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Thermally Conductive Device

Abstract

A thermally conductive device includes an electrically insulating but thermally conductive layer, a first thermally conductive lead frame, and a second thermally conductive lead frame. The electrically insulating but thermally conductive layer has a top surface, a bottom surface, and a sidewall therebetween. The first thermally conductive lead frame has a top metal plate, a first extending part, and a second extending part. The top metal plate is disposed on the top surface. The first extending part horizontally extends from the top metal plate and goes beyond the sidewall. The second extending part extends from the first extending part and goes beyond the bottom surface. The second thermally conductive lead frame has a bottom metal plate and a third extending part. The bottom metal plate is disposed on the bottom surface. The third extending part extends downward from the bottom metal plate.

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Background/Summary

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0001] The present application relates to a thermally conductive device, and more specifically, to a thermally conductive device having a lead frame structure for thermal conduction.

(2) Description of the Related Art

[0002] It is well-known that electronic products generate heat during operation, and their performance is compromised once the accumulation of heat reaches a certain threshold. Therefore, substrates (e.g., PCB) in electronic products often include additional thermally conductive devices, or alternatively, the substrates are directly replaced with thermally conductive boards having excellent heat-conductive characteristics. Regarding the thermally conductive devices, please refer to a thermally conductive device **100** in FIG. **1**, which shows its front view.

[0003] In FIG. **1**, the thermally conductive device **100** includes an electrode **10**, an electrode **12**, and an electrically insulating but thermally conductive layer **11** laminated therebetween. The electrode **10** and the electrode **12** are made of metal, while the electrically insulating but thermally conductive layer **11** is made of a ceramic material, by which the electrode **10** is electrically isolated from the electrode **12**. On a substrate, one pad to be welded is disposed on a region adjacent to a heat-generating device (e.g., a power device or other active/passive devices requiring cooling), while the other pad to be welded is disposed on a region away from the heat-generating device. The electrode **10** is welded to the pad adjacent to the heat-generating device, and the electrode **12** is welded to the pad away from the heat-generating device. Because the thermally conductive device **100** is superior to the substrate in thermal conduction, heat prioritizes the thermally conductive device **100** as its thermally conductive path. In this way, the heat from the heat-generating device can be rapidly conducted from the electrode **10** to the electrode **12** to reduce the accumulation of heat.

[0004] However, numerous issues arise from this type of structural design that places the electrodes on the right and left sides. For example, the electrode **10** is quite far from the electrode **12**. This structural design stretches the distance between the electrode **10** and the electrode **12**, consequently reducing the amount of heat conducted from the electrode **10** to the electrode **12**. In addition, both the electrode **10** and the electrode **12** exhibit better thermal conductivity than that of the electrically insulating but thermally conductive layer **11** in thermal conduction, and therefore the transfer efficiency of heat is compromised due to the excessive length of the electrically insulating but thermally conductive layer **11**.

[0005] Second, the contact area between the electrode **10** (or the electrode **12**) and the electrically insulating but thermally conductive layer **11** is small. It is understood that the amount of heat received is positively correlated with the cross-sectional area perpendicular to the heat flow direction. If the contact area is small, the amount of heat to be conducted is also small, and vice versa. Moreover, due to the poor conductive efficiency of the conventional device **100**, a significant amount of solder is required to cover both the electrode **10** and the electrode **12** to enhance thermal conduction. Conventionally, the solder covers the bottoms of the electrode **10** and the electrode **12**, and then climbs upwards along their sides. The thermally conductive capability of the thermally conductive device is significantly affected by the usage amount of the solder. However, the usage amount of solder is difficult to be precisely controlled, causing inconsistencies in performance during mass production.

[0006] Accordingly, there is a need to improve the structural design so as to address the issues of the thermally conductive device **100** as described above.

SUMMARY OF THE INVENTION

[0007] The present invention provides a thermally conductive device having a lead frame structure for thermal conduction. More specifically, the thermally conductive device of the present invention includes an electrically insulating but thermally conductive layer, and at least two thermally conductive lead frames (e.g., a first thermally conductive lead frame and a second thermally conductive lead frame hereinafter). The first thermally conductive lead frame has a metal plate and a lead extended from the metal plate. The first thermally conductive lead frame attaches to the top surface of the electrically insulating but thermally conductive layer through the metal plate, and its lead bends and extends downward. Similarly, the second thermally conductive lead frame has a metal plate and a lead extended from the metal plate. The second thermally conductive lead frame attaches to the bottom surface of the electrically insulating but thermally conductive layer through the metal plate, and its lead bends and extends downward, by which the lead of the second thermally conductive lead frame and the lead of the first thermally conductive lead frame are on the same side. This design enlarges the cross-sectional area perpendicular to the heat flow direction while decreasing the thickness of the electrically insulating but thermally conductive layer, effectively shortening the conductive path. The structure of the present invention significantly improves the efficiency of thermal conduction, eliminating the need for using as much solder as usual.

[0008] In accordance with an aspect of the present invention, a thermally conductive device includes an electrically insulating but thermally conductive layer, a first thermally conductive lead frame, and a second thermally conductive lead frame. The electrically insulating but thermally conductive layer has a top surface, a bottom surface, and a sidewall. The top surface is opposite to the bottom surface, and the sidewall connects to the top surface and the bottom surface. The first thermally conductive lead frame has a top metal plate, a first extending part, and a second extending part. The top metal plate is disposed on the top surface. The first extending part is parallel to the electrically insulating but thermally conductive layer, and extends from the top metal plate and extends beyond the sidewall. The second extending part extends from the first extending part and extends beyond the bottom surface. The second thermally conductive lead frame has a bottom metal plate and a third extending part. The bottom metal plate is disposed on the bottom surface. The third extending part extends from the bottom metal plate and extends in a direction away from the electrically insulating but thermally conductive layer.

[0009] In an embodiment, the electrically insulating but thermally conductive layer has a length. The first extending part extends beyond the sidewall by a first distance. If the sum of the length and the first distance are calculated as 100%, the first distance ranges from 19% to 51%.

[0010] In an embodiment, the first thermally conductive lead frame further includes a first connecting terminal connected to the second extending part, and the second thermally conductive lead frame further includes a second connecting terminal connected to the third extending part. The first connecting terminal extends parallel to the bottom metal plate toward the second connecting terminal, and the second connecting terminal extends parallel to the bottom metal plate toward the first connecting terminal.

[0011] In an embodiment, the first connecting terminal has a first bottom surface, and the second connecting terminal has a second bottom surface. The first bottom surface and the second bottom surface are on the same horizontal plane. The second extending part extends beyond the bottom metal plate by a second distance, and the bottom metal plate is spaced apart from the horizontal plane by a third distance. If the third distance is calculated as 100%, the second distance ranges from 35% to 80%.

[0012] In an embodiment, the first thermally conductive lead frame further includes a first connecting terminal connected to the second extending part, and the second thermally conductive lead frame further includes a second connecting terminal connected to the third extending part. The first connecting terminal and the second connecting terminal extend toward each other. The first connecting terminal has a first bottom surface, and the second connecting terminal has a second bottom surface. The first bottom surface and the second bottom surface are on the same horizontal plane. An angle is formed between the first bottom surface of the first connecting terminal and the horizontal plane, and the angle is less than 30 degrees.

[0013] In an embodiment, an angle is formed between the second bottom surface of the second connecting terminal and the horizontal plane, and the angle is less than 30 degrees.

[0014] In an embodiment, the thermally conductive device further includes a first sputtering layer and a second sputtering layer. The first sputtering layer covers the top surface of the electrically insulating but thermally conductive layer, and the second sputtering layer covers the first sputtering layer.

[0015] In an embodiment, the first sputtering layer has a first lattice constant, and the electrically insulating but thermally conductive layer has a second lattice constant. A ratio of the first lattice constant to the second lattice constant ranges from 0.9 to 1.2.

[0016] In an embodiment, a ratio of a thickness of the first sputtering layer to a thickness of the second sputtering layer is in a range from 1:1 to 1:4.

[0017] In an embodiment, the thermally conductive device further includes a first electroplating layer and a second electroplating layer. The first electroplating layer covers the second sputtering layer, and the second electroplating layer covers the first electroplating layer, by which the second electroplating layer is able to be securely connected to the top metal plate through solder.

[0018] In an embodiment, a ratio of a thickness of the first electroplating layer to a thickness of the second electroplating layer is in a range from 1:2 to 1:4.

[0019] In an embodiment, the thermally conductive device further includes a packaging layer. The packaging layer entirely covers the top metal plate, the electrically insulating but thermally conductive layer, and the bottom metal plate. The packaging layer partially covers the first extending part and the third extending part.

[0020] In an embodiment, the first thermally conductive lead frame further includes a first connecting terminal connected to the second extending part, and the second thermally conductive lead frame further includes a second connecting terminal connected to the third extending part, wherein the first connecting terminal and the second connecting terminal extend toward each other. The first connecting terminal of the first thermally conductive lead frame physically contacts the packaging layer, and the second connecting terminal of the second thermally conductive lead frame physically contacts the packaging layer.

[0021] In an embodiment, the first extending part of the first thermally conductive lead frame has a first corner and a second corner. The first extending part extends to the first corner in a direction parallel to the electrically insulating but thermally conductive layer, extends from the first corner to the second corner in a direction parallel to the sidewall, and then extends from the second corner in a direction away from the sidewall, thereby connecting to the second extending part. The third extending part of the second thermally conductive lead frame has a third corner, a fourth corner, and a fifth corner. The third extending part extends to the third corner in a direction parallel to the electrically insulating but thermally conductive layer, extends from the third corner to the fourth corner in a direction parallel to the sidewall, extends from the fourth corner to the fifth corner in a direction away from the sidewall, and then extends from the fifth corner in a direction parallel to the sidewall, thereby extending away from the electrically insulating but thermally conductive layer.

[0022] In an embodiment, the thermally conductive device further includes a packaging layer. The packaging layer entirely covers the top metal plate, the electrically insulating but thermally conductive layer, and the bottom metal plate. The packaging layer partially covers the first extending part and the third extending part.

[0023] In an embodiment, the first thermally conductive lead frame further includes a first connecting terminal connected to the second extending part, and the second thermally conductive lead frame further includes a second connecting terminal connected to the third extending part, wherein the first connecting terminal and the second connecting terminal extend toward each other. The first connecting terminal of the first thermally conductive lead frame physically contacts the packaging layer, and the second connecting terminal of the second thermally conductive lead frame physically contacts the packaging layer.

[0024] In an embodiment, a thickness of the first thermally conductive lead frame ranges from 0.1 mm to 0.25 mm.

[0025] In an embodiment, the thermally conductive device includes a plurality of the first thermally conductive lead frames and a plurality of the second thermally conductive lead frames.

[0026] In an embodiment, the first thermally conductive lead frame and the second thermally conductive lead frame are made of copper or copper alloy.

[0027] In an embodiment, the thermally conductive device further includes an adhesive layer disposed between the electrically insulating but thermally conductive layer and the first thermally conductive lead frame. The adhesive layer is made of a material selected from the group consisting of epoxy resin, silicone, acrylic resin, polyurethane, and a mixture or copolymer of combinations thereof.

[0028] In an embodiment, the electrically insulating but thermally conductive layer is made of epoxy resin and a thermally conductive filler. The thermally conductive filler is selected from the group consisting of zirconium nitride, boron nitride, aluminum nitride, silicon nitride, aluminum oxide, magnesium oxide, zinc oxide, silicon dioxide, titanium dioxide, and any combination thereof.

[0029] In an embodiment, the electrically insulating but thermally conductive layer is made of a ceramic material. The ceramic material is selected from the group consisting of zirconium nitride, boron nitride, aluminum nitride, silicon nitride, aluminum oxide, magnesium oxide, zinc oxide, silicon dioxide, titanium dioxide, and any combination thereof.

[0030] In an embodiment, a roughness (Ra) of the top surface and the bottom surface of the electrically insulating but thermally conductive layer ranges from 0.01 μm to 10 μm.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] The present application will be described according to the appended drawings in which:

[0032] FIG. **1** shows a front view of a conventional thermally conductive device;

[0033] FIG. **2** shows a three-dimensional view of a thermally conductive device of the present invention;

[0034] FIG. **3** shows a cross-sectional view of the thermally conductive device along the line AA depicted in FIG. **2**;

[0035] FIG. **4** shows an embodiment of the thermally conductive device depicted in FIG. **3**;

[0036] FIG. **5** shows another embodiment of the thermally conductive device depicted in FIG. **3**;

[0037] FIG. **6**A shows a cross-sectional view of a thermally conductive device of the present invention after packaging;

[0038] FIG. **6**B shows the cross-sectional view of the thermally conductive device depicted in FIG. **6**A after punching; and

[0039] FIG. **7** to FIG. **9** show three-dimensional views of a thermally conductive device of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0040] The making and using of the presently preferred illustrative embodiments are discussed in detail below. It should be appreciated, however, that the present application provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific illustrative embodiments discussed are merely illustrative of specific ways to make and use the invention, and do not limit the scope of the invention.

[0041] Please refer to FIG. **2**, which presents a three-dimensional view of a thermally conductive device **200** of the present invention. For clarity, FIG. **2** illustrates the x-axis, y-axis, and z-axis to show the orientation in space. The thermally conductive device **200** includes a first thermally conductive lead frame **20**, an electrically insulating but thermally conductive layer **30**, and a second thermally conductive lead frame **40**. The first thermally conductive lead frame **20** and the second thermally conductive lead frame **40** are made of copper or copper alloy. For example, copper foils can be punched into small pieces with structures identical to those of the first thermally conductive lead frame **20** and the second thermally conductive lead frame **40** as shown in FIG. **2**. Subsequently, the first thermally conductive lead frame **20** and the second thermally conductive lead frame **40** are assembled onto the electrically insulating but thermally conductive layer **30** for each thermally conductive device **200**. In this manner, the first thermally conductive lead frame **20** attaches to the top of the electrically insulating but thermally conductive layer **30**, with a bent lead extending downward. The second thermally conductive lead frame **40** attaches to the bottom of the electrically insulating but thermally conductive layer **30**, also with a bent lead extending downward. The lead of the first thermally conductive lead frame **20** and the lead of the second thermally conductive lead frame **40** can be welded to different regions, thereby facilitating the conduction of heat from one region to the other one. The electrically insulating but thermally conductive layer **30** is laminated between the first thermally conductive lead frame **20** and the second thermally conductive lead frame **40**, thereby electrically isolating the first thermally conductive lead frame **20** from the second thermally conductive lead frame **40** and preventing arcing. The electrically insulating but thermally conductive layer **30** may be made of a composite material or a ceramic material. In an embodiment, the electrically insulating but thermally conductive layer **30** is made of epoxy resin and a thermally conductive filler (i.e., made of the composite material as previously mentioned), and the thermally conductive filler is selected from the group consisting of zirconium nitride, boron nitride, aluminum nitride, silicon nitride, aluminum oxide, magnesium oxide, zinc oxide, silicon dioxide, titanium dioxide, and any combination thereof. In an embodiment, in order to enhance the adhesion between the composite material and metal, the thermally conductive device **200** further includes an adhesive layer disposed between the electrically insulating but thermally conductive layer **30** and the first thermally conductive lead frame **20**, and the adhesive layer is made of a material selected from the group consisting of epoxy resin, silicone, acrylic resin, polyurethane, and a mixture or copolymer of combinations thereof. In an embodiment, the thermally conductive device **200** also includes an adhesive layer, identical to the aforementioned one, disposed between the electrically insulating but thermally conductive layer **30** and the second thermally conductive lead frame **40**. In another embodiment, the metal compounds of the composite material do not act as fillers and can solely constitute the electrically insulating but thermally conductive layer **30**, that is, the electrically insulating but thermally conductive layer **30** is made of the ceramic material selected from the group consisting of zirconium nitride, boron nitride, aluminum nitride, silicon nitride, aluminum oxide, magnesium oxide, zinc oxide, silicon dioxide, titanium dioxide, and any combination thereof.

[0042] Please refer to FIG. **2** again. A substrate has two regions, a hot zone H and a cold zone C, respectively. The hot zone H is a region adjacent to a heat-generating device (e.g., a power device), and the temperature around it is relatively higher. The cold zone C is a region away from the heat-generating device, and the temperature around it is relatively lower. The lead of the first thermally conductive lead frame **20** can be welded to the hot zone H, while the lead of the second thermally conductive lead frame **40** can be welded to the cold zone C. This setup allows for rapid conduction of the heat accumulated around the heat-generating device from the hot zone H to the cold zone C, thereby reducing the temperature of the heat-generating device. It is understood that the cold region C may be any specified plane on the substrate, a region where a heat sink is located, a region where a thermally conductive film is located, or any other preset low-temperature regions. In an embodiment, the thermally conductive device **200** of the present invention has a length L ranging from 4 mm to 9 mm, a width W ranging from 1.5 mm to 6 mm, and a thickness T ranging from 1.5 mm to 3.5 mm. This structural design enlarges the cross-sectional area, which is perpendicular to the heat flow direction (i.e., y-axis). The cross-sectional area is substantially the top-view area of the electrically insulating but thermally conductive layer **30**, ranging from 2 mm.sup.2 to 40 mm.sup.2, preferably from 13 mm.sup.2 to 40 mm.sup.2. In an embodiment, the top-view area of the electrically insulating but thermally conductive layer **30** may be 1.5 mm×1.5 mm, 1.8 mm×1.8 mm, 2.1 mm×2.1 mm, 4.5 mm×3.1 mm, 4 mm×4 mm, 5 mm×5 mm, or 6 mm×6 mm. For more specific details, please continuously refer to FIG. **3**.

[0043] FIG. **3** shows a cross-sectional view of the thermally conductive device **200** along the line AA depicted in FIG. **2**. The thermally conductive device **200** includes the electrically insulating but thermally conductive layer **30**, the first thermally conductive lead frame **20**, and the second thermally conductive lead frame **40**. The electrically insulating but thermally conductive layer **30** has a top surface **31**, a bottom surface **32**, and a sidewall **33**. The top surface **31** is opposite to the bottom surface **32**, and the sidewall **33** connects to the top surface **31** and the bottom surface **32**. The sidewall **33** is substantially perpendicular to the top surface **31** and the bottom surface **32**. The first thermally conductive lead frame **20** has a top metal plate **20***a*, a first extending part **20***b*, and a second extending part **20***c*. The top metal plate **20***a* is disposed on the top surface **31** of the electrically insulating but thermally conductive layer **30**. The first extending part **20***b* is parallel to the electrically insulating but thermally conductive layer **30**, and extends from the top metal plate **20***a* and extends beyond the sidewall **33** along the z-axis. The second extending part **20***c* extends from the first extending part **20***b* and extends beyond the bottom surface **32** along the y-axis. The second thermally conductive lead frame **40** has a bottom metal plate **40***a* and a third extending part **40***b*. The bottom metal plate **40***a* is disposed on the bottom surface **32** of the electrically insulating but thermally conductive layer **30**. The third extending part **40***b* extends from the bottom metal plate **40***a* and extends in a direction away from the electrically insulating but thermally conductive layer **30** along the y-axis. The space above the top surface **31** of the electrically insulating but thermally conductive layer **30** is defined as an upper side, while the space below the bottom surface **32** of the electrically insulating but thermally conductive layer **30** is defined as a lower side. Accordingly, the terminal of the second extending part **20***c* of the first thermally conductive lead frame **20** and the terminal of the third extending part **40***b* of the second thermally conductive lead frame **40** are on the same side, that is, the lower side. The first thermally conductive lead frame **20** has a first thickness T**1** ranging from 0.3 mm to 0.7 mm, such as 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.7 mm. The second thermally conductive lead frame **40** has the same thickness as that of the first thermally conductive lead frame **20**. The electrically insulating but thermally conductive layer **30** has a second thickness T**2** ranging from 0.1 mm to 0.3 mm, such as 0.1 mm, 0.15 mm, 0.2 mm, 0.25 mm, or 0.3 mm. To increase the peel strength between the electrically insulating but thermally conductive layer **30** and the metal layers, a roughening process is performed on the top surface **31** and the bottom surface **32**, thereby increasing the contact area between them and enhancing the effect of mechanical interlocking. A roughness (Ra) of the top surface **31** and the bottom surface **32** of the electrically insulating but thermally conductive layer **30** ranges from 0.01 μm to 10 μm. For the structural design of the thermally conductive lead frame of the present invention, the roughness (Ra) preferably ranges from 0.04 μm to 0.1 μm so as to provide sufficient peel strength.

[0044] It is noted that the first extending part **20***b* of the first thermally conductive lead frame **20** needs to extend a certain length to prevent the second extending part **20***c* from getting too close to the bottom metal plate **40***a* of the second thermally conductive lead frame **40**. If the second extending part **20***c* of the first thermally conductive lead frame **20** is too close to, or even contacts, the bottom metal plate **40***a* of the second thermally conductive lead frame **40**, it may lead to arcing during the operation of the thermally conductive device **200**. Details are described hereinafter. The electrically insulating but thermally conductive layer **30** has a first length L**1**. The first extending part **20***b* extends beyond the sidewall **33** along the z-axis by a first distance D**1**. If the sum of the first length L**1** and the first distance D**1** are calculated as 100%, the first distance D**1** ranges from 19% to 51%, such as 19%, 27%, 35%, 43%, or 51%. If the percentage of the first distance D**1** is less than 19%, the second extending part **20***c* is too close to, or even contacts, the bottom metal plate **40***a* of the second thermally conductive lead frame **40**, potentially causing arcing. If the percentage of the first distance D**1** is more than 51%, the horizontal length of the first thermally conductive lead frame **20** becomes excessively long and does not meet the required specifications in the industry. In an embodiment, the first length L**1** may be 1.5 mm, 1.8 mm, 2.1 mm, 3.1 mm, 4.5 mm, 5 mm, or 6 mm. For example, if the first length L**1** is 1.5 mm, the first extending part **20***b* should extend beyond the sidewall **33** along the z-axis by the first distance D**1** of at least 0.35 mm. If the first length L**1** is 1.8 mm, the first extending part **20***b* should extend beyond the sidewall **33** along the z-axis by the first distance D**1** of at least 0.42 mm. For conciseness, other first lengths L**1** can be deduced in the same way without further elaboration. Furthermore, from the top-down perspective, the top-view area of the top metal plate **20***a* is the same as the top-view area of the electrically insulating but thermally conductive layer **30** of the first thermally conductive lead frame **20**. The top metal plate **20***a* and the electrically insulating but thermally conductive layer **30** of the first thermally conductive lead frame **20** may have the same length and the width, and therefore the aforementioned first length L**1** also represents the length of the top metal plate **20***a*. Similarly, the top-view area of the bottom metal plate **40***a* is the same as the top-view area of the electrically insulating but thermally conductive layer **30** of the second thermally conductive lead frame **40**, and therefore the aforementioned first length L**1** also represents the length of the bottom metal plate **40***a*.

[0045] For convenience of welding the thermally conductive device **200** to the substrate, the first thermally conductive lead frame **20** and the second thermally conductive lead frame **40** further include a first connecting terminal **20***d* and a second connecting terminal **40***c*, respectively. The first thermally conductive lead frame **20** includes the first connecting terminal **20***d* connected to the second extending part **20***c*, and the second thermally conductive lead frame **40** includes the second connecting terminal **40***c* connected to the third extending part **40***b*. The first connecting terminal **20***d* extends parallel to the bottom metal plate **40***a* toward the second connecting terminal **40***c* along the z-axis, and the second connecting terminal **40***c* extends parallel to the bottom metal plate **40***a* toward the first connecting terminal **20***d* along the z-axis. The first extending part **20***b*, the second extending part **20***c*, and the first connecting terminal **20***d* together form the lead of the first thermally conductive lead frame **20**. The third extending part **40***b* and the second connecting terminal **40***c* together form the lead of the second thermally conductive lead frame **40**. The first connecting terminal **20***d* of the first thermally conductive lead frame **20** is substantially coplanar with the second connecting terminal **40***c* of the second thermally conductive lead frame **40**. The first connecting terminal **20***d* has a first bottom surface **20***e*, and the second connecting terminal **40***c* has a second bottom surface **40***d*. The first bottom surface **20***e* and the second bottom surface **40***d* are on the same horizontal plane (i.e., the xy-plane). In another embodiment, the first connecting terminal **20***d* and the second connecting terminal **40***c* extend in directions opposite to each other along the z-axis, by which the first connecting terminal **20***d* protrudes outward from the sidewall of the second extending part **20***c* (forming a reverse L-shape profile, not shown) and the second connecting terminal **40***c* protrudes outward from the sidewall of the third extending part **40***b* (forming an L-shape profile, not shown). If the first connecting terminal **20***d* of the first thermally conductive lead frame **20** adopts the design of the aforementioned “reverse L-shape” structure, it prevents the first connecting terminal **20***d* from getting too close to the bottom metal plate **40***a* of the second thermally conductive lead frame **40**, thereby reducing the risk of arcing. Similarly, if the second connecting terminal **40***c* of the second thermally conductive lead frame **40** adopts the design of the aforementioned "L-shape" structure, it increases the distance between the second connecting terminal **40***c* and the first connecting terminal **20***d*, thereby reducing the likelihood of contact between the two terminals. For instance, if excessive amount of solder is accidentally applied to these two terminals, it ensures that a sufficient distance can be maintained between the solder on one terminal and the solder on the other terminal.

[0046] It is noted that the second extending part **20***c* of the first thermally conductive lead frame **20** needs to extend a certain length to prevent the first connecting terminal **20***d* from getting too close to the bottom metal plate **40***a* of the second thermally conductive lead frame **40**. If the first connecting terminal **20***d* of the first thermally conductive lead frame **20** is too close to, or even contacts, the bottom metal plate **40***a* of the second thermally conductive lead frame **40**, it may lead to arcing during the operation of the thermally conductive device **200**. Therefore, the present invention raises the bottom metal plate **40***a* of the second thermally conductive lead frame **40** by a specific distance relative to the first connecting terminal **20***d*. The second extending part **20***c* extends beyond the bottom metal plate **40***a* by a second distance D**2**, and the bottom metal plate **40***a* is spaced apart from the horizontal plane by a third distance D**3**. If the third distance D**3** is calculated as 100%, the second distance D**2** ranges from 35% to 80%, such as 35%, 44%, 53%, 62%, 71%, or 80%. If the percentage of the second distance D**2** is less than 35%, the first connecting terminal **20***d* is too close to, or even contacts, the bottom metal plate **40***a* of the second thermally conductive lead frame **40**, potentially causing arcing. If the percentage of the second distance D**2** is more than 80%, the bottom metal plate **40***a* is excessively raised and the device's size does not meet the required specifications in the industry. For example, in an embodiment, if the third distance D**3** is 1.1 mm, the second distance D**2** may range from 0.38 mm to 0.88 mm.

[0047] Please refer to FIG. **4**. FIG. **4** shows an embodiment of the thermally conductive device **200** depicted in FIG. **3**. The difference between FIG. **4** and FIG. **3** lies in the inclination of the terminal of the lead (i.e., the inclination of the first connecting terminal **20***d* or the second connecting terminal **40***c*). Besides that, the structural design and dimensions of the first thermally conductive lead frame **20**, the second thermally conductive lead frame **40**, and the electrically insulating but thermally conductive layer **30** in FIG. **4** are the same as previously described and not described in detail again. In FIG. **4**, the first connecting terminal **20***d* of the first thermally conductive lead frame **20** extends toward the second connecting terminal **40***c* of the second thermally conductive lead frame **40**, and likewise, the second connecting terminal **40***c* of the second thermally conductive lead frame **40** extends toward the first connecting terminal **20***d* of the first thermally conductive lead frame **20**. An angle θ is formed between the first bottom surface **20***e* of the first connecting terminal **20***d* and the horizontal plane, and the angle θ is less than 30 degrees. On the basis of this design, more space is available for accommodating the solder beneath the first bottom surface **20***e* of the first connecting terminal **20***d*, which is beneficial for welding. It is noted that there is a limitation on the angle θ. If the angle θ is more than 30 degrees, the first connecting terminal **20***d* is too close to the bottom metal plate **40***a*, potentially causing arcing. Similarly, an angle (not shown) may be formed between the second bottom surface **40***d* of the second connecting terminal **40***c* and the horizontal plane. The inclined angle of the second connecting terminal **40***c* is the same as the inclined angle θ of the first connecting terminal **20***d*, and this symmetry in angle provides process convenience during punching. In an embodiment, the angle θ is 5 degrees, 10 degrees, 15 degrees, 20 degrees, 25 degrees, or 30 degrees. In a preferred embodiment, the angle θ is less than 10 degrees, thereby providing more tolerance to measurement error.

[0048] FIG. **5** shows another embodiment of the thermally conductive device **200** depicted in FIG. **3**. The difference between FIG. **5** and FIG. **3** lies in additional layers between the metal plate and the electrically insulating layer. Besides that, the structural design and dimensions of the first thermally conductive lead frame **20**, the second thermally conductive lead frame **40**, and the electrically insulating but thermally conductive layer **30** in FIG. **5** are the same as previously described and not described in detail again. For ease of describing, certain reference numerals (e.g., L for length, L**1** for first length, D**1** for first distance, D**2** for second distance, D**3** for third distance, T**1** for first thickness, and T**2** for second thickness) are omitted herein. In FIG. **5**, the thermally conductive device **200** further includes a first sputtering layer **51** and a second sputtering layer **52**. By using a sputtering method, a first metal film (i.e., the first sputtering layer **51**) can be formed on the surface of the electrically insulating but thermally conductive layer **30**, thereby enhancing its adhesion to metal substrates. Considering the subsequent process of electroplating, a second metal film (i.e., the second sputtering layer **52**) can be formed on the first sputtering layer **51** through the sputtering method. That is, the first sputtering layer **51** covers the top surface **31** of the electrically insulating but thermally conductive layer **30**, and the second sputtering layer **52** covers the first sputtering layer **51**. In an embodiment, the first sputtering layer **51** is made of titanium, zirconium, or tungsten. In an embodiment, the second sputtering layer **52** is made of copper or gold. It is noted that in order to reduce defects at the interface between the first sputtering layer **51** and the electrically insulating but thermally conductive layer **30**, the difference in lattice constant between them should not be too large. For example, the first sputtering layer **51** has a first lattice constant, and the electrically insulating but thermally conductive layer **30** has a second lattice constant. Ideally, the optimal ratio of the first lattice constant to the second lattice constant is 1, meaning that the lattice constant of the first sputtering layer **51** completely matches the lattice constant of the electrically insulating but thermally conductive layer **30**. In the present invention, a ratio of the first lattice constant to the second lattice constant may vary in a range from 0.9 to 1.2. In addition, the thicknesses between the first sputtering layer **51** and the second sputtering layer **52** need to be carefully controlled within a specific range. A ratio of the thickness of the first sputtering layer **51** to the thickness of the second sputtering layer **52** is in a range from 1:1 to 1:4, such as 1:1, 1:2, 1:3, or 1:4. Please refer to FIG. **5**. The thermally conductive device **200** further includes a first electroplating layer **53** and a second electroplating layer **54**. The first electroplating layer **53** covers the second sputtering layer **52**, and the second electroplating layer **54** covers the first electroplating layer **53**, by which the second electroplating layer **54** is able to be securely connected to the top metal plate **20***a* through solder. In an embodiment, the first electroplating layer **53** is made of nickel or copper. In an embodiment, the second electroplating layer **54** is made of tin.

[0049] Through the operation of electroplating, the top metal plate **20***a* of the first thermally conductive lead frame **20** can be welded to the electroplating layers so as to be assembled onto the top surface **31** of the electrically insulating but thermally conductive layer **30**. Moreover, the thicknesses between the first electroplating layer **53** and the second electroplating layer **54** also need to be carefully controlled within a specific range. A ratio of the thickness of the first electroplating layer **53** to the thickness of the second electroplating layer **54** is in a range from 1:2 to 1:4, such as 1:2, 1:3, or 1:4. It is understood that the same design, as previously mentioned, can be applied to the layers between the bottom metal plate **40***a* of the second thermally conductive lead frame **40** and the bottom surface **32** of the electrically insulating but thermally conductive layer **30**. That is, the thermally conductive device **200** may also include the sputtering layers and the electroplating layers laminated between the bottom metal plate **40***a* and the bottom surface **32**. Similarly, the sputtering layers and the electroplating layers laminated between the bottom metal plate **40***a* and the bottom surface **32** may have the lattice-constant ratios and the thickness ratios as previously mentioned. Furthermore, the sputtering layers are not limited to two layers, nor are the electroplating layers. Additional metal layers can be further included between the first thermally conductive lead frame **20** (or the second thermally conductive lead frame **40**) and the top surface **31** (or the bottom surface **32**) in order to securely assemble the thermally conductive lead frames onto the electrically insulating but thermally conductive layer **30** or meet other requirements.

[0050] FIG. **6**A and FIG. **6**B show a thermally conductive device **300** after packaging. If the thermally conductive device needs to be packaged, slight variations in the manufacturing process may be necessary to conform to the standard equipment commonly used in the industry. For the thermally conductive device **200** without a packaging structure, the first thermally conductive lead frame **20** and the second thermally conductive lead frame **40** have been punched into the bending structures as shown in FIG. **3** beforehand, and then are assembled onto the top surface **31** and the bottom surface **32** of the electrically insulating but thermally conductive layer **30**.

[0051] For the thermally conductive device **300** with a packaging structure, the first thermally conductive lead frame **20** and the second thermally conductive lead frame **40** are not punched into the bending structures (i.e., both of them are in the form of plate structures) at the beginning, and then these two plates are assembled onto the electrically insulating but thermally conductive layer. Then, as shown in FIG. **6**A, the first thermally conductive lead frame **20** and the second thermally conductive lead frame **40** are slightly bent, and a packaging layer **60** packages the electrically insulating but thermally conductive layer, a part of the first thermally conductive lead frame **20**, and a part of the second thermally conductive lead frame **40** through an injection molding operation. Afterward, a punching operation is performed to form the structure of the thermally conductive device **300** as shown in FIG. **6**B. The aforementioned "slightly bent" is to make the central axis of the first thermally conductive lead frame **20** and the central axis of the second thermally conductive lead frame **40** align with the central axis of the electrically insulating but thermally conductive layer, as indicated by the dashed line shown in FIG. **6**A. This alignment provides process convenience and the device can be punched into the final structure as shown in FIG. **6**B. Actually, in terms of the final structure, the difference between the unpackaged thermally conductive device **200** and the packaged thermally conductive device **300** lies in the slightly bent portions (i.e., where the first extending part **20***b* and third extending part **40***b* are located). The details are described below. In FIG. **6**B, the packaging layer **60** entirely covers the top metal plate **20***a*, the electrically insulating but thermally conductive layer **30**, and the bottom metal plate **40***a*, and partially covers the first extending part **20***b* of the first thermally conductive lead frame **20** and the third extending part **40***b* of the second thermally conductive lead frame **40**. The first extending part **20***b* of the first thermally conductive lead frame **20** has a first corner C**1** and a second corner C**2**. The first extending part **20***b* extends to the first corner C**1** in a direction parallel to the electrically insulating but thermally conductive layer **30** along the z-axis, extends from the first corner C**1** to the second corner C**2** in a direction parallel to the sidewall **33** along the y-axis, and then extends from the second corner C**2** in a direction away from the sidewall **33** along the z-axis, thereby connecting to the second extending part **20***c*. The third extending part **40***b* of the second thermally conductive lead frame **40** has a third corner C**3**, a fourth corner C**4**, and a fifth corner C**5**. The third extending part **40***b* extends to the third corner C**3** in a direction parallel to the electrically insulating but thermally conductive layer **30** along the z-axis, extends from the third corner C**3** to the fourth corner C**4** in a direction parallel to the sidewall **33** along the y-axis, extends from the fourth corner C**4** to the fifth corner C**5** in a direction away from the sidewall **33** along the z-axis, and then extends from the fifth corner C**5** in a direction parallel to the sidewall **33** along the y-axis, thereby extending away from the electrically insulating but thermally conductive layer **30**. After being packaged by the packaging layer **60**, the breakdown voltage of the thermally conductive device **300** is significantly increased. For example, at dimensions of about 7 mm in length L, about 5 mm in width W, and about 2 mm in thickness T, the AC breakdown voltage of the thermally conductive device **200** in FIG. **3** exceeds 0.6 kV and its DC breakdown voltage exceeds 1 kV. However, at the same dimensions, the AC breakdown voltage of the thermally conductive device **300** in FIG. **6**B exceeds 3.5 kV and its DC breakdown voltage exceeds 5 kV. It is noted that if the thermally conductive device is packaged, its thermally conductive lead frames can be designed to be thinner. For example, the first thickness

[0052] Tl of the first thermally conductive lead frame **20** of the thermally conductive device **300** may range from 0.1 mm to 0.25 mm, and so does the thickness of the second thermally conductive lead frame **40**. Since the packaging layer **60** provides good electrical insulation, the second distance D**2** maintained after punching the lead terminals (e.g., first connecting terminal **20***d* of the first thermally conductive lead frame **20**) does not need to be carefully considered. During the punching operation, the surface of the packaging layer **60** may also serve as the stop surface where the first connecting terminal **20***d* and the second connecting terminal **40***c* abut against the packaging layer **60**. That is, the first connecting terminal **20***d* and the second connecting terminal **40***c* extend toward each other so that the first connecting terminal **20***d* and the second connecting terminal **40***c* physically contact the packaging layer **60** (not shown). There are various designs for the above structure. The first connecting terminal **20***d* (or the second connecting terminal **40***c*) may be adhered parallel to the packaging layer **60**, or extended at a specified angle (such as the angle **0** in FIG. **4**) with only its end contacting the packaging layer **60**. In one embodiment, the first connecting terminal **20***d* extends parallel to the bottom metal plate **40***a* toward the second connecting terminal **40***c* to contact the packaging layer **60**, and the second connecting terminal **40***c* extends parallel to the bottom metal plate **40***a* toward the first connecting terminal **20***d* to contact the packaging layer **60**. In another embodiment, the first connecting terminal **20***d* extends at a specified angle relative to the horizontal plane until it contacts the packaging layer **60**, while the second connecting terminal **40***c* also extends at a specified angle relative to the horizontal plane until it contacts the packaging layer **60**. It is noted that all the aforementioned designs related to the first thermally conductive lead frame **20**, second thermally conductive lead frame **40**, and the electrically insulating but thermally conductive layer **30** can also be applied to the thermally conductive device **300** in FIG. **6**B.

[0053] FIG. **7** to FIG. **9** show that a thermally conductive device **400** includes a plurality of the first thermally conductive lead frames **20** and a plurality of the second thermally conductive lead frames **40**. For simplification and ease of understanding, only critical elements are indicated by reference numerals. To put it simply, a plurality of the thermally conductive lead frames may be derived from a single layer. In FIG. **7**, the first thermally conductive lead frames **20** attach to the top surface of the electrically insulating but thermally conductive layer **30**, and extend outward from one side of the thermally conductive device **400** along the x-axis. The second thermally conductive lead frames **40** attach to the bottom surface of the electrically insulating but thermally conductive layer **30**, and extend outward from the opposite side of the thermally conductive device **400** along the x-axis. The top surface of the electrically insulating but thermally conductive layer **30** is opposite to the bottom surface of the electrically insulating but thermally conductive layer **30**. Each first thermally conductive lead frame **20** and each second thermally conductive lead frame **40** extend in opposite directions along the x-axis. It is noted that in the thermally conductive device **400**, the third extending part **40***b* of the second thermally conductive lead frame **40** is slightly modified. The third extending part **40***b* extends outward along the x-axis by a distance, and then extends in a direction away from the electrically insulating but thermally conductive layer **30**. Alternatively, the second thermally conductive lead frame **40** in FIG. **7** may be designed to be identical to the second thermally conductive lead frame **40** in FIG. **3**. This design (i.e., the structure of multiple leads extended from a single layer) not only offers flexibility in configuration but also enhances thermal conduction. For example, in FIG. **8**, the substrate has two hot zones H and two cold zones C, and the thermally conductive device **400** has two first thermally conductive lead frames **20** and two second thermally conductive lead frames **40**. All the first thermally conductive lead frames **20** may be welded to the hot zones H, while all the second thermally conductive lead frames **40** may be welded to the cold zones C. Alternatively, as depicted in the embodiment in FIG. **9**, the opposing ones of the first thermally conductive lead frame **20** and the second thermally conductive lead frame **40** form a pair of lead frames, resulting in two pairs. One pair is welded to these two cold zones C, while the other pair is welded to these two hot zones H. It is noted that this structural design significantly increases the number of adjacent leads, and therefore the device may be packaged in order to prevent arcing. In an embodiment, the thermally conductive device **400** further includes the packaging layer **60** as previously mentioned.

[0054] The above-described embodiments of the present invention are intended to be illustrative only. Numerous alternative embodiments may be devised by persons skilled in the art without departing from the scope of the following claims.

Claims

1. A thermally conductive device, comprising: an electrically insulating but thermally conductive layer having a top surface, a bottom surface, and a sidewall, wherein the top surface is opposite to the bottom surface, and the sidewall connects to the top surface and the bottom surface; a first thermally conductive lead frame having a top metal plate, a first extending part, and a second extending part, wherein: the top metal plate is disposed on the top surface; the first extending part is parallel to the electrically insulating but thermally conductive layer, and extends from the top metal plate and beyond the sidewall; and the second extending part extends from the first extending part and extends beyond the bottom surface; and a second thermally conductive lead frame having a bottom metal plate and a third extending part, wherein: the bottom metal plate is disposed on the bottom surface; and the third extending part extends from the bottom metal plate and extends in a direction away from the electrically insulating but thermally conductive layer.
2. The thermally conductive device of claim 1, wherein: the electrically insulating but thermally conductive layer has a length; the first extending part extends beyond the sidewall by a first distance; and if the sum of the length and the first distance are calculated as 100%, the first distance ranges from 19% to 51%.
3. The thermally conductive device of claim 1, wherein the first thermally conductive lead frame further comprises a first connecting terminal connected to the second extending part, and the second thermally conductive lead frame further comprises a second connecting terminal connected to the third extending part, wherein the first connecting terminal extends parallel to the bottom metal plate toward the second connecting terminal, and the second connecting terminal extends parallel to the bottom metal plate toward the first connecting terminal.
4. The thermally conductive device of claim 3, wherein: the first connecting terminal has a first bottom surface, and the second connecting terminal has a second bottom surface, wherein the first bottom surface and the second bottom surface are on the same horizontal plane; the second extending part extends beyond the bottom metal plate by a second distance, and the bottom metal plate is spaced apart from the horizontal plane by a third distance; and if the third distance is calculated as 100%, the second distance ranges from 35% to 80%.
5. The thermally conductive device of claim 1, wherein: the first thermally conductive lead frame further comprises a first connecting terminal connected to the second extending part, and the second thermally conductive lead frame further comprises a second connecting terminal connected to the third extending part, wherein the first connecting terminal and the second connecting terminal extend toward each other; the first connecting terminal has a first bottom surface, and the second connecting terminal has a second bottom surface, wherein the first bottom surface and the second bottom surface are on the same horizontal plane; and an angle is formed between the first bottom surface of the first connecting terminal and the horizontal plane, and the angle is less than 30 degrees.
6. The thermally conductive device of claim 5, wherein an angle is formed between the second bottom surface of the second connecting terminal and the horizontal plane, and the angle is less than 30 degrees.
7. The thermally conductive device of claim 1, further comprising a first sputtering layer and a second sputtering layer, wherein the first sputtering layer covers the top surface of the electrically insulating but thermally conductive layer, and the second sputtering layer covers the first sputtering layer.
8. The thermally conductive device of claim 7, wherein the first sputtering layer has a first lattice constant, and the electrically insulating but thermally conductive layer has a second lattice

constant, wherein a ratio of the first lattice constant to the second lattice constant ranges from 0.9 to 1.2.
9. The thermally conductive device of claim 8, wherein a ratio of a thickness of the first sputtering layer to a thickness of the second sputtering layer is in a range from 1:1 to 1:4.
10. The thermally conductive device of claim 7, further comprising a first electroplating layer and a second electroplating layer, wherein the first electroplating layer covers the second sputtering layer, and the second electroplating layer covers the first electroplating layer, whereby the second electroplating layer is able to be securely connected to the top metal plate through solder.
11. The thermally conductive device of claim 10, wherein a ratio of a thickness of the first electroplating layer to a thickness of the second electroplating layer is in a range from 1:2 to 1:4.
12. The thermally conductive device of claim 1, further comprising a packaging layer, wherein the packaging layer entirely covers the top metal plate, the electrically insulating but thermally conductive layer, and the bottom metal plate, and wherein the packaging layer partially covers the first extending part and the third extending part.
13. The thermally conductive device of claim 12, wherein: the first thermally conductive lead frame further comprises a first connecting terminal connected to the second extending part, and the second thermally conductive lead frame further comprises a second connecting terminal connected to the third extending part, wherein the first connecting terminal and the second connecting terminal extend toward each other; and the first connecting terminal of the first thermally conductive lead frame physically contacts the packaging layer, and the second connecting terminal of the second thermally conductive lead frame physically contacts the packaging layer.
14. The thermally conductive device of claim 1, wherein: the first extending part of the first thermally conductive lead frame has a first corner and a second corner, wherein the first extending part extends to the first corner in a direction parallel to the electrically insulating but thermally conductive layer, extends from the first corner to the second corner in a direction parallel to the sidewall, and then extends from the second corner in a direction away from the sidewall, thereby connecting to the second extending part; and the third extending part of the second thermally conductive lead frame has a third corner, a fourth corner, and a fifth corner, wherein the third extending part extends to the third corner in a direction parallel to the electrically insulating but thermally conductive layer, extends from the third corner to the fourth corner in a direction parallel to the sidewall, extends from the fourth corner to the fifth corner in a direction away from the sidewall, and then extends from the fifth corner in a direction parallel to the sidewall, thereby extending away from the electrically insulating but thermally conductive layer.
15. The thermally conductive device of claim 14, further comprising a packaging layer, wherein the packaging layer entirely covers the top metal plate, the electrically insulating but thermally conductive layer, and the bottom metal plate, and wherein the packaging layer partially covers the first extending part and the third extending part.
16. The thermally conductive device of claim 15, wherein: the first thermally conductive lead frame further comprises a first connecting terminal connected to the second extending part, and the second thermally conductive lead frame further comprises a second connecting terminal connected to the third extending part, wherein the first connecting terminal and the second connecting terminal extend toward each other; and the first connecting terminal of the first thermally conductive lead frame physically contacts the packaging layer, and the second connecting terminal of the second thermally conductive lead frame physically contacts the packaging layer.
17. The thermally conductive device of claim 14, wherein a thickness of the first thermally conductive lead frame ranges from 0.1 mm to 0.25 mm.
18. The thermally conductive device of claim 1, wherein the thermally conductive device comprises a plurality of the first thermally conductive lead frames and a plurality of the second thermally conductive lead frames.
19. The thermally conductive device of claim 1, wherein the first thermally conductive lead frame

and the second thermally conductive lead frame are made of copper or copper alloy.

20. The thermally conductive device of claim 1, further comprising an adhesive layer disposed between the electrically insulating but thermally conductive layer and the first thermally conductive lead frame, wherein the adhesive layer is made of a material selected from the group consisting of epoxy resin, silicone, acrylic resin, polyurethane, and a mixture or copolymer of combinations thereof.

21. The thermally conductive device of claim 1, wherein the electrically insulating but thermally conductive layer is made of epoxy resin and a thermally conductive filler, wherein the thermally conductive filler is selected from the group consisting of zirconium nitride, boron nitride, aluminum nitride, silicon nitride, aluminum oxide, magnesium oxide, zinc oxide, silicon dioxide, titanium dioxide, and any combination thereof.

22. The thermally conductive device of claim 1, wherein the electrically insulating but thermally conductive layer is made of a ceramic material, wherein the ceramic material is selected from the group consisting of zirconium nitride, boron nitride, aluminum nitride, silicon nitride, aluminum oxide, magnesium oxide, zinc oxide, silicon dioxide, titanium dioxide, and any combination thereof.

23. The thermally conductive device of claim 21, wherein a roughness (Ra) of the top surface and the bottom surface of the electrically insulating but thermally conductive layer ranges from 0.01 μm to 10 μm.