

US Patent & Trademark Office

Patent Public Search | Text View

United States Patent Application Publication

20250260339

Kind Code

A1

Publication Date

August 14, 2025

Inventor(s)

Choi; Edward

SYSTEMS AND METHODS FOR AN INTERLOCKING FEATURE ON A POWER MODULE

Abstract

A system includes a power module, wherein the power module includes an interlocking feature on a first surface of the power module; and at least one heat sink, wherein the surface of the at least one heat sink includes a layer of thermal interface material.

Inventors: Choi; Edward (Lake Orion, MI)

Applicant: BorgWarner US Technologies LLC (Wilmington, DE)

Family ID: 1000008561372

Assignee: BorgWarner US Technologies LLC (Wilmington, DE)

Appl. No.: 19/193058

Filed: April 29, 2025

Related U.S. Application Data

parent US continuation 18159449 20230125 parent-grant-document US 12316257 child US 19193058

us-provisional-application US 63377486 20220928

us-provisional-application US 63377501 20220928

us-provisional-application US 63377512 20220928

us-provisional-application US 63378601 20221006

Publication Classification

Int. Cl.: H02M7/5387 (20070101); B60L3/00 (20190101); B60L15/00 (20060101); B60L15/08 (20060101); B60L15/20 (20060101); B60L50/40 (20190101); B60L50/51 (20190101); B60L50/60 (20190101); B60L50/64 (20190101); B60L53/20 (20190101); B60L53/22

(20190101); **B60L53/62** (20190101); **B60R16/02** (20060101); **G01R15/20** (20060101); **G06F1/08** (20060101); **G06F13/40** (20060101); **H01L21/48** (20060101); **H01L23/00** (20060101); **H01L23/15** (20060101); **H01L23/367** (20060101); **H01L23/373** (20060101); **H01L23/40** (20060101); **H01L23/467** (20060101); **H01L23/473** (20060101); **H01L23/495** (20060101); **H01L23/538** (20060101); **H01L25/00** (20060101); **H01L25/07** (20060101); **H02J7/00** (20060101); **H02M1/00** (20070101); **H02M1/08** (20060101); **H02M1/084** (20060101); **H02M1/088** (20060101); **H02M1/12** (20060101); **H02M1/32** (20070101); **H02M1/42** (20070101); **H02M1/44** (20070101); **H02M3/335** (20060101); **H02M7/00** (20060101); **H02M7/537** (20060101); **H02M7/5395** (20060101); **H02P27/06** (20060101); **H02P27/08** (20060101); **H02P29/024** (20160101); **H02P29/68** (20160101); **H03K19/20** (20060101); **H05K1/14** (20060101); **H05K1/18** (20060101); **H05K5/02** (20060101); **H05K7/20** (20060101); **H10D64/01** (20250101)

U.S. Cl.:

CPC **H02M7/5387** (20130101); **B60L3/003** (20130101); **B60L15/007** (20130101); **B60L15/08** (20130101); **B60L50/40** (20190201); **B60L50/51** (20190201); **B60L50/60** (20190201); **B60L50/64** (20190201); **B60L53/20** (20190201); **B60L53/22** (20190201); **B60L53/62** (20190201); **B60R16/02** (20130101); **G01R15/20** (20130101); **G06F1/08** (20130101); **G06F13/4004** (20130101); **H01L21/4882** (20130101); **H01L23/15** (20130101); **H01L23/3672** (20130101); **H01L23/3675** (20130101); **H01L23/3735** (20130101); **H01L23/4006** (20130101); **H01L23/467** (20130101); **H01L23/473** (20130101); **H01L23/49562** (20130101); **H01L23/5383** (20130101); **H01L24/32** (20130101); **H01L24/33** (20130101); **H01L25/072** (20130101); **H01L25/50** (20130101); **H02J7/0063** (20130101); **H02M1/0054** (20210501); **H02M1/08** (20130101); **H02M1/084** (20130101); **H02M1/088** (20130101); **H02M1/123** (20210501); **H02M1/32** (20130101); **H02M1/322** (20210501); **H02M1/327** (20210501); **H02M1/4258** (20130101); **H02M1/44** (20130101); **H02M7/003** (20130101); **H02M7/537** (20130101); **H02M7/53871** (20130101); **H02M7/53875** (20130101); **H02M7/5395** (20130101); **H02P27/06** (20130101); **H02P27/08** (20130101); **H02P27/085** (20130101); **H02P29/024** (20130101); **H02P29/027** (20130101); **H02P29/68** (20160201); **H05K1/145** (20130101); **H05K1/181** (20130101); **H05K1/182** (20130101); **H05K5/0247** (20130101); **H05K7/20154** (20130101); **H05K7/2039** (20130101); **H05K7/2049** (20130101); **H05K7/20854** (20130101); **H05K7/209** (20130101); **H05K7/20927** (20130101); **H10D64/018** (20250101); **B60L15/20** (20130101); **B60L2210/30** (20130101); **B60L2210/40** (20130101); **B60L2210/42** (20130101); **B60L2210/44** (20130101); **B60L2240/36** (20130101); **G06F2213/40** (20130101); **H01L2023/405** (20130101); **H01L2023/4087** (20130101); **H01L2224/32225** (20130101); **H01L2224/32245** (20130101); **H01L2224/33181** (20130101); **H02J2207/20** (20200101); **H02M1/0009** (20210501); **H02M3/33523** (20130101); **H02P2207/05** (20130101); **H03K19/20** (20130101); **H05K2201/042** (20130101); **H05K2201/10166** (20130101)

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION(S) [0001] This application claims the benefit of priority to U.S. patent application Ser. No. 18/159,449, filed Jan. 25, 2023; which claims priority to U.S. Provisional Patent Application No. 63/377,486, filed Sep. 28, 2022, U.S. Provisional Patent Application No. 63/377,501, filed Sep. 28, 2022, U.S. Provisional Patent

TECHNICAL FIELD

[0002] Various embodiments of the present disclosure relate generally to power modules, and more specifically, to systems and methods for providing Bond-Line-Thickness (BLT) control and an interlocking feature on a power module to, e.g., facilitate aligning the power module with one or more heat sinks during an assembly process.

INTRODUCTION

[0003] The power module is one of the key components in a traction inverter for controlling performance and/or efficiency of a driving system. A critical aspect for performance and reliability stems from the correct Bond-Line-Thickness Control of TIM (Thermal-Interface-Material) and from the correct placement of the power module on the heat sink in a manner that creates a strong bonding integrity between the power module and heat sink.

SUMMARY OF THE DISCLOSURE

[0004] In some aspects, the techniques described herein relate to a system including: a power module, wherein the power module includes an interlocking feature on a first surface of the power module; and at least one heat sink, wherein the surface of the at least one heat sink includes a layer of thermal interface material.

[0005] In some aspects, the techniques described herein relate to a system, wherein the power module includes the first interlocking feature on a second surface of the power module, wherein the second surface is separated from the first surface by a width of the power module.

[0006] In some aspects, the techniques described herein relate to a system, wherein the interlocking feature is a protruding interlocking feature.

[0007] In some aspects, the techniques described herein relate to a system, wherein the surface of the at least one heat sink is a flat surface.

[0008] In some aspects, the techniques described herein relate to a system, wherein the layer of thermal interface material includes thermal tapes, gels, thermal epoxies, solders, greases, gap-filled pads, and phase change materials.

[0009] In some aspects, the techniques described herein relate to a system, wherein the first surface and second surface include an epoxy mold compound or a copper layer.

[0010] In some aspects, the techniques described herein relate to a system, wherein the first interlocking feature on the first surface or second surface mates with the surface of the at least one heat sink to form a gap between the first surface or second surface of the power module and the surface of the at least one heat sink.

[0011] In some aspects, the techniques described herein relate to a system, wherein the gap between the first surface or second surface of the power module and the surface of the at least one heat sink is filled with thermal interface material.

[0012] In some aspects, the techniques described herein relate to a system, wherein the thermal interface material extends across an area of the at least one heat sink where the first interlocking feature on the power module does not mate with the surface of the at least one heat sink.

[0013] In some aspects, the techniques described herein relate to a system, wherein the at least one heat sink includes an inlet port or an outlet port.

[0014] In some aspects, the techniques described herein relate to a system including: a power module, wherein the power module includes a first interlocking feature on a first surface of the power module; and at least one heat sink, wherein the at least one heat sink includes a second interlocking feature on a surface of the at least one heat sink, wherein the first interlocking feature includes a height greater than a depth of the second interlocking feature, and wherein the surface of the at least one heat sink includes a layer of thermal interface material.

[0015] In some aspects, the techniques described herein relate to a system, wherein the power

module includes the first interlocking feature on a second surface of the power module, wherein the second surface is separated from the first surface by a width of the power module.

[0016] In some aspects, the techniques described herein relate to a system, wherein the first interlocking feature is a protruding interlocking feature.

[0017] In some aspects, the techniques described herein relate to a system, wherein the second interlocking feature is a recessed interlocking feature.

[0018] In some aspects, the techniques described herein relate to a system, wherein the recessed interlocking feature is a blind cavity.

[0019] In some aspects, the techniques described herein relate to a system, wherein the first interlocking feature on the first surface or second surface mates with the second interlocking feature on the surface of the at least one heat sink to form a gap between the first surface or second surface of the power module and the surface of the at least one heat sink.

[0020] In some aspects, the techniques described herein relate to a system claim **16**, wherein the gap between the first surface or second surface of the power module and the surface of the at least one heat sink is filled with thermal interface material.

[0021] In some aspects, the techniques described herein relate to a system, wherein the thermal interface material extends across an area of the surface of the at least one heat sink where the first interlocking feature on the power module does not mate with the second interlocking feature on the at least one heat sink.

[0022] In some aspects, the techniques described herein relate to a system, wherein the at least one heat sink includes an inlet port or an outlet port.

[0023] In some aspects, the techniques described herein relate to a system, wherein the first surface and second surface include an epoxy mold compound or a copper layer.

[0024] Additional objects and advantages of the disclosed embodiments will be set forth in part in the description that follows, and in part will be apparent from the description, or may be learned by practice of the disclosed embodiments. The objects and advantages of the disclosed embodiments will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

[0025] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the disclosed embodiments, as claimed.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate various exemplary embodiments and together with the description, serve to explain the principles of the disclosed embodiments.

[0027] FIG. **1** depicts an exemplary system infrastructure for a vehicle including a traction inverter, according to one or more embodiments.

[0028] FIG. **2A** and FIG. **2B** depict a side view of an exemplary system of interlocking features on a power module and heat sinks, according to embodiments of the present disclosure.

[0029] FIG. **3A** and FIG. **3B** depict another embodiment of the exemplary system of interlocking features on a power module and heat sinks.

[0030] FIG. **4A** and FIG. **4B** depict another embodiment of the exemplary system of interlocking features on a power module and heat sinks.

[0031] FIG. **5A** and FIG. **5B** depict another embodiment of the exemplary system of interlocking features on a power module and heat sinks.

[0032] FIG. **6** depicts an exemplary method for aligning interlocking features on a heat sink to

interlocking features on a power module.

DETAILED DESCRIPTION OF EMBODIMENTS

[0033] Both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the features, as claimed. As used herein, the terms “comprises,” “comprising,” “has,” “having,” “includes,” “including,” or other variations thereof, are intended to cover a non-exclusive inclusion such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements, but may include other elements not expressly listed or inherent to such a process, method, article, or apparatus. In this disclosure, unless stated otherwise, relative terms, such as, for example, “about,” “substantially,” and “approximately” are used to indicate a possible variation of $\pm 10\%$ in the stated value. In this disclosure, unless stated otherwise, any numeric value may include a possible variation of $\pm 10\%$ in the stated value.

[0034] The terminology used below may be interpreted in its broadest reasonable manner, even though it is being used in conjunction with a detailed description of certain specific examples of the present disclosure. Indeed, certain terms may even be emphasized below; however, any terminology intended to be interpreted in any restricted manner will be overtly and specifically defined as such in this Detailed Description section. For example, in the context of the disclosure, the power module may be described as a device, but may refer to any device for controlling the flow of power in an electrical circuit. For example, a power module may be a metal-oxide-semiconductor field-effect transistor (MOSFETs), bipolar junction transistor (BJTs), insulated-gate bipolar transistor (IGBTs), or relays, for example, or any combination thereof, but are not limited thereto.

[0035] An interlocking feature, as described herein, on a power module and/or heat sink may eliminate the tools required, during packaging assembly, for ensuring the correct placement of a power module on a heat sink. In addition, the interlocking feature may provide for an increase in the strength of bonding integrity between a power module and a heat sink. The increase in strength provided by the interlocking feature may reduce failure or cracking on a power module by creating strong interlocking bonding and tight control of bond line thickness.

[0036] Turning now to FIG. 1, there is depicted an exemplary system infrastructure for a vehicle including traction inverter **102**, according to one or more embodiments of the present disclosure. Electric vehicle **100** may include traction inverter **102**, drive motor **106**, battery **110**, and connectors **104** connecting the inverter **102** and battery **110**. Traction inverter **102** may include components to receive electrical power from an external source and output electrical power to charge battery **110** of electric vehicle **100**. Traction inverter **102**, through the use of a power module, may convert DC power from battery **110** in electric vehicle **100** to AC power, to power motor **106** and wheels **108** of electric vehicle **100**, for example, but the embodiments are not limited thereto. The power module may be bidirectional, and may convert DC power to AC power, or convert AC power to DC power, such as during regenerative braking, for example. Traction inverter **102** may be a three-phase inverter, a single-phase inverter, or a multi-phase inverter.

[0037] FIGS. 2A and 2B depict a side view of system **200**, which may include power module **202**, first heat sink **204**, second heat sink **206**, protruding interlocking features **208**, recessed interlocking features **210** and **212**, and thermal interface materials **222** and **224**. System **200** may include power module **202** where first heat sink **204** may be located above first surface **218** (e.g., a top surface **218**) of power module **202** and second heat sink **206** may be located beneath second surface **220** (e.g., a bottom surface **220**) of power module **202**. The power module **202** may include a plurality of protruding interlocking features **208**. Protruding interlocking features **208** may include any suitable shape, geometry and configuration. For example, in some embodiments, protruding interlocking features **208** may actually be replaced with recesses configured to receive corresponding mating protrusions on heat sinks **204**, **206**. As shown in FIG. 2A, however, in one embodiment, protruding interlocking features **208** include a plurality of protrusions on top surface

218 where the protruding interlocking features **208** include of extensions of top surface **218**. Power module **202** may also include a plurality of protruding interlocking features **208** on bottom surface **220** of power module **202** where protruding interlocking features **208** include of extensions of bottom surface **220**.

[0038] The protruding interlocking features **208** may include any suitable size, shape, or configuration. Moreover, though FIG. 2A depicts only two protruding interlocking features **208** on each of top surface **218** and bottom surface **220**, those of ordinary skill in the art will understand that any suitable number of protruding interlocking features **208** are within the scope of the embodiments described herein. Indeed, as shown in FIG. 3A, alternative embodiments may include, e.g., four protruding interlocking features, as described in detail below. Still further, the number, size, or configuration of the protruding interlocking features **208** on top surface **218** may be the same as, or differ in one more aspects from, the protruding interlocking features **208** on bottom surface **220**. Furthermore, one or more of the protruding interlocking features **208** may include any suitable material known in the art, including, but not limited to, copper, aluminum, or an alloy of copper and aluminum. Each of the protruding interlocking features **208** may be made of the same material composition, or one or more interlocking features **208** may include a material composition that differs from the material composition other protruding interlocking features **208**.

[0039] In another implementation, only one side of power module **202** may include a plurality of protruding interlocking features **208**. For instance, the top surface **218** of the power module may comprise of a plurality of protruding interlocking features **208** but bottom surface **220** of power module **202** may include a flat surface.

[0040] The plurality of protruding interlocking features **208** may all be located at an equal distance from the edges of power module **202**. For example, one of the plurality of protruding interlocking features **208** may be located, e.g., approximately 2 mm from first edge **226** of power module and one of the other plurality of protruding interlocking features **208** may be located, e.g., approximately 2 mm from a second edge **228** of power module **202**. In another implementation, the location of protruding interlocking features **208** from first edge **226** and second edge **228** of the power module **202** may differ in comparison to each other. For instance, one of the plurality of protruding interlocking features **208** may be located, e.g., approximately 3 mm from first edge **226** of power module **202** while one of the other protruding interlocking features **208** may be located, e.g., approximately 5 mm from second edge **228** of power module **202**.

[0041] Power module **202** may include, e.g., an approximately 800-Volt Silicon Carbide Inverter (e.g., for electrified vehicles), although other suitable structures and uses also are contemplated. Power module **202** may include one or more silicon carbide (SiC)-based power modules that deliver relatively high power densities and efficiencies needed to extend battery range and performance. Power module **202** may contain circuitry and components configured to convert direct current (DC) from the electric vehicle battery to alternating current (AC) current, which can be utilized within the electric motor that drives the propulsion system. Power module **202** may be installed on one or more power board assemblies. Power module **202** may include a combination of transistors, diodes, metal oxide semiconductor field effect transistors (MOSFETs), insulated-gate bipolar transistors (IGBTs), and silicon-controlled rectifiers (SCRs). Power module **202** may include a combination of transistors configured to both a half-bridge and H-bridge configuration, which may allow for the switch ability of the direction of the current through a motor from a single voltage power supply. Additionally, Power module **202** may also include up to six transistors for inverting applications such as switching direct current electricity into alternating current.

[0042] First heat sink **204** may include a plurality of recessed interlocking features **210** on surface **216**, where the recessed interlocking features **210** include a blind cavity in surface **216**. Second heat sink **206** may also include a plurality of recessed interlocking features **212** on surface **214**, where the recessed interlocking features include a blind cavity in surface **214**.

[0043] Recessed interlocking features **210** and **212** may include any suitable size, shape, or

configuration. Moreover, though FIG. 2A depicts only two recessed interlocking features **210** and **212** on each of surface **216** of first heat sink **204** and surface **214** of second heat sink **206**, those of ordinary skill in the art will understand that any suitable number of recessed interlocking features **210** and **212** are within the scope of the embodiments described herein. Indeed, as shown in FIG. 3A, alternative embodiments may include, e.g., four recessed interlocking features, as described in detail below. Still further, the number, size, or configuration of the recessed interlocking features **210** on surface **216** may be the same as, or differ in one more aspects from, the recessed interlocking features **212** on surface **214**.

[0044] The plurality of recessed interlocking features **210** and **212** may all be located at an equal distance from the edges of either first heat sink **204** or second heat sink **206**. For example, one of the plurality of recessed interlocking features **210** may be located, e.g., approximately 2 mm from a first edge **230** of first heat sink **204** and one of the other plurality of recessed interlocking features **210** may be located, e.g., approximately 2 mm from a second edge **232** of first heat sink **204**. In another implementation, the location of recessed interlocking features **210** and **212** from the edges of either first heat sink **204** and second heat sink **206** may differ between each other. For instance, one of the plurality of recessed interlocking features **210** may be, e.g., approximately 3 mm from first edge **230** of first heat sink **204** while one or more of the other plurality of recessed interlocking features **210** may be, e.g., approximately 5 mm from second edge **232** of heat sink **204**.

[0045] The recessed interlocking features **210** and **212** and protruding interlocking features **208**, when engaged, may produce a force that more uniformly spreads the TIM layer (discussed in greater detail below) on first and second heat sinks **204** and **206** which in turn may reduce the bond line thickness. In some examples, the entirety of the applied TIM layer may be within 15%, 10%, 5%, 3%, 2%, 1% or less of a median thickness. Moreover, the entirety of the outer surfaces of all power modules (except for exposed electrical connections) may be covered with TIM. The reduction in bond line thickness may relieve pressure on power module **202**, which may reduce the risk of cracks and failure of the power module structure.

[0046] Surface **216** of first heat sink **204** and surface **216** of second heat sink **206** may include a layer of thermal interface material (TIM) **222** and **224**, respectively, to further aid thermal conduction between first heat sink **204** and power module **202** as well as between second heat sink **206** and power module **202**. TIM layers **222** and **224** may include any suitable thermal tapes, gels, thermal epoxies, solders, greases, gap-filled pads, phase change materials, or combinations thereof.

[0047] TIM layers **222** and **224** on either surface **214** or **216** may include TIM extending across a substantial entirety, or across only a portion, of either surface **214** and **216**. Additionally, TIM layers **222** and **224** may include TIM across a portion of surface **214** and **216** between recessed interlocked features **210** and **212**. The amount of TIM extending across surface **214** may be the same as, or differ in one more aspects from, the amount of TIM extending across surface **216**. Furthermore, TIM layers **222** and **224** may include any suitable material known in the art, including, but not limited to, silicone elastomer, fiberglass, or combination thereof. Surface **214** may include TIM layer **222** which may be made of the same material composition as TIM layer **224** included on surface **216**, or TIM layer **222** may include a material composition that differs from the material composition of TIM layer **224**.

[0048] TIM layers **222** and **224** may be uniformly composed of the same material. In another implementation, TIM layers **222** and **224** be a composite of different materials. For example, TIM layers **222** and **224** may include a combination of a gel and a grease. In another implementation, for example, TIM layers **222** and **224** disposed in the blind cavity of recessed interlocking features **210** and **212** may be composed of a different material from the TIM layers **222** and **224** included on surfaces **214** and **216**.

[0049] First heat sink **204** and second heat sink **206** may provide a thermal heat dissipation for power module **202**. Heat sinks **204** and **206** may include multiple components. The material of heat sink **204** and **206** may be selected based on the required thermal performance needed to draw heat

away from power module **202**. For example, heat sinks **204** and **206** may be include an aluminum alloy having a high thermal conductivity while being mechanically soft. In another embodiment, heat sinks **204** and **206** may be include copper. In some embodiments, heat sinks **204** and **206** may be similar to a radiator used in an internal combustion engine and may include a circulating fluid or gas therein. Heat sinks **204** and **206** may be in an extruded, folded fin, bonded fin, active fan, stamping, or cross-cut configuration.

[0050] As shown in FIG. 2B, the plurality of protruding interlocking features **208** on top surface **218** of power module **202** may be mated with the plurality of recessed interlocking features **210** of first heat sink **204**. Additionally, the plurality of protruding interlocking features **208** on bottom surface **220** of power module **202** may be mated with the plurality of recessed interlocking features **212** of second heat sink **206**. The plurality of recessed interlocking features **210** and **212** may be wider than the plurality of protruding interlocking features **208** of power module **202** such that a substantial entirety of protruding interlocking features **208** are received therein. A lubricating material may be included on top of TIM layers **222** and **224** in order to facilitate mating of protruding interlocking features **208** with recessed interlocking features **210** and **212**. Top surface **218** and bottom surface **220** of the power module **202** may include an adhesive material (not shown) to keep heat sinks **204** and **206** mated with power module **202** when large amounts of heat is generated by power module **202**.

[0051] FIG. 3A and FIG. 3B depict another embodiment system **300**. In the embodiment of system **300**, protruding interlocking features **314** on power module **304** may be located on an epoxy mold compound **308** (as shown in FIG. 3A) or a copper layer **324** (as shown in FIG. 3B). Protruding interlocking features **314** may be located on any area of the epoxy mold compound **308** or copper layer **324** as long as the protruding interlocking features **314** align with corresponding recessed interlocking features **312** located on heat sinks **302** and **316**. In both FIGS. 3A and 3B, the TIM layers **322** on both heat sinks **302** and **316** may include TIM extending across a substantial entirety or across only a portion of the surfaces of heat sinks **302** and **316**. In another embodiment, TIM may only be included in the area in which the power module **304** will mate with heatsinks **302** and **316**.

[0052] Heat sinks **302** and **316** may include integral fluid conducting micro-channels used for liquid cooling. In particular, heat sinks **302** and **316** may comprise one or more inlet ports **306** for supplying liquid coolants within the respective heat sink and one or more outlet ports **326** for exhausting coolant that has passed through the fluid conducting micro-channels. Heat sinks **302** and **316** may also include a fluid seal **310** to fluidly seal the inlet port **306** and outlet port **326**. The fluid conducting micro-channels coupled with TIM layers may allow for more efficient cooling of the power module.

[0053] FIG. 4A and FIG. 4B depict another exemplary embodiment system **400** which is similar to the embodiment system **200** (as shown in FIGS. 2A and 2B). However, system **400** differs from system **200** in that surface **216** of first heat sink **204** and surface **214** of second heat sink **206** do not include a plurality of recessed interlocking features (as shown in FIG. 4A). Surface **216** of first heat sink **204** and surface **214** of second heat **206** may be a substantially, flat, or otherwise continuous surface.

[0054] The plurality of protruding interlocking features **208** on top surface **218** of power module **202** may be in contact with surface **216** of first heat sink **204** where a gap is formed between surface **216** and top surface **218**. Additionally, the plurality of protruding interlocking features **208** on bottom surface **220** of power module **202** may be in contact with surface **214** of second heat sink **206** where a gap is formed between surface **214** and bottom surface **220**. The gap formed between the heat sink **204** and **206** and power module **202** may be uniform. In another implementation, the height of the plurality of protruding interlocking features **208** on top surface **218** may differ than the height of the plurality of protruding interlocking on the bottom surface **220**. Therefore, the height of the gap formed when the protruding interlocking features **208** on top

surface **218** is in contact with surface **216** of first heat sink **204** may differ from the height of the gap formed when the protruding interlocking features **208** on bottom surface **220** is in contact with surface **214** of second heat sink **206**.

[0055] TIM layers **222** and **224** on either surface **214** or **216** may include TIM extending across a substantial entirety, or across a portion of an area in which the power module does not mate with heat sinks **204** and **206**. Moreover, the thickness of TIM layers **222** and **224** may fill the entire gap formed between the surfaces of the heat sink and power module. In another implementation, the amount of TIM filling the gap between top surface **218** and surface **216** of first heat sink **204** may be the same as, or differ in one or more aspects from, the amount of TIM filling the gap between bottom surface **220** and surface **214** of second heat sink **206**.

[0056] In another embodiment, as shown in FIG. 4B, system **400** may include a power module **202** and a single heat sink **204** (or **206**). The plurality of protruding interlocking features **208** may only be included on a single surface (top surface **218** or bottom surface **220**) of power module **202** while the other surface (top surface **218** or bottom surface **220**) may be a flat or otherwise free surface. The single heat sink **204** (or **206**) may not include a plurality of recessed interlocking features **210** (or **212**). Surface **218** (or **220**) includes the plurality of protruding interlocking features **208** on power module **202** may be brought into proximity of or in contact with surface **216** (or **214**) of the single heat sink **204** or **206** such that a gap is formed between surface **216** (or **214**) of heat sink **204** or **206** and surface **218** (or **220**) of power module **202**. TIM layer **222** (or **224**) may uniformly fill the gap between surface **216** (or **214**) of heat sink **204** (or **206**) and surface **218** (or **220**) of power module **202**. Furthermore, TIM layer **222** (or **224**) on surface **216** (or **214**) of the single heat sink **204** (or **206**) may include TIM extending across an substantial entirety, or across a portion of an area in which the power module may not be in contact with the single heat sink **204** (or **206**).

[0057] FIG. 5A and FIG. 5B depict another embodiment system **500** which is similar to embodiment system **200** (as shown in FIGS. 2A and 2B). However, system **500** differs from system **200**, as shown in FIG. 5A, in that the height of the plurality of protruding interlocking features **208** on top surface **218** may be greater than the depth of the plurality of recessed interlocking features **210** on surface **216** of first heat sink **204**. Additionally, the height of the plurality of protruding interlocking features **208** on bottom surface **220** of power module **202** may be greater than the depth of the plurality of recessed interlocking features **212** on surface **214** of second heat sink **206**.

[0058] The plurality of protruding interlocking features **208** on top surface **218** of power module **202** may be mated with the plurality of recessed interlocking features **210** of first heat sink **204** such that a gap is formed between surface **216** and top surface **218**. Additionally, the plurality of protruding interlocking features **208** on bottom surface **220** of power module **202** may be mated with the plurality of recessed interlocking features **212** of second heat sink **206** such that a gap is formed between surface **214** and bottom surface **220**. The gap formed between the heat sink **204** and **206** and power module **202** may be uniform. In another implementation, the height of the plurality of protruding interlocking features **208** on the top surface **218** may differ than the height of the plurality of protruding interlocking on the bottom surface **220**. Therefore, the height of the gap formed when the protruding interlocking features **208** on top surface **218** are mated to the plurality of recessed interlocking features **210** of first heat sink **204** may differ from the height of the gap formed when the protruding interlocking features **208** on bottom surface **220** are mated to the plurality of recessed interlocking features **212** of second heat sink **206**.

[0059] TIM layers **222** and **224** on either surface **214** or **216** may include TIM extending across a substantial entirety, or across a portion of an area in which power module **202** does not make contact with heat sinks **204** and **206**. Moreover, the thickness of TIM layers **222** and **224** may fill the entire gap formed between the surface of the heat sink and power module. In another implementation, the amount of TIM filling the gap between top surface **218** and surface **216** of first heat sink **204** may be the same as, or differ in one or more aspects from, the amount of TIM filling the gap between bottom surface **220** and surface **214** of second heat sink **206**.

[0060] In another embodiment, as shown in FIG. 5B, system 500 may include a power module 202 and a single heat sink 204 (or 206). The plurality of protruding interlocking features 208 may only be included on a single surface (top surface 218 or bottom surface 220) of power module 202 while the other surface (top surface 218 or bottom surface 220) may be a flat, free surface. The single heat sink 204 (or 206) may include a plurality of recessed interlocking features 210 (or 212) which may have a depth that is less than the height of the plurality of protruding interlocking features 208. The plurality of protruding interlocking features 208 on power module 202 may be received within a plurality of recessed interlocking features of heat sink 204 (or 206) such that a gap is formed between surface 216 (or 214) of heat sink 204 (or 206) and surface 218 (or 220) of power module 202. TIM layer 222 (or 224) may uniformly fill the gap between surface 216 (or 214) of heat sink 204 (or 206) and surface 218 (or 220) of power module 202. Furthermore, TIM layer 222 (or 224) on surface 216 (or 214) of heat sink 204 (or 206) may include TIM extending across a substantial entirety, or across a portion of an area in which the power module does not mate with the single heat sink 204 (or 206).

[0061] FIG. 6 depicts an exemplary method 600 for aligning a heat sink to a power module. As shown in FIG. 6, a method 600 may include, at step 610, forming one or more interlocking features on heat sinks 204, 206 and power module 202. For example, slabs of copper may be soldered to external surface of power module 202 to create protruding interlocking features 208.

Correspondingly recessed interlocking features 210, 212 may be machined or laser drilled into surfaces 214, 216 of heat sinks 204, 206. Moreover, any suitable analyses, e.g., finite element analysis, may be performed to determine ideal locations for both protruding interlocking features 208 and recessed interlocking features 210, 212.

[0062] Once protruding interlocking features 208 and recessed interlocking features 210 and 212 have been formed on power module 202 and heat sinks 204, 206 respectively, thermal interface material 222, 224 may be applied to surfaces of heat sinks 204, 206 or surfaces 218, 220 of power module 202 at step 620. For example, solder paste, silver sinter paste, or a pump may be used to dispense the TIM material on to at least one heat sink 204, 206 or power module 202. In one example, the pump may be a piston pump which may create little to no friction during dispensing of the TIM. In other examples, the pump may be a screw pump for dispensing the TIM. The TIM may be dispensed or otherwise deposited onto heat sinks 204, 206 or power module 202 in any suitable pattern, including, but not limited to, such as a dot, serpentine, or spiral.

[0063] Once the TIM has been dispensed on heat sinks 204, 206, protruding interlocking features 208 may be aligned with recessed interlocking features 210 and 212. Subsequently, the protruding interlocking features 208 may be mated (e.g., inserted into) with recessed interlocking features 210, and 212, thereby aligning the one more heat sinks 204, 206 with power module 202 at step 630. Heat sinks 204, 206 and power module 202 may be aligned with one another with a deformable washer or a spring-action clamp. Heat sinks 204, 206 and power module 202 may be interlocked with one another at step 640.

[0064] Other embodiments of the disclosure will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

Claims

1. A system comprising: a power module, wherein the power module includes a first interlocking feature on a first surface of the power module and a second interlocking feature on a second surface of the power module, wherein the first surface is opposite of the second surface; and a first heat sink, wherein the first heat sink includes a surface including a first layer of thermal interface material, wherein the first interlocking feature mates with the surface of the first heat sink to form a

- first gap between the first surface and the surface of the first heat sink, wherein the first gap is located both interior and exterior to the first interlocking feature.
2. The system of claim 1, wherein the second surface is separated from the first surface by a width of the power module.
 3. The system of claim 1, wherein the first interlocking feature is a protruding interlocking feature.
 4. The system of claim 1, wherein the surface of the first heat sink is a flat surface.
 5. The system of claim 1, wherein the first layer of thermal interface material includes one or more of thermal tapes, gels, thermal epoxies, solders, greases, gap-filled pads, or phase change materials.
 6. The system of claim 1, wherein the first surface and second surface include a copper layer.
 7. The system of claim 1, wherein a portion of the surface of the first heat sink located outwardly from where the first interlocking feature mates with the surface of the first heat sink includes the first layer of thermal interface material.
 8. The system of claim 1, wherein the first gap between the first surface of the power module and the surface of the first heat sink is filled with the first layer of thermal interface material.
 9. The system of claim 1, wherein the first layer of thermal interface material extends across an area of the first heat sink where the first interlocking feature on the power module does not mate with the surface of the first heat sink.
 10. The system of claim 1, wherein the first heat sink includes an inlet port or an outlet port.
 11. A system comprising: a power module, wherein the power module includes a first interlocking feature on a first surface of the power module; and at least one heat sink, wherein the at least one heat sink includes a second interlocking feature on a surface of the at least one heat sink, wherein the first interlocking feature of the first surface of the power module mates with the second interlocking feature on the surface of the at least one heat sink, and wherein the surface of the at least one heat sink includes a first portion located interior to the second interlocking feature and a second portion located exterior to the second interlocking feature.
 12. The system of claim 11, wherein the power module includes a third interlocking feature on a second surface of the power module, wherein the second surface is separated from the first surface by a width of the power module.
 13. The system of claim 11, wherein the first interlocking feature is a protruding interlocking feature.
 14. The system of claim 11, wherein the second interlocking feature is a recessed interlocking feature.
 15. The system of claim 14, wherein the recessed interlocking feature is a blind cavity.
 16. The system of claim 12, wherein the first interlocking feature on the first surface mates with the second interlocking feature on the surface of the at least one heat sink to form a gap between the first surface of the power module and the surface of the at least one heat sink.
 17. The system of claim 16, wherein the gap between the first surface of the power module and the surface of the at least one heat sink is filled with thermal interface material.
 18. The system of claim 11, wherein the at least one heat sink includes an inlet port or an outlet port.
 19. The system of claim 12, wherein the first surface and second surface include a copper layer.
 20. A system comprising: a power module, wherein the power module includes a first interlocking feature on a first surface of the power module and a second interlocking feature on a second surface of the power module, wherein the first surface is opposite of the second surface, wherein the first interlocking feature forms a gap located exterior and interior to the first interlocking feature.
-