Micro Deformation Technology – Applied to Liquid Cooling of Power Electronics

iMAPS 2010
MDT (micro deformation technology) is a new manufacturing method developed to enhance the surface of materials for heat transfer. This presentation will highlight MDT’s application in coldplates and baseplates for liquid cooling of power electronics.

In this presentation, Wolverine will demonstrate:

- The MDT process, its capability, and flexibility.
- MDT used in a coldplate application for a hybrid truck.
- Demonstration of MDT flexibility used to meet unique automotive flow requirements.
- Empirical comparison of aluminum MDT surfaces to a common lanced and offset fin.
- MDT applied directly to an IGBT module to increase direct cooling performance.
- Future uses for MDT.
Coldplate Vs Baseplate for Power Electronics

Standard IGBT module mounted to a coldplate

IGBT module mounted with a coldplate surface integrated into the baseplate
Typical Liquid Coldplate and Integrated Baseplate Manufacturing Methods

**Coldplate**
- Gun Drilling
- Die Casting
- Brazed folded fin
- Copper tube mated with Al plate

**Baseplate**
- Metal Injection Molding
- Forging
- Cast AlSiC
- Brazed on pins
MDT technology originated from tube surface enhancing technology

Enhanced Tube

Enhanced Flat Surface
MDT – Micro Deformation Technology

• Patented tooling and process.
• Work piece is cut, deformed and stretched by up to 150%.
• No loss of material during the fining operation.
• Fining is done without the addition of heat and can be done without lubrication if needed.
• Little tooling or setup required, similar to CNC machining.
MDT Flexibility

- **Fins per inch**: 650-8 (255-3 Fins/Centimeter)
- Fin thickness to fin gap ratio: 1:1 – 1:3
- Fin height to fin thickness ratio up to 15:1
- Max fin gap: 1.2mm +
- Pins can be formed in either an in-line or staggered pattern.
- Pin diameter and gap vary from 1mm to 0.5mm
- Pin height to diameter ratio up to 8:1
- Fins or pins can be applied over large surfaces up to 1X1 meter
- Fins or pins can be added in specific "island" locations or on across entire surface
- All of these options can be varied with little to no setup or tooling (a customer could easily try multiples of different fin or pin geometries with one fixture)

![Diagram of fin and pin array with labels for thickness (Thk) and gap.](image-url)

**Example**
- 150 fins per inch (60 f/cm) 1mm tall
- 12 fins per inch (5 f/cm) 5mm tall
MDT Geometry Options - Fins

### Common Fin Pitches

- 200 fpi = 0.0625mm thk
- 100 fpi = 0.125mm thk
- 50 fpi = 0.25mm thk
- 25 fpi = 0.5mm thk
- 12 fpi = 1.0mm thk

### Design Flexibility

- Fins can be created in both copper and aluminum
- Fins can have knife edge or be flat (see above)
- Fins can be straight or slightly curved (see above)
- Back-wall minimum thickness 1mm
- Fin thickness to gap normally 1:1 but can vary
MDT Geometry Options – Pins

- Pins can be staggered or in-line
- Pins can be created from 12 FPI to 200fpi, [20fpi (0.5mm) shown to the left]
- Pins can be created on both aluminum and copper.
- Pins can have pointed or flat tops (see above)
## MDT Material Options

<table>
<thead>
<tr>
<th>Copper</th>
<th>Aluminum</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>C110</td>
<td>1000 series</td>
<td>CuNi</td>
</tr>
<tr>
<td>C101</td>
<td>3000 series</td>
<td>Steel*</td>
</tr>
<tr>
<td>Most copper</td>
<td>6000 series*</td>
<td>Titanium*</td>
</tr>
<tr>
<td>alloys</td>
<td>7000 series*</td>
<td>Plastics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CTE materials**</td>
</tr>
</tbody>
</table>

* More difficult  
** Limited success with current materials but open to R&D of new materials
Major Development Effort for Class 8 HEV
• Program funding from US DOE – NREL
• Wolverine designed and tested the base plate
• Major thermal load: 12KW of heat loss
• Cooling 12 Infineon Prime Pack Modules
• Only base plate to meet thermal requirements
Class 8 HEV Truck Coldplate

- Flow-rate: 5 GPM @ 50 °C
- Die temps not to exceed 125 °C
- Coldplate surface temp not to exceed 76°C
- 1060W per IGBT

Needed to achieve less than a 26 deg C rise from the fluid to the max coldplate surface at 2000+ watts and only .83 GPM (thermal resistance less than 0.013C/W)
Class 8 HEV Truck Coldplate

Two geometries tried
- 25fpi 4mm tall straight fin
- 25fpi 4mm tall pin fin
Class 8 HEV Truck Coldplate

IGBT 2 Die Max Temp
- pin fin: 113.5
- fin: 123.9

Coldplate Max Temp
- pin fin: 70.9
- fin: 72.2

Thermal Performance
- Flow Rate (GPM)
- Thermal Resistance (°C/W)
- 4mm 25FPI, 4mm Pin Fin

Flow Performance
- Flow Rate (GPM)
- Pressure Drop (psig)
- 4mm 25FPI, 4mm in-line pin fin, 5mm density

Wolverine - MicroCool Confidential 2010
Automotive Baseplate - CFD fin and pin optimization

CFD analysis data comparing different fin structures to meet customer challenging requirements:

- Cool 92 W/cm² with a 20°C temp rise from the coolant to the coldplate surface
- Thermal resistance less than 0.12 c/w
- Maintain a pressure drop of less than 1.5psi (0.103 bar)
- Maintain a gap between the fins greater than 1mm to prevent particulates from blocking the flow channels

- 8 fins per in /w 90° x-cut
  - Fin height: 5 mm - 6mm
  - Fin thickness: 1 - 1.6 mm
  - Fin gap: 1 - 1.6 mm

- 10 fins per inch
  - Fin height: 5 mm
  - Fin thickness: 1.27 mm
  - Fin gap: 1.27 mm
Automotive Baseplate - Analysis Conditions

- 166 Watts per 15x12mm area (1000 W total)
- Heat flux: 92 w/cm²

Fin geometries used for this analysis
- Straight Fin 5mm Tall
- In line Pin Fin 5mm Tall
- In line Pin Fin 6mm Tall

Customer Requirements
- Pressure Drop less than 1.5psi
- Thermal resistance less than .12 c/w
- 1mm min fin gap

50/50 Ethylene-Glycol Water

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1027 kg/m³</td>
</tr>
<tr>
<td>Dynamic viscosity</td>
<td>0.00169 Pa*s</td>
</tr>
<tr>
<td>Specific heat (Cp)</td>
<td>3300 J/(kg*K)</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>0.388 W/(m*K)</td>
</tr>
</tbody>
</table>

20 deg C 50/50 EGW
Flow rates: 2, 3, 4, 5 & 6 L/min
**Automotive Baseplate - Results Summary**

**Straight Fin 5mm Tall**

<table>
<thead>
<tr>
<th>Flow Rate (l/min)</th>
<th>Pressure Drop (psi)</th>
<th>Max CP temp under IGBT 1 (°C)</th>
<th>Max CP temp under IGBT 2 (°C)</th>
<th>Max CP temp under IGBT 3 (°C)</th>
<th>Max CP temp under IGBT 4 (°C)</th>
<th>Max CP temp under IGBT 5 (°C)</th>
<th>Max CP temp under IGBT 6 (°C)</th>
<th>Thermal Resistance (°C/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.250</td>
<td>54.60</td>
<td>62.32</td>
<td>67.43</td>
<td>71.40</td>
<td>73.59</td>
<td>70.56</td>
<td>0.208</td>
</tr>
<tr>
<td>3</td>
<td>0.593</td>
<td>51.59</td>
<td>59.72</td>
<td>64.24</td>
<td>67.68</td>
<td>69.67</td>
<td>66.97</td>
<td>0.190</td>
</tr>
<tr>
<td>4</td>
<td>0.956</td>
<td>49.31</td>
<td>56.76</td>
<td>60.32</td>
<td>62.79</td>
<td>64.08</td>
<td>61.09</td>
<td>0.177</td>
</tr>
<tr>
<td>5</td>
<td>1.403</td>
<td>47.53</td>
<td>54.41</td>
<td>57.51</td>
<td>59.10</td>
<td>59.90</td>
<td>57.19</td>
<td>0.166</td>
</tr>
<tr>
<td>6</td>
<td>1.900</td>
<td>45.98</td>
<td>51.55</td>
<td>53.95</td>
<td>55.34</td>
<td>56.24</td>
<td>53.91</td>
<td>0.157</td>
</tr>
</tbody>
</table>

**In-Line Pin Fin 5mm Tall**

<table>
<thead>
<tr>
<th>Flow Rate (l/min)</th>
<th>Pressure Drop (psi)</th>
<th>Max CP temp under IGBT 1 (°C)</th>
<th>Max CP temp under IGBT 2 (°C)</th>
<th>Max CP temp under IGBT 3 (°C)</th>
<th>Max CP temp under IGBT 4 (°C)</th>
<th>Max CP temp under IGBT 5 (°C)</th>
<th>Max CP temp under IGBT 6 (°C)</th>
<th>Thermal Resistance (°C/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.649</td>
<td>43.58</td>
<td>44.95</td>
<td>47.06</td>
<td>48.93</td>
<td>50.66</td>
<td>52.48</td>
<td>0.142</td>
</tr>
<tr>
<td>3</td>
<td>1.327</td>
<td>41.01</td>
<td>41.88</td>
<td>43.39</td>
<td>44.73</td>
<td>45.85</td>
<td>47.29</td>
<td>0.127</td>
</tr>
<tr>
<td>4</td>
<td>2.234</td>
<td>39.48</td>
<td>40.13</td>
<td>41.28</td>
<td>42.36</td>
<td>43.23</td>
<td>44.34</td>
<td>0.117</td>
</tr>
<tr>
<td>5</td>
<td>3.339</td>
<td>38.44</td>
<td>38.96</td>
<td>39.93</td>
<td>40.82</td>
<td>41.53</td>
<td>42.44</td>
<td>0.111</td>
</tr>
<tr>
<td>6</td>
<td>4.655</td>
<td>37.69</td>
<td>38.13</td>
<td>38.97</td>
<td>39.69</td>
<td>40.28</td>
<td>41.05</td>
<td>0.107</td>
</tr>
</tbody>
</table>

**In-Line Pin Fin 6mm Tall**

<table>
<thead>
<tr>
<th>Flow Rate (l/min)</th>
<th>Pressure Drop (psi)</th>
<th>Max CP temp under IGBT 1 (°C)</th>
<th>Max CP temp under IGBT 2 (°C)</th>
<th>Max CP temp under IGBT 3 (°C)</th>
<th>Max CP temp under IGBT 4 (°C)</th>
<th>Max CP temp under IGBT 5 (°C)</th>
<th>Max CP temp under IGBT 6 (°C)</th>
<th>Thermal Resistance (°C/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1.498</td>
<td>39.15</td>
<td>40.11</td>
<td>41.53</td>
<td>42.49</td>
<td>43.26</td>
<td>44.21</td>
<td>0.115</td>
</tr>
</tbody>
</table>

* Thermal resistance is calculated from inlet temp to max surface temp under the first IGBT die divided by the power of one die (166W).
Automotive Baseplate - Contour Plots: In-Line Pin Fin 6mm Tall - 5l/min

Thermal Resistance: 0.115 c/w

- 6mm tall spiral pin fins, 8fpi
- Flush with cover
Automotive Baseplate - Contour Plots: In-Line Pin Fin 6mm Tall - 5l/min

Pressure Drop = 1.498 psi

Velocity: Under 2m/s
Aluminum Comparison of MicroCool® to Folded Fin

MicroCool Straight Fin
- 8 FPI
- 4mm tall
- 1.5mm fin
- 1.5mm gaps

MicroCool Staggered Pin
- 8 FPI
- 4mm tall
- 1.5mm fin
- 1.5mm gaps

MicroCool In-Line Pin
- 8 FPI
- 4mm tall
- 1.5mm fin
- 1.5mm gaps

Brazed Folded Fin
- 4mm tall
- Offset Folded Fin
- 0.05mm fin thickness
- 2mm min gap

Not Tested
Aluminum Comparison of MicroCool® to Folded Fin

Mock IGBT with 4 Cartridge heaters

TIM layer

Test Plate

Tub
• Coolant 50/50 EGW

• Differential pressure measurements include fittings and 6” of tubing

• Thermal resistance measurement:
  - Inlet coolant temperature minus the average of the 4 heater thermocouples, divided by the total power on the heater.
  - Thermal resistance included the thermal interface material.
Aluminum Comparison of MicroCool® to Folded Fin

- Embedded thermocouples
- 4X 250 watt cartridge heaters
Thermal Resistance *lower is better

- Aluminum Folded Fin
- MicroCool™ Aluminum Straight Fin 12fpi
- MicroCool™ Aluminum In-Line Pin Fin 8fpi

Flow Rate (l/min)

<table>
<thead>
<tr>
<th>Flow Rate</th>
<th>Thermal Resistance (C/W)</th>
<th>3X</th>
<th>2.2X</th>
<th>2.1X</th>
<th>2.7X</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.0597</td>
<td>0.0274</td>
<td>0.0198</td>
<td>0.0177</td>
<td>0.0169</td>
</tr>
<tr>
<td>4</td>
<td>0.0510</td>
<td>0.0241</td>
<td>0.0177</td>
<td>0.0169</td>
<td>0.0169</td>
</tr>
<tr>
<td>5</td>
<td>0.0455</td>
<td>0.0218</td>
<td>0.0169</td>
<td>0.0169</td>
<td>0.0169</td>
</tr>
</tbody>
</table>
Pressure Drop* (lower is better)

- Aluminum Folded Fin
- MicroCool™ Aluminum Straight Fin 12fpi
- MicroCool™ Aluminum In-Line Pin Fin 8fpi

<table>
<thead>
<tr>
<th>Flow Rate (l/min)</th>
<th>Pressure Drop (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.55</td>
</tr>
<tr>
<td>4</td>
<td>0.91</td>
</tr>
<tr>
<td>5</td>
<td>1.36</td>
</tr>
</tbody>
</table>

Pressure Drop: 3.13
Thermal Resistance per Pressure Drop

For the same amount of pressure drop the coldplates with MicroCool™ MDT surfaces have a much lower thermal resistance.

For example: At 1psi pressure drop the folded fin coldplate has a thermal resistance of about 0.049 C/W and for the same pressure drop the MicroCool Straight Fin has about 0.026 C/W thermal resistance. This is over 1.8X better, at a 1000W this equals a 23°C improvement at the same pressure drop.
Integrated Baseplate Testing

Comparison of an direct cooled IGBT with no baseplate enhancement vs. an enhanced copper baseplate.
Integrated Baseplate Testing

Coolant runs in 1.27mm channel under each IGBT. The IGBT’s are stock with no modification to the nickel plated copper baseplates.

O-rings seal IGBT baseplate to plastic tub using 4 IGBT mounting holes.
Integrated Baseplate Testing

**Iterations:**
1. Baseline with flat bottom IGBTs
2. 2mm tall fins 12 fins per inch
3. **2mm tall fins 25 fins per inch**
4. 4mm tall fins 25 fins per inch

- 396 watts on each 30x22mm area (3 locations on each IGBT)
- 1188 watts on each IGBT
- 3564 watts total
- 3.7gpm (1.23gpm under ea IGBT)
- 47.2 °C (117.4 ° F) water

IGBT (top plastic cover of IGBT not shown)

Plastic Tub

• 396 watts on each 30x22mm area (3 locations on each IGBT)
• 1188 watts on each IGBT
• 3564 watts total
Integrated Baseplate Testing

- By enhancing the baseplate with MDT the thermal resistance can be reduced by 59.4% with no increase in pressure drop.
- Empirical testing by customer showed a 29 deg C improvement with 2mm 25fpi.

*Thermal Resistance is defined as max baseplate temperature minus inlet fluid temperature divided by the power of one IGBT module (1188 Watts)
Integrated Baseplate Testing

Baseline: 87°C

2mm fin 12fpi: 71°C

2mm fin 25fpi: 65.9°C

4mm fin 25fpi: 63.3°C
Integrated Baseplate Testing

Baseline
Pressure Drop: 1.00 psi

2mm tall 12 FPI
Pressure Drop: 1.46 psi
Pre-made baseplate sent to IGBT manufacture

1. MicroCool™ produced MDT nickel plated copper baseplate

2. Sent to IGBT module manufacture for substrate attach and build up of module

3. Finished IGBT module with MDT baseplate
Pre-made baseplate w/ integrated cover sent to IGBT manufacture

1. MicroCool™ produced MDT nickel plated copper baseplate and cover brazed together to make a full coldplate.

2. Coldplate sent to IGBT module manufacture for substrate attach and build up of module.

3. Finished IGBT module with MDT Baseplate with integrated cover.

Stamping or machining copper cover

Brazing temp to attach cover must be higher than substrate die attach temp.
Future use of MDT

Liquid cooling at IGBT substrate level
Thank You