

MULTI-PART THERMAL INTERFACE SYSTEM

TECHNICAL FIELD

[001] Various embodiments of the present disclosure relate generally to thermal systems for electronic circuit assemblies and, more particularly, to a multi-part thermal interface system.

BACKGROUND

[002] Integrated circuit (IC) chips, dies, and/or packages are typically assembled to other components, circuits, or other systems (e.g., heat exchangers or heat sinks) using an interface material. Typically, IC packages are asymmetrical and mechanically unbalanced. This asymmetry, along with the different materials used in the packaging, cause both mechanical and thermal stresses, which in turn lead to package warpage and co-planarity issues.

[003] Interface materials are frequently configured to disperse generated heat. For instance, a heat spreader or disperser may be applied to a package over a die to aid in dispersing excess heat and to reduce package warping. The interface material may eliminate air gaps between surfaces and conduct heat better than air to facilitate heat dispersion. A die or other surface may be interfaced with the heat spreader by an adhesive material that conducts heat from the die to the heat spreader. However, current heat spreaders and/or adhesive materials are generally not highly effective at simultaneously performing heat transfer, warp prevention, and adhesion. In addition, current interface materials may be susceptible to “pump-out,” where the interface material may be squeezed out of the package due to thermal expansion and

contraction, and “dry-out,” where the interface material may lose conformability or flexibility which prevents the interface material from moving (e.g., expanding and contracting) as needed to maintain contact with the surfaces to which the interface material is applied.

[004] The thermal interface system of the present disclosure may solve one or more of the problems set forth above and/or other problems in the art.

SUMMARY OF THE DISCLOSURE

[005] According to certain aspects of the disclosure, a thermal interface system may include a first device and a thermal interface material (TIM) assembly. The first device may have a first surface extending in a first direction. The thermal interface material (TIM) assembly may be configured to be adhered to the first device to facilitate a transfer of heat to or from the first device. The TIM assembly may be aligned with the first surface in a second direction. The TIM assembly may include a first TIM having a first elasticity and configured to be adhered to the first surface, and a second TIM having a second elasticity. The first TIM may surround the second TIM. The first elasticity may be greater than the second elasticity.

[006] The first TIM may include a material configured to expand and contract with the second TIM. The first elasticity may be in a range of at least 101% of the second elasticity.

[007] The first TIM may surround the second TIM in the first direction to be in a plane parallel to the first surface. The first TIM may not overlap with the second TIM in the second direction.

[008] The first device may include an integrated circuit package. A second device may include a cold rail configured to absorb heat from the first device. The TIM assembly may be provided between the first and second devices.

[009] A second device may be configured to exchange heat with the first device. The TIM assembly may be provided between, in the second direction, the first device and the second device to facilitate heat exchange. One of the first or the second device may include a thermal device configured to absorb heat from the other of the first or the second device.

[010] The first surface may include a step. The first TIM may be provided in the step. The first surface may include a recess. The second TIM may be provided in the recess.

[011] A first wettable layer may be provided on the first surface between the second TIM and the first surface. The first wettable layer may be non-overlapping with the first TIM.

[012] A thermal device may have a second surface including a recess. The first TIM may be provided in the recess.

[013] A thermal device may have a second surface including a step. The second TIM may be provided in the step.

[014] A second device may have a second surface. The TIM assembly may be provided between the first device and the second device.. A second wettable layer may be provided on the second surface between the second TIM and the second surface.

[015] According to certain aspects of the disclosure, a first device may have a first surface extending in a first direction, and a TIM assembly may be configured to be

adhered to the first surface. The TIM assembly may be configured to facilitate a transfer of heat from the first device. The TIM assembly may be aligned with the first surface in a second direction. The TIM assembly may include a primary TIM having a first side facing the first surface and a second side opposite the first side and a first wettable layer provided at the first side or the second side of the primary TIM. The first wettable layer may be wettable to the primary TIM. The primary TIM may not be wettable to the first surface.

[016] An outer TIM may laterally surround the primary TIM. The first wettable layer may not align, in the second direction, with the outer TIM so as to directly contact the first device.

[017] A second device may be configured to exchange heat with the first device. The TIM assembly may be provided between, in the second direction, the first and second devices. A second wettable layer may be provided. The first wettable layer may be provided between the first device and the first side of the primary TIM. The second wettable layer may be provided between the second device and the second side of the primary TIM.

[018] According to certain aspects of the disclosure, a thermal interface system may include a first device and a first thermal interface material (TIM). The first device may have a first surface extending in a first direction. The first device may include an integrated circuit (IC) package. The first thermal interface material (TIM) may be provided on the first surface and define an inner space above, in a second direction, the first surface. The inner space may extend in the first direction in a plane parallel to the first surface. The first TIM may include a room temperature vulcanizing (RTV) material

configured to facilitate a transfer of heat from the first device. The first TIM may have a first shore hardness in a range of 0 to 60 A.

[019] According to certain aspects of the disclosure, a method of manufacturing the thermal interface system may include overmolding the first TIM on the first surface during a molding process of the first device to define the inner space within the first TIM. The method may further include applying a second TIM on the first surface in the inner space within the first TIM. The second TIM may have a second shore hardness equal to or greater than the first shore hardness.

[020] 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.

[021] 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.

BRIEF DESCRIPTION OF THE DRAWINGS

[022] 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.

[023] FIG. 1 depicts a cross-sectional view of a package assembly or thermal system according to an exemplary embodiment.

[024] FIG. 2 depicts a top view of a thermal interface material (TIM) assembly of FIG. 1.

[025] FIG. 3 depicts a top view of a first or outer TIM of FIG. 2.

[026] FIG. 4 depicts a cross-sectional view of the package assembly of FIG. 1 in an expanded state.

[027] FIG. 5 depicts a cross-sectional view of the package assembly of FIG. 1 in a contracted state.

[028] FIG. 6 depicts a cross-sectional view of a package assembly according to another embodiment.

[029] FIGs. 7-8 depict cross-sectional views of a package assembly according to another embodiment which includes one or more wettable layers.

[030] FIGs. 9-14 depict cross-sectional views of a package assembly according to another embodiment which includes one or more grooves or recesses.

[031] FIGs. 15A – 15C depicts a manufacturing process of a package assembly according to an exemplary embodiment.

[032] FIG. 16 is a flow-chart illustrating a method of manufacturing a package assembly according to an exemplary embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

[033] 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.

[034] Various embodiments of the present disclosure relate generally to thermal interface materials or processes for electronic circuit assemblies and, more particularly, to a two-part thermal interface system.

[035] 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. The term “substrate” may broadly refer to a wafer, surface, or a board that acts as a mounting substrate (e.g., a resin-impregnated fiberglass structure, ceramic based, etc.).

[036] A thermal interface material (TIM) such as a phase change material (PCM) may be used to attach cold rails and/or heat sinks to power packages. However, retaining the TIM may be difficult, especially during thermal cycling and vibration or during a vertical application. Squeezed out TIM may cause shorts if the TIM contains conductive ingredients or materials. The TIM may also dry out or be pumped out during

use, which can decrease reliability of a system or device where the power package is installed.

[037] Aspects of the present disclosure may provide a two-part TIM having an inner TIM and an outer TIM, where the outer TIM is more compliant and elastic than the inner TIM and expands and contracts with the inner TIM. Aspects of the present disclosure may provide a method of manufacturing a two-part TIM having an inner TIM and an outer TIM, where the outer TIM is manufactured or applied before the inner TIM. The outer TIM may be manufactured in an overmolding process during manufacturing of a power package, where the outer TIM may be made of a same molding material and/or compound used to overmold the power package. Alternatively, the outer TIM may be made of a different molding material than the material used to overmold the power package. The outer and inner TIMS may alternatively be referred to as first and second TIMS. As an alternative to overmolding the outer TIM with the power package, the outer and inner TIMS may be integrated and produced (e.g., by a TIM supplier) side by side as an isolated TIMS assembly in the form of a pad and/or film, which may be provided to TIM users and/or purchasers to apply straight on a substrate (e.g., of a power package device, thermal device, etc).

[038] Aspects of the present disclosure may enhance a positioning of a TIM and restrain the TIM while still allowing for a flexible expansion and contraction of the TIM. Aspects of the present disclosure may restrain a TIM and prevent or reduce a pumping or drying out of the TIM. Aspects of the present disclosure may provide strong interfacial adhesion to prevent a TIM from being displaced or seeping outside of an installation area or device.

[039] FIG. 1 depicts a cross-sectional view of a package assembly or thermal system 1. The package assembly 1 may include a first or primary device 100, a second device 200, and a thermal interface material (TIM) assembly 300 provided between the first device 100 and the second device 200. The package assembly 1 may be used in various applications, such as in inverter systems, power switch systems, heat sink systems, an electrically-powered vehicle, etc. The first device 100, TIM assembly 300, and second device 200 may be aligned in a Z-direction, as indicated in FIG. 1. Although FIG. 1 depicts the Z-direction as a vertical direction such that the package assembly 1 appears to have a horizontal orientation, the package assembly 1 may alternatively be positioned in a vertical orientation (such that the first device 100, TIM assembly 300, and second device 200 are aligned in a horizontal direction) in certain applications or at various steps during a manufacturing process.

[040] The first device 100 may be a semiconductor device such as a power package device having one or more printed circuit boards (PCB), metal lead frames or composites, ceramic-based substrates, insulated metal substrates (IMS), and/or one or more dies, but aspects disclosed herein are not limited. As an alternative, the first device 100 may be a single substrate. The first device 100 may generate heat, while the second device 200 may be a thermal device (e.g., heat sink, heat exchanger, or cold rail) configured to transfer heat away from the first device 100. As an alternative, the first device 100 may be thermal device configured to transfer heat away from the second device 200 and may be a thermal device (e.g., heat sink, cold rail, or heat exchanger).

[041] For convenience of description, the first device 100 will be described as a power package device 100, and the second device 200 will be described as a thermal device. The power package device 100 may be an integrated circuit (IC) package. When operated, the power package device 100 may generate heat. The power package device 100 may have a first surface or substrate 110.

[042] The thermal device 200 may be a cold rail or heat sink configured to disperse heat from the power package device 100. The thermal device 200 may include one or more of aluminum (Al), copper (Cu), Silicon (Si), Silicon Carbide (SiC), alloys or composites thereof, and/or another suitable material. For example, the thermal device 200 may include or be integrated with aluminum silicon carbide (AlSiC). The thermal device 200 may have a second surface or substrate 210.

[043] The TIM assembly 300 may be provided between the first and second surfaces 110 and 210 and be configured to transfer heat from the power package device 100 to the thermal device 200. The TIM assembly 300 may also be made of materials configured to facilitate adhesion between the power package device 100 and the thermal device 200 and to enhance a stability of the package assembly 1. The TIM assembly 300 may be configured to fill in gaps or other imperfections in the first and second surfaces 110 and 210 and have a coefficient of heat transfer which is greater than air. For example, the TIM assembly 300 may include one or more gels, pastes, greases, putties, B-Stage resins or epoxies, thermal pads, PCM, metallic alloys, metals, solders, conductive adhesives, or other fluid-like materials configured to be applied or cured on at least one of the first and second surfaces 110 and 210. Specific materials

and characteristics of the TIM assembly 300 will be described in more detail with reference to FIGS. 2-3.

[044] The TIM assembly 300 may include at least two thermal interface materials (TIMs) 310 and 320. The at least two TIMS may include a first or outer TIM 310 and a second or inner TIM 320.

[045] FIG. 2 depicts a top view of the TIM assembly 300, and FIG. 3 depicts a top view of the first TIM 310. Referring to FIGs. 1-3, the first TIM 310 may surround the second TIM 320 in a lateral direction (X and Y directions in FIG. 2) to maintain a position of the second TIM 320. The first TIM 310 may not, or in some cases does not, however, surround or overlap with the second TIM 320 in the Z-direction (FIG. 1). The first TIM 310 may be formed before the second TIM 320, and the second TIM 320 may be provided within an inner space or area 312 of the first TIM 310. For example, the first TIM 310 may be applied or installed on the first surface 110 (FIG. 2) at a position that defines the inner space 312. The first TIM 310 may define a boundary of the inner space 312. Then, the second TIM 320 may be applied to the first surface 110 within the inner space 312 defined by the first TIM 310 (FIG. 2). A manufacturing process of the TIM assembly 300 will be described in more detail with reference to FIGs. 15-16.

[046] The first TIM 310 may be configured to maintain a position of the second TIM 320 while also being elastic, compliant, compressible, and reworkable. The first TIM 310 may have a strong interfacial strength and adhesion to prevent the second TIM 320 from seeping beyond edges of the first and second surfaces 110 and 210 to an outside of the power package assembly 1. The first TIM 310 may be configured to confine or maintain a position of the second TIM 320, maintain a uniformity and

consistency of the second TIM 320, and prevent pump-out (or squeezed out or spillage due to thermal expansion and contraction) and dry-out (or a loss of flexibility) of the second TIM 320. The first TIM 310 may have a liquid form, a B-stage or partially cured form, a solid form, or viscoelastic form. The first TIM 310 may be made of any of the materials described in paragraph [027], such as rubber, a room-temperature vulcanizing (RTV) material (e.g., silicone), a form-in-place material, or an overmolded material.

[047] The second TIM 320 may have a high thermal conductivity and facilitate wetting at the first and/or second surface 110 and 210. The second TIM 320 may be made of any of the materials described in paragraph [027] such as a PCM, a rubber, a silicone material, or an elastic polymer. For example, the second TIM 320 may include a Honeywell PTM3180 Phase Change Thermal Interface Material. Techniques disclosed herein may not be limited to materials of the second TIM 320.

[048] The first TIM 310 may be configured to be more elastic or compliant than the second TIM 320 in the completed package assembly 1. The first TIM 310 may have a first shore hardness, a first elasticity or elastic modulus, and a first coefficient of thermal expansion (CTE). The first shore hardness may be a hardness on the Shore A or the Shore 00 scale. For example, the first shore hardness may have a range of 0 to 60 A (e.g., 30 A) on the Shore A scale and/or a range of 0-100 on the Shore 00 scale. The first TIM 310 may be configured to enhance adhesion. The second TIM 320 may have a second shore hardness, a second elasticity or elastic modulus, and a second CTE. The second shore hardness may have a range of 0 to 100 A and/or 20-80A (e.g., 60 A). The second TIM 320 may be configured to enhance thermal conductivity. The first shore hardness may be less than the second shore hardness. The first elasticity

may be greater than the second elasticity. The first CTE may be greater than or equal to the second CTE.

[049] For example, the first shore hardness may be in a range of 0-100% such as 30-80% (e.g. 50% or half) of the second shore hardness. The first elasticity may be in a range of over 100% (e.g., at least 101%) such as 110-150% (e.g., 125%) of the second elasticity. The first CTE may be in a range of over 100% (e.g., at least 101%) such as 110-150% (e.g., 125%) of the second CTE.

[050] The first TIM 310 may be configured to expand and contract together and simultaneously with the second TIM 320 during heating, cooling, vibration, and/or any other displacement or disruptions from any external forces acting on the package assembly 1. FIG. 4 depicts the first and second TIMS 310 and 320 expanding together in the package assembly 1, and FIG. 5 depicts the first and second TIMS 310 and 320 contracting together in the package assembly 1. Expansion and contraction may occur during heating and cooling, respectively, or vice versa depending on materials used for the first and second TIMS 310 and 320. FIGs. 4 and 5 illustrate the first and second TIMS 310 and 320 expanding and contracting that results in a similar total displacement in a lateral (e.g., X-direction in FIG. 4) such that the first and second TIMS 310 and 320 may remain adhered to and/or adjacent to each other throughout expansion and contraction., The first TIM 310 may more readily expand than the second TIM 320, as the first TIM 310 may be more flexible, compliant, and soft than the second TIM 320.

[051] The TIM assembly 300 may reduce or prevent pump-out or dry-out phenomena. Pump-out may occur more frequently with liquid thermal interface materials (e.g., greases, pastes, or PCM) as the material moves and spreads to an

outside of the package assembly 1 and/or beyond, in the X-direction, the power package device 100 and/or the thermal device 200. In vertically oriented package assemblies 1, pump-out may cause short-circuiting if the pumped-out material includes conductive materials. Dry-out may occur over time with most TIMs, e.g. grease type TIM materials, which may harden over time and may not be able to expand and contract efficiently during thermal cycling. The TIM assembly 300 disclosed herein, however, may provide a dual structure having the first TIM 310 surrounding the second TIM 320, where the first TIM 310 is softer and more compliant, malleable, and flexible than the second TIM 320. The first TIM 310 may be applied or installed first before the second TIM 320 to establish a boundary of the second TIM 320. However, aspects disclosed herein are not necessarily limited to the first TIM 310 being applied first. For example, the second TIM 320 may be applied or installed before the first TIM 310.

[052] The TIM assembly 300 disclosed herein may prevent pump-out or seeping of the second TIM 320 by forming a boundary with the first TIM 310, and may prevent dry-out by configuring the first TIM 310 to be more compliant and elastic, and less hard, than the second TIM 320. The first TIM 310 may also be more adhesive and have a stronger interfacial strength than the second TIM 320 to prevent seeping out of the second TIM 320. By reducing pump-out and dry-out, the TIM assembly 300 disclosed herein may prevent or reduce failures caused by overheating or hot spots that may typically occur due to pump-out and dry-out.

[053] FIG. 6 depicts an example of a package assembly 1 using double-sided cooling. In this example, the TIM assembly 300 may be referred to as a first TIM assembly 300, and the package assembly 1 may include a third device 400 and a

second TIM assembly 500. The third device 400 may be another thermal device such as a heat sink, cold rail, heat exchanger, etc. The third device 400 may be a same or similar device as the second device 200 and may have a third surface 410. For convenience of description, the thermal device 200 will be referred to as a first thermal device 200, and the third device 400 will be referred to as a second thermal device 400. The power package device 100 may be provided between the first and second thermal devices 400 to facilitate heat transfer at opposite sides of the power package device 100.

[054] The power package device 100 may be provided between the first and second TIMS assemblies 300 and 500. The power package device 100 may have a fourth surface or substrate 120 opposite to the first surface 110, and the second TIM assembly 500 may be provided between the third and fourth surfaces 410 and 120.

[055] The second TIM assembly 500 may have a same or similar configuration as the first TIM assembly 300. The second TIM assembly 500 may have a first or outer TIMS 510 and a second or inner TIM 520. The first TIM 510 of the second TIM assembly 500 may have the same or similar properties as the first TIM 310 of the first TIM assembly 300. The second TIM 520 of the second TIM assembly 500 may have the same or similar properties as the second TIM 320 of the first TIM assembly 300. The first TIM 510 of the second TIM assembly 500 may be more flexible, compliant, soft, and/or elastic than the second TIM 520 of the second TIM assembly 500.

[056] The first TIM 310 of the first TIM assembly 300 and the first TIM 510 of the second TIM assembly 500 may be aligned in the Z-direction as shown in FIG. 6. The second TIM 320 of the first TIM assembly 300 and the second TIM 520 of the

second TIM assembly 500 may similarly be aligned in the Z-direction. FIG. 6 shows an example where the first and second thermal devices 100 and 200 extend laterally, in the X-direction, beyond outer edges of the first and second TIMS assemblies 300 and 500 and the power package device 100. Alternatively, outer edges of the first and second thermal devices 100 and 200 may align with the outer edges of the first and second TIMS assemblies 300 and 500 and the power package device 100.

[057] FIGS. 7-8 depict an example of a package assembly 1 including one or more wettable layers 610, 620. The one or more wettable layers 610, 620 may include a single layer and/or multiple stacked layers and may be pre-applied on the first and second surfaces 110 and 210. The one or more wettable layers 610, 620 may be configured to be compatible with the second TIM 320 types and may include materials such as low melting temperature solders, metals, or alloys, liquid metals, metallic materials that are very soft and malleable at room temp, etc. The one or more wettable layers 610/620 may include a material to which the second TIM 320 is wettable. “Wettable” may mean capable of being wetted, made soluble or receptive to moisture, rendered attractive or cohesive, or made to facilitate flow.

[058] For example, the one or more wettable layers 610, 620 may include a nickel (Ni) or a Ni-Au plating layer. The one or more wettable layers 610, 620 may be applied on the thermal device 200, which may be made of a material to which the second TIM 320 is not wettable (e.g., an aluminum or Al heatsink and/or cold rail) to confine the second TIM 320 in place. A solder of the second TIM 320 may not wet or flow to the Al surface of the thermal device that is outside of a coverage area or boundary of the Ni (or Ni-Au) plating layer of the one or more wettable layers 610, 620,

since solder may be wettable to Ni and/or Ni-Au, but not compatible and/or wettable to Al.

[059] The one or more wettable layers 610, 620 may be configured to facilitate good wetting, adhesion, and contact between a wettable and/or compatible second TIM 320 to the first and second surfaces 110 and 210. The one or more wettable layers 610, 620 may be configured to confine the second TIM 320 and prevent spreading or flowing in an X-direction beyond the one or more wettable layers 610, 620. The one or more wettable layers 610, 620 may be made of a highly conductive (e.g., metallic or semimetallic) material that is only wettable to the second TIM 320. For example, the one or more wettable layers may include Indium Corporation Solder TIM or Liquid Metal products. The one or more wettable layers 610, 620 may be applied to the first and/or second surfaces 110 and 210, and may include nickel, tin, silver (Ag), palladium (Pd), gold (Au), copper, a solder alloy, etc.

[060] The one or more wettable layers 610, 620 may include a first wettable layer 610 and a second wettable layer 620. The first and second wettable layers 610 and 620 may have a same or similar configuration and composition. The first and second wettable layers 610 and 620 may be provided at opposite sides of the second TIM 320 to help retain the second TIM 320, but may not be required to contact the first TIM 310 to retain the first TIM 310. The second TIM 320 may be wettable and/or compatible to the first and second wettable layers 610, 620, while the first TIM 310 may be configured to adhere to the first and second surfaces 110 and 210 via interfacial strength, instead of or in addition to wettability. The first and second wettable layers 610 and 620 may align with the second TIM 320 in the Z-direction or vertical direction but

may be non-overlapping, in the Z-direction, with the first TIM 310. The first and second wettable layers 610 and/or 620 may be adjacent to the first TIM 310 in the lateral X and/or Y directions. The first TIM 310 may surround the first and/or second wettable layers 610 and/or 620 to prevent or reduce TIM 320 from seepage or spill-out beyond the first and/or second wettable layers 610 and/or 620 (e.g., at high temperatures), to reduce or prevent short circuit events.

[061] The first wettable layer 610 may be provided between the first surface 110 of the power package device 100 and the second TIM 320. The first wettable layer 610 may be applied on the first surface 110 of the power package device 100 before the first and second TIMS 310 and 320 are installed. The first surface 110 may be ceramic with direct bonding copper (DBC). Alternatively, the first wettable layer 610 may be applied on the second TIM 320 after the second TIM 320 is applied and before the power package device 100 is placed.

[062] The second wettable layer 620 may be provided between the second surface 210 of the thermal device 200 and the second TIM 320. The second wettable layer 620 may be applied on the second surface 210 of the thermal device 200 before the first and second TIMS 310 and 320 are installed. The second surface 210 may be aluminum or aluminum-based, and the second wettable layer 620 may be a nickel plated later. Alternatively, the second wettable layer 620 may be applied on the second TIM 320 after the second TIM 320 is applied and before the thermal device 200 is placed.

[063] As shown in FIG. 8, when first and second wettable layers 610 and 620 are provided, in some embodiments, the first TIM 310 may be omitted. The first TIM

310 may be omitted when the second TIM 320 will not drip off over lifetime, with strong enough surface tension between 610 and 620. Alternatively or in addition thereto, any one of the first and/or second wettable layers 610 and/or 620 may be omitted. The first and/or second wettable layers 610 and/or 620 may be combined with any of the exemplary embodiments described with reference to FIGS. 1-15.

[064] Figures 9-14 illustrate exemplary arrangements where at least one of the first TIM 310 or the second TIM 320 may be provided in a recess formed in at least one of the power package device 100 or the thermal device 200. For example, in FIG. 9, the first surface 110 of the power package device 100 may have a first inner recess 112, and the second surface 210 of the thermal device 200 may have a second inner recess 212 which aligns with the first inner recess 112. The first and second inner recesses 112 and 212 may be formed at a central location of the first and second surfaces 110 and 210. The second TIM 320 may be provided between the first and second inner recesses 112 and 212, which may further reduce or prevent pump-out of the second TIM 320 or spillage if the second TIM 320 is first applied in a liquid state. The first TIM 310 may surround the second TIM 320 at a position outside of the first and second recesses 112 and 212. As an alternative, one of the first or second inner recesses 112 and 212 may be omitted.

[065] In the example of FIG. 9, the second TIM 320 may be thicker in the Z-direction than the first TIMS 310 in an installed state. The first TIM 310 may initially have a same thickness, in the Z-direction, as the second TIM 320, and may then be compressed between the first and second surface 110 and 210 to facilitate adhesion

between the first and second surfaces 110 and 320. Alternatively, the first TIM 310 may initially be thinner than the second TIM 320.

[066] FIG. 10 shows an example where the first surface 110 of the power package device 100 may have a first step 114, and the second surface 210 of the thermal device 200 may have a second step 214 which aligns with the first step 112. The first and second steps 114 and 214 may be formed at an outer side or along a perimeter of the first and second surfaces 110 and 210. The first TIM 310 may be provided between the first and second outer steps 114 and 214, which may further reduce or prevent pump-out of the second TIM 320. The first TIM 310 may be thicker in the Z-direction than the second TIM 320.

[067] In the examples of FIGs. 10-14, the second TIM 320 may be thinner than the first TIM 310 to facilitate wetting and/or to provide room for one or more wettable layers 610, 620 applied to the second TIM 320. In addition, the second TIM 320 may be thinner to conform to or fill in trenches, grooves, or other surface irregularities in the first and/or second surfaces 110 and 210. The second TIM 320 may be thinner to facilitate a closer distance and heat dissipation between the first and second surface 110 and 210.

[068] Alternatively or in addition thereto, the second TIM 320 may initially have a same thickness as the first TIM 310 in the Z-direction, and may be compressed while the first TIM 310 fills in the first and/or second outer steps 114 and 214. In such an example, areas of the first and/or second surfaces 110 and 210 that are between the first and/or second outer steps 114 and/or 214 may be referred to as first and second protrusions, and shearing of the first TIM 310, second TIM 320 and/or an elastic seal

created between the TIM assembly 300 and the first and/or second surfaces 110 and 210 may be reduced.

[069] FIG. 11 shows an example similar to FIG. 10, but exemplifies a case where the first and second outer steps 114 and 214 may not be provided at an outermost perimeter of the first and second surfaces 110 and 210. Outer sides of the first and second surfaces 110 and 210 may extend beyond, in the X-direction, outer edges of the first TIM 310. In the examples of FIGs. 11 and 13, the first and second outer steps 114 and 214 may alternatively be referred to as first and second outer recesses, grooves, or cavities and may reduce sliding between the first and/or second surface 110 and/or 210 and the TIM assembly 300.

[070] As exemplified in Figures 12, 13, and 14, one of the first or second outer steps or recesses 114 and 214 may be omitted. FIG. 12 shows an example where the second outer step 214 is omitted. In such an example, the power package device 100 may be prepared with the TIM assembly 300, and the power package device 100 and the TIM assembly 300 may be packaged together for later installation with the thermal device 200. The first TIM 310 may be provided along the outer edge or perimeter of the first surface 110 and/or the second surface 210. FIG. 13 shows an alternative example where outer sides of the first surface 110 extends beyond, in the X-direction, outer edges of the first TIM 310.

[071] FIG. 14 shows an example where the first outer recess 114 is omitted. In such an example, the thermal device 200 may be prepared with the TIM assembly 300, and the thermal device 200 and the TIM assembly may be packaged together for later installation with the power package device 100. In the example in FIG. 14, the first

TIM 310 may be provided along an outer edge or perimeter of the second surface 210 and/or first surfaces 110, but alternatively, one or both of the first and second surface 110 and/or 210 may extend beyond the first TIM 310 in the X-direction.

[072] Referring to FIGS. 15A-C and 16, the TIM assembly 300 may be primarily applied to or installed on one of the power package device 100 or the thermal device 200. Although FIG. 9 exemplifies the TIM assembly 300 being first installed on the power package device 100, the TIM assembly 300 may alternatively be first installed on the thermal device 200 or on another type of substrate or device.

[073] As exemplified in FIG. 15A and FIG. 16, a method of preparing a TIM assembly 300 may include a step 1610 of applying the first TIM 310 to the first surface 110 of the power package device 100 to define the inner space 312. The first TIM 310 may initially be a liquid or B-phase material and cured. Alternatively, the first TIM 310 may be solid. Although FIG. 15A shows a flat first surface 110, alternatively, the first TIM 310 may be provided in a first outer step or recess 114 (FIGs. 10 and 11) or may surround a first inner recess or cavity 112 (FIG. 9).

[074] The step 1610 of applying the first TIM 310 to the first surface 110 may include overmolding (e.g., transfer or injection overmolding) the first TIM 310. The overmolding of the first TIM 310 may be performed during a molding process of the power package device 100. The first TIM 310 may be overmolded using a same material as a molding compound (e.g. RTV silicone, elastomers, epoxy molding compounds, etc.) used to overmold the power package device 100 and/or the package assembly 1. Alternatively, the first TIM 310 may be overmolded onto the thermal device 200. For an overmold type first TIM 310, the first TIM 310 may include a rigid type of

material , and the thermal device 200 may include mechanical locking features (e.g., a recess or cavity) to confine the second TIM 320 and prevent the power package device 100 from sliding over lifetime and vibration.

[075] The method may include step 1612 of applying the first wettable layer 610 to the first surface 110 at a position surrounded by the first TIM 310 (FIG. 7). The first wettable layer 610. Alternatively, step 1612 may be omitted, and the first TIM 310 may be pre-applied on the surface 110, such as when the second TIM 320 includes metallic materials, such as low melting temperature solders, metals, or alloys, or liquid metals, that are very soft and malleable at room temp.

[076] As exemplified in FIG. 15B and FIG. 16, the method 1600 may include a step 1620 of applying the second TIM 320 to the first surface 110 (and/or the first wettable layer 610) within the inner space 312 such that the first TIM 310 will surround the second TIM 320. The second TIM 320 may be in a liquid phase, paste, pad, film etc. but aspects disclosed herein are not limited. The first TIM 310 may define a boundary in which the second TIM 320 is applied. Alternatively or in addition thereto, a first outer step or recess 114 (FIGs. 10 and 11) may define the boundary and/or inner space 312 in which the second TIM 320 is applied, or a first inner recess 114 (FIG. 9) may define the inner space 312 in which the second TIM 320 is applied. Together, the first and second TIMS 310 and 320 may form a TIM assembly 300.

[077] The step 1620 of applying the second TIM 320 may be performed later after the first TIM 310 has cured at a different location and/or by a different entity. For example, the first TIM 310 may be overmolded on the power package device 100, and the power package device 100 and overmolded first TIM 310 may be moved from a

supplier to a manufacturer or customer, and the manufacturer or customer may apply the second TIM 320 and/or the thermal device 200. The second TIM 320 may be a thermal interface paste, resin, grease, gel, pad, film, etc. that the manufacturer or customer has on hand. Aspects disclosed herein are not limited. Alternatively, step 1620 may be performed in a same process or soon after steps 1610 and/or 1612.

[078] The method 1600 may include a step 1622 of applying a second wettable layer 620 over the second TIM 320. Alternatively, step 1622 may be omitted, and the second TIM 320 may be pre-applied on the second surface 210, such as when the second TIM 320 includes metallic materials, such as low melting temperature solders, metals, or alloys, or liquid metals that are very soft and malleable at room temp.

[079] As shown in FIG. 15C and FIG. 16, the method 1600 may include a step 1630 of applying or installing the thermal device 200 over the TIM assembly 300. The second surface 210 may be provided over the TIM assembly 300. The step 1630 may be performed at a different time and/or location of steps 1610-1622. For example, steps 1610-1622 may be performed by a supplier (e.g., TIMS supplier), and step 1630 may be performed by a manufacturer. The first and second TIMS 310 and/or 320 may be settled and/or cured before step 1630 is started. Alternatively, step 1630 may be applied right after steps 1620 and/or 1622 while the first and/or second TIMS 310 and/or 320 are wetting, spreading or curing.

[080] As another alternative, the TIM assembly 300 may be provided by a supplier to a manufacturer in a pad form isolated from the first surface 110. In such a case, instead of applying the first and second TIMS 310 and 320 to the first surface 110 of the power package device 100, the supplier may apply the first and second TIMS 310

and 320 to a surface of a temporary or delivery substrate (such as a release film) or manufacturing device. The supplier may perform steps 1610-1622, and further perform a step of removing the TIM assembly 300 from the surface or, alternatively, delivering the TIM assembly 300 on such temporary or delivery substrate. The manufacturer may receive the TIM assembly 300 and then perform a step of applying the TIM assembly 300 to the first surface 110 of the power package device 100 (or alternatively, the second surface 210 of the thermal device 200) and then perform step 1630. The case where the TIM assembly 300 is delivered on the temporary substrate, the manufacturer may first remove the TIM assembly 300 from the temporary substrate before applying the TIM assembly 300 to the first surface 110 of the power package device 100 and/or the second surface 210 of the thermal device 200.

[081] As another example, the first TIM 310 may be applied to a thermal device 200 or other substrate in step 1610, and the second TIM 320 and/or the first wettable layer 610 may be applied to the thermal device 200 in steps 1620 and/or 1622. In step 1630, the thermal device 200 and TIM assembly 300 may be installed with a power package device 100 or another device to be cooled.

[082] Aspects of the present disclosure are not limited to TIM assemblies 300 provided between a power package device 100 and a thermal device 200. The TIM assembly 300 disclosed herein may be used with any device or circuitry component configured to generate heat, such as a copper (Cu) lead frame, a ceramic substrate with direct bonded aluminum (DBA) or DBC, composites, IMS, a chip, flip chip, chip scale package, ball grid array (BGA), package on package assembly (Pop), diode, transistor,

or a die (e.g., a die or chip that has been encapsulated in an organic, an inorganic, or a combination organic and inorganic housing).

[083] One of ordinary skill in the art will appreciate that the technical aspects disclosed herein may be applied to a wide range of semiconductor applications that may involve thermal systems, heat generating systems or heat exchange systems, high-power packages, etc. The exemplary dimensions and characteristics given for the first and second TMS 310 and/or 320 may be altered based on manufacturing needs, etc.

[084] Embodiments disclosed herein may provide an efficient way to cool devices by providing a multi-part (e.g., dual-part) thermal interface material (TIM). Embodiments disclosed herein are not limited to any particular machinery, types of substrates, or types of devices. Aspects disclosed herein may be used with heat sinks, cold rails, heat exchangers, etc.

[085] 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 thermal interface system, comprising:
 - a first device, wherein the first device has a first surface extending in a first direction;
 - a thermal interface material (TIM) assembly configured to be adhered to the first device to facilitate a transfer of heat to or from the first device, the TIM assembly being aligned with the first surface in a second direction and including:
 - a first TIM having a first elasticity and configured to be adhered to the first surface; and
 - a second TIM having a second elasticity,
 - wherein an innermost surface of the first TIM surrounds an outermost surface of the second TIM such that the first TIM confines the second TIM to maintain the uniformity and consistency of the second TIM, and
 - wherein the first elasticity is between 10% and 50% greater than the second elasticity,
 - and
 - wherein a shore hardness of the first TIM is between 30% and 80% of a shore hardness of the second TIM; and
 - a first wettable layer provided on the first surface between the second TIM and the first surface, wherein the first TIM is not wettable to the first surface.
2. The thermal interface system of claim 1, wherein the first TIM includes a material configured to expand and contract with the second TIM.
3. The thermal interface system of claim 1, wherein the first TIM surrounds the second TIM in the first direction to be in a plane parallel to the first surface, and the first TIM does not overlap with the second TIM in the second direction.
4. The thermal interface system of claim 1, wherein the first device includes an integrated circuit package.

5. The thermal interface system of claim 1, further comprising a second device including a cold rail configured to absorb heat from the first device, wherein the TIM assembly is provided between the first and second devices.

6. The thermal interface system of claim 1, further comprising a second device configured to exchange heat with the first device, wherein the TIM assembly is provided between, in the second direction, the first device and the second device to facilitate heat exchange, wherein one of the first or the second device includes a thermal device configured to absorb heat from the other of the first or the second device.

7. The thermal interface system of claim 1, wherein the first surface includes a step, and the first TIM is provided in the step.

8. The thermal interface system of claim 1, wherein the first surface includes a recess, and the second TIM is provided in the recess.

9. The thermal interface system of claim 1, further comprising a thermal device, wherein the thermal device has a second surface including a recess, and the first TIM is provided in the recess.

10. The thermal interface system of claim 1, further comprising a thermal device, wherein the thermal device has a second surface including a step, and the second TIM is provided in the step.

11. The thermal interface system of claim 1, further comprising:
a second device having a second surface, wherein the TIM assembly is provided between the first device and the second device; and
a second wettable layer provided on the second surface between the second TIM and the second surface.

12. A thermal interface system, comprising:

a first device having a first surface extending in a first direction;

a TIM assembly configured to be adhered to the first surface, the TIM assembly being configured to facilitate a transfer of heat from the first device, the TIM assembly being aligned with the first surface in a second direction and including:

a primary TIM having a first side facing the first surface and a second side opposite the first side;

a first wettable layer provided at the first side or the second side of the primary TIM, wherein the first wettable layer is wettable to the primary TIM, and the primary TIM is not wettable to the first surface; and

an outer TIM including an innermost surface that laterally surrounds an outermost surface of the primary TIM such that the outer TIM confines the primary TIM to maintain the uniformity and consistency of the primary TIM, wherein an elasticity of the outer TIM is between 10% and 50% greater than the primary TIM, and wherein a shore hardness of the outer TIM is between 30% and 80% of a shore hardness of the primary TIM.

13. The thermal interface system of claim 12, wherein the first wettable layer does not align, in the second direction, with the outer TIM so as to directly contact the first device.

14. The thermal interface system of claim 12, further comprising:

a second device configured to exchange heat with the first device, the TIM assembly being provided between, in the second direction, the first and second devices; and

a second wettable layer, wherein:

the first wettable layer is provided between the first device and the first side of the primary TIM, and

the second wettable layer is provided between the second device and the second side of the primary TIM.

15. A thermal interface system, comprising:

a first device having a first surface extending in a first direction, the first device including an integrated circuit (IC) package;

a first thermal interface material (TIM) provided on the first surface and defining an inner space above, in a second direction, the first surface, wherein:

the inner space extends in the first direction in a plane parallel to the first surface,
the first TIM includes a room temperature vulcanizing (RTV) material being configured to facilitate a transfer of heat from the first device, and

the first TIM has a first shore hardness in a range of 0 to 60 A; and
a second thermal interface material (TIM) provided on the first surface,
wherein an innermost surface of the first TIM surrounds an outermost surface of the second TIM,

wherein the first shore hardness of the first TIM is between 30% and 80% of a second shore hardness of the second TIM,

wherein an elasticity of the first TIM is between 10% and 50% greater than the second TIM, and

wherein the first TIM is not wettable to the first surface.

16. A method of manufacturing the thermal interface system of claim 15, comprising:

overmolding the first TIM on the first surface during a molding process of the first device to define the inner space within the first TIM.

17. The thermal interface system of claim 15, wherein the first surface includes a step, and the first TIM is provided in the step.

18. The thermal interface system of claim 15, wherein the first surface includes a recess, and the second TIM is provided in the recess.