTOR

CREE

TOSHIBA

BJT

FAIRCHILD SEMICONDUCTOR

GlobalPower Technologies Group

GeneSiC SEMICONDUCTOR

JFET

infineon

USCi

United Silicon Carbide, Inc.
GaN vs. Silicon

Ionel Dan Jitaru
Rompower Energy Systems
To make a direct comparison in a given application between the utilization of GaNs and Silicon Mosfets of similar On resistance and packaged in 8 x 8 Thinpak
APPLICATION 1

1000W PFC using two interleaved, 500W Totem Pole Bridgeless Power Trains

Vin = 90-264 Vac

Vo=385V & Io=2.6A
TOTEM POLE
BRIDGELESS P.F.C.
- Input current
- PFC current

\[ t_0 - t_1 \]
- Input current
- PFC current

$t_1 - t_2$
- Input current
- PFC current

\( t_2 - t_3 \)
- Input current
- PFC current

\[ t_3 - t_4 \]
CRITICAL CONDUCTION PFC

Critical/Boundary Mode Operation

Frequency Variation

Minimum ON or OFF Time Controlled

$I_{pb}$ Controlled

$I_{positive}$

$I_{negative}$
VOLTAGE ACROSS THE SWITCHING DEVICES ON EACH 500W CELL

13-Nov-14
19:22:50

Reading Floppy Disk Drive

1 µs
100 V
3.1 V

1 µs
100 V
18.8 V

1 µs
10 V DC
5.556 µs
1/Δt 179.99 kHz

10 V DC

20 mV DC

1 DC 288 V

1 GS/s

STOPPED
1000W PFC MODULE

\[ \eta = 99\% \]
120mΩ GaN versus 130mΩ Silicon MOSFET

230Vac/60HZ 250W

22.5° Switching Transitions

Operating Conditions:
Ipk1 = 1.088 A
Ipk2 = −0.5 A
Irms = 0.545 A
Fs = 174.314 kHz

GaN

Operating Conditions:
Ipk1 = 1.388 A
Ipk2 = −0.8 A
Irms = 0.697 A
Fs = 126.519 kHz

Silicon

Note: Zoom 40nS/Div

Ch.1 Switching Node
Ch.2 Low Side Vgs
**120mΩ GaN versus 130mΩ Silicon MOSFET**

*230Vac/60HZ*  
*250W*

**90° Switching Transitions**

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**Operating Conditions:**
- Ipk1 = 2.037 A
- Ipk2 = −0.5 A
- Irms = 1.062 A
- Fs = 109.119 kHz

**GaN**

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**Operating Conditions:**
- Ipk1 = 2.337 A
- Ipk2 = −0.8 A
- Irms = 1.188 A
- Fs = 88.25 kHz

**Silicon**

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*Ch.1 Switching Node*  
*Ch.2 Low Side Vgs*

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Note: Zoom 40nS/Div
120mΩ GaN versus 130mΩ Silicon MOSFET

230Vac/60HZ  250W

Note: Zoom 40nS/Div

Ch.1 Switching Node
Ch.2 Low Side Vgs
GAN versus Silicon MOSFET

230Vac/60HZ  500W

- 0.13% better efficiency at 500W
- 11% reduction in power dissipation
- 0.3% better efficiency at 250W
- 25.8% reduction in power dissipation
- 0.49% better efficiency at 125W
- 27.5% reduction in power dissipation
CONCLUSION

- To remove the larger charge of the silicon Mosfet requires larger current amplitudes and that increases the RMS current in switching devices and magnetics. In addition to that the larger current amplitude increases the flux swing in the magnetic core and leads to higher core loss.

- To remove the charge we can also increase the dead time and that seams to be slightly more efficient. However, the efficiency is still lower than GaNs due to the decrease of the power processing duty cycle.
APPLICATION 2

45W Adapter

Vin = 90-264 Vac

Vo=15V & Io=3A
Rompower

45W in 10W Apple package
Flyback Topology

The ‘Old’ Flyback

The “Old” Flyback with a “facelift”
Flyback Topology

The “Old” Flyback with a “facelift”

The “Old” Flyback with a second “facelift”
GaN vs. Silicon MOSFET Switching Comparison

45W Adapter Application

130mΩ MOSFET

90Vac/60HZ - 25% Load Condition

Operating Condition: Fs = 61.9 kHZ

120mΩ GaN

90Vac/60HZ - 100% Load Condition

Operating Condition: Fs = 115.6 kHZ

Ch.1 MOSFET Vds
Ch.2 MOSFET Vgs

Operating Condition: Fs = 124.5 kHZ

Ch.1 GaN Vds
Ch.2 GaN Vgs
GaN vs. Silicon MOSFET Efficiency Comparison

45W Adapter Application

90Vac/60HZ

GaN Vs. MOSFET - 45W Flyback Efficiency
90Vac

1.11% better efficiency at 45W
14% reduction in power dissipation
GaN vs. Silicon MOSFET Switching Comparison

45W Adapter Application

130mΩ MOSFET
230Vac/50HZ - 25% Load Condition

Operating Condition:
Fs = 45.1 kHZ

Ch.1 MOSFET Vds
Ch.2 MOSFET Vgs

120mΩ GaN

Operating Condition:
Fs = 49.4 kHZ

230Vac/50HZ - 100% Load Condition

Operating Condition:
Fs = 113.6 kHZ

Ch.1 GaN Vds
Ch.2 GaN Vgs

Operating Condition:
Fs = 110.5 kHZ
GaN vs. Silicon MOSFET Efficiency Comparison
45W Adapter Application

230Vac/50HZ

GaN Vs. MOSFET - 45W Flyback Efficiency
230Vac

0.94% better efficiency at 45W
13% reduction in power dissipation
CONCLUSION

- The impact in efficiency is approximately 1% due to higher driving loss and secondary effects such as higher circulating currents impacting the magnetic losses.
GaN vs. Silicon MOSFET Switching Comparison
45W Adapter Application

250mΩ MOSFET

90Vac/60HZ - 25% Load Condition
Operating Condition: Fs = 71.7 kHz

90Vac/60HZ - 100% Load Condition
Operating Condition: Fs = 111.4 kHz

120mΩ GaN

Operating Condition: Fs = 68.3 kHz

Operating Condition: Fs = 124.5 kHz

Ch.1 MOSFET Vds
Ch.2 MOSFET Vgs

Ch.1 GaN Vds
Ch.2 GaN Vgs
GaN vs. Silicon MOSFET Efficiency Comparison

45W Adapter Application

An ideal switch will add just another 0.23% in efficiency at 45W to 92.7%

0.21% better efficiency at 45W
3% reduction in power dissipation
56% reduction in power dissipation on the main switch
CONCLUSION

- The power dissipation on the main switch represents 0.5% of the total power. At low line the power dissipation on the main switch is lowered by half and the impact on the total efficiency is only 0.21%.

- In this application silicon Mosfet has a very good dynamic characteristics.

- The “ideal” flyback leaves little room for a much better switching element.
GENERAL CONCLUSION

- Though the GaN advantages may have a perceived marginal benefits in some applications, there are applications wherein they can make a significant impact.

- The availability of GaNs will stimulate advances in power conversion technology facilitating higher frequency and higher power density.
ACKNOWLEDGEMENT

This work was made possible through the support of On Semiconductor and Transphorm by providing the samples for the evaluation.
Thanks!
Wide Band-Gap Semiconductors
GaN & SiC

Who

What

Where

When

Why

Your 2015 APEC Rap Session

17 of March 2015 – Charlotte, NC
Panel?

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Embedded Power Labs
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Infineon
Rompower
VISHAY
GAN Systems

Wide Band Gap - Rap Session 2015
In Memory of Bob Pease

“What’s all this wide bandgap stuff anyway?”
Why?

- Why have WBG devices not taken off yet?
- Why do we need more reliability information?
  - If we had it then would you use it? What’s the real constraint – impediments?
- Why are packaged modules not available with WBG devices + Drivers + Controllers
- Why do we not have more benchmarks?
Who?

- Who are the suppliers going to be?

- Who are the customers
  - Which ones (markets) will be first?

- Who is going to make the test equipment needed to test the parts?

- Who are going to be the first to make a product utilizing WBG – Esp. GaN?
What?

• What are the **impediments to using WBG**?

• What are the **markets that will value WBG**?

• What are the **major objections** to using it or better stated
Where?

- Where will be the first region of the world to use it in volume production?
- Where can I buy a product that has WBG in it today?
- Where is all the evidence that the reality matches the historical hype?
- Where is it going to be used? Topology or market or…
When?

• When will **the investors get a ROI?**
  – Or better stated – profitable and self funding
• When will there be compelling data that causes designers to use **WBG vs. CoolMos**?
• Will we **NOT** be having a rap session to **discuss it** because WBG is mainstream?
Thank you

From…

Rompower
VISHAY
excelsys
GaN Systems
Point the Gap

To…

All of You

Embedded Power Labs