Wide Band Gap Materials: Revolution in Automotive Power Electronics

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IEEE forum

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A global semiconductor leader
• The largest European semiconductor company
• 2014 revenues of $7.40B
• Approximately 43,600 employees worldwide
• Approximately 8,700 people working in R&D
• 11 manufacturing sites
• Listed on New York Stock Exchange, Euronext Paris and Borsa Italiana, Milano

As of December 31, 2014
Strategy & Growth Driver

Sense & Power and Automotive Products

Embedded Processing Solutions

addressing a ~140B$ market globally
~26B$ market for Automotive worldwide

Automotive
Smart Power
MEMS & Sensors
Microcontrollers
Application Processors & Digital Consumer
Innovation: from Active Safety to Autonomous Driving

From Active Safety

- Blind Spot Detection: 3.9%
- Lane Departure Warning: 5.2%
- Obstacle Detection: 4.4%
- Emergency Braking

2013: Semi-autonomous driving is a standard option in $30K cars

2013 penetration rate

To Autonomous Car

- Radar
- CMOS Camera
- Vision Processing
- High precision GNSS
- Multiple-core MCU
- Sensor Fusion
- Functional safety

202x: Full-autonomous driving will become a standard equipment

Source: Strategy Analytics, Jan 2014
Connectivity

- Satellite Radio
  - Sirius XM Receivers (ASICS)

- Positioning & Telematics
  - Multi-Constellation Positioning
  - Telematics Processor

- Telematics – Insurance Box
  - Tolling
  - Insurance Trading
  - Car Rescue

- Vehicle to Vehicle
  - Wi-Fi 11-P for Car to Car communication

Infotainment

- Terrestrial Radio
  - AM/FM Receivers
  - Digital Receivers for DAB/DMB/HD

- Car Infotainment Processors
  - Processors with Phone Connectivity, Media-player & Display control

- Premium Audio
  - High Fidelity Amplifiers
  - Multichannel Class D Amplifiers

Processing

- Teseo2 & 3
  - Enable Beidou with Teseo family positioning accuracy

- Processing
  - Accordo & Telemaco
  - The highest performing and cost effective solution for Entry Infotainment

- Tuners
  - STAR & DOT
  - OEM performance, scalability and multi-standards

- Amplifiers
  - ClassAB / D
  - Leading innovation, robustness
• Unmatched V2X system solution co-development combining
  • Autotalks V2X technology lead and
  • ST Automotive and Telematics Expertise with Global Infrastructure and services
• First ISO26262 ASIL-B grade V2X Processor integrating
  • WiFi modem
  • Security
  • Vehicle network connectivity
  • Multi-Core CPU processing
• Leveraging best-in-class Multi-GNSS positioning of Teseo Family Receivers

IHS 2014 report forecasts worldwide V2X communication sales will amount to nearly 700,000 units in 2017, rising to 55 million in 2025

Connected cars need security
CO₂ reduction mandate

Historical fleet CO₂ emissions performance and current or proposed standards

[1] China’s target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
In EV/HEV car, dealing with......

- New voltage classes never seen before in a car, up to 1,200 Volts !!!
- Power of 100’s of Kilowatts
- High temperature environment and huge thermal power cycling stresses
- Mechatronics integration complexity requiring new cooling techniques
- New functional safety boundaries, not really covered by previous mission profiles
- and all of this, keeping it within an affordable cost......

**THIS IS CALLED REVOLUTION !**
The power semiconductors in the center of the challenges

- Power Handling
- Cost
- Efficiency
  - Size
  - Weight
  - Power Losses & Temperature
  - Switching Frequency

Impact on Wiring Harness

Impact on Cooling elements

Impact on Passive components

Cost

$P = V \uparrow \times I \downarrow$
### Wide Band Gap Materials
Breaking the paradigm

<table>
<thead>
<tr>
<th>Property</th>
<th>Si</th>
<th>GaN</th>
<th>4H-SiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_g ) (eV) – Band gap</td>
<td>1.1</td>
<td>3.4</td>
<td>3.3</td>
</tr>
<tr>
<td>( V_s ) (cm/s) – Electron saturation velocity</td>
<td>( 1 \times 10^7 )</td>
<td>( 2.2 \times 10^7 )</td>
<td>( 2 \times 10^7 )</td>
</tr>
<tr>
<td>( \varepsilon_r ) – Dielectric constant</td>
<td>11.8</td>
<td>10</td>
<td>9.7</td>
</tr>
<tr>
<td>( E_c ) (V/cm) – Critical electric field</td>
<td>( 3 \times 10^5 )</td>
<td>( 2.2 \times 10^6 )</td>
<td>( 3 \times 10^6 )</td>
</tr>
<tr>
<td>( k ) (W/cm K) – Thermal conductivity</td>
<td>1.5</td>
<td>1.7</td>
<td>5</td>
</tr>
</tbody>
</table>

- \( E_c \) — low on resistance
- \( E_g \) — low leakage, high \( T_j \)
- \( k \) — Operation > 200 °C
  - Reduced Cooling Requirements
- \( V_s \) — Higher switching frequency
  - Lower switching losses

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\( V \) (cm/s)

\( E \) (V/cm)

\( \varepsilon \) (dielectric constant)

\( g \)

\( s \)
ST’s long History on the SiC market

- **SiC G1 release** (2008)
- **SiC G1 range enlargement (D²PAK)** (2010)
- **SiC G2 release** (2012)
- **SiC 650V G2 range extension** (2013)
- **SiC 1200V release 6A in DPAK HV**
- **SiC 1200V range extension from 5 to 50A including Die Business** (2014)
- **SiC 650V G2 extension to Automotive** (2014)
- **SiC 650V G2 extension to Flat Packages & low current (2-3A)** (2014)

Now Qualified for Automotive Markets
And now Power MOSFET.....

<table>
<thead>
<tr>
<th>1200V SiC MOSFET</th>
<th>SCT20N120</th>
<th>SCT30N120</th>
<th>SCT50N120</th>
</tr>
</thead>
<tbody>
<tr>
<td>In</td>
<td>20 A</td>
<td>45 A</td>
<td>65 A</td>
</tr>
<tr>
<td>$R_{on,(typ)}$</td>
<td>&lt; 240 mΩ</td>
<td>&lt; 90 mΩ</td>
<td>&lt; 70 mΩ</td>
</tr>
<tr>
<td>$Q_{g,(typ)}$</td>
<td>&lt; 45nC</td>
<td>&lt; 105nC</td>
<td>&lt; 130nC</td>
</tr>
</tbody>
</table>

Gate Driving Voltage = 20 V
HiP247 Package: $T_{j,max}=200^\circ$C
On-resistance Variation vs. Temperature

ST SiC MOSFET specified in Rdson at 200°C with only 25% increase vs 25°C
# Unmatched switching losses vs IGBT

<table>
<thead>
<tr>
<th>ST SiC MOSFET vs. best in class IGBT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ST SiC MOSFET</strong> (SiC MOSFET)</td>
</tr>
<tr>
<td><strong>Chip size (Normalized)</strong></td>
</tr>
<tr>
<td><strong>V\text{on typ (V)} (25°C, 20A)</strong></td>
</tr>
<tr>
<td><strong>V\text{on typ (V)} (175°C, 20A)</strong></td>
</tr>
<tr>
<td><strong>E\text{on (µJ)} (20A, 900V)</strong></td>
</tr>
<tr>
<td><strong>E\text{off (µJ)} (25°C / 175°C)</strong></td>
</tr>
<tr>
<td><strong>E\text{off (µJ)} (25°C / 175°C)</strong></td>
</tr>
<tr>
<td><strong>E\text{off difference (%)</strong>}</td>
</tr>
<tr>
<td><strong>SCT30N120</strong></td>
</tr>
<tr>
<td><strong>0.45</strong></td>
</tr>
<tr>
<td><strong>2</strong></td>
</tr>
<tr>
<td><strong>2.4</strong></td>
</tr>
<tr>
<td><strong>725 / 965</strong></td>
</tr>
<tr>
<td><strong>245 / 307</strong></td>
</tr>
<tr>
<td><strong>+25%</strong></td>
</tr>
<tr>
<td><strong>IGBT (competition)</strong></td>
</tr>
<tr>
<td><strong>1.00</strong></td>
</tr>
<tr>
<td><strong>1.95</strong></td>
</tr>
<tr>
<td><strong>2.35</strong></td>
</tr>
<tr>
<td><strong>2140 / 3100</strong></td>
</tr>
<tr>
<td><strong>980 / 1850</strong></td>
</tr>
<tr>
<td><strong>+90%</strong></td>
</tr>
</tbody>
</table>

* Measured by using the SiC intrinsic body diode

- **Switching losses significantly lower**
  - E\text{on} 3x lower, E\text{off} 4x lower
- **Moderate dependancy on temperature variations**
  - Valid for R\text{DS(ON)} and Switching Losses
Simulation Results at $V_{dc} = 900V$, $200A_{pk}$, $f_{sw} = 20kHz$

<table>
<thead>
<tr>
<th>Loss Energy</th>
<th>Si-IGBTs Solution</th>
<th>Full-SiC Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total chip-area</td>
<td>300 mm$^2$</td>
<td>168 mm$^2$</td>
</tr>
<tr>
<td>Conduction losses (W)</td>
<td>125</td>
<td>55</td>
</tr>
<tr>
<td>Turn-on losses (W)</td>
<td>280</td>
<td>90</td>
</tr>
<tr>
<td>Turn-off losses (W)</td>
<td>246</td>
<td>40</td>
</tr>
<tr>
<td>Body diode conduction losses (W)</td>
<td>NA</td>
<td>12.3</td>
</tr>
<tr>
<td>Diode conduction losses (W)</td>
<td>5</td>
<td>NA</td>
</tr>
<tr>
<td>Diode’s $Q_{rr}$ losses (W)</td>
<td>260</td>
<td>5.3</td>
</tr>
<tr>
<td>Total losses (W)</td>
<td>916</td>
<td>203</td>
</tr>
</tbody>
</table>

**SiC vs Si**
- > 2x lower
- > 3x lower
- > 6x lower
- 2x higher, but no external diode
- 50 x lower

**Total Power Dissipation**

About 75% lower by using Full SiC-Solution
Main Module Specs

- Full SiC Power Module
- Topology: 3-ph, full-bridge
- Nominal Power = 60kW
- Bus Voltage = 900V
- Current capability = 200A peak

Description & Purpose:
Custom Power Module for 3-φ inverter to drive an electric turbo 1200V, 300A
Liquid cooling (baseplate with fins)

Key Products:
- x 72 1200V/80mΩ SiC MOSFET (12 x switch)
- No freewheeling diode
- Gate resistors embedded

20% smaller vs. previous IGBT based Module

Can be further improve thanks to:
- larger die size (with less die to be put in parallel)
- By integration of Rg into SiC structure
SiC Value Proposition in EV/HEV Main Inverter

>1% efficiency improvement (75% lower loss)

→ Longer battery life

75% cooling system downsize on Inverter side

→ Smaller and Lighter Power Unit

Up to 50% module size reduction

→ Smaller and Lighter Power Unit
A deeper look on Boost converters and on-board chargers
Various Switching Topologies

HV DC/DC converter

3 phase fast charger

PFC block

DC/DC block

1 phase charger

PFC block

DC/DC block
SiC enables new ‘Efficiency-switching frequency’ vs Silicon technology

1200V SiC MOSFET guarantees similar efficiency at 100 kHz compared to a 1200V Si IGBT (+ SiC boost diode) at 25 kHz… And…..
Boost Inverter in detail

- Fully integrated and compact solution:
  - Power stage, aux. SMPS, controller, signal processing
- Main ST products:
  - SCT30N120 (1200V / 45A SiC MOSFET)
  - STPSC6H12B (1200V / 6A SiC Diode)
  - TD350ED (GapDrive also tested with equal results)
  - L5991D (current mode PWM controller)
- Optimized for 100kHz switching
- Board available to selected Customers

### Performance

<table>
<thead>
<tr>
<th>Input Voltage (VDC)</th>
<th>Output Power (W)</th>
<th>Heatsink Temperature (°C)</th>
<th>Total efficiency including AUX (%)</th>
<th>Total efficiency without AUX* (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>2094</td>
<td>57.5</td>
<td>99.11</td>
<td><strong>99.29</strong></td>
</tr>
</tbody>
</table>

* Efficiency of boost inverter itself (SiC MOSFET, SiC diodes and main choke)
And.....space/cost saving impact on inductor

- **Almost 50% less volume** *
- **30% lower Losses on Magnetic** *
- **60% lower Weight** *
- **Cost halved!!** *

(*) Study conducted by **F.E.EM Sas**, Italian company which manufactures Electric and Electromagnetic components on a 5kW Boost converter. Report available.

Overall System cost cheaper with SiC
SiC MOSFET price roadmap keeps improving year after year thanks to:

- Industrial maturity
- More competition among wafer suppliers
- 6” wafer
- Epi in house
- New techno generations

Epi in house
Conclusion:
Application areas of WBG in cars

- **Traction inverter**
  - Low Frequency Operation
  - High Power
  - High Thermal environment

- **DC/DC Converters**
  - On board Chargers
    - High Frequency
    - High Passive Content
    - Compactness
Conclusion: Application areas of WBG in cars

- **Traction inverter**
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  - High Power
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  - On board Chargers
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    - Compactness

- **Smaller cooling systems**
  - Smaller Power Modules

- **Smaller Passive components**
  - Light & compact systems
Merci  Grazzie  Thank you!

ST stands for  \textit{life.augmented}