This application note describes the thermal composite flip chip ball-grid array (TCFCBGA) package for the Arria® V device family.

TCFCBGA improves board real-estate use by allowing closer spacing between passive components and the flip chip die, providing better warpage control for thin core substrates, and improving solder joint reliability.

This application note includes the following sections:

- “TCFCBGA Overview”
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- “Heat-Sink Attachment” on page 5
- “Device Reworkability” on page 8
- “Handling and Transfer” on page 10
- “Selecting Heat Sink for Small Heat Source” on page 10
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**TCFCBGA Overview**

TCFCBGA packages are designed to allow die protrusion over the mold cap. This feature ensures the thinnest band line and best thermal impedance between the flip chip die and the attached heat sink.

The TCFCBGA is produced in an exposed die configuration. This configuration maintains the excellent thermal performance of a bare die flip chip BGA and is enhanced by providing a support surface around the bare die for a direct heat-sink attachment.
Figure 1 and Figure 2 show the package construction and cross-section of the TCFCBGA.

**Figure 1. Package Construction of a TCFCBGA**

**Figure 2. Cross-Sectional View of an TCFCBGA Package**

**Note to Figure 2:**
(1) Build-up layers stack on both sides of the bismaleimide triazine (BT) core.
Die to Package Profile

To calculate the amount of thermal interface material type II (TIM II) for the heat-sink attachment, you must consider the height of the die above the package body. Figure 3 and Table 1 list the dimensions of the TCFCBGA package. For phase change materials (PCMs), thermal conductive tapes, and thermal gap fillers, make sure there is enough TIM II to cover the edge of the die. This practice protects the die edge from chipping or cracking.

Figure 3. Die to Package Profile

Table 1. Die to Package Dimensions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_{\text{edge}} )</td>
<td>35 µm</td>
<td>43 µm</td>
</tr>
<tr>
<td>( p_{\text{center}} )</td>
<td>46 µm</td>
<td>65 µm</td>
</tr>
<tr>
<td>( H )</td>
<td>109 µm</td>
<td>143 µm</td>
</tr>
<tr>
<td>( W )</td>
<td>2.5 mm</td>
<td>2.9 mm</td>
</tr>
</tbody>
</table>
Case Studies

The following sections describe the test cases for different combinations of heat-sink types and TIM IIs.

Simulated Data

This case study was set up to determine the heat sinks and TIM IIs for use with the thermal composite TCFCBGA. Altera simulated the thermal tests using the parameters in Table 2.

Table 2. Heat Sink and TIM II Simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test Case 1</th>
<th>Test Case 2</th>
<th>Test Case 3</th>
<th>Test Case 4</th>
<th>Test Case 5</th>
<th>Test Case 6</th>
<th>Test Case 7</th>
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<tbody>
<tr>
<td>Heat sink size (mm²)</td>
<td>40 x 40</td>
<td>40 x 40</td>
<td>40 x 40</td>
<td>40 x 40</td>
<td>40 x 40</td>
<td>40 x 40</td>
<td>50 x 50</td>
</tr>
<tr>
<td>Fin count</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Heat sink type</td>
<td>Non-mechanical attachment</td>
<td>Non-mechanical attachment</td>
<td>Non-mechanical attachment</td>
<td>Mechanical attachment, same body size</td>
<td>Mechanical attachment, same body size</td>
<td>Mechanical attachment, same body size</td>
<td>Mechanical attachment, larger body size</td>
</tr>
<tr>
<td>Fastener</td>
<td>Regular</td>
<td>Regular</td>
<td>Regular</td>
<td>Z-clips</td>
<td>Z-clips</td>
<td>Z-clips</td>
<td>Push pins</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Talon clips</td>
<td>Talon clips</td>
<td>Talon clips</td>
<td>Shoulder screw</td>
</tr>
<tr>
<td>Power (W)</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>TIM II</td>
<td>Epoxy</td>
<td>Epoxy</td>
<td>Epoxy</td>
<td>PCM</td>
<td>PCM</td>
<td>PCM</td>
<td>PCM</td>
</tr>
<tr>
<td>Interface loss (°C)</td>
<td>2.2</td>
<td>5.5</td>
<td>11</td>
<td>0.1</td>
<td>0.4</td>
<td>0.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Actual case temp (°C)</td>
<td>63.6</td>
<td>76.5</td>
<td>98.0</td>
<td>61.5</td>
<td>71.3</td>
<td>87.7</td>
<td>81.4</td>
</tr>
<tr>
<td>Case/Junction temp target (°C)</td>
<td>85.0</td>
<td>85.0</td>
<td>85.0</td>
<td>85.0</td>
<td>85.0</td>
<td>85.0</td>
<td>85.0</td>
</tr>
<tr>
<td>Difference (°C)</td>
<td>21.4</td>
<td>8.5</td>
<td>-13.0</td>
<td>23.5</td>
<td>13.7</td>
<td>-2.7</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Notes to Table 2:
(1) The case studies were conducted using a 40 mm x 40 mm TCFCBGA package with a representative die size of 13 mm x 14 mm, and an air flow of 200 ft/min.
(2) This study was based on a specific die size and air flow. Different conditions will produce different results. Contact your local Altera® sales office or sales representative for specific application needs.

Simulation Summary

Test cases 1, 2, and 3 use epoxy as TIM II with a non-mechanical heat-sink attachment.

- At 2 W to 5 W, the non-mechanical heat sink with epoxy is sufficient
- As power approaches and exceeds 10 watts, consider a mechanical attachment with heat sinks that are larger than package body size

Test cases 4, 5, and 6 use PCM as TIM II with a mechanical heat-sink attachment.

- At 2 W to 5 W, the mechanical attachment heat sinks with PCM is sufficient
- As power approaches and exceeds 10 watts, consider mechanical attachment with heat sinks that are larger than package body size
Test case 7 uses PCM as TIM II with a mechanical heat-sink attachment.

- The mechanical heat-sink attachment has a body size larger than the TCFCBGA package. This setup is sufficient to cool down the device for a high power operation.

Heat-Sink Attachment

There are two types of attachments for heat sinks: mechanical and non-mechanical. Figure 4, Figure 5, and Figure 6 show the different heat-sink attachments.

**Figure 4. Non-Mechanical Attachment Type**

- Regular heat sink with epoxy
- Regular heat sink with thermal tape

**Figure 5. Mechanical Attachment Type with Minimum Extra Space**

- Z-clips
- Talon clips
Non-mechanical heat-sink attachments are preferred if there are space constraints on the existing boards. There is no additional process of drilling holes on the PCB for locking pins. The TIM II associated with these non-mechanical heat-sink attachments are epoxy or thermal conductive tape. These TIM IIs usually have low conductivity.

Mechanical heat-sink attachments need extra space around the device for push pins or shoulder screws, although Z-clips and talon clips require less extra PCB space. The TIM II associated with these mechanical heat-sink attachments are PCM, thermal grease, and thermal gap filler. The conductivity of these TIM IIs are usually higher than epoxy and thermal conductive tape.

Although the case studies indicated that epoxy thermal performance is similar to PCM, heat sinks with non-mechanical attachments may damage the die. It is also more difficult to control the bond line thickness of epoxy with manual attachment, making it harder to control the thermal performance of the heat sinks.

Figure 7 and Figure 8 show the risk of die damage and poor thermal performance due to uneven heat sink placement for non-mechanical heat-sink attachment.
With mechanical heat-sink attachments, there is even force on all sides of the heat sink, resulting in an even bond line thickness of the TIM II and even dissipation of heat from the heat sink. Figure 9 shows the even compressive force on the heat-sink mount with mechanical attachment.

**Figure 8. Uneven Bond Line Thickness of TIM II**

![Image showing uneven bond line thickness]

**Figure 9. Mechanical Heat-Sink Attachment**

![Image showing mechanical heat-sink attachment]
Device Reworkability

Table 3 summarizes the reworkability of different combinations of heat sinks and TIM IIs.

<table>
<thead>
<tr>
<th>Heat Sink Type</th>
<th>TIM II Type</th>
<th>Application</th>
<th>Reworkability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-mechanical attachment</td>
<td>Epoxy</td>
<td>Difficult to control the bond line thickness. May not have optimal thermal performance.</td>
<td>High risk of damaging the device or PCB</td>
</tr>
<tr>
<td>Thermal conductive tape</td>
<td></td>
<td>Difficult to conform to the contours of the TCFCBGA package, as shown in Figure 3. May not have optimal thermal performance.</td>
<td>High risk of damaging the device or PCB</td>
</tr>
<tr>
<td>Mechanical attachment</td>
<td>PCM</td>
<td>Pre-cut to size. Conforms to contour of device</td>
<td>Easy to remove</td>
</tr>
<tr>
<td></td>
<td>Gap filler</td>
<td>Pre-cut to size. Conforms to contour of device. May not have optimal thermal performance</td>
<td>Easy to remove</td>
</tr>
<tr>
<td></td>
<td>Thermal grease</td>
<td>High performance, Conforms to contour of device. Pump-out concerns.</td>
<td>Easy to remove</td>
</tr>
</tbody>
</table>

Rework or Removal of Heat Sinks

To remove a heat sink attached with thermal conductive tape, perform the following steps:

1. Carefully insert the edge of a razor blade between the device and the heat sink. Avoid inserting the entire blade. You only need to create a narrow separation space.

2. Remove the blade and insert the spatula. Twist the spatula slowly to exert upward pressure on the package while moving it inward as the heat sink begins to separate. Avoid touching the die with the metal spatula.

3. To remove the remaining adhesive from the device surface, apply isopropyl alcohol on the remaining adhesive. After few seconds, wipe the adhesive away carefully.

4. Check for damage to the die edge.

Figure 10 shows the removal of the heat sink attached with thermal conductive tape.

Figure 10. Thermal Conductive Tape Removal
To remove a heat sink attached with epoxy, perform the following steps:

1. Pre-heat unit uniformly in an oven to 115° C – 120° C.

2. Insert the spatula between the heat sink and PCB. Twist the spatula slowly to exert upward pressure. The heat sink will separate from package immediately. Avoid touching the die with the metal spatula.

   Ease of removal is temperature sensitive.

3. Use a sharp single-edge razor blade to carefully remove the cured acrylic from the die area.

4. Allow the device to cool to room temperature before cleaning with isopropyl alcohol.

5. Check for damage to the die edge.

   Figure 11 shows the removal of the heat sink attached with epoxy.

Figure 11. Epoxy Removal

To remove a heat sink attached with PCM or thermal gap filler, perform the following steps:

1. Remove push pins or clips holding the mechanically attached heat sink.

2. Insert a single-edge razor blade into the TIM II bond line between the heat sink and the component.

3. Slowly twist the blade forward with an upward tilt force until the surfaces are separated.

4. Use a sharp single-edged razor blade to carefully remove cured PCM from the die area before cleaning with isopropyl alcohol.

5. Check for damage to the die edge.

   Do not use a heat gun to remove heat sinks with mechanical or non-mechanical attachments. The high temperature from the heat gun may cause delamination to the underfill of the TCFCBGA device, destroying the device in the process.
Handling and Transfer

TCFCBGA devices must be handled with great care at all times. They should remain secure in their TCFCBGA tray carriers except during transfer operations from tray to tray. You must use the correct TCFCBGA trays specified for the size and pin count of the thermal composite TCFCBGA. Table 4 lists the TCFCBGA tray specifications for the different TCFCBGA packages.

Do not use tweezers of any form to pick up the TCFCBGA device. Tweezers can cause mechanical damage to the die, whether as scratches to the top of the die or to the bulk silicon in the form of chipped-outs, micro-cracks, or cracks. Altera recommends you manually handle the devices using suitable design tools such as vacuum pencils with rubberized tips for pick-ups.

You must use a soft silicon or rubber tip for automated pick and place machines. The pick and place pressure must be minimized to prevent damage to the die area of the device.

If you must replace the existing solder balls of the device, use the right fixture to prevent the die chipping on the device.

Table 4. TCFCBGA Tray Specifications

<table>
<thead>
<tr>
<th>Package Size (Pin Count)</th>
<th>Tray Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 mm x 27 mm (F672)</td>
<td>Daewon 125-2727-919</td>
</tr>
<tr>
<td>29 mm x 29 mm (F780)</td>
<td>Daewon 1F1-2929-C19</td>
</tr>
<tr>
<td>31 mm x 31 mm (F896)</td>
<td>Kostat KS-880120</td>
</tr>
<tr>
<td>35 mm x 35 mm (F1152)</td>
<td>Daewon 125-3535-919</td>
</tr>
<tr>
<td>40 mm x 40 mm (F1517)</td>
<td>Kostat KS-886H</td>
</tr>
</tbody>
</table>

Selecting Heat Sink for Small Heat Source

It is difficult to cool a smaller heat source because the heat sink’s base material resists the spreading of the heat, through the base, to the outer fins. Figure 12 shows an aluminum heat sink with a small heat source.

Current Altera devices that are small heat sources are the lidless FBGA and the TCFCBGA.

Figure 12. Small Heat Source with Aluminium Heat Sink
To spread the heat from a small heat source to the entire base, some heat sink vendors offer efficient and reliable copper embedded heat sinks. Figure 13 shows a copper embedded heat sink. For a list of TIM II, heat sink, and TCFCBGA tray vendors, refer to “Vendors List” on page 14.

**General Properties of TIM II**

Altera recommends you consider early in your design what type of suitable TIM II to use. TIM IIs can be the limiting factors in the expense of thermal management designs. You can use TIM II effectively to help reduce the size of the heat sinks and the need for larger cooling fans. The extended benefit of an effective TIM II is a solution that is faster, easier to apply, and less costly than changing heat sinks or redesigning a chassis.

Several material solutions exist that can perform the functions of a TIM II—adhesives, grease, gels, PCMs, and pads. There are advantages and disadvantages associated with each of these TIM II solutions.

**Thermal Adhesives or Epoxies**

Thermal adhesives are particle-laden, one- or two-component materials that are applied via dispensing or stencil printing. Adhesives are cured to allow for cross-linking of the polymer, which provides the adhesive property. Thermal adhesives are advantageous because they provide structural support, eliminating the need for mechanical clamping.

The disadvantages of using thermal adhesives or epoxies include the following:

- They may not provide sufficient bond strength because of the small contact area
- The relative high impedance will affect the thermal performance significantly
- Device rework is very difficult and may result in damaging the device
Thermal Conductive Tapes

Thermally conductive adhesive tapes are convenient for heat-sink attachments with mid-range thermal performance. They eliminate the need for mechanical clamping.

The disadvantages of using thermal conductive tapes include the following:

- Thermal conductive tape works best on flat surfaces. Plastic ICs are usually concave in the center and heat-sink surfaces may vary. This unevenness can result in air gaps in the interface.
- May not be able to fill up all the gaps because of the contours of the TCFCBGA (See Figure 3 on page 3). This can result in air gaps in the interface.
- Device rework is very difficult and may result in damaging the device.
- Heat sinks may come off over time because of the heat and weight of the heat sinks for PCBs that are mounted vertically.

Thermal Grease

Thermal grease contains silicone oils that are loaded with thermally conductive filler. Thermal grease does not require curing and it flows and conforms to surfaces. It also offers a reworkable thermal interface layer. Thermal grease requires mechanical clamping.

A disadvantage of using thermal grease is that it can degrade, pump-out, or dry out during extended operation and over time, causing the thermal performance of the TIM II system using the grease to suffer significantly.

Thermal Gels

Thermal gels are low modulus, paste-like materials that are lightly cross-linked. They perform like grease with respect to their ability to conform to surfaces, while reducing material pump-out. Thermal gels require mechanical clamping.

PCMs

PCMs undergo a transition from a solid to a semi-solid phase with the application of heat and pressure. The material is in a liquid phase at die-operating conditions. PCMs offer several advantages, including the ability to conform to the mating surfaces and no curing is needed. PCMs require mechanical clamping.

Thermal Pads

Thermal pads are fabricated by molding non-reinforced silicone with conductive fillers. Reinforcements for thermal pads can include woven glass, metal foils, and polymer films. Thermal pads are pre-cut and offer gap-filling functionality. They have limited thermal performance and are pressure sensitive. Thermal pads require mechanical clamping.
Compression During Heat Sink Attachments

- Altera’s recommendation for constant compressive load on the packages with eutectic SnPb balls:
  - 3g per solder ball for 0.5mm pitch MBGA package
  - 6g per solder ball for 0.8mm pitch UBGA package
  - 8g per solder ball for 1mm pitch FBGA package
  - 12g per solder ball for 1.27mm pitch BGA package

- For SAC solder balls, customers can use the following constant compressive loads in use:
  - 7g per solder ball for 0.5mm pitch MBGA package
  - 12g per solder ball for 0.8mm pitch UBGA package
  - 16g per solder ball for 1mm pitch FBGA package
  - 24g per solder ball for 1.27mm pitch BGA package

- For heat-sink application, Altera’s recommendation is to not exceed 20g load per solder ball.

- Typical TIM2 vendor recommendation is to apply a 50 psi load during TIM2 curing.

Table 5 lists the TIM IIIs recommended by Altera TIM II vendors. Typical application recommendations are based on factors such as gap-filling capability, conductivity of materials, compatibility with molding compound, and ease of use.

Table 5. TIM IIls Recommended for the TCFCBGA Package (1)

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Product</th>
<th>Type</th>
<th>Conductivity</th>
<th>Format</th>
<th>Typical Application</th>
</tr>
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<tbody>
<tr>
<td>Laird Technologies</td>
<td>Tpcm 780</td>
<td>Phase change</td>
<td>5.5 W/m*K</td>
<td>Pad</td>
<td>Desktop and laptop PCs</td>
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<tr>
<td>Laird Technologies</td>
<td>Tpcm 780SP</td>
<td>Phase change</td>
<td>5.5 W/m*K</td>
<td>Liquid</td>
<td>Desktop and laptop PCs</td>
</tr>
<tr>
<td>Laird Technologies</td>
<td>Tpcm 580</td>
<td>Phase change</td>
<td>3.8 W/m*K</td>
<td>Pad</td>
<td>CPUs, custom ASIC, GPUs</td>
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<tr>
<td>Laird Technologies</td>
<td>Tgrease 980</td>
<td>Thermal grease</td>
<td>3.8 W/m*K</td>
<td>Grease</td>
<td>CPUs, custom ASIC, GPUs</td>
</tr>
<tr>
<td>Laird Technologies</td>
<td>Tgrease 880</td>
<td>Thermal grease</td>
<td>3.1 W/m*K</td>
<td>Grease</td>
<td>CPUs, custom ASIC, GPUs</td>
</tr>
<tr>
<td>Laird Technologies</td>
<td>Tgrease 2500</td>
<td>Thermal grease</td>
<td>3.8 W/m*K</td>
<td>Paste</td>
<td>High performance CPUs and GPUs</td>
</tr>
<tr>
<td>Bergquist</td>
<td>3500S35</td>
<td>Gap filler (2 parts)</td>
<td>3.6 W/m*K</td>
<td>Pad</td>
<td>PCBA to housing</td>
</tr>
<tr>
<td>Chomerics</td>
<td>T777</td>
<td>Phase change</td>
<td>3.5 W/m*K</td>
<td>Pad</td>
<td>CPUs, GPUs, chipsets</td>
</tr>
<tr>
<td>Chomerics</td>
<td>976</td>
<td>Gap filler</td>
<td>3.0 W/m*K</td>
<td>Pad</td>
<td>CPUs, GPUs, chipsets</td>
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<td>Chomerics</td>
<td>579</td>
<td>Gap filler</td>
<td>1.5 W/m*K</td>
<td>Pad</td>
<td>CPUs, GPUs, chipsets</td>
</tr>
<tr>
<td>Chomerics</td>
<td>T411</td>
<td>Thermal tape</td>
<td>0.5 W/m*K</td>
<td>Tape</td>
<td>CPUs, GPUs, chipsets</td>
</tr>
<tr>
<td>Laird Technologies</td>
<td>T Flex HR600</td>
<td>Gap filler</td>
<td>3.0 W/m*K</td>
<td>Pad</td>
<td>Cooling to chassis, frames</td>
</tr>
<tr>
<td>Laird Technologies</td>
<td>T Flex HR400</td>
<td>Gap filler</td>
<td>1.8 W/m*K</td>
<td>Pad</td>
<td>Cooling to chassis, frames</td>
</tr>
</tbody>
</table>

Note to Table 5:
(1) When applying TIM II to heat sink and package, make sure that there is enough TIM II to cover the edges of the die to prevent the die from chipping or cracking.
Vendors List

The following lists contains recommended TIM II vendors:
■ Laird Technologies (www.lairdtech.com)
■ Chomerics (www.chomerics.com)
■ The Bergquist Company (www.bergquistcompany.com)
■ 3M (www.3m.com)
■ ShinEtsu MicroSi (www.microsi.com)

The following lists contains recommended heat sink vendors:
■ Alpha Company (www.alphanovatech.com)
■ Malico (www.malico.com.tw)
■ Aavid Thermalloy (www.aavidthermalloy.com)
■ Radian Heatsinks (www.radianheatsinks.com)

The following lists contains recommended TCFCBGA tray vendors:
■ Daewon (www.daewonspic.com)
■ Kostat (www.kostat.com)

Document Revision History

Table 6 lists the revision history for this document.

<table>
<thead>
<tr>
<th>Date</th>
<th>Version</th>
<th>Changes</th>
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<tr>
<td>November 2017</td>
<td>1.4</td>
<td>Added recommendations for new packages in the Compression During Heat Sink Attachments section.</td>
</tr>
<tr>
<td>June 2016</td>
<td>1.3</td>
<td>Updated the Compression During Heat Sink Attachments section.</td>
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<tr>
<td>August 2014</td>
<td>1.2</td>
<td>Updated Compression During Heat Sink Attachments section.</td>
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<tr>
<td>July 2012</td>
<td>1.1</td>
<td>■ Updated FCmBGA to thermal composite flip chip ball-grid array (TCFCBGA).</td>
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<td></td>
<td></td>
<td>■ Added note to Figure 2.</td>
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<tr>
<td>January 2012</td>
<td>1.0</td>
<td>Initial release.</td>
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