Silicon Carbide market update:
From discrete devices to modules...

Dr. Kamel Madjour,
Technology & Market Analyst, Yole Développement
Who is Yole Developpement?

- Market, technology and strategy consulting company, founded in 1998.

- Research performed by our in-house analysts
- 30 full time analysts with technical and marketing degrees
- Primary research including over 3,500 interviews per year

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40% of our activity

Offices in Lyon (HQ), Nantes, Nice & Paris

30% of our activity

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Yole Inc.

SystemPlus

KnowMade

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News feed / Technology Magazines / Webcasts

REPORTS
Market & technology
Patent Investigation
Reverse costing

CONSULTING
Market research
Technology & Strategy
Patent Investigation
Reverse costing

WORKSHOPS
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YOLE FINANCE
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Overall power electronics industry outlook
Power electronics market metrics

2006 - 2020 overall PE market size, split by family

It includes:
- Power discretes: MOSFET, rectifier, IGBT, Bipolar....
- Power modules: IGBT, diode or MOSFET modules, IPM
- Power IC: power management IC: mainly voltage regulators (POL) and drivers

Source: Yole Développement (2014)
2013 - 2020 power electronics foreseen evolution (1/2)

Source: "Power GaN 2014" Report

Power Electronics, by voltage. Comparison 2013 - 2020

Source: Yole Développement (2014)

<table>
<thead>
<tr>
<th>Voltage Range</th>
<th>2013</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Voltage 400 → 900V</td>
<td>$7,747M</td>
<td>$12,203M</td>
</tr>
<tr>
<td>Medium Voltage 1.2kV → 1.7kV</td>
<td>$1,769M</td>
<td>$3,520M</td>
</tr>
<tr>
<td>High Voltage 2kV → 3.3kV</td>
<td>$672M</td>
<td>$1,241M</td>
</tr>
<tr>
<td>Very High Voltage &gt; 3.3kV</td>
<td>$462M</td>
<td>$949M</td>
</tr>
</tbody>
</table>
2013 - 2020 power electronics foreseen evolution (2/2)

• Significant increase of Automotive sector following EV and HEV ramp-up that will boost the 650, 900 and 1.2 kV segments

• Renewable energies and smart-grid implementation will drive industry sector ramp-up with a positive impact on the “1.2 kV+ device market size”

• Rail traction will stay very dynamic as well. Along with electricity grid momentum, it should boost the “> 3.3 kV segment” by more than 100% from 2013 to 2020.

• Steady erosion of Consumer-related 600V segments market share due to pressure on price (However, volumes (units) will keep on increasing).
Life-Cycle of Power Device Technologies

A new generation every ~20 years…

Bipolar

Diode
Thyristor

GTO

IGCT

SiC BJT

Unipolar

Field Effect Transistors

IGBT

Gen. 2
Max. 600V

IGBT

Gen. 6
Max. 6500V

MOSFET

SJ

MOSFET

SiC MOSFET

SiC diode

SiC JFET

GaN HEMT

Silicon
SiC
GaN

Yole Développement (2014)

Thyristor & MOSFET era

Si IGBT era

SiC era ?

1970

1990

2010

2014

>2020
SiC Value Proposition

As Fast as MOSFET, as Powerful as Thyristor

New capabilities offered by SiC: several kV, several kA, several 100’s kHz

Applications:
- All type of inverter
  - Range kW to MW

Applications:
- Motor control, PV, Wind, Grid, rail traction
  - High to very high voltage

Applications:
- Grid / Very high voltage

Yole Développement (2014)
SiC industry outlook
SiC Devices

Possible applications in silicon power electronics

SiC can displace Silicon in:

- **IT & Consumer**
  - PFC / Power supplies
  - Converter / Inverter
  - Electronic appliances & Computing
  - UPS

- **Automotive**
  - DC/AC Inverter
  - DC/DC Converter
  - Hybrid automotive

- **Industry**
  - Power distribution
  - Rail transport.
  - P.V.
  - Motor control
  - UPS
  - Wind turbines

SiC & GaN possible competition

< 500 W

1 – 5 kW

30 – 350 kW

5 – 50 kW

5 – 100 kW

100 kW

1 MW

> 1 MW

SiC only

Source: Yole Développement (2014)
Implementation of SiC Materials in Power Electronics

Time to market for SiC

SiC diode only

SiC diode & transistor

SiC in Solar Inverters

SiC Schottky diodes in Power Factor Correctors

SiC in Wind Turbines

SiC in AC motor drives

SiC in HEV/EV

SiC in Rail Traction

Source: Yole Développement (2014)
Projection of SiC Power Device Market Size

Split by application: Nominal scenario

10 years long-term market forecast for SiC devices in various power applications

(EV/HEV nominal scenario)

Source: Yole Développement (2014)
2002 – 2020 shares of SiC revenues evolution by company headquarter location

% of SiC revenues by headquarter location

<table>
<thead>
<tr>
<th>Year</th>
<th>Asia</th>
<th>Japan</th>
<th>US</th>
<th>Europe</th>
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</thead>
<tbody>
<tr>
<td>2002</td>
<td>0.0%</td>
<td>0.0%</td>
<td>95.0%</td>
<td>5.0%</td>
</tr>
<tr>
<td>2003</td>
<td>0.0%</td>
<td>0.0%</td>
<td>87.0%</td>
<td>13.0%</td>
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<tr>
<td>2004</td>
<td>0.0%</td>
<td>0.1%</td>
<td>74.0%</td>
<td>26.0%</td>
</tr>
<tr>
<td>2005</td>
<td>0.0%</td>
<td>0.7%</td>
<td>65.0%</td>
<td>34.9%</td>
</tr>
<tr>
<td>2006</td>
<td>0.3%</td>
<td>1.1%</td>
<td>60.0%</td>
<td>39.7%</td>
</tr>
<tr>
<td>2007</td>
<td>0.7%</td>
<td>1.6%</td>
<td>55.0%</td>
<td>44.3%</td>
</tr>
<tr>
<td>2008</td>
<td>1.1%</td>
<td>2.0%</td>
<td>50.0%</td>
<td>48.9%</td>
</tr>
<tr>
<td>2009</td>
<td>1.6%</td>
<td>2.9%</td>
<td>45.0%</td>
<td>53.4%</td>
</tr>
<tr>
<td>2010</td>
<td>2.0%</td>
<td>3.5%</td>
<td>43.9%</td>
<td>54.1%</td>
</tr>
<tr>
<td>2011</td>
<td>2.9%</td>
<td>6.0%</td>
<td>39.1%</td>
<td>57.4%</td>
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<tr>
<td>2012</td>
<td>3.5%</td>
<td>10.0%</td>
<td>37.6%</td>
<td>58.9%</td>
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<tr>
<td>2013</td>
<td>6.0%</td>
<td>16.0%</td>
<td>36.2%</td>
<td>57.8%</td>
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<tr>
<td>2014</td>
<td>10.0%</td>
<td>22.0%</td>
<td>34.8%</td>
<td>55.2%</td>
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<tr>
<td>2015</td>
<td>16.0%</td>
<td>25.0%</td>
<td>33.4%</td>
<td>50.1%</td>
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<tr>
<td>2016</td>
<td>22.0%</td>
<td>29.0%</td>
<td>32.1%</td>
<td>45.0%</td>
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<tr>
<td>2017</td>
<td>25.0%</td>
<td>33.0%</td>
<td>30.9%</td>
<td>42.6%</td>
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<td>2018</td>
<td>29.0%</td>
<td>37.0%</td>
<td>29.7%</td>
<td>38.6%</td>
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<tr>
<td>2019</td>
<td>33.0%</td>
<td>37.0%</td>
<td>28.6%</td>
<td>34.9%</td>
</tr>
<tr>
<td>2020</td>
<td>37.0%</td>
<td>37.0%</td>
<td>27.5%</td>
<td>30.5%</td>
</tr>
</tbody>
</table>

Source: “SiC 2014” Report
SiC is now implemented in several power systems and is gaining momentum and credibility.

We stay convinced that the most pertinent market for SiC lands in high and very high voltage (> 1.2kV), where applications are less cost-driven and where few incumbent technologies can’t compete in performance. This transition is on its way as several device/module makers have already planned such products at short term.

Thus, even though EV/HEV skips SiC, industry could expand among other apps. Now, the only question remains: Is there enough business to make so many contenders live decently? Probably yes as green-techs are also expanding fast, strongly requesting SiC. But, any new comers should carefully manage its strategy and properly size its capex according to the market size…
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www.i-micronews.com

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Thank You!

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