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(54) **THERMAL DIFFUSER AND COOLING APPARATUS FOR COOLING HEAT SOURCE USING THE SAME**

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(52) **U.S. Cl.** **165/135**; 165/185; 29/890.03

(57) **ABSTRACT**

A thermal diffuser includes a plurality of thermally-conductive plates, each of which has a strip-like shape. The plurality of thermally-conductive plates is laminated onto one another in a plate-thickness direction of the strip-like shape to form a laminated body. Each of the plurality of thermally-conductive plates has thermal conductivities in a longitudinal direction and in a width direction of the strip-like shape better than a thermal conductivity in the plate-thickness direction. The thermally-conductive plates has sides, each of which extends in the longitudinal direction. The laminated body is formed such that the sides of the thermally-conductive plates form a plate surface of the laminated body, which surface extends in the plate-thickness direction that serves as a lamination direction, in which the thermally-conductive plates of the laminated body are laminated. A direction perpendicular to the plate surface corresponds to a thickness direction of the laminated body.

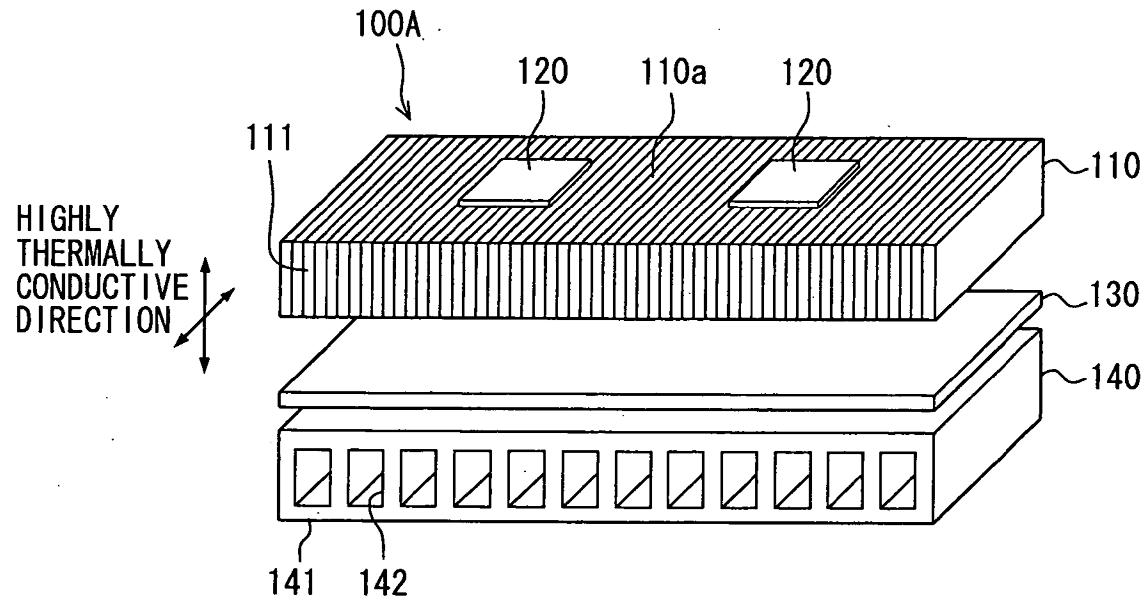


FIG. 1

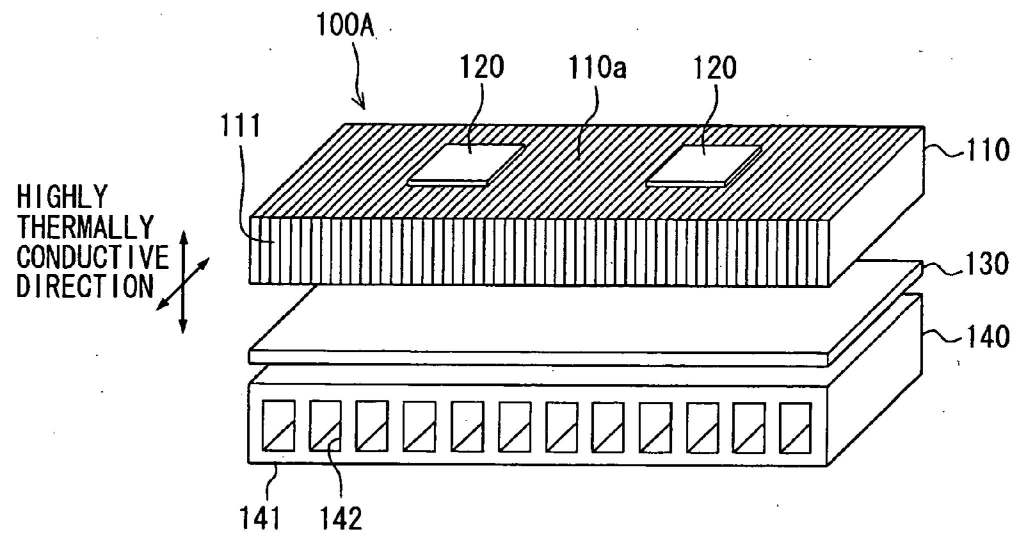


FIG. 2A

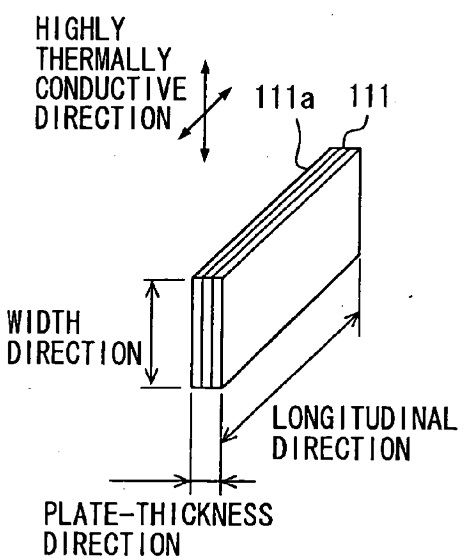


FIG. 2B

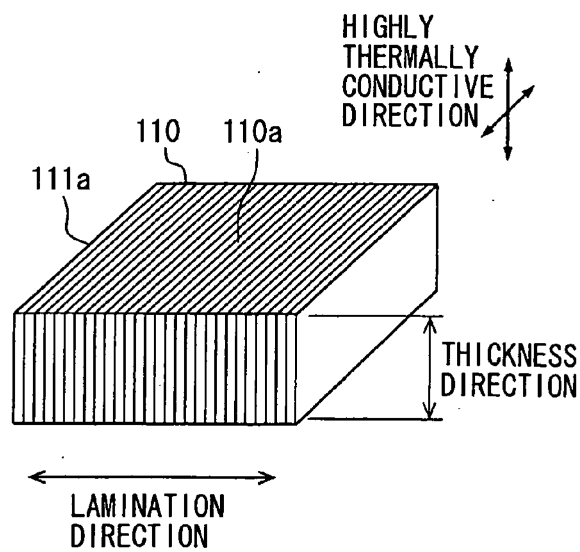


FIG. 3A

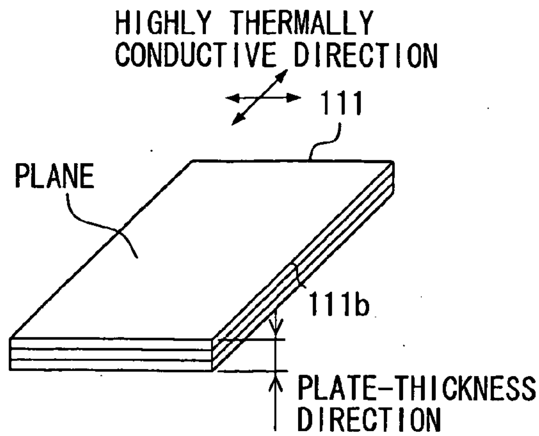


FIG. 3B

LAMINATED BODY

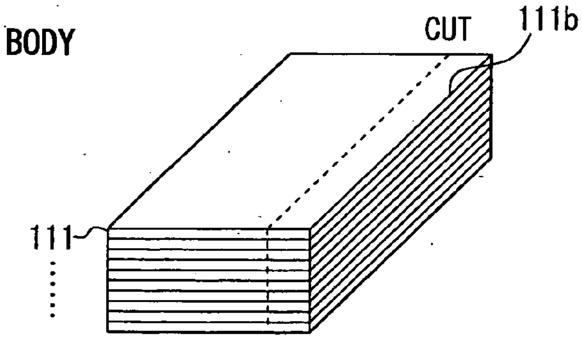


FIG. 3C

PLATE MEMBER

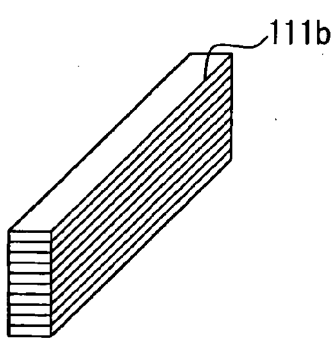


FIG. 3D

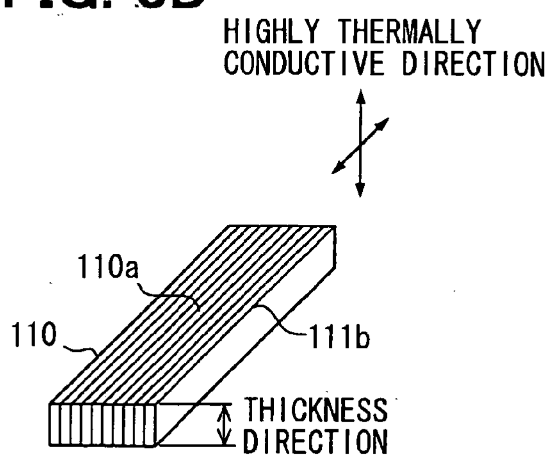


FIG. 4

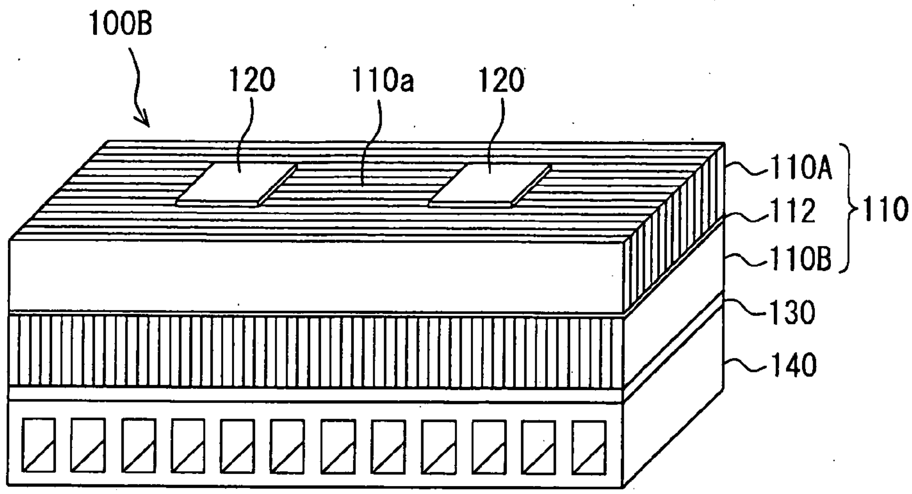


FIG. 5A

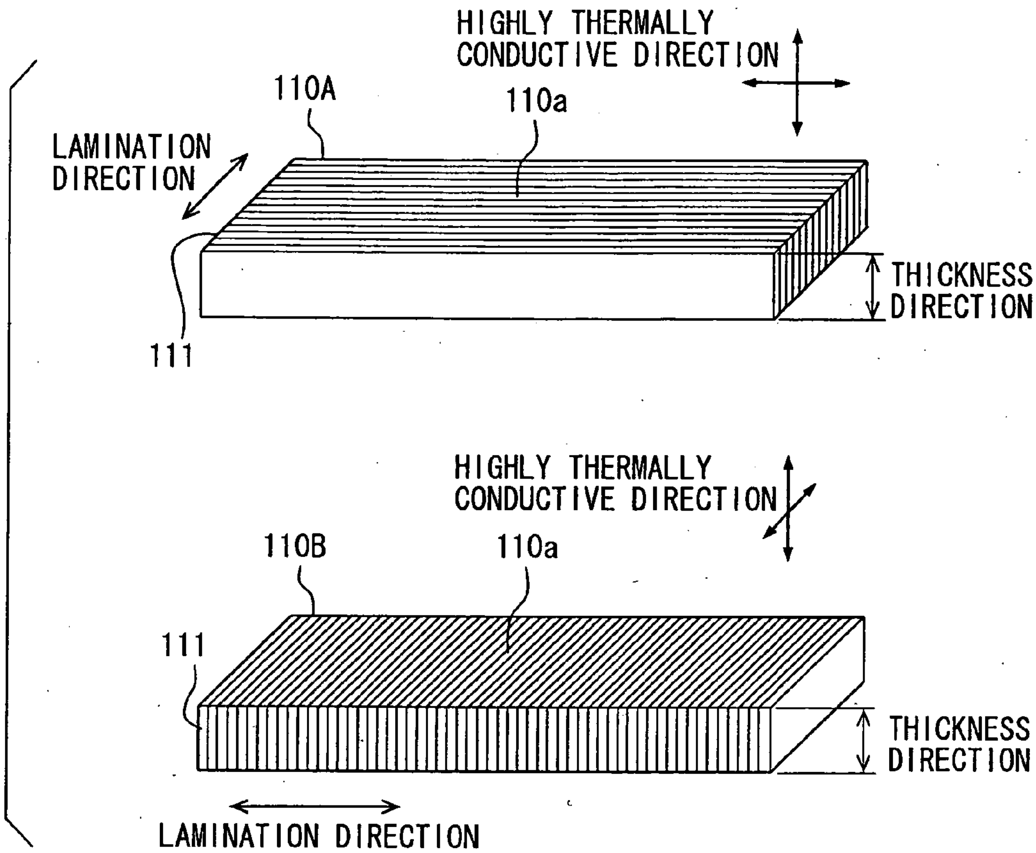

HIGHLY THERMALLY
CONDUCTIVE DIRECTION
110A
110a
LAMINATION
DIRECTION
THICKNESS
DIRECTION
111
HIGHLY THERMALLY
CONDUCTIVE DIRECTION
110B
110a
111
THICKNESS
DIRECTION
LAMINATION DIRECTION

FIG. 5B

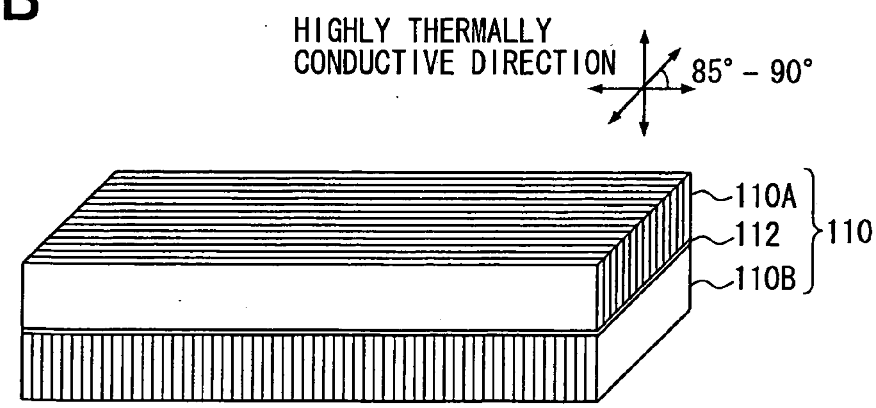

HIGHLY THERMALLY
CONDUCTIVE DIRECTION
85° - 90°
110A
112
110B
110

FIG. 6

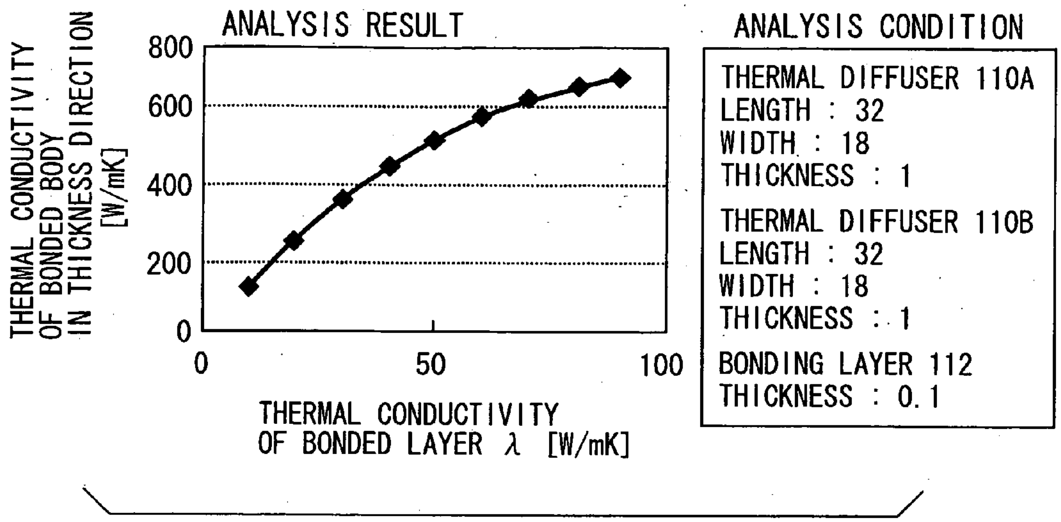

ANALYSIS RESULT
THERMAL CONDUCTIVITY OF BONDED BODY IN THICKNESS DIRECTION [W/mK]
800
600
400
200
0
0
50
100
THERMAL CONDUCTIVITY OF BONDED LAYER λ [W/mK]
ANALYSIS CONDITION
THERMAL DIFFUSER 110A
LENGTH : 32
WIDTH : 18
THICKNESS : 1
THERMAL DIFFUSER 110B
LENGTH : 32
WIDTH : 18
THICKNESS : 1
BONDING LAYER 112
THICKNESS : 0.1

FIG. 7

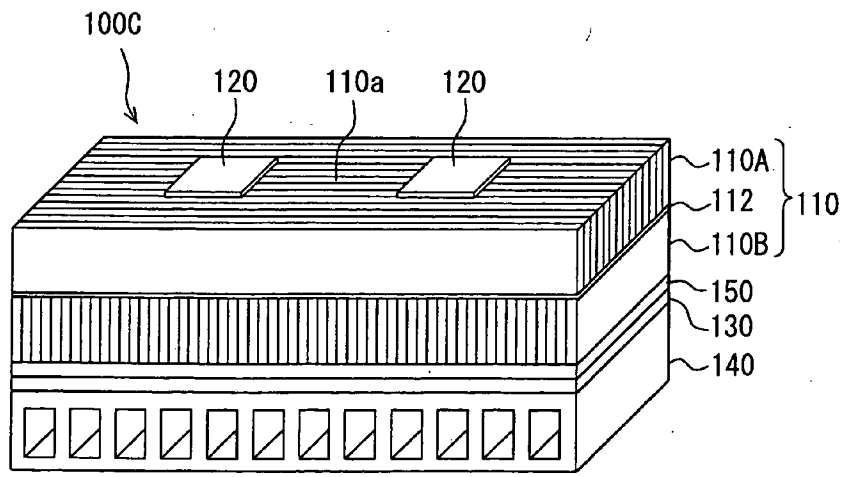

100C
120
110a
120
110A
112
110
110B
150
130
140

FIG. 8

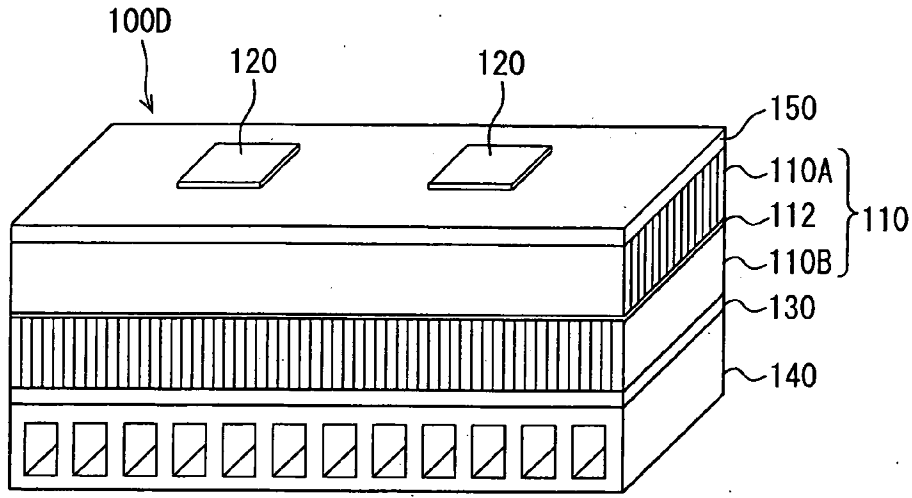

100D
120
120
150
110A
112
110
110B
130
140

FIG. 9

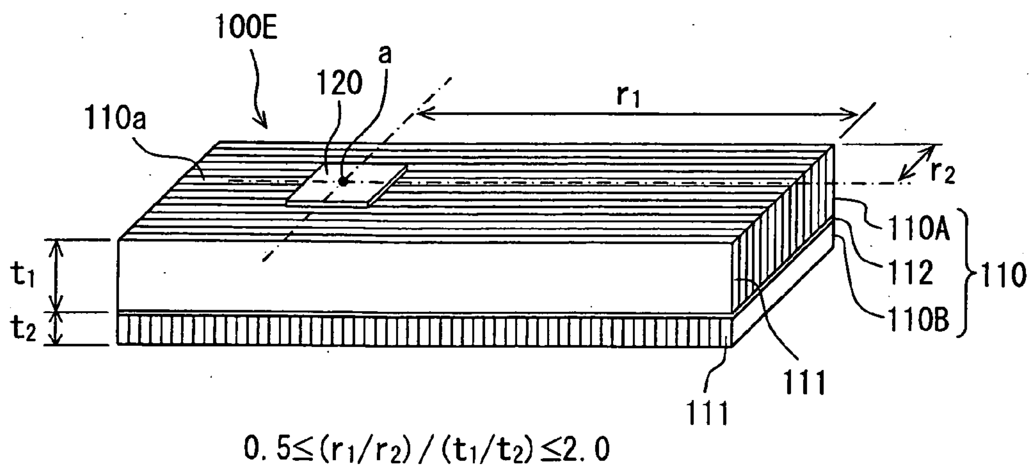

100E
a
120
110a
r1
r2
110A
112
110
110B
t1
t2
111
111
0.5≤(r1/r2)/(t1/t2)≤2.0

FIG. 10

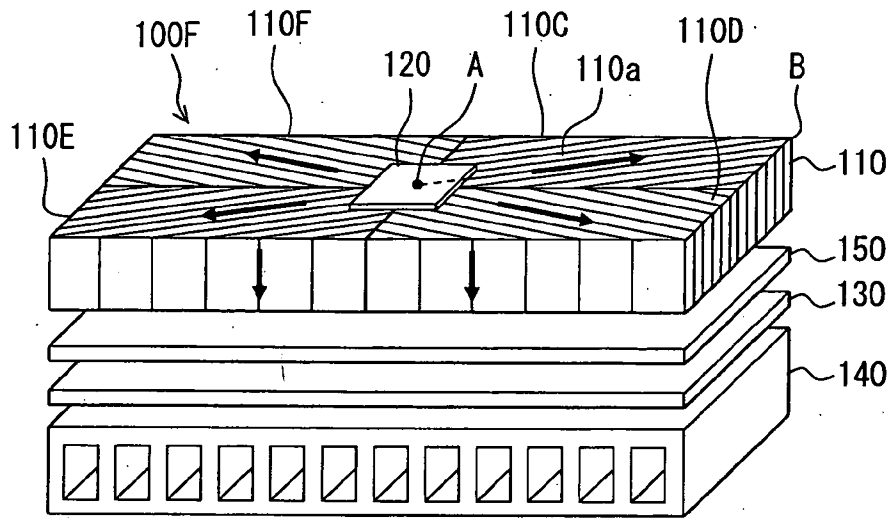

100F
110F
110C
110D
120
A
110a
B
110E
110
150
130
140

FIG. 11

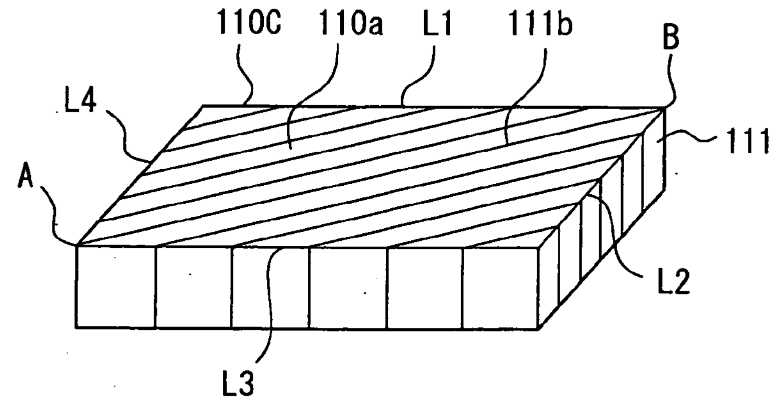

110C
110a
L1
111b
B
L4
111
A
L2
L3

FIG. 12A

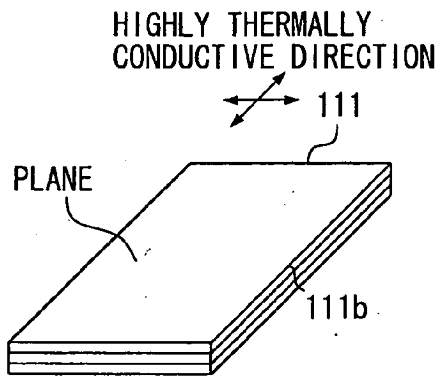


FIG. 12B

LAMINATED BODY

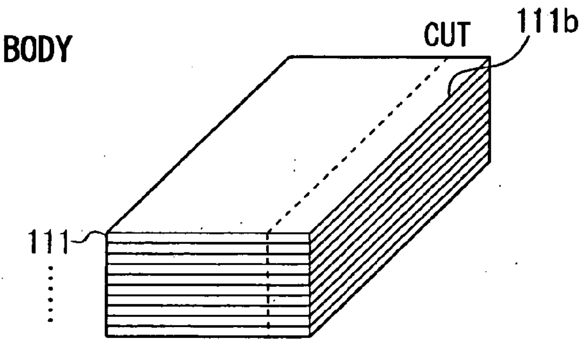


FIG. 12C

PRIMARY PLATE MEMBER

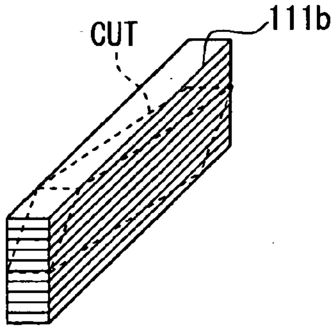
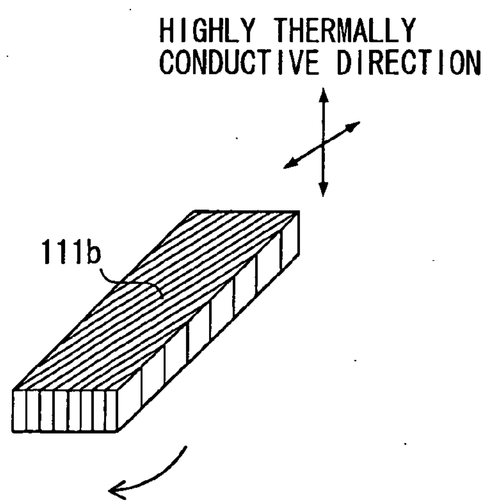


FIG. 12D

SECONDARY PLATE MEMBER



THERMAL DIFFUSER AND COOLING APPARATUS FOR COOLING HEAT SOURCE USING THE SAME

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is based on and incorporates herein by reference Japanese Patent Application No. 2010-132076 filed on Jun. 9, 2010.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a thermal diffuser that transfers heat of a heat source, such as a semiconductor device, and relates to a cooling apparatus that uses the thermal diffuser to cool the heat source.

[0004] 2. Description of Related Art

[0005] JP-A-2005-272164 shows a conventional thermal diffuser (high thermal conductivity member) for cooling a heat source. The conventional thermal diffuser employs, for example, a graphite structure to replace a metal material, such as copper and aluminum. A single graphite structure (or a graphene) has an a-b axial direction, which extends in a plane direction of the graphene. The thermal conductivity of the graphite structure in the a-b axial direction exceeds 1000 W/mK, and is twice or more of the thermal conductivity (350 to 400 W/mK) of copper and is four times or more of the thermal conductivity (200 to 250 W/mK) of aluminum. However, the single graphite structure has a thermal conductivity in the layer direction (or the thickness direction), which is equal to or less than 10 W/mK. In order to improve the thermal conductivity in the layer direction, JP-A-2005-272164 proposes a certain graphite structure, which has the a-b axis oriented in the direction (plane direction) parallel to a plate surface, and which has a carbon structure therein.

[0006] Thus, while the high thermal conductivity in the plane direction of the graphite structure, which serves as a mother body, is maintained, it is possible to efficiently transmit the heat in the layer direction through the carbon structure due to the carbon structure, which is made of carbon fiber polymer, and which is provided within the graphite structure as required. As a result, compared with the single graphite structure, it is possible to improve the thermal conductivity in the layer direction, and also it is possible to increase the tensile strength and the thickness of the thermal conductivity member.

[0007] However, in the description (paragraphs 0077, 0083, 0086, 0093) in JP-A-2005-272164, the thermal conductivity in the layer direction is about 20 to 100 W/mK even after the thermal conductivity has been improved. Thus, the improved thermal conductivity in the layer direction is still several times to ten times of the thermal conductivity (10 W/mK) of the single graphite structure in the layer direction. As a result, the improved thermal conductivity is still very low compared with the thermal conductivity of the metal material, such as copper or aluminum.

SUMMARY OF THE INVENTION

[0008] The present invention is made in view of the above disadvantages. Thus, it is an objective of the present invention to address at least one of the above disadvantages.

[0009] To achieve the objective of the present invention, there is provided a thermal diffuser that includes a plurality of thermally-conductive plates, each of which has a strip-like shape. The plurality of thermally-conductive plates is laminated onto one another in a plate-thickness direction of the strip-like shape to form a laminated body. Each of the plurality of thermally-conductive plates has thermal conductivities in a longitudinal direction and in a width direction of the strip-like shape better than a thermal conductivity in the plate-thickness direction. The thermally-conductive plates have sides, each of which extends in the longitudinal direction. The laminated body is formed such that the sides of the thermally-conductive plates form a plate surface of the laminated body, which surface extends in the plate-thickness direction that serves as a lamination direction, in which the thermally-conductive plates of the laminated body are laminated. A direction perpendicular to the plate surface corresponds to a thickness direction of the laminated body.

[0010] To achieve the objective of the present invention, there is also provided a cooling apparatus for a heat source, the cooling apparatus including the thermal diffuser, a heat source, an insulating plate, and a cooling unit. The plate surface of the thermal diffuser is one of a plurality of plate surfaces. The heat source is provided to one of the plurality of plate surfaces of the thermal diffuser. The insulating plate is provided to the other one of the plurality of plate surfaces of the thermal diffuser. The cooling unit is provided to a surface of the insulating plate opposite from the thermal diffuser.

[0011] To achieve the objective of the present invention, there is also provided a cooling apparatus for a heat source, the cooling apparatus including the thermal diffuser, a heat source, and an insulating plate. The thermal diffuser includes two laminated bodies. The plate surface of the thermal diffuser is one of a plurality of plate surfaces. The heat source is provided to one of the plurality of plate surfaces of the thermal diffuser. The insulating plate is provided to the other one of the plurality of plate surfaces of the thermal diffuser. The cooling unit is provided to a surface of the insulating plate remote from the thermal diffuser. One of the two laminated bodies of the thermal diffuser has a thickness dimension of **t1**. The other one of the two laminated bodies has a thickness dimension of **t2**. A distance, which is measured from a center position of the heat source to an end of the thermal diffuser in a longitudinal direction of the thermally-conductive plates of the one of the laminated bodies, is defined as **r1**. A distance, which is measured from the center position of the heat source to another end of the thermal diffuser in the longitudinal direction of the thermally-conductive plates of the other one of the laminated bodies, is defined as **r2**. The dimensions **t1**, **t2**, and the distances **r1**, **r2** satisfy the equation of $0.5 \leqq (t1/t2)/(r1/r2) \leqq 2$.

[0012] To achieve the objective of the present invention, there is also provided a method of manufacturing a thermal diffuser. In the method, a laminated body is formed by laminating a plurality of thermally-conductive plates, each of which has a plate shape, in a plate-thickness direction of the plate shape. Each of the plurality of thermally-conductive plates has a thermal conductivity in a plane direction of the plate shape better than a thermal conductivity in the plate-thickness direction. A plate member is formed by cutting the laminated body in a lamination direction, in which the thermally-conductive plates are laminated, along one sides of the thermally-conductive plates such that the plate member has a plate shape. The plate member is formed such that one sides of the thermally-conductive plate form a plate surface that extends in the lamination direction. A direction perpendicular to the plate surface corresponds to a thickness direction of the plate member.

[0013] To achieve the objective of the present invention, there is also provided a method for manufacturing a thermal diffuser. In the method, a laminated body is formed by laminating a plurality of thermally-conductive plates, each of which has a plate shape, in a plate-thickness direction of the plate shape. Each of the plurality of thermally-conductive plates has a thermal conductivity in a plane direction of the plate shape better than a thermal conductivity in the plate-thickness direction. A primary plate member is formed by cutting the laminated body in the lamination direction along one sides of the thermally-conductive plates such that the primary plate member has a plate shape. The primary plate member is formed such that the one sides of the thermally-conductive plates form a plate surface that extends in a lamination direction, in which the plurality of thermally-conductive plates is laminated. A direction perpendicular to the plate surface corresponds to a thickness direction of the primary plate member. A secondary plate member is formed by cutting off four corners of the primary plate member such that the secondary plate member has a rectangular shape, wherein a direction, in which the one sides of the thermally-conductive plates extend, is angled relative to each side of the secondary plate member. The forming of the secondary plate member includes forming a plurality of secondary plate members. The plurality of secondary plate members is arranged in a direction, in which the plate surface extends. A part of the plate surface of each of the plurality of secondary plate members is included in a connecting region that is connected with a heat source. Each of the plurality of secondary plate members has an outer peripheral section that forms an outer periphery of an entirety of the plurality of secondary plate members. Any point within the connecting region and any point on the outer peripheral section of each of the plurality of secondary plate members define an imaginary line therebetween. A direction of the one sides of the thermally-conductive plates of each of the plurality of secondary plate members is parallel to the imaginary line.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The invention, together with additional objectives, features and advantages thereof, will be best understood from the following description, the appended claims and the accompanying drawings in which:

[0015] FIG. **1** is an exploded perspective view illustrating a cooling apparatus for cooling a heat source according to the first embodiment of the present invention;

[0016] FIGS. **2**A and **2**B are perspective views each illustrating a thermal diffuser in FIG. **1**;

[0017] FIGS. **3**A to **3**D are perspective views illustrating a method for manufacturing a thermal diffuser according to the second embodiment of the present invention;

[0018] FIG. **4** is an exploded perspective view illustrating a cooling apparatus for cooling a heat source according to the third embodiment of the present invention;

[0019] FIGS. **5**A and **5**B are perspective views illustrating a method for manufacturing a thermal diffuser in FIG. **4**;

[0020] FIG. **6** is a chart illustrating the thermal conductivity in the thickness direction of the thermal diffuser shown in FIG. **4**;

[0021] FIG. **7** is a perspective view illustrating a cooling apparatus for cooling a heat source according to the fourth embodiment of the invention;

[0022] FIG. **8** is a perspective view illustrating a cooling apparatus for cooling a heat source according to the fifth embodiment of the present invention;

[0023] FIG. **9** is a perspective view illustrating a cooling apparatus for cooling a heat source according to the sixth embodiment of the present invention;

[0024] FIG. **10** is an exploded perspective view illustrating a cooling apparatus for cooling a heat source according to the seventh embodiment of the present invitation;

[0025] FIG. **11** is a perspective view illustrating the thermal diffuser shown in FIG. **10**; and

[0026] FIGS. **12**A to **12**D are perspective views illustrating a method for manufacturing the thermal diffuser shown in FIG. **10**.

DETAILED DESCRIPTION OF EMBODIMENTS

[0027] Several embodiments of the present invention will be described below with reference to accompanying drawings. Components, which have been already described in the preceding embodiment, are indicated by the same numeral used in the preceding embodiment, and the redundant description thereof may be omitted. When only a part of the configuration of the embodiment is described, the other part of the configuration may employ the description of the preceding embodiment. Any combination of parts of the embodiments is possible even though the above combination is not explicitly described in the embodiments provided that the combination does not cause any significant deficiency.

First Embodiment

[0028] A cooling apparatus **100**A for cooling a heat source in the first embodiment will be described blow with reference to FIG. **1** and FIGS. **2**A and **2**B. FIG. **1** is an exploded perspective view illustrating the cooling apparatus **100**A of the heat source, and FIGS. **2**A and **2**B are perspective views each illustrating a thermal diffuser **110** made of thermal conductivity plates in FIG. **1**.

[0029] As shown in FIG. **1**, the cooling apparatus **100**A for cooling the heat source (hereinafter, simply referred to as the cooling apparatus **100**A) includes the thermal diffuser **110**, a heat source **120**, an insulating plate **130**, and a cooling unit **140**. The cooling apparatus **100**A cools the heat source **120** by transmitting heat of the heat source **120** to the cooling unit **140** through the thermal diffuser **110**.

[0030] As shown in FIG. **2**, the thermal diffuser **110** is a plate that efficiently transmits heat of the heat source **120** toward the cooling unit **140**, and the thermal diffuser **110** includes multiple thermally-conductive plates **111**. Each of the thermally-conductive plates **111** is a very thin plate member having a strip-like shape. The thermally-conductive plate **111** has thermal conductivities in a longitudinal direction and in a width direction better than a thermal conductivity in a plate-thickness direction. The thermally-conductive plate **111** is made of, for example, a graphite material, or alternatively of a composite material, which has graphite and metal. The metal of the above composite material employs, for example, copper and aluminum. Specifically, as above, the graphite material has great thermal conductivities in a plate-thickness direction and in a width direction of the thermally-conductive plate **111**. In other words, the graphite material is a highly oriented graphite material having great thermal conductivities in two directions that extend along a plate surface (or a top surface) of the graphite material.

[0031] The thermally-conductive plates **111** are laminated onto one another in the plate-thickness direction to form a plate-shaped laminated body. In the first embodiment, the laminated body serves as the thermal diffuser **110**. In other words, in the laminated body, the thermally-conductive plate **111** has a long side **111***a* that extends in a longitudinal direction, and the long sides **111***a* forms a plate surface **110***a* having a plate shape that extends in a lamination direction, in which the thermally-conductive plates **111** are laminated (see FIG. **2**B). Furthermore, a direction orthogonal to the plate surface **110***a* corresponds to a thickness direction of the laminated body having the plate shape. The thermal diffuser **110** has a plate shape that has a dimension in the lamination direction greater than a dimension of the thermally-conductive plate **111** in the width direction. The plate surface **110***a* is, in other words, a plane defined by (a) the long side **111***a* and (b) a side that extends in the lamination direction. The thermal diffuser **110** has a dimension in the thickness direction, which dimension is equivalent to a dimension of the thermally-conductive plate **111** in the width direction. As a result, the thermal diffuser **110** has better thermal conductivities in two directions (see FIGS. **2**A and **2**B in this regard). More specifically, the two directions include the direction of the long side **111***a* of the plate surface **110***a*, and the thickness direction of the plate-shaped laminated body.

[0032] It is noted that the thermal diffuser **110** is formed as the laminated body by laminating the multiple thermally-conductive plates **111** onto one another, and then by baking the thermally-conductive plates **111**. Alternatively, a gaseous material, such as a highly oriented graphite material, or a composite material having a highly oriented graphite and metal, is sequentially sprayed on a plane to form the laminated body.

[0033] The heat source **120** is a semiconductor device, for example, an IGBT (insulated gate bipolar transistor) or an FWD (flywheel diode), which generates heat when operated. For example, the thermal diffuser **110** includes two plate surfaces **110***a* (top and bottom plate surfaces **110***a*). There are multiple heat sources **120** (two generators **120** in the present embodiment), and the heat sources **120** are provided to contact one of the plate surfaces **110***a* of the thermal diffuser **110**.

[0034] The insulating plate **130** is a plate member made of a ceramics for electrically insulating the heat source **120**, for example. The insulating plate **130** is provided to contact the other one of the plate surfaces **110***a* of the thermal diffuser **110** opposite from the one plate surface **110***a*, to which the heat source **120** is provided.

[0035] The cooling unit **140** is a heat exchanger that cools the heat source **120** by transferring heat of the heat source **120** to a cooling medium that flows through the internal passages **142**. The cooling unit **140** is provided to contact a surface of the thermal diffuser **110** opposite from the insulating plate **130**. The cooling unit **140** includes a main body part **141** having a plate shape and defining therein the main passages **142**. The passages **142** are formed to admit cooling medium (for example, cooling air, coolant) to flow therethrough.

[0036] In the above cooling apparatus **100**A, heat of the heat source **120** spreads along the plate surface **110***a* of the thermal diffuser **110** (or spreads in the direction of the long side **111***a*) to an outer periphery, and also is transferred in the thickness direction of the thermal diffuser **110**. Furthermore, the heat is transferred in a plate-thickness direction of the insulating plate **130** to reach the main body part **141** of the cooling unit **140**. In the cooling unit **140**, the above transferred heat of the heat source **120** is given to the cooling medium flowing through the internal passages **142**, and thereby the heat source **120** is successfully cooled.

[0037] In the present embodiment, the thermally-conductive plate **111** of the thermal diffuser **110** has better thermal conductivities in the longitudinal direction and in the width direction than a thermal conductivity in the plate-thickness direction. The thermal diffuser **110** is made by laminating the thermally-conductive plates **111** in the plate-thickness direction. In the above, the plate surface **110***a* is formed by the longitudinal sides **111***a* of the thermally-conductive plates **111** and extends in the lamination direction. Because of the above formed plate surface **110***a*, it is possible to provide a better thermal conductivity in the longitudinal direction of the thermally-conductive plate **111**. Also, in the above configuration, the thickness direction, which is orthogonal to the plate surface **110***a* of the thermal diffuser **110**, coincides with the width direction of the thermally-conductive plate **111** as shown in FIG. **2**B. As a result, it is possible to provide a better thermal conductivity in the thickness direction of the thermal diffuser **110**. Thereby, the thermal diffuser **110** has better thermal conductivities in two directions (see the highly thermal conductive directions shown in FIGS. **1**, **2**A and **2**B). More specifically; one of the two directions, in which the thermal conductivities act better, is a direction parallel to the plate surface **110***a* of the thermal diffuser **110** and perpendicular to the lamination direction. The other of the two directions is the thickness direction (or a layer direction) of the thermal diffuser **110**. As a result, it is possible to efficiently transfer the heat of the heat source **120** to the cooling unit **140**.

Second Embodiment

[0038] FIGS. **3**A to **3**D show a thermal diffuser **110** of the second embodiment, and more specifically show a manufacturing process of the thermal diffuser **110**. The method of manufacturing the thermal diffuser **110** in the second embodiment is different from the manufacturing method in the first embodiment (FIG. **1**, FIG. **2**).

[0039] The method for manufacturing the thermal diffuser **110** will be described below. Firstly, the plate-shaped thermally-conductive plates **111** having a better thermal conductivity in the plane direction than the thermal conductivity in the plate-thickness direction are prepared (FIG. **3**A). The thermally-conductive plates **111** are laminated on one another in the plate-thickness direction to form a laminated body (FIG. **3**B).

[0040] Next, the laminated body formed as above is cut in the lamination direction along the one side **111***b* of the thermally-conductive plate **111** to form a plate member as shown in FIG. **3**C. Then, in the plate member, the plate surface **110***a* of the thermal diffuser **110** is defined by a surface made by the lamination of the one sides **111***b* of the thermally-conductive plates **111** in the lamination direction. Also, the thickness direction of the thermal diffuser **110** is defined to be orthogonal to the plate surface **110***a* (FIG. **3**D).

[0041] As a result, the thermal diffuser **110**, which is equivalent to the thermal diffuser **110** described in the first embodiment, is easily formed.

Third Embodiment

[0042] FIGS. **4** to **6** show a cooling apparatus **100**B of the third embodiment. In contrast to the first embodiment (FIGS.

1 and 2), the thermal diffuser **110** of the third embodiment is made of multiple thermal diffusers **110**A, **110**B.

[0043] As shown in FIGS. **4**, **5**A, and **5**B, the thermal diffuser **110** is made of two thermal diffusers (or two laminated bodies). More specifically, the thermal diffuser **110** includes a first thermal diffuser **110**A and a second thermal diffuser **1108**. Each of the thermal diffusers **110**A, **110**B is similar to the thermal diffuser **110** described in the first embodiment. The thermal diffuser **110**A is arranged such that the lamination direction of the thermally-conductive plates **111** of the thermal diffuser **110**A is different from the lamination direction of the thermally-conductive plates **111** of the thermal diffuser **110**B. Thus, the adjacent thermal diffusers (laminated bodies) **110**A, **110**B have the respective lamination directions of the thermally-conductive plates **111** different from each other.

[0044] In other words, in the first thermal diffuser **110**A, the lamination direction, in which the thermally-conductive plates **111** are laminated, corresponds to a depth direction in FIG. **5**A. Thereby, the first thermal diffuser **110**A has better thermal conductivities in a left-right direction of the plate surface **110***a* in FIG. **5**A (or the longitudinal direction of the thermally-conductive plate **111**) and in the thickness direction of the first thermal diffuser **110**A.

[0045] In contrast, in the second thermal diffuser **110**B, a lamination direction, in which the thermally-conductive plates **111** are laminated, corresponds to the left-right direction in FIG. **5**A. As a result, the second thermal diffuser **110**B has better thermal conductivities in the depth direction of the plate surface **110***a* in FIG. **5**A (or in the longitudinal direction of the thermally-conductive plate **111**) and in the thickness direction of the second thermal diffuser **110**B.

[0046] The first thermal diffuser **110**A and the second thermal diffuser **110**B are laminated in the thickness direction, and an inorganic bonding layer (inorganic layer) **112** interposed between the thermal diffusers **110**A, **110**B bonds the thermal diffusers **110**A, **110**B each other. The bonding layer **112** includes at least one of titanium (Ti), nickel (Ni), tin (Sn), lead (Pb), and gold (Au). In the present embodiment, the bonding layer **112** is solder having tin (Sn). Solder has a thermal conductivity of 60 W/mK.

[0047] The thermal diffuser **110** formed as above includes the first thermal diffuser **110**A and the second thermal diffuser **110**B, and the lamination direction of the thermally-conductive plates **111** of the first thermal diffuser **110**A is different from the lamination direction of the thermally-conductive plates **111** of the second thermal diffuser **110**B. More specifically, the above lamination directions intersect with each other. Specifically, the lamination directions intersect at a right angle (or at the angle of 90 degrees). The angle defined by the lamination directions may be in a range from 85 to 90 degrees in order to enhance the thermal conductivities in the two axial directions along the plate surface **110***a*.

[0048] In the thermal diffuser **110** of the present embodiment, the plate surface **110***a* of the first thermal diffuser **110**A has a first direction, in which the thermal conductivity of the first thermal diffuser **110**A acts better, and the plate surface **110***a* of the second thermal diffuser **1108** has a second direction, in which the thermal conductivity of the second thermal diffuser **110**B acts better. In the thermal diffuser **110** of the present embodiment, the first direction and the second direction define therebetween the angle in a range from 85 to 90 degrees. As a result, when observed as the entirety of the thermal diffuser **110**, which has the thermal diffusers **110**A, **110**B laminated in thickness direction, it is possible to cause the thermal diffuser **110** to have better thermal conductivities in the thickness direction and also in the two directions, which are orthogonal to each other, along the plate surface **110***a*. Thus, it is possible to provide the thermal diffuser **110** that has thermal conductivities that acts better in three axial directions, and thereby it is possible to efficiently cool the heat source **120**.

[0049] FIG. **6** is a chart illustrating a thermal conductivity in the thickness direction of the thermal diffuser **110** made of the multiple thermal diffusers **110**A, **1108** as a function of the thermal conductivity of the bonding layer **112**. In one model of the present embodiment, each of the thermal diffusers **110**A, **1108** has a length of 32 mm, a width of 18 mm, and a thickness of 1 mm. The bonding layer **112** has a thickness of 0.1 mm. In the above dimension, the thermal conductivity in the thickness direction of the thermal diffuser **110** is studied. When the bonding layer **112** (or solder) has the thermal conductivity of 60 W/mK, the thermal conductivity in the thickness direction of the thermal diffuser **110** indicates 600 W/mK. The above value is much higher than the thermal conductivity of copper or aluminum.

[0050] In the embodiment, the thermal diffuser **110** includes two thermal diffusers **110**A, **110**B. However, the thermal diffuser **110** may alternatively include three or more thermal diffusers that are laminated. In the above alternative case, the adjacent thermal diffusers among the three or more thermal diffusers may be arranged such that the direction, in which one thermal diffuser has a better thermal conductivity, is set different from the direction, in which the adjacent thermal diffuser has a better thermal conductivity. More specifically, the above directions of the adjacent thermal diffusers may define the angle in a range from 85 to 90 degrees.

Fourth Embodiment

[0051] FIG. **7** shows a cooling apparatus **100**C according to the fourth embodiment. In the fourth embodiment, a metal plate **150** is added to the structure of the third embodiment (FIG. **4**).

[0052] The metal plate **150** is a highly conductive plate made of, for example, copper or aluminum, and is provided between the thermal diffuser **110** and the insulating plate **130**.

[0053] In the present embodiment, the insulating plate **130** prevents electric leakage toward the cooling unit **140**, and the metal plate **150** is employed as an electric power output terminal of the heat source (semiconductor device) **120**.

Fifth Embodiment

[0054] FIG. **8** shows a cooling apparatus **100**D according to the fifth embodiment of the present invention. In the fifth embodiment, a position of the metal plate **150** is changed from a position in the fourth embodiment (FIG. **7**).

[0055] In the fourth embodiment (FIG. **7**), the metal plate **150** is provided between the thermal diffuser **110** and the insulating plate **130**. However, in the present embodiment (FIG. **8**), the metal plate **150** is alternatively provided between the heat source **120** and the thermal diffuser **110**.

[0056] In the present embodiment, it is possible to bring the heat source (semiconductor device) **120** into direct contact with the metal plate **150**. As a result, in a case, where the heat source **120** is used with a large electric current, it is possible to more effectively limit the influence of the electrical resistance of the thermal diffuser **110** compared with the fourth embodiment (FIG. **7**). Therefore, it is possible to effectively employ the metal plate **150** as the electric power output terminal of the heat source **120**.

Sixth Embodiment

[0057] FIG. **9** shows a cooling apparatus **100**E according to the sixth embodiment of the present invention. The sixth embodiment is a modification of the third embodiment (FIG. **4**). In the present embodiment, a dimension of the thermal diffuser **110** in the thickness direction is effectively defined in consideration of the position of the heat source **120** relative to the thermal diffuser **110**.

[0058] The first thermal diffuser **110**A of the thermal diffuser **110** serves as one of the two laminated bodies that constitute the thermal diffuser **110**. In the first thermal diffuser **110**A, the longitudinal direction of the thermally-conductive plate **111** coincides with a left-right direction in FIG. **9**. In other words, a direction (highly thermally conductive direction), which the thermal conductivity of the plate surface **110***a* of the first thermal diffuser **110**A acts better corresponds to the left-right direction in FIG. **9**. In addition to the above, the thermal conductivity of the plate surface **110***a* of the first thermal diffuser **110**A acts better in the thickness direction of the first thermal diffuser **110**A. Also, the second thermal diffuser **1108** of the thermal diffuser **110** serves as the other one of the laminated bodies that constitute the thermal diffuser **110**. In the second thermal diffuser **110**B, the longitudinal direction of the thermally-conductive plate **111** coincides with the depth direction in FIG. **9**. In other words, a direction, in which the thermal conductivity of the plate surface **110***a* of the second thermal diffuser **110**B acts better, coincides with the depth direction in FIG. **9**. In addition to the above, the thermal conductivity of the plate surface **110***a* of the second thermal diffuser **110**B acts better in the thickness direction of the second thermal diffuser **110**B. Also, the first thermal diffuser **110**A has a dimension of t**1** in the thickness direction, and the second thermal diffuser **110**B has a dimension of t**2** in the thickness direction.

[0059] The single heat source **120** is provided to the plate surface **110***a* of the thermal diffuser **110** (or the first thermal diffuser **110**A). The heat source **120** has a center position a when observed from the upper side in FIG. **9** (or observed in a direction orthogonal to the plate surface **110***a*). In the plate surface **110***a* of the first thermal diffuser **110**A, a longer distance measured in the highly thermally conductive direction (left-right direction) of the first thermal diffuser **110**A from the center position a to an end portion of the first thermal diffuser **110**A is defined as r**1**. Also, in the plate surface **110***a* of the first thermal diffuser **110**A, a longer distance measured in the highly thermally conductive direction (depth direction) of the second thermal diffuser **110**B from the center position a to an end portion of the first thermal diffuser **110**A is defined as r**2**.

[0060] In the present embodiment, the dimensions t**1**, t**2** in the thickness direction and the distances r**1**, r**2** satisfy the following relation shown by equation 1.

$$0.5 \leqq (t1/t2)/(r1/r2) \leqq 2 \qquad \text{(equation 1)}$$

[0061] In the present embodiment, in the first thermal diffuser **110**A, when the distance r**1** is greater, it is better to transfer the heat of the heat source **120** in the direction toward the end, to which the distance r**1** is measured. Similarly, in the second thermal diffuser **110**B, when the distance r**2** is greater, it is better to transfer the heat of the heat source **120** in the direction toward the end, to which the distance r**2** is measured. Then, the dimension of each of the thermal diffusers **110**A, **110**B in the thickness direction is changed to larger or smaller depending on the heat to be transferred. In other words, when the distance r**1** (r**2**) is large, it is possible to increase the dimension t**1** (t**2**). In contrast, when the distance r**1** (r**2**) is small, it is necessary to decrease the dimension t**1** (t**2**). As a result, in order to achieve the good thermal conductivity of the thermal diffuser **110**, theoretically, the ratio of r**1** to r**2** is made coincide with the ratio of t**1** to t**2**. In other words, a value of (r**1**/r**2**) is made equivalent to a value of (t**1**/t**2**), and thereby an equation of (t**1**/t**2**)/(r**1**/r**2**)=1 is satisfied. In practice, the value of (t**1**/t**2**)/(r**1**/r**2**) is set in a range from 0.5 to 2.0 around the above theoretical value of 1, and thereby it is possible to achieve the good thermal conductivity of the thermal diffuser **110**. As a result, it is possible to effectively cool the heat source **120**.

[0062] In the present embodiment, the metal plate **150** may be provided similarly to the fourth embodiment (FIG. **7**), or to the fifth embodiment (FIG. **8**).

Seventh Embodiment

[0063] FIGS. **10** to **12**D show a cooling apparatus **100**F according to the seventh embodiment of the present invention. In the seventh embodiment, in contrast to the first and second embodiments (FIG. **1** to FIG. **3**D), the thermal diffuser **110** includes thermal diffusers **110**C to **110**F, and the thermal diffuser **110** is provided between the insulating plate **130** and the metal plate **150**, which is described in the fourth embodiment (FIG. **7**). Also, the single heat source **120** is provided to the plate surface **110***a* of the thermal diffuser **110**.

[0064] As shown in FIG. **10**, the thermal diffuser **110** is made of the four thermal diffusers **110**C to **110**F in the present embodiment. Each of the thermal diffusers **110**C to **110**F is a laminated body made by laminating the multiple thermally-conductive plates **111**, and has the plate surface **110***a* that forms a rectangular plate shape. Each of the thermal diffusers **110**C to **110**F is provided such that the respective plate surface **110***a* of each of the thermal diffusers **110**C to **110**F is flush with each other. Also, simultaneously, the thermal diffusers **110**C to **110**F respectively have one corner portions that are located at a certain position such that adjacent sides of the thermal diffusers **110**C to **110**F are in contact with each other.

[0065] Because a part (corner portion) of each of the thermal diffusers **110**C to **110**F is located around the certain position, an area around the certain position serves as a connecting region that is connected with the heat source **120**. The connecting region is connected with the heat source **120**, and the heat source **120** is connected with the part (corner portion) of each of the thermal diffusers **110**C to **110**F.

[0066] FIG. **11** shows the thermal diffuser **110**C as a representative of the thermal diffusers **110**C to **110**F. As shown in FIG. **11**, each of the thermal diffusers **110**C to **110**F has the longitudinal direction of the thermally-conductive plates **111** (or the direction of the one sides **111***b*), which is different from each other in contrast to the thermal diffuser **110** of the first and second embodiments (FIG. **1** to FIG. **3**D). Hereinafter, "the longitudinal direction of the thermally-conductive plates **111**, or the direction of the one sides **111***b*" is referred to as "the direction of the one side **111***b* of the thermally-conductive plate **111**" as shown in FIGS. **12**A to **12**D. For example, the direction of the one side **111***b* of the thermally-conductive plate **111** of the thermal diffuser **110**C is different from the direction of the one side **111***b* of the thermally-conductive plate **111** of the thermal diffuser **110**D.

[0067] For example, each of the thermal diffusers **110**C to **110**F has four sides L**1**, L**2**, L**3**, L**4** that define an outer periphery of the rectangular shape thereof as shown in FIG. **11**. The direction of the one side **111***b* of the thermally-conductive plate **111** in each of the thermal diffusers **110**C to **110**F is designed to be angled relative to each of the four sides L**1**, L**2**, L**3**, L**4**. More specifically, in the present embodiment, each of the thermal diffusers (or laminated bodies) **110**C to **110**F has a certain side (or an outer peripheral section) that forms an outer periphery of an entirety (or integral body) of the four thermal diffusers **110**C to **110**F. In the example of the thermal diffuser **110**C of FIG. **11**, the sides L**1**, L**2** serve as the certain side. Any point (A) within the connecting region, which is connected with the heat source **120**, and any point (B), which is located on the certain side (or the outer peripheral section) of each of the thermal diffusers **110**C to **110**F, defines an imaginary line therebetween. In the above definition, the direction of the one side **111***b* of the thermally-conductive plate **111** of each of the thermal diffusers **110**C to **110**F is parallel to the corresponding imaginary line defined between the point (A) and the point (B).

[0068] In the present embodiment, the corner portion of each of the thermal diffusers **110**C to **110**F contact each other at any point (hereinafter, point A) in the connecting region. Also, the sides L**1**, L**2** intersect at the point B, which corresponds to a corner portion defined by the sides L1 and L**2**. The imaginary line is equivalent to one of the diagonal lines that extend from the point A in the thermal diffusers **110**C to **110**F. As a result, the one side **111***b* of the thermally-conductive plate **111** in the thermal diffuser **110** radially outwardly extends from the point A (see FIG. **10**). Due to the above configuration, the thermal diffuser **110**C and the thermal diffuser **110**E, which are positioned diagonally to each other, are substantially the same. Also, the thermal diffuser **110**D and the thermal diffuser **110**F, which are positioned diagonally to each other, are substantially the same.

[0069] Each of the thermal diffusers **110**C to **110**F is manufactured in a process, for example, as shown in FIGS. **12**A to **12**D. In other words, similarly to the second embodiment (FIGS. **3**A to 3D), the following three steps are executed in the present embodiment (FIGS. **12**A to **12**C). The thermally-conductive plates **111** are prepared (FIG. **12**A), and subsequently the thermally-conductive plates **111** are laminated on one another in the plate-thickness direction to form the laminated body (FIG. **12**B). Then, the laminated body is cut in the lamination direction along the one sides **111***b* of the thermally-conductive plates **111** to form a primary plate member from the laminated body (FIG. **12**C). Furthermore, four corner portions of the primary plate member are cut off, and thereby there is formed a secondary plate member having another rectangular shape inscribed in the rectangular shape of the primary plate member (FIGS. **12**C and **12**D). As a result, it is possible to manufacture the thermal diffusers **110**C to **110**F, in which the one sides **111***b* of the thermally-conductive plates **111** are angled relative to each side of the secondary plate member.

[0070] Alternatively, the thermal diffuser **110** of the present embodiment may be manufactured in the following manner by using the thermally-conductive plates **111** each having the strip-like shape. For example, the thermally-conductive plates **111** are laminated in the plate-thickness direction in the ascending order of the longitudinal dimension of the thermally-conductive plates **111**. Then, the thermally-conductive plates **111** are further laminated in the plate-thickness direction in the descending order of the longitudinal dimension of the thermally-conductive plates **111**. As above, the plate surface **110***a*, which is formed by the longitudinal sides of the thermally-conductive plates **111**, and which extends in the lamination direction, is formed into the rectangular shape.

[0071] In the present embodiment, each of the thermal diffusers **110**C to **110**F has the one side **111***b* of the thermally-conductive plate **111**, which side is directed in parallel to the imaginary line extending from the point A to the point B. As a result, it is possible to cause the good thermal conductivities in the thickness direction and in the direction parallel to the imaginary line from the point A to the point B on the plate surface **110***a*. Furthermore, in the thermal diffuser **110** formed by the thermal diffusers **110**C to **110**F, it is possible to cause the good thermal conductivities in the thickness direction and in the directions that radially outwardly extend from the point A of the thermal diffuser **110**.

[0072] As a result, in the thermal diffuser **110**, the heat of the heat source **120** is effectively transferred in the direction that radially outwardly extends from the heat source **120** (point A) toward the outer periphery of the thermal diffuser **110**, and also, the heat of the heat source **120** is effectively transferred in the thickness direction of the thermal diffuser **110**. Thereby, it is possible to effectively cool the heat source **120**.

[0073] In the present embodiment, in the formation of the thermal diffuser **110**, the four thermal diffusers **110**C to **110**F are employed. However, the present invention is not limited to the above. For example, the thermal diffuser **110** may alternatively include three thermal diffusers, or may include five or more thermal diffusers.

[0074] Also, the imaginary line between the point A to the point B on each of the thermal diffusers **110**C to **110**F is not limited to the diagonal line. However, the point A may be located at any position in the connecting region of the heat source **120**, and the point B may be located on any position on the sides L**1**, L**2**. Thus, an imaginary line may be defined between the above alternative point A and the alternative point B. In other words, the direction of the one side **111***b* of the thermally-conductive plate **111** is determined such that the direction of the one side **111***b* extends from a position within the connecting region of the heat source **120** toward the outer periphery of the thermal diffuser **110**.

[0075] Additional advantages and modifications will readily occur to those skilled in the art. The invention in its broader terms is therefore not limited to the specific details, representative apparatus, and illustrative examples shown and described.

What is claimed is:

1. A thermal diffuser comprising:

a plurality of thermally-conductive plates, each of which has a strip-like shape, wherein:

the plurality of thermally-conductive plates is laminated onto one another in a plate-thickness direction of the strip-like shape to form a laminated body;

each of the plurality of thermally-conductive plates has thermal conductivities in a longitudinal direction and in a width direction of the strip-like shape better than a thermal conductivity in the plate-thickness direction;

the thermally-conductive plates has sides, each of which extends in the longitudinal direction;

the laminated body is formed such that the sides of the thermally-conductive plates form a plate surface of the laminated body, which surface extends in the plate-thickness direction that serves as a lamination direction, in which the thermally-conductive plates of the laminated body are laminated; and

a direction perpendicular to the plate surface corresponds to a thickness direction of the laminated body.

2. The thermal diffuser according to claim **1**, wherein the laminated body is one of a plurality of laminated bodies and the plurality of laminated bodies is laminated in the thickness direction,

the thermal diffuser further comprising:

an inorganic layer that is provided between the plurality of laminated bodies to bond the plurality of laminated bodies with each other; and

adjacent ones of the plurality of laminated bodies have the respective lamination directions of the plurality of thermally-conductive plates different from each other.

3. The thermal diffuser according to claim **2**, wherein:

the lamination directions of the plurality of thermally-conductive plates define therebetween an angle in a range from 85 to 90 degrees.

4. The thermal diffuser according to claim **2**, wherein:

the inorganic layer includes at least one of titanium, nickel, tin, lead, and gold.

5. The thermal diffuser according to claim **1**, wherein:

the laminated body is one of a plurality of laminated bodies that is arranged in a direction, in which the plate surface extends;

a part of the plate surface of each of the plurality of laminated bodies is included in a connecting region that is connected with a heat source;

each of the plurality of laminated bodies has an outer peripheral section that forms an outer periphery of an entirety of the plurality of laminated bodies;

any point within the connecting region and any point on the outer peripheral section of each of the plurality of laminated bodies defines an imaginary line therebetween; and

the respective longitudinal direction of the thermally-conductive plates of each of the plurality of laminated bodies is parallel to the imaginary line.

6. The thermal diffuser according to claim **5**, wherein:

the plurality of laminated bodies includes four laminated bodies, the plate surface of which has a rectangular shape; and

the rectangular shape of each of the laminated body has one corner portion that is included in the connecting region.

7. The thermal diffuser according to claim **1**, wherein:

the laminated body has a thermal conductivity in the thickness direction equal to or greater than 600 W/mK.

8. The thermal diffuser according to claim **1**, wherein:

the thermally-conductive plate is made of one of a graphite material and a composite material, which has graphite and metal.

9. A cooling apparatus for a heat source comprising:

a thermal diffuser according to claim **1**, wherein the plate surface of the thermal diffuser is one of a plurality of plate surfaces;

a heat source provided to one of the plurality of plate surfaces of the thermal diffuser;

an insulating plate provided to the other one of the plurality of plate surfaces of the thermal diffuser; and

a cooling unit provided to a surface of the insulating plate opposite from the thermal diffuser.

10. The cooling apparatus according to claim **9**, wherein the heat source is a semiconductor device,

the cooling apparatus further comprising:

a metal plate that is provided between the thermal diffuser and the insulating plate.

11. The cooling apparatus according to claim **9**, wherein the heat source is a semiconductor device,

the cooling apparatus further comprising:

a metal plate that is provided between the heat source and the thermal diffuser.

12. A cooling apparatus for a heat source, comprising:

a thermal diffuser according to claim **3**, wherein the thermal diffuser includes two laminated bodies, wherein the plate surface of the thermal diffuser is one of a plurality of plate surfaces;

a heat source provided to one of the plurality of plate surfaces of the thermal diffuser;

an insulating plate provided to the other one of the plurality of plate surfaces of the thermal diffuser; and

a cooling unit provided to a surface of the insulating plate remote from the thermal diffuser,

wherein:

one of the two laminated bodies of the thermal diffuser has a thickness dimension of t**1**;

the other one of the two laminated bodies has a thickness dimension of t**2**;

a distance, which is measured from a center position of the heat source to an end of the thermal diffuser in a longitudinal direction of the thermally-conductive plates of the one of the laminated bodies, is defined as r**1**;

a distance, which is measured from the center position of the heat source to another end of the thermal diffuser in the longitudinal direction of the thermally-conductive plates of the other one of the laminated bodies, is defined as r**2**; and

the dimensions t**1**, t**2**, and the distances r**1**, r**2** satisfy the following equation:

$$0.5 \leqq (t1/t2)/(r1/r2) \leqq 2.$$

13. A method of manufacturing a thermal diffuser, the method comprising:

forming a laminated body by laminating a plurality of thermally-conductive plates, each of which has a plate shape, in a plate-thickness direction of the plate shape,

wherein each of the plurality of thermally-conductive plates has a thermal conductivity in a plane direction of the plate shape better than a thermal conductivity in the plate-thickness direction; and

forming a plate member by cutting the laminated body in a lamination direction, in which the thermally-conductive plates are laminated, along one sides of the thermally-conductive plates such that the plate member has a plate shape,

wherein the plate member is formed such that one sides of the thermally-conductive plate form a plate surface that extends in the lamination direction,

wherein a direction perpendicular to the plate surface corresponds to a thickness direction of the plate member.

14. A method for manufacturing a thermal diffuser, the method comprising:

forming a laminated body by laminating a plurality of thermally-conductive plates, each of which has a plate shape, in a plate-thickness direction of the plate shape,

wherein each of the plurality of thermally-conductive plates has a thermal conductivity in a plane direction of the plate shape better than a thermal conductivity in the plate-thickness direction;

forming a primary plate member by cutting the laminated body in the lamination direction along one sides of the thermally-conductive plates such that the primary plate member has a plate shape,

wherein the primary plate member is formed such that the one sides of the thermally-conductive plates form a plate surface that extends in a lamination direction, in which the plurality of thermally-conductive plates is laminated,

wherein a direction perpendicular to the plate surface corresponds to a thickness direction of the primary plate member;

forming a secondary plate member by cutting off four corners of the primary plate member such that the secondary plate member has a rectangular shape,

wherein a direction, in which the one sides of the thermally-conductive plates extend, is angled relative to each side of the secondary plate member,

wherein the forming of the secondary plate member includes forming a plurality of secondary plate members; and

arranging the plurality of secondary plate members in a direction, in which the plate surface extends,

wherein a part of the plate surface of each of the plurality of secondary plate members is included in a connecting region that is connected with a heat source,

wherein each of the plurality of secondary plate members has an outer peripheral section that forms an outer periphery of an entirety of the plurality of secondary plate members,

wherein any point within the connecting region and any point on the outer peripheral section of each of the plurality of secondary plate members define an imaginary line therebetween,

wherein a direction of the one sides of the thermally-conductive plates of each of the plurality of secondary plate members is parallel to the imaginary line.

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