Power Electronics Overview:
What are the markets and trends?
Power Electronics and 21st century challenges
POWER ELECTRONICS AND 21ST CENTURY CHALLENGES

World Evolution lead to new challenges for power electronics

- Population Growth
- Mega Cities
- Energy Production
- Transportation needs
- Renewable Energy
- Efficiency Improvement
- Limited Resources
- CO₂ Emission Reduction

© Yole Développement – Semicon Europa 2015 – Power electronics
2014 growth was smaller than expected but still high. Forecasts for 2020 for power modules show a regular growth.
What evolution for power devices between 2014 and 2020? Split per voltage

Power Electronics, by voltage. Comparison 2014 - 2020

Very high voltage devices growth is driven by energy T&D, while energy production uses mainly medium (or low) voltage devices.

Medium voltage devices will have the highest growth by 2020, whereas very high voltage devices market will know very little growth.

Low Voltage: 400 -> 900V
- 2014: $8,430M
- 2020: $11,881M

Medium Voltage: 1.2kV -> 1.7kV
- 2014: $2,036M
- 2020: $3,541M

High Voltage: 2kV -> 3.3 kV
- 2014: $748M
- 2020: $1,208M

Very High Voltage: > 3.3kV
- 2014: $327M
- 2020: $552M

© Yole Developpement – Semicon Europa 2015 – Power electronics
What evolution for power devices between 2014 and 2020? Split per type of device

Even though each product type market will grow, the biggest increase will be in power modules.
Power device market: Geographical split

- **Asia is still the destination** of more than 75% of power products. Most of the integrators are located in China, Japan or Korea.

- **Europe** is very dynamic as well with top players in traction, grid, PV inverters and motor control.

- **The big names of the power electronics industry are historically from Japan.** Their industry is very much vertically integrated, with a considerable part of devices sold in the local market in Japan.
Power electronics market perspectives are very optimistic with a CAGR superior of 6% for the period 2014-2020.
Power electronics market split per application and main expectations by 2020 (in M$)

**2014 Overall Power Electronics Market by Applications**

- Automotive: 18%
- Industry: 18%
- Consumer: 20%
- Computer and office equip.: 23%
- Lighting: 5%
- Transportation: 2%
- Military & Aerospace: 1%
- Energy: 0%
- Others: 2%

Total: ~$11.5B market

**Breakdown of 2014**

**2020 Overall Power Electronics Market by Applications**

- Automotive: 23%
- Industry: 20%
- Consumer: 16%
- Computer and office equip.: 17%
- Lighting: 7%
- Transportation: 3%
- Military & Aerospace: 4%
- Energy: 2%
- Others: 2%

Total: ~$17.2B market

Automotive and industry market shares are expected to grow by 2020

© Yole Developpement – Semicon Europa 2015 – Power electronics
Inverter market and trends
In 2014, the business was dominated by industrial motor drives and UPS.
Overall inverter market in 2014 exceeded $45 billion.

Drivers for inverter innovation:
- Size reduction
- Weight reduction
- Efficiency improvement
- Cost reduction

Drivers for inverter application growth:
- Increase of CO₂ emission taxes
- Demand and regulations for clean energy generation
- Need for efficient transportation
- Need for mass transportation
- Data center and data storage market increase
- Need for energy efficiency
- Utility grid stress increasing due to the use of clean energy

Inverter markets:
- Wind turbines: $2.7 B, +2.1%
- Motor drives: $19.4 B, +8%
- UPS: $10 B, +0.5%
- Rail traction: $3.3 B, +5.2%
- EV/HEV: $2.5 B, +15%
- PV inverter: $7 B, +2.2%
- Motor drives: $19.4 B, +8%
- Rail traction: $3.3 B, +5.2%
- EV/HEV: $2.5 B, +15%
- PV inverter: $7 B, +2.2%

Inverter market and trends © Yole Development – Semicon Europa 2015 – Power electronics
## INVERTER MARKET AND TRENDS

<table>
<thead>
<tr>
<th>Applications</th>
<th>Drivers</th>
<th>Cost</th>
<th>Performance (efficiency)</th>
<th>Reliability Lifetime</th>
<th>Form factor</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PV inverters</strong></td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td><strong>EV/HEV</strong></td>
<td>+++</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>++++</td>
</tr>
<tr>
<td><strong>Electric/ Hybrid bus</strong></td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>++++</td>
</tr>
<tr>
<td><strong>Wind turbines</strong></td>
<td>+</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td><strong>Rail traction</strong></td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>++++</td>
</tr>
<tr>
<td><strong>UPS</strong></td>
<td>+++</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><strong>Industrial motor drives</strong></td>
<td>+++</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

+++: Strong driver  
++: Medium driver  
+: Low driver
INVERTER MARKET AND TRENDS

Technical breakthrough required in power electronics

**Power Assembly Architecture**
- Converter Topologies (mainly for LV-HV DC/DC and AC/DC)
- Inverter has to be developed according to the electric motor

**Passive Elements (Cooling, capacitors, busbars, etc…)**
- High Temperature Capacitors, Laminated Busbars
- Enhanced cooling of the power converter

**Power Packaging**
- Low stray inductance packaging
- High Temperature and reliable assemblies

**Wide Band gap Semiconductors**
- High Temperature operation
- More compact inverters

Symbols:
- $/kW
- kW/kg
- kW/l
INVERTER MARKET AND TRENDS

Example of companies in different markets of power electronics

Overview of the current power electronics landscape

* Curamik is a power module parts manufacturer (DBCs)
The recent moves: M&As, partnerships and developments

Many relevant merges and acquisitions have taken place recently. Mainly between power module, busbar and capacitor manufacturers.

* Curamik is a power module parts manufacturer (DBCs)

© Yole Développement – Semicon Europa 2015 – Power electronics
Power packaging innovation, market end trends
Power module market will double between 2015 and 2020

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric/Hybrid bus</td>
<td>$5M</td>
<td>$11M</td>
<td>$15M</td>
<td>$19M</td>
<td>$22M</td>
<td>$25M</td>
<td>$26M</td>
<td>$28M</td>
<td>$30M</td>
<td>$31M</td>
<td>$33M</td>
</tr>
<tr>
<td>Motors</td>
<td>$475M</td>
<td>$509M</td>
<td>$491M</td>
<td>$521M</td>
<td>$567M</td>
<td>$606M</td>
<td>$653M</td>
<td>$706M</td>
<td>$759M</td>
<td>$813M</td>
<td>$867M</td>
</tr>
<tr>
<td>UPS</td>
<td>$51M</td>
<td>$62M</td>
<td>$71M</td>
<td>$84M</td>
<td>$99M</td>
<td>$126M</td>
<td>$149M</td>
<td>$182M</td>
<td>$216M</td>
<td>$264M</td>
<td>$317M</td>
</tr>
<tr>
<td>Rail</td>
<td>$194M</td>
<td>$198M</td>
<td>$190M</td>
<td>$205M</td>
<td>$210M</td>
<td>$215M</td>
<td>$220M</td>
<td>$231M</td>
<td>$244M</td>
<td>$256M</td>
<td>$269M</td>
</tr>
<tr>
<td>Wind</td>
<td>$93M</td>
<td>$100M</td>
<td>$112M</td>
<td>$94M</td>
<td>$101M</td>
<td>$105M</td>
<td>$109M</td>
<td>$114M</td>
<td>$118M</td>
<td>$126M</td>
<td>$137M</td>
</tr>
<tr>
<td>EV/HEV</td>
<td>$269M</td>
<td>$373M</td>
<td>$564M</td>
<td>$775M</td>
<td>$914M</td>
<td>$1,068M</td>
<td>$1,255M</td>
<td>$1,580M</td>
<td>$2,019M</td>
<td>$2,625M</td>
<td>$3,509M</td>
</tr>
<tr>
<td>PV</td>
<td>$274M</td>
<td>$406M</td>
<td>$468M</td>
<td>$621M</td>
<td>$732M</td>
<td>$843M</td>
<td>$956M</td>
<td>$1,047M</td>
<td>$1,250M</td>
<td>$1,379M</td>
<td>$1,553M</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$1,360M</td>
<td>$1,659M</td>
<td>$1,911M</td>
<td>$2,319M</td>
<td>$2,645M</td>
<td>$2,988M</td>
<td>$3,368M</td>
<td>$3,888M</td>
<td>$4,636M</td>
<td>$5,494M</td>
<td>$6,686M</td>
</tr>
</tbody>
</table>

© Yole Developpement – Semicon Europa 2015 – Power electronics
POWERS PACKAGING MARKET AND TRENDS

What is power module packaging?

• Power module with baseplate is the standard design (70 to 80% of available power modules). DBC (Direct Bond Copper) packaging is the most widespread packaging. These modules are complex and expensive.
• Common failure in a power module is caused by thermal cycling. Mismatching CTE (coefficient of thermal expansion) can make layers detach from one another. Some gel filling also cannot handle high temperatures.

In orange: Common failure locations

© Yole Developpement – Semicon Europa 2015 – Power electronics
POWER PACKAGING MARKET AND TRENDS

Which evolution for each part of modules?

Both materials and designs are evolving in power modules.
In the future power modules will be entirely reshaped, with changes done depending on the power targeted.

**Bosch example**
- Molded package
- Double side soldering
- Low inductance

**Mitsubishi example**
- Six Pack IGBT/Diode Package
- Cooling fin
- Thick copper layer for thermal spreading
- Direct substrate cooling

**High-power modules**
- Encapsulation with parylene
- Ribbon bonding
- Silver (Ag) sintering for die attach
- Pin-fin baseplate

**Mid-power modules**
- Die on heatsink
  - Ceramic heatsink?
  - Ball bonding?

**2018**
- Wide use of leadframe
- Over-molded package
- Top interconnections
- Ag sintering for die attach

**2020**
- Ceramic heatsink?
- Ball bonding?
POWER PACKAGING MARKET AND TRENDS

Reliability and cost are the two main drivers for evolution

Depending on the level of reliability needed, power modules need to be optimized or not.

Cost pressure

- Thermal grease
- Al wirebonding
- Silicone gel encapsulation
- Soldering for die attach
- Al$_2$O$_3$ ceramics
- Double side cooling
- DBC substrate
- Over-molded PM
- Pin-fin baseplate
- Si$_3$N$_4$ ceramic
- Die on leadframe
- Parylene for encapsulation
- Cu wirebonding
- Ribon bonding
- Cu wirebonding
- Micro-channel cooling
- PCM
- Parylene for encapsulation
- AIN ceramic
- Gold alloys soldering
- Ag sintering for die attach
- Soldering

Currently widespread
In expansion phase
In development phase

© Yole Developpement – Semicon Europa 2015 – Power electronics
POWER PACKAGING MARKET AND TRENDS

What evolution for discrete devices packaging?

- Discrete components packaging evolution is motivated by the same reasons as power modules:
  - Miniaturization
  - Power density increase
  - Yield/Efficiency increase

Key drivers for discretes are the same as for power modules: Efficiency and power density increase.
POWER PACKAGING MARKET AND TRENDS

WBG semiconductors packaging case study: GaN Systems and AT&S

GaNPX

• During PCIM 2014 conference, AT&S and GaN Systems companies presented their new package solution for GaN devices: GaNPX
  • 100V/60A in 5x5mm

• This device is one of the first ones to take into account WBG specificities in an efficient package: Die is embedded at substrate level

• GaN devices focus is a good strategy:
  • Planarity of devices (easier integration)
  • Needs for good heat management
  • Promising future market

• Yole expects GaNPX package to inspire the way for future WBG semiconductors packaging

Sources: GaN Systems/AT&S and Yole’s report “GaN System GS66508P 650V 30A 52mohm GaN on Si HEMT normally-off transistor”
POWER PACKAGING MARKET AND TRENDS

Wafer-Level-Package: Different markets and technologies

- There are two main types of Wafer-Level-Packaging: Fan-In WLP (also known as Wafer Level Chip Scale Packaging) and Fan-Out WLP
- FIWLP is quasi-equivalent to Flip-Chip Ball Grid Array (FC-BGA), except that there is an intermediate layer for FC BGA. This solution is already widespread in the industry

Other packages exist in telecom industry and trend is to go to WLP. A source of inspiration?

"Fan-in” WLCSP

- With Fan-In solution, ball grid array is implemented below the chip (nothing out of die)

"Fan-Out” WLP

- Fan-Out solution is more flexible as the balls can be "larger" than the chip thanks to connections

Source: Yole’s report “Embedded dies and Fan-Out Technologies and Market Trends”
Semiconductor Devices
Opportunities for Wide Band Gap (WBG)
SEMICONDUCTOR DEVICES: OPPORTUNITIES FOR WIDE BAND GAP

Life–Cycle of Power Device Technologies

A new generation every ~20 years...

Bipolar

Diode
Thyrister
GTO
IGCT

BJT

SiC BJT

IGBT

MOSFET

SH MOSFET

SiC diode

SiC JFET

Silicon
SiC
GaN

Unipolar

Field Effect Transistors

Thyrister & MOSFET era

Si IGBT era

2015

WBG era??

1970

1990

2020

© Yole Developpement – Semicon Europa 2015 – Power electronics
SEMICONDUCTOR DEVICES: OPPORTUNITIES FOR WIDE BAND GAP
GaN vs. SiC vs. Si: Figure-of-merit

- SiC will stay the preferred choice for high T° application
- GaN could possibly reach high-voltage values but thus will require bulk-GaN as substrate.
- Silicon cannot compete at high-frequency range

Based upon intrinsic properties, Wide Band Gap capabilities are much better than Silicon.
SEMICONDUCTOR DEVICES: OPPORTUNITIES FOR WIDE BAND GAP

Reasons for Wide Band Gap devices added value

Intrinsic properties

High Junction $T^\circ$

High electron mobility

No recovery time during switching

Low losses
Less energy to dissipate

Fewer cooling needs

System size and weight reduction

Impact on operation

High switching frequency

Smaller filters and passives

Impact on power module

Intrinsic properties

High electron mobility and high junction temperature are the key characteristics.
SEMICONDUCTOR DEVICES: OPPORTUNITIES FOR WIDE BAND GAP

Power device technology positioning and evolution

- Historically, silicon had the complete monopoly of the semiconductors industry in Integrated Circuits (IC), in Microchips and in Power Electronics.
- New raw materials for semiconductors such as Silicon Carbide (SiC) and Gallium Nitride (GaN) have been developed for some decades now.

WBG devices are primarily positioned in high-end applications and have potential in automotive

**Voltage**
- **200V**
  - Home appliances
  - Consumer systems
- **600V or less**
- **1200V or more**
  - Industry, Energy
  - Mass transportation
- **3.3kV and more**

**Product range**
- **High end**
  - MOSFET
  - Triacs
  - Bipolar
- **Low end**
  - GaN
  - SiC

**Thyristor IGCT**

© Yole Developpement – Semicon Europa 2015 – Power electronics
SEMICONDUCTOR DEVICES: OPPORTUNITIES FOR WIDE BAND GAP
Implementation of SiC Materials in Power Electronics

- **SiC diodes** today are already in production, mainly coupled with IGBT technology.

- Penetration of **SiC in Wind turbines** will happen later than expected. For all other segments, Yole Développement roadmaps have been confirmed. Use of SiC in industrial motor drives is still unclear.

---

© Yole Developpement – Semicon Europa 2015 – Power electronics
• Characteristics of GaN-based inverters will be:
  • They will primarily target medium voltage applications (in the 200 – 600V range)
  • GaN targeted applications will be very different from SiC, at first. We will observe a competition in PV inverters, and potentially, both technologies will be used. For the EV/HEV, GaN devices will first enter the DC/DC converters and the chargers, but not the power train inverter.
  • GaN devices are excluded from high-voltage applications such as wind turbines and rail traction.
Conclusions
CONCLUSIONS

• 21st century challenges are leading to new needs, new drivers, new opportunities

• To face these evolutions power electronics industry will reshape itself to meet specific application requirements
  • Power density
  • Overall system weight
  • Efficiency improvement

• Technical breakthrough are expected at each level of the value chain:
  • System architectures and topologies
  • Packaging
  • Semiconductor devices
Any questions?
The slides of this presentation were extracted from the following reports:

- **GaN and SiC Devices for Power Electronics Applications**
  Released in July 2015 – More info [here](#).

- **Status of Power Electronics Industry 2015**
  Released in February 2015 – More info [here](#).

- **Power Packaging Technology Trends and Market Expectations**
  Released in March 2015 – More info [here](#).
Pierric Gueguen

Dr Pierric GUEGUEN is Business Unit Manager for Power Electronics and Compound Semiconductor activities at Yole Développement. He has a PhD in Micro and Nano Electronics and an master degree in Micro and Nanotechnologies for Integrated Circuits. He worked as PhD student at CEA-Leti in the field of 3D Integration for Integrated Circuits and Advanced Packaging. He then joined Renault SAS, and worked for 4 years as technical project manager in R&D division. During this time, he oversaw power electronic converters and integration of Wide Band Gap devices in Electric Vehicles. He is author and co-author of more than 20 technical papers and 15 patents.

gueguen@yole.fr

Jérôme Azémar

Jérôme Azémar is a Senior Technology & Market Analyst and Business Developer at Yole Développement for 2 years, specialized in Advanced Packaging, Power Electronics and Semiconductor Manufacturing. Upon graduating from INSA Toulouse with a master’s in Microelectronics and Applied Physics in 2007, he joined ASML and worked in Veldhoven for three years as an Application Support Engineer, specializing in immersion scanners. During this time he acquired Photolithography skills which he then honed over a two-year stint as a Process Engineer at STMicroelectronics. While with ST he developed new processes, co-authored an international publication and worked on metrology structures embedded on reticules before joining Yole Développement in 2013.

azemar@yole.fr

ABOUT THE AUTHORS

Biography & contact
FIELDS OF EXPERTISE

Yole Développement’s 30 analysts operate in the following areas:

- Imaging
- Photonic Sensors
- MEMS & Sensors
- Compound Semi.
- LED
- Power Electronics
- PV
- Advanced Packaging
- MedTech
- Manufacturing
4 BUSINESS MODELS

○ Consulting and Analysis
  • Market data & research, marketing analysis
  • Technology analysis
  • Strategy consulting
  • Reverse engineering & costing
  • Patent analysis

  www.yole.fr

○ Financial services
  • M&A (buying and selling)
  • Due diligence
  • Fundraising
  • Maturation of companies
  • IP portfolio management & optimization

  www.yolefinance.com
  Blu Morpho

○ Reports
  • Market & Technology reports
  • Patent Investigation and patent infringement risk analysis
  • Teardowns & Reverse Costing Analysis
  • Cost Simulation Tool

  www.i-Micronews.com/reports

○ Media
  • i-Micronews.com website
  • @Micronews e-newsletter
  • Technology magazines
  • Communication & webcast services
  • Events

  www.i-Micronews.com
A GROUP OF COMPANIES

- Market, technology and strategy consulting
  - www.yole.fr

- M&A operations
  - Due diligences
  - www.yolefinance.com

- Fundraising
  - Maturation of companies
  - IP portfolio management & optimization
  - www.bmorpho.com

- Manufacturing costs analysis
  - Teardown and reverse engineering
  - Cost simulation tools
  - www.systemplus.fr

- IP analysis
  - Patent assessment
  - www.knowmade.fr
40% of our business is in EU countries
30% of our business is in Asia
30% of our business is in North America
SERVING THE ENTIRE SUPPLY CHAIN

Our analysts provide market analysis, technology evaluation, and business plan along the entire supply chain.

Integrators and end-users

Device makers

Suppliers: material, equipment, OSAT, foundries...

Financial investors, R&D centers
CONTACT INFORMATION

○ Consulting and Specific Analysis
  • North America: Steve LaFerriere, Director of Northern America Business Development, Yole Inc.
    Email: laferriere@yole.fr
  • Japan: Yutaka Katano, General Manager, Yole Japan & President, Yole K.K.
    Email: katano@yole.fr
  • EMEA: Jerome Azemar, Senior Analyst and Business Development Manager, Yole Développement
    Email: azemar@yole.fr
  • RoW: Jean-Christophe Eloy, President & CEO, Yole Développement
    Email: eloy@yole.fr

○ Report business
  • North America: Steve LaFerriere, Director of Northern America Business Development, Yole Inc.
    Email: laferriere@yole.fr
  • EMEA: Jerome Azemar, Senior Analyst and Business Development Manager, Yole Développement
    Email: azemar@yole.fr
  • Japan & Asia: Takashi Onozawa, Sales Asia & General Manager, Yole K.K.
    Email: onozawa@yole.fr
  • Korea: Hailey Yang, Business Development Manager, Korean Office
    Email: yang@yole.fr

○ Financial services
  • Jean-Christophe Eloy, CEO & President
    Email: eloy@yole.fr