Optimized 1200V αSiC MOSFETs for High System Efficiency

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AOS: Powering a Greener Future™
AOS able to provide optimal solution for customer
AOS Fabrication/Assembly

Shanghai A&T

Back End & Assembly

Oregon 8” Fab

300mm Wafer Fab

CQ JV: 12” Fab + A&T
AOS Silicon Carbide MOSFETs

- **AOS 1200V SiC MOSFETs**
  - Leveraging AOS position as leader in Si MOSFETs
  - Team has over 30 years SiC design/qualification experience
  - **Gen2: Most efficient SiC MOSFET**
  - State of the art 150mm wafers in IATF16949 qualified Fab

![SiC Technology Expansion](chart.png)

**SiC Technology Expansion**

- Market Size (\$M)
- **You are Here**

Source: IHS 2018

**150mm 1200V SiC Technology**
Years of development focused on developing the most efficient SiC Power Switch

- **Gate Oxide**
  - High Reliability
  - Optimized 15V drive
  - $V_{TH,typ} > 2.5V$

- **Drift**
  - Optimized Ron
  - > 1500V Avalanche

- **Gate**
  - Low $R_G$ for fast switching

- **Channel**
  - Low leakage
  - Low Ron vs T
  - Short circuit rugged

- **Body**
  - UIS Tested
  - Rugged Body Diode
  - Low VF Body Diode
SiC Materials Supply Chain

- Tier 1 SiC Materials Supply Chain
- Multiple sources for high volume / high quality SiC wafers
- **Multi-Year Wafer Supply Agreement**

SiC Supplier A
- Tier 1 Qualified Supplier

SiC Supplier B
- Tier 1 Supplier under qual

SiC Supplier C
- New suppliers under consideration
### AOS MOSFET vs. Competition

- Drive voltage compatible with IGBT drivers (-5 → 15V)

<table>
<thead>
<tr>
<th></th>
<th>AOS SiC MOS</th>
<th>PlanarA SiC MOS</th>
<th>PlanarB SiC MOS</th>
<th>PlanarC SiC MOS</th>
<th>TrenchA SiC Trench</th>
<th>TrenchB SiC Trench</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{DS,ON}$</td>
<td>70mΩ</td>
<td>75mΩ</td>
<td>75mΩ</td>
<td>80mΩ</td>
<td>80mΩ</td>
<td>60mΩ</td>
</tr>
<tr>
<td>$V_{DSS}$</td>
<td>1200V</td>
<td>1200V</td>
<td>1200V</td>
<td>1200V</td>
<td>1200V</td>
<td>1200V</td>
</tr>
<tr>
<td>$V_{TH,typ}$</td>
<td>2.6V</td>
<td>2.5V</td>
<td>3.2V</td>
<td>2.5V</td>
<td>2.8V</td>
<td>4.5V</td>
</tr>
<tr>
<td>$R_{DS,on 150C/25C}$</td>
<td>1.3X</td>
<td>1.3X</td>
<td>1.9X</td>
<td>1.4X</td>
<td>1.6X</td>
<td>1.7X</td>
</tr>
<tr>
<td>$R_G$</td>
<td>&lt;2</td>
<td>10</td>
<td>1</td>
<td>1.7</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>$C_{ISS (800V)}$</td>
<td>1460pF</td>
<td>1350pF</td>
<td>1230pF</td>
<td>1110pF</td>
<td>2080pF</td>
<td>1060pF</td>
</tr>
<tr>
<td>$C_{OSS (800V)}$</td>
<td>70pF</td>
<td>60pF</td>
<td>56pF</td>
<td>80pF</td>
<td>77pF</td>
<td>58pF</td>
</tr>
</tbody>
</table>

Ease of use
Ron vs. Temperature $\rightarrow$ AOS SiC has low Ron increase

- More efficient at higher temperature
- Reduced risk of thermal runaway
- Fastest SiC MOSFET with $V_{GS}=-5/+15\text{V}$ OR $V_{GS}=0/+15\text{V}$
- Comparison to “Best in Class” 15V drive VendorA and SiC Trench

![Graph showing switching energy vs. drain current](image)
### Efficiency Figure of Merit

#### Key Parameters
- **DC**
  - $R_{DS,ON}$: 75mΩ, 75mΩ, 75mΩ, 80mΩ, 80mΩ, 60mΩ

- **ON @150C**
  - 1.3X, 1.3X, 1.9X, 1.4X, 1.6X, 1.7X

#### AC Performance
- **Total Switching Energy (μJ)**
  - $V_{GS} = -5/+15$: 348μJ, 460μJ, 300μJ, 400+μJ, 741μJ, 274μJ
  - $V_{GS} = 0/18$: 348μJ, 460μJ, 300μJ, 400+μJ, 741μJ, 274μJ

- **Normalized Switching FOM**
  - 1X, 1.3X, 0.9X, 1.15X, 2.1X, 0.8X

- **FOM**
  - 1.3, 1.7, 1.7, 1.6, 3.4, 1.4
SiC Applications / Benefits

- SiC application benefits:
  - Lower $R_{on}$ vs Temp → Larger $R_{on}$ (smaller die) required for same $\eta$
  - Low $E_{off}$ / $E_{off}$ vs $I_D$ → High efficiency in LLC applications

### Automotive

- eV Inverter with SiC
  - 50% smaller
  - 50% reduced cooling loop
  - 5-10% increased range
  - Save 5-10% battery cost

- SiC OBC
  - Higher frequency/efficiency
  - Smaller / lighter
  - Saves system costs

- Charging Stations
  - Higher efficiency/reduced size
  - Reduced cooling requirements

### Industrial

- UPS Inverter
  - Higher efficiency
  - UPS continuously operating 24/7
  - Lower Operating Costs (TCO)

- Solar Inverter
  - Higher frequency / efficiency
  - 3-Level to 2-Level topology
  - Reduced BOM/shipping/operating
  - Lower Product and TCO

- Welding

- Motor Drive
Application Example 3kW Charger
System Information

- **System Picture**

<table>
<thead>
<tr>
<th>Topology</th>
<th>Input Range</th>
<th>Output</th>
<th>Max. Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boost + HB LLC</td>
<td>200Vdc ~ 880Vdc</td>
<td>27.5V</td>
<td>110A</td>
</tr>
</tbody>
</table>

Board Top View

Board Bottom View
AOS Solutions available depending on Voltage/Efficiency

- AOS αSiC MOSFET
- AOS αMOS SJ MOSFET
- AOS MV MOSFET

Diagram showing CCM Boost Stage and LLC/SRC Stage.
Low side switching waveform @600Vin 80A load

- Run in HB SRC mode, Fs=78.39KHz.
3kW SiC Charger Efficiency Comparison

- Competitor vs AOS Efficiency Over Output Load @600V Input

<table>
<thead>
<tr>
<th>Output Load current (A)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>94.50%</td>
</tr>
<tr>
<td>60</td>
<td>95.10%</td>
</tr>
<tr>
<td>80</td>
<td>95.70%</td>
</tr>
<tr>
<td>100</td>
<td>95.90%</td>
</tr>
</tbody>
</table>

- Competitor AOS AOK075V120X2
- Competitor B SiC
- Competitor C SiC
- Competitor D SiC
SiC oxide quality is key to reliability and long term performance

Lower SiC/SiO$_2$ barrier and traps lead to $V_{TH}$ drift

SiC Oxide defects lead to early failures and lower MTTF

*Chbili, NIST
SiC MOSFET Oxide Quality & Reliability

- KEY reliability metric for state-of-the-art SiC MOSFETs

1) MOSFETs show very low VTH drift during accelerated HTGB → stable application

2) MOSFETs have extremely low extrinsic defectivity → high reliability applications (auto)
# AOS αSiC Discrete MOSFET Schedule

<table>
<thead>
<tr>
<th>$R_{DS,ON}$ (TYP)</th>
<th>TO247-3L</th>
<th>TO247-4L</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20mΩ</td>
<td>Coming</td>
<td>Coming</td>
</tr>
<tr>
<td>40mΩ</td>
<td>Q2 2020</td>
<td>Q2 2020</td>
</tr>
<tr>
<td>70mΩ</td>
<td>Sampling Now</td>
<td>Q2 2020</td>
</tr>
<tr>
<td>160mΩ</td>
<td>TBD</td>
<td>-</td>
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</table>
### 1200V SiC Schottky Diode Specifications

<table>
<thead>
<tr>
<th>ID&lt;sub&gt;(TYP)&lt;/sub&gt;</th>
<th>TO247-3L</th>
<th>TO247-2L</th>
</tr>
</thead>
<tbody>
<tr>
<td>10A</td>
<td>-</td>
<td>Q2 2020</td>
</tr>
<tr>
<td>15A</td>
<td>-</td>
<td>Q2 2020</td>
</tr>
<tr>
<td>20A</td>
<td>Q1 2020</td>
<td>Q2 2020</td>
</tr>
<tr>
<td>30A</td>
<td>Q2 2020</td>
<td>-</td>
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</table>
THANK YOU!