

METAL-BASED THERMAL INTERFACE MATERIAL (TIM) AND METHOD OF PRODUCING THE SAME

Field of the Invention

[0001] The present invention relates to thermal interface materials (TIMs). More
5 specifically, it relates to metal-based TIMs and method of producing the same.

Background

[0002] Efficient thermal management is a critical for modern electronic devices. Thermal interface materials (TIMs) are widely used to facilitate heat transfer between
10 electronic components **230**, such as microprocessors, and heat dissipation systems 220, such as heat sinks or cooling plates. As shown in **FIG. 3A**, TIMs **250** are placed between two solid surfaces to minimize thermal resistance by filling microscopic air gaps **255** that would otherwise impede heat flow.

15 **[0003]** TIMs **250** are available in various forms, each offering unique advantages and drawbacks based on their composition and properties. Among which, the most effective materials for high-performance applications are metal-based TIMs, which exhibit superior thermal conductivity compared to polymer-based alternatives. Metal-based TIMs, such as indium and its alloys, are particularly valued for their ability to
20 conform to surface irregularities, thanks to their malleability and flexibility. However, these materials also present certain challenges, particularly when used at elevated temperatures. It is important to note that during operation, the TIM is subjected to constant pressure as it is clamped between two contacting surfaces, which can exacerbate issues like material deformation or oozing under thermal stress.

[0004] Indium-based TIMs, for example, transition from a solid state to a liquid state at temperatures exceeding 150°C. As shown in **FIG. 3C**, when the phase change occurs, the indium can ooze out from the mechanical assembly, possibly resulting in
5 voids or surface cracks within the interface as shown by image **380** of the TIM **350**. This deformation may degrade the heat transfer performance, causing overheating and compromising the reliability of electronic devices. Similarly, liquid metals, while capable of filling microscopic gaps due to their fluidity at room temperature, tend to leak from compressed surfaces. This leakage not only reduces the effectiveness of the thermal
10 interface but may also result in cosmetic or electrical shorting problems within the device.

[0005] In addition to liquid metals, metallic phase change materials (PCMs) have been developed to address thermal management needs. These materials remain solid at
15 room temperature but liquefy at moderate temperatures, such as 60°C, allowing them to fill gaps between surfaces. However, like indium and liquid metals, metallic PCMs are prone to oozing during phase change, which can cause similar issues in terms of thermal performance and device aesthetics.

[0006] Accordingly, the selection of TIMs play a critical role in ensuring
20 effective heat dissipation and the longevity of electronic components. A key challenge in this field is preventing the oozing and overflow of metal-based TIMs during phase transitions and/or under mechanical pressure while maintaining optimal heat transfer capabilities.

[0007] The patent US2019195577A1 addresses similar issues related to thermal interface materials by providing a solution to the deformation and oozing problems associated with conventional TIMs. It discloses a thermal interface material comprising a composite structure that enhances the reliability of the heat transfer process by incorporating a combination of high thermal conductivity materials. However, while it provides an alternative approach to contain the oozing, there remains room for improvement in addressing mechanical compression and material overflow during high-temperature operation.

[0008] Existing solutions, fail to address this fundamental challenge without compromising the heat transfer performance or mechanical integrity of the device. There is a need for an innovative TIM design that maintains structural integrity during phase transitions, prevents material leakage, and ensures consistent thermal conductivity across the interface.

Summary

[0009] In one aspect of the present invention, there is provided a thermal interface material (TIM) for improving heat transfer between a heat source and a cooling means. The TIM comprises a metal-based TIM layer, including indium alloy, liquid metal, or metallic phase change material (PCM), adapted to fill microscopic gaps between the surfaces of the heat source and the cooling solution; and a plurality of stoppers, wherein the stoppers act as mechanical hard stops to maintain a fixed bond-line thickness, preventing excessive compression of the TIM during operation.

[0010] In one embodiment, the stoppers are made of a material selected from the group consisting of metal, ceramic, diamond, or similar hard materials capable of withstanding temperatures exceeding 300°C.

[0011] In another embodiment, the stoppers come in the form of spherical balls.

5 **[0012]** In yet another embodiment, the stoppers are embedded within the TIM layer.

[0013] In a further embodiment, the stoppers have a dimension ranging from 0.03 mm to 0.5 mm, depending on the required bond-line thickness for the TIM.

10 **[0014]** In yet a further embodiment, the stoppers are scattered on the TIM in random.

[0015] In another aspect of the present invention, there is further provided a method for improving the mechanical stability and thermal performance of a metal-based TIM. The method comprises incorporating spherical balls as mechanical hard stops within the TIM layer to prevent deformation and material oozing during operation at
15 elevated temperatures.

Brief Description of the Drawings

[0016] This invention will be described by way of non-limiting embodiments of
20 the present invention, with reference to the accompanying drawings, in which:

[0017] **FIG. 1** illustrates a thermal interface material (TIM) in accordance with an embodiment of the present invention;

[0018] **FIG. 2A** illustrates an application of the TIM of **FIG. 1** in accordance with an embodiment of the present invention;

[0019] **FIG. 2B** illustrates the application of FIG. 2A, showing that the TIM is
5 under conditions of increase vertical pressure during its phase change;

[0020] **FIG. 3A** shows a conventional TIM sandwiched between a cooling means and a heat source;

10 [0021] **FIG. 3B** shows a known application of the TIM; and

[0022] **FIG. 3C** shows the known application of TIM in FIG. 3B during a phase change state.

Detailed Description

[0023] In line with the above summary, the following description of a number of specific and alternative embodiments are provided to understand the inventive features of the present invention. It shall be apparent to one skilled in the art, however that this invention may be practiced without such specific details. Some of the details may not be described at length so as not to obscure the invention. For ease of reference, common reference numerals will be used throughout the figures when referring to the same or similar features common to the figures.

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[0024] The present invention aims to solve the aforementioned problems by introducing, in one embodiment, spherical structures, such as metal, ceramic, or diamond balls, within the TIM of the present invention. These spherical balls act as mechanical hard stops, or stoppers, preventing the compression of the TIM beyond a predetermined bond-line thickness during phase transitions and/or under mechanical pressure. By incorporating these spherical elements, the invention ensures that the TIM maintains its thermal performance without suffering from material leakage, void formation, or surface deformation.

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[0025] This invention is applicable to a variety of metal-based TIMs, including indium alloys, liquid metals, and metallic PCMs, and is designed to operate effectively at temperatures exceeding 300°C. The inclusion of spherical balls within the TIM offers a robust, scalable solution for improving thermal management in high-performance electronic devices.

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[0026] In an alternative embodiment of the present invention, the spherical balls may be replaced with other geometric shapes, such as cubes, pyramids, or irregular forms, provided that they serve the same purpose of acting as mechanical hard stops. These alternative shapes, which can be referred to as "stoppers," "spacers," or any other
5 suitable name, similarly prevent excessive compression of the thermal interface material (TIM) operationally. The shape and size of the stoppers can be selected based on the specific application requirements, ensuring that they maintain the desired bond-line thickness while still allowing optimal thermal conductivity. These alternative geometries provide additional flexibility in manufacturing and design, offering improved
10 adaptability for various heat management systems.

[0027] **FIG. 1** illustrates a thermal interface material (TIM) **100** according to an embodiment of the present invention. The TIM **100** comprises a base sheet **110** into which spherical balls **120** are embedded. The spherical balls **120** are randomly dispersed within
15 the TIM, forming a mechanical hard-stop that plays an important role in preventing the material from being over-compressed under applied pressure during its application.

[0028] The spherical balls **120** may include of materials that possess a high degree of mechanical strength and thermal stability, such as metals, ceramics, or diamonds, which allow them to withstand the extreme temperatures often encountered
20 in high-performance electronic devices. Without limiting the scope of the invention, the size of these spherical balls **120** may vary, ranging from 0.03 mm or more, depending on the specific application requirements. The TIM **100** itself can be fabricated from metal-based materials, including indium alloys, liquid metals, or metallic phase change materials (PCMs), which are known for their excellent thermal conductivity and
25 malleability as heat management of electronic devices.

[0029] The primary function of these spherical balls is to maintain a fixed bond-line thickness across the TIM, regardless of the pressure applied during operation. By doing so, the spherical balls prevent the TIM's material oozing or overflow at its liquid or semi-liquid form due to the continued pressure applied. For materials like indium and metallic PCMs, oozing occurs only when they transition to their liquid state under continued pressure. In contrast, liquid metals, which remain in a liquid state even at room temperature, do not undergo a phase change but may still experiencing oozing due to compression. The spherical balls help mitigate these effects by maintaining a consistent bond-line thickness, ensuring optimal heat transfer while preventing material leakage during the TIM's phase change or continuous use. Additionally, the fixed bond-line thickness ensures consistent and optimal heat transfer between the surfaces it connects, thus enhancing the performance of the overall thermal management system.

[0030] **FIG. 1** illustrates an exemplary embodiment of the thermal interface material (TIM) **100** with spherical balls **120** distributed throughout the material. It is important to note that the spherical configuration of the balls **120** is provided by way of example and not limitations. The spherical balls **120** can be of any shapes or configurations, such as ellipsoidal, cuboidal, or irregular geometries, depending on the specific design requirements or performance characteristics desired, in accordance with further embodiments of the present invention.

[0031] Moreover, while **FIG. 1** shows the spherical balls **120** can be distributed randomly, alternative embodiments could arrange the balls in an organized pattern or specific orientation to achieve particular mechanical or thermal objectives. It is also desired that all the spherical balls be fabricated with substantially the same "height" or

thickness to maintain a consistent bond-line thickness across the TIM **100** when in use. This ensures uniform compression and prevents irregular deformation when the TIM is subjected to pressure, thereby enhancing the overall thermal performance and structural integrity of the interface.

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[0032] **FIG. 2A** illustrates an application of the TIM **100** of FIG. 1 in accordance with an embodiment of the present invention. When in use, the TIM **100** is clamped between a heat source **230** and a cooling means **220**. The heat source **230** can be an electronic component, such as a microprocessor, that generates significant amounts of
10 heat during operation. The cooling means **220** can be a heat sink or cooling plate designed to dissipate the heat away from the heat source **230** to prevent overheating.

[0033] In this configuration, vertical pressure is applied, as indicated by the arrows, to secure the cooling means **220** against the heat source **230**, with the TIM **100**
15 sandwiched in between. At this stage, typically, the cooling means **220** can be secured onto the heat source **230** by screws or clips to tighten the TIM **100** between the two surfaces. The spherical balls **120** may be suspended in the TIM **100**, at different heights and different locations randomly.

20 **[0034]** **FIG. 2B** illustrates the TIM **100** under conditions of increased vertical pressure, simulating continuous use environments when the device is operating. When the temperature increases, the TIM, composed of materials such as indium alloy, liquid metal, or metallic phase change material (PCM), undergoes a phase change, transitioning into its liquid state. When this transition occurs, the liquid TIM may flow due to the

pressure exerted between the surfaces or may naturally flow out due to gravity, depending on the mounting method.

[0035] For example, liquid metal remains in a liquid state even at room temperature, so during the final assembly process, which involves integrating components like ICs and cooling means, the excess liquid metal may be forced out by the compression. In another example, Indium liquefies at temperatures above 150°C, and this typically happens in specific scenarios, such as when a product undergoes a solder reflow process, for example, where temperatures exceed 250°C, causing the indium to melt and flow for a short duration. Another scenario where indium may liquefy is in the event of a thermal runaway, such as when the cooling system malfunctions or the temperature sensor fails, allowing the indium to reach its melting point. Similarly, metallic PCMs will transition to a liquid state at temperatures above 60°C and may exhibit similar flow behaviour under pressure or gravity once the phase change occurs.

[0036] In this scenario, the spherical balls **120** embedded in the TIM **100** act as hard stops, preventing further compression and limiting the degree of deformation against the base TIM material. The spherical balls **120** maintain the structural integrity of the TIM by enforcing a fixed minimum bond-line thickness, which ensures that the material remains in effective contact with both the cooling means **220** and the heat source **230**. As a result, only minimal oozing is observed along the edges, reducing the risk of performance degradation due to material loss.

[0037] An actual image **250** of a used TIM, in accordance with an embodiment of the present invention, is provided. The used TIM was removed from the heat source **230**, and as shown, the material exhibits minimal oozing, with a relatively uniform shape.

This demonstrates the effectiveness of the design in mitigating the common issues of material overflow and distortion, confirming that the invention successfully addresses the challenges typically associated with metal-based TIMs during operation. Furthermore, the inclusion of spherical balls within the TIM **100** mitigates the common
5 problem of void formation, which occurs when a TIM is compressed beyond its design limits, leading to air gaps that can significantly hinder heat transfer. By maintaining the integrity of the TIM and ensuring consistent contact with both surfaces, the spherical balls **120** contribute to the reliability of the device's thermal management system.

10 **[0038]** Additionally, the spherical balls **120** can withstand high operational temperatures, further enhancing the reliability of the TIM **100**. Whether the TIM is made from indium alloys, liquid metals, or metallic PCMs, these materials are prone to becoming liquid or semi-liquid at elevated temperatures. The spherical balls, being composed of thermally stable materials such as diamond or ceramics, continue to provide
15 structural support and limit material deformation even as the base TIM material transitions to a softer or more fluid state.

[0039] The TIM **100** is designed to function across a broad range of operational temperatures, with the spherical balls **120** ensuring that the material maintains its
20 structural properties and continues to perform effectively, even in challenging thermal environments. By minimizing material oozing and maintaining consistent contact between the heat source and the cooling solution, the TIM **100** improves the overall efficiency and reliability of the thermal management system in electronic devices.

[0040] According to another embodiment, the thermal interface material (TIM) can be manufactured by first preparing a mixture of the desired TIM material in its liquid or semi-liquid form, such as molten indium alloy, liquid metal, or a phase change material (PCM). Once the material is in its liquid state, stoppers, which may be spherical
5 balls or other shapes made from materials like metal, ceramic, or diamond, are introduced into the mixture. The stoppers are thoroughly mixed with the liquid TIM material to ensure distribution throughout. The mixture is then molded or cast into the desired shape, such as a sheet, pad, or other customized forms that match the specific application requirements.

10 **[0041]** After the TIM material is shaped, it is allowed to cool and solidify, or is cured if necessary, depending on the nature of the material being used. Upon solidification, the TIM forms a solid layer with the stoppers embedded within, creating a structure that ensures mechanical stability during use.

[0042] While specific embodiments have been described and illustrated, it is
15 understood that many changes, modifications, variations and combinations thereof could be made to the present invention without departing from the scope of the invention.

Claims

1. A thermal interface material (TIM) for improving heat transfer between a heat source and a cooling means, the TIM comprising:
 - 5 a metal-based TIM layer, including indium alloy, liquid metal, or metallic phase change material (PCM), designed to fill microscopic gaps between the surfaces of the heat source and the cooling solution; and
 - a plurality of stoppers , wherein the stoppers act as mechanical hard stops to maintain a fixed bond-line thickness, preventing excessive compression of the TIM
 - 10 during operation.
2. The TIM of claim 1, wherein the stoppers are made of a material selected from the group consisting of metal, ceramic, diamond, or similar hard materials capable of withstanding temperatures exceeding 300°C.
- 15 3. The TIM of claim 1, wherein the stoppers come in the form of spherical balls.
4. The TIM of claim 1, wherein the stoppers are embedded within the TIM layer.
- 20 5. The TIM of claim 1, wherein the stoppers have a dimension ranging from 0.03 mm to 0.5 mm, depending on the required bond-line thickness for the TIM.
6. The TIM of claim 1, wherein the stoppers are embedded within the TIM in random.

7. A method for improving the mechanical stability and thermal performance of a metal-based TIM of claim 1, the method comprising incorporating spherical balls as mechanical hard stops within the TIM layer to prevent deformation and material oozing during operation at elevated temperatures.

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8. A method of fabricating the TIM of claim 1, the method comprising:
preparing a mixture of desired TIM material in its liquid or semi-liquid form;
introducing and mixing the stoppers into the mixture;
casting the mixture into a desire shape; and
curing the mixture.

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9. The method of claim 8, wherein the TIM is casted a sheet, pad, or other customized forms that match the specific application.