US 20090090490A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2009/0090490 A1**

(43) **Pub. Date: Apr. 9, 2009**

Yoshida et al.

(54) **COOLER**

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(21) Appl. No.: **12/293,469**

(22) PCT Filed: **Mar. 28, 2007**

(86) PCT No.: **PCT/JP2007/057522**

§ 371 (c)(1), (2), (4) Date: **Sep. 18, 2008**

(30) **Foreign Application Priority Data**

Apr. 6, 2006 (JP) 2006-105056

Publication Classification

(51) **Int. Cl.**
F28D 15/00 (2006.01)

(52) **U.S. Cl.** **165/104.33**

(57) **ABSTRACT**

A cooler includes a substrate for disposing a semiconductor device thereon, a plate member fixed to a back surface of the substrate, a primary pipe, and a secondary pipe. A space sandwiched between the substrate and the primary pipe defines a first flow path for a coolant. The primary pipe and the secondary pipe configure a second flow path for a coolant. The secondary pipe is positioned to jet a coolant toward a region opposite to that having the semiconductor device disposed therein. The second flow path is separated from the first flow path.

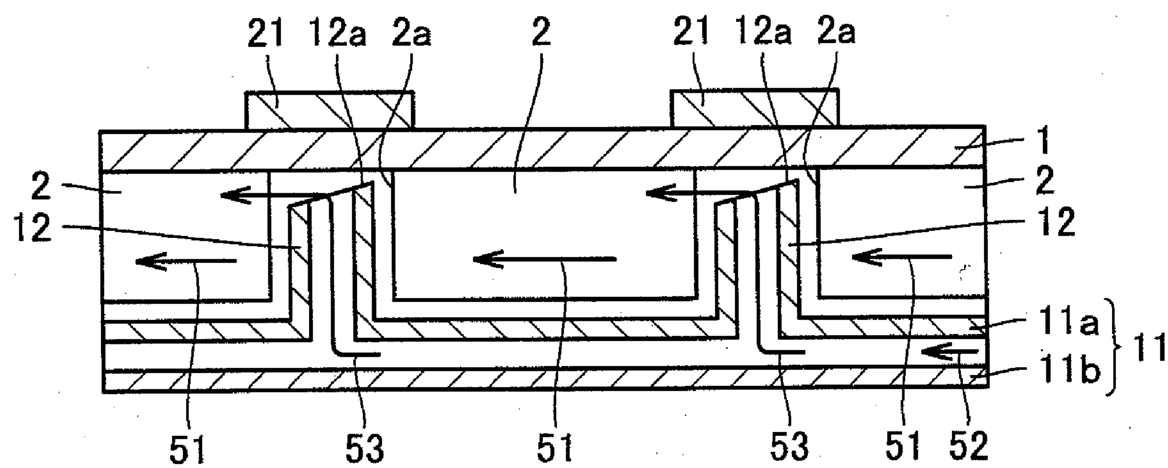


FIG.1

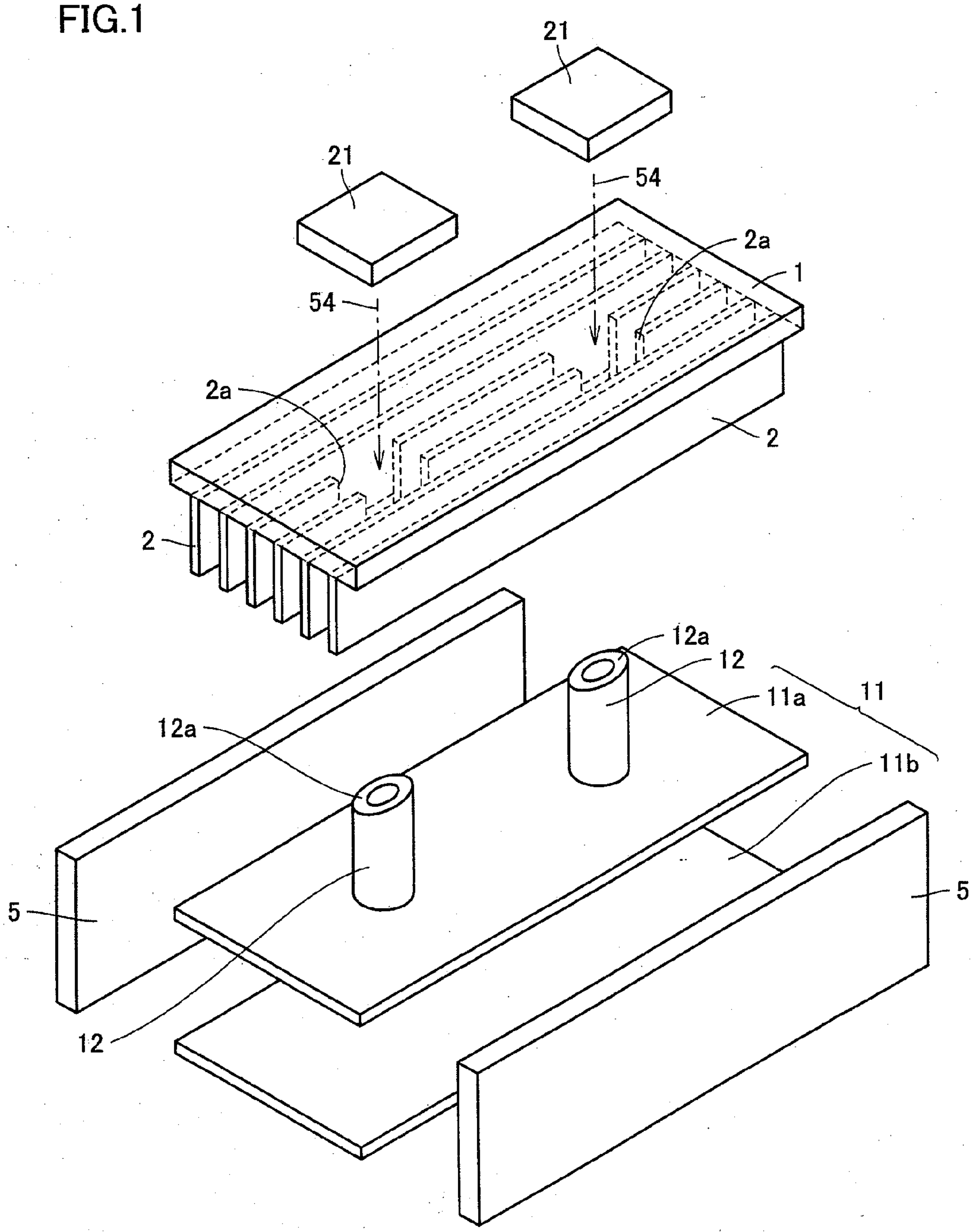


FIG.2

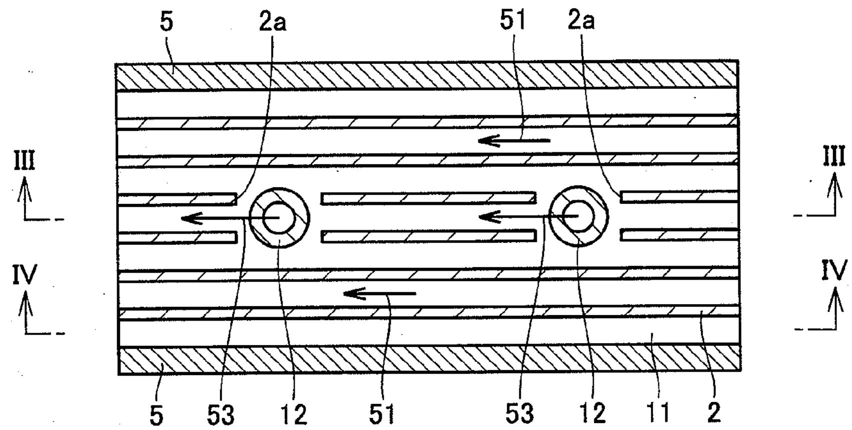


FIG.3

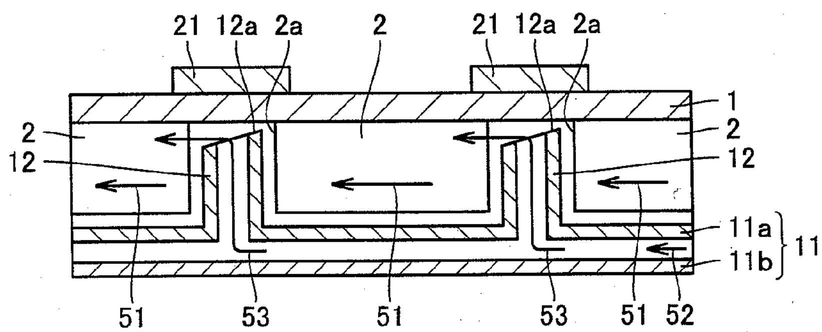


FIG.4

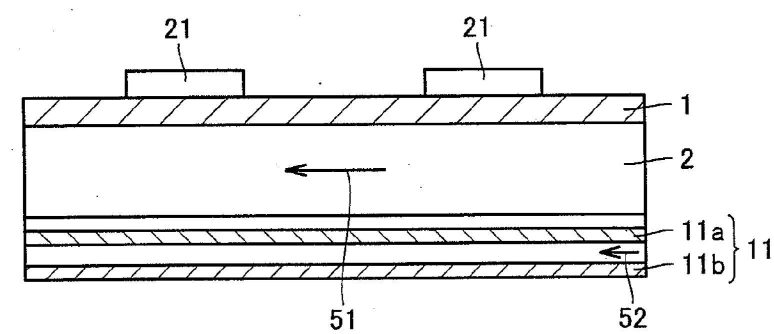


FIG.5

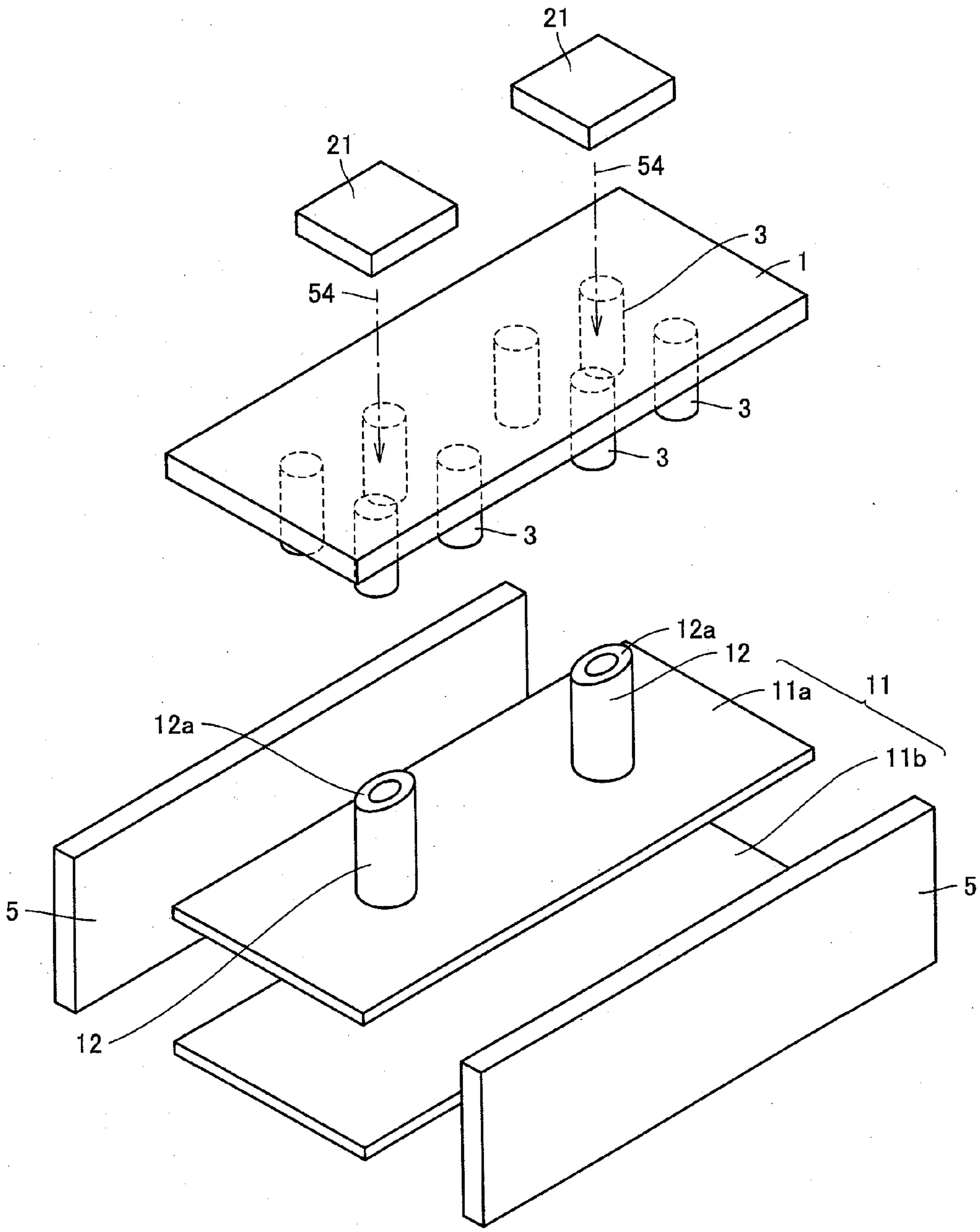


FIG.6

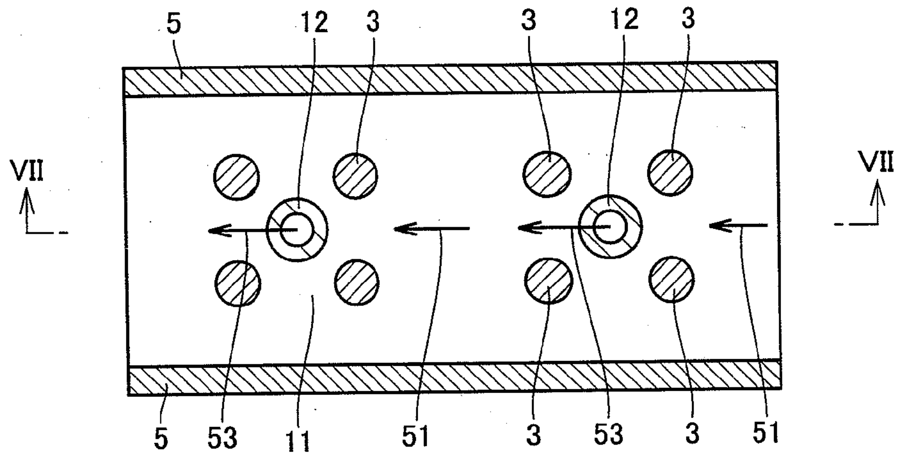

5
12
3
3
12
3
VII
VII
5
53
11
51
3
53
3
51

FIG.7

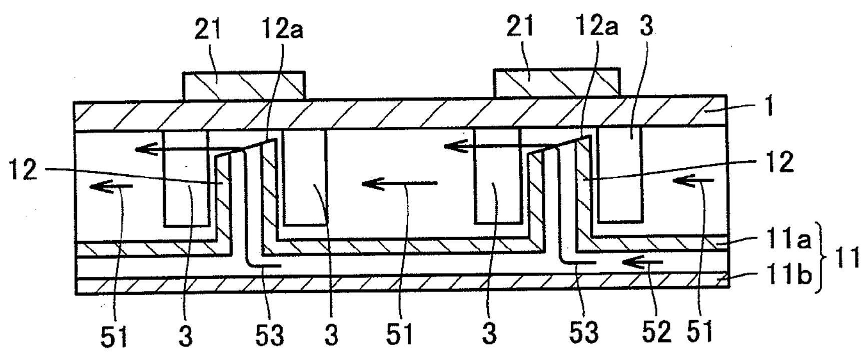

21
12a
21
12a
3
1
12
12
11a
11
11b
51
3
53
3
51
3
53
52
51

FIG.8

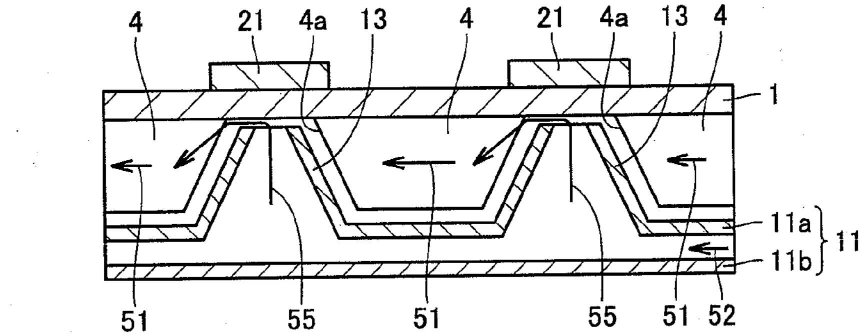


FIG.9

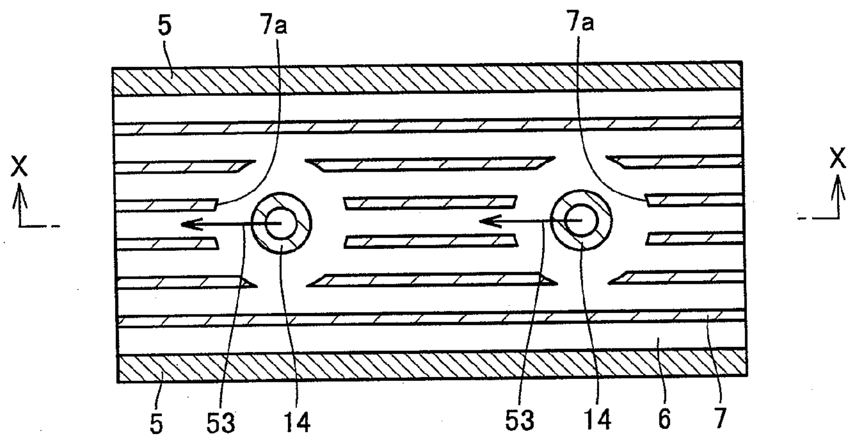
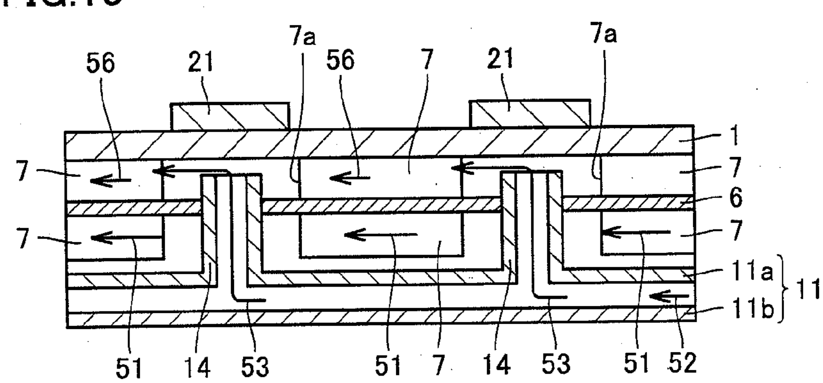


FIG.10



COOLER

TECHNICAL FIELD

[0001] The present invention relates to coolers, and particularly to coolers for electric power converters.

BACKGROUND ART

[0002] In recent years, hybrid vehicles, electric vehicles, fuel cell vehicles having a fuel cell mounted therein, and other similar vehicles employing electric power as a source of motive power are increasingly gaining attention. A hybrid vehicle is a vehicle employing a conventional engine and in addition thereto a motor as motive power. The hybrid vehicle drives the engine to obtain motive power and also converts direct current voltage that is received from a direct current power supply into alternate current voltage which is in turn used to drive the motor to obtain motive power. An electric vehicle is a vehicle converting direct current voltage that is received from a direct current power supply into alternate current voltage which is in turn used to drive the motor to obtain motive power.

[0003] Such vehicles employing electricity as a source of motive power has an electric power converter mounted therein. The electric power converter includes e.g., an inverter, a converter and/or a similar power semiconductor device. The power semiconductor device includes e.g., a power MOSFET (Metal Oxide Semiconductor Field-Effect Transistor), an IGBT (Insulated Gate Bipolar Transistor), and the like.

[0004] An electric power converter mounted in a vehicle or the like may require large electric power to provide the vehicle with high motive power performance. An electric power converter or the like of large electric power generates a large quantity of heat. Accordingly a cooler is mounted to cool the electric power converter.

[0005] To cool an electric power converter or the like of large electric power or a similar heat generating element, it is useful to bond a cooling plate (or fin) to a member that is directly adjacent to the electric power converter or the like to transfer heat across an increased area to more efficiently cool the element, or to cause a jet stream of coolant water to impinge on a region that has the electric power converter therein to cool it. Furthermore, it is effective to combine these techniques together.

[0006] Japanese Patent Laying-Open No. 2-100350 discloses a structure including a cooling plate having a fin for cooling an integrated circuit. The disclosed structure includes: an integrated circuit having a plurality of integrated circuit devices mounted on a substrate; a substrate frame holding the substrate; a cooling plate having a counter boring at a surface of the substrate opposite to the integrated circuit devices, and also having a fin in the form of a sector disposed at a bottom surface of the counter boring; and a nozzle jetting a coolant to the center of the fin in the form of the sector. The publication discloses that the structure can reduce thermal resistance between the integrated circuit devices and the coolant and reduce the coolant in flow rate to efficiently discharge heat to outside the equipment.

[0007] Japanese Patent Laying-Open No. 5-3274 discloses a semiconductor cooling apparatus including: a plurality of semiconductor devices aligned on a substrate; a coolant medium supplying header opposite to the substrate with a corresponding semiconductor device interposed therebetween; a tubular coolant medium supplying member communicating with the coolant medium supplying header; a coolant medium jetting outlet provided at an end of the coolant medium supplying member to jet a coolant medium that is received from the coolant medium supplying header toward a corresponding semiconductor device; and a coolant medium return header. In this semiconductor cooling apparatus, the substrate is provided perpendicularly and a coolant medium return pipe is provided to communicate with the coolant medium return head, and a diaphragm member is also provided to provide a diaphragm between the semiconductor devices. The publication discloses that this semiconductor cooling apparatus can prevent bubbles of the coolant medium generated at each device from flowing to the other devices and cool each device independently, and thus reduce the difference in temperature between the devices.

[0008] Japanese Patent Laying-Open No. 6-112385 discloses a structure having a radiator and a nozzle combined together for cooling a semiconductor device. In this structure the radiator has a bottom heat sink and first and second perpendicular heat sinks and the bottom heat sink is provided at a heat radiating surface of a case mounted on an interconnection substrate and having a semiconductor device mounted therein. The first perpendicular heat sink is formed of a plurality of curved heat radiating plates. Their curved projecting surfaces face each other, and therebetween a flow path for a jet stream is formed. The second perpendicular heat sink is provided at a jet stream outlet of a path formed by the first perpendicular heat sink, and the nozzle jets a coolant through the path formed by the first perpendicular heat sink to cause the coolant to impinge on the bottom heat sink. The publication discloses that the structure allows the coolant that has once impinged in a jet stream to again impinge on a heat sink in a jet stream to more efficiently cool the device without increasing the coolant in flow velocity, flow rate or the like.

[0009] Japanese Patent Laying-Open No. 5-190716 discloses a semiconductor apparatus having on a multilayer ceramic substrate a large number of integrated circuit packages each having a cooling jacket attached thereto. Each cooling jacket has a flexible tube connected thereto. A flexible flow path is internally provided with a nozzle for causing a coolant fluid to flow into the cooling jacket in a jet stream in the form of a slit. The cooling jacket is internally provided with a fin, and a space for returning the coolant fluid. The publication discloses that the semiconductor apparatus can utilize water, which has a high ability as a coolant, as a coolant medium, use a fin in the form of a flat plate helping to provide an increased heat transferring area, and provide a jet stream in the form of a slit allowing each fin to receive the coolant fluid uniformly, so that a semiconductor apparatus of an excellent cooling structure can be provided.

[0010] When an electric power converter elevates in temperature, it may be impaired in efficiency or a semiconductor device included in the electric power converter may be damaged. Accordingly, as has been described above, a cooler may be mounted to cool the electric power converter, and in particular, it is an important issue to cool the electric power converter or a similar a heat generating element accommodating large electric power.

DISCLOSURE OF THE INVENTION

[0011] The present invention contemplates a cooler excellent in performance for cooling an electric power converter.

[0012] The present cooler includes: a substrate for disposing a heat generating element on one surface thereof; a heat radiating member fixed to an other surface of the substrate; first flow path configuring means for configuring a first flow path formed to allow a coolant to contact the heat radiating member; and second flow path configuring means for configuring a second flow path formed to jet a coolant toward the other surface opposite to a region having the heat generating element disposed therein. The second flow path is separated from the first flow path.

[0013] In the present invention preferably the heat radiating member includes at least one of a plate member and a bar member.

[0014] In the present invention preferably the heat radiating member surrounds a region opposite to that having the heat generating element disposed therein. The second flow path configuring means includes a primary pipe remote from the other surface of the substrate, and a secondary pipe projecting from the primary pipe toward the substrate. The secondary pipe is opposite to the region of the substrate having the heat generating element disposed therein. The first flow path includes a space sandwiched between the primary pipe and the substrate.

[0015] In the present invention preferably the secondary pipe has an end surface opposite to the substrate, and the end surface inclines to provide a larger flow path in a direction in which the coolant flows along the first flow path configuring means.

[0016] In the present invention preferably the secondary pipe is tapered to be narrower toward the substrate.

[0017] In the present invention preferably the present cooler further includes third flow path configuring means for discharging the coolant flowing through the second flow path. The third flow path configuring means includes a diaphragm between the primary pipe and the substrate. The secondary pipe penetrates the diaphragm. The secondary pipe is fixed to the diaphragm without a gap.

[0018] In the present invention preferably the substrate has the one surface extending in one of a vertical direction and a direction inclined relative to the vertical direction.

[0019] In the present invention preferably the substrate has the one surface facing downward in a vertical direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. **1** is a general exploded perspective view of a semiconductor apparatus in a first embodiment.

[0021] FIG. **2** is a first general cross section of the semiconductor apparatus in the first embodiment.

[0022] FIG. **3** is a second general cross section of the semiconductor apparatus in the first embodiment.

[0023] FIG. **4** is a third general cross section of the semiconductor apparatus in the first embodiment.

[0024] FIG. **5** is a general exploded perspective view of a semiconductor apparatus in a second embodiment.

[0025] FIG. **6** is a first general cross section of the semiconductor apparatus in the second embodiment.

[0026] FIG. **7** is a second general cross section of the semiconductor apparatus in the second embodiment.

[0027] FIG. **8** is a general cross section of a semiconductor apparatus in a third embodiment.

[0028] FIG. **9** is a first general cross section of a semiconductor apparatus in a fourth embodiment.

[0029] FIG. **10** is a second general cross section of the semiconductor apparatus in the fourth embodiment.

BEST MODES FOR CARRYING OUT THE INVENTION

First Embodiment

[0030] With reference to FIGS. **1** to **4**, the present invention in a first embodiment provides a cooler, as will be described hereinafter. In the present embodiment the cooler is a cooler for cooling an electric power converter as an object to be cooled.

[0031] The electric power converter includes an inverter for converting direct current electric power to alternate current electric power, a converter for changing voltage, and other similar components. For example the electric power converter includes a power MOSFET, an IGBT or an other similar power semiconductor device.

[0032] FIG. **1** is a general exploded perspective view of a semiconductor apparatus in the present embodiment. In the present embodiment the semiconductor apparatus includes an electric power converter serving as electronics, and a cooler for cooling the electric power converter.

[0033] In the present embodiment the semiconductor apparatus includes the electric power converter that is implemented as a semiconductor device **21**. Semiconductor device **21** is formed to be rectangular as seen in a plane. Semiconductor device **21** is connected to an external electric circuit (not shown). Semiconductor device **21** is a heat generating element generating heat when it is driven. In the present embodiment, semiconductor device **21** is an object to be cooled.

[0034] In the present embodiment the cooler includes a substrate **1** having one surface with semiconductor device **21** disposed thereon. Substrate **1** is in the form of a plate. In the present embodiment, substrate **1** has a front surface with a plurality of semiconductor devices **21** mounted thereon. Semiconductor device **21** is disposed to have a major surface bonded to substrate **1**, as indicated by an arrow **54**. In the present embodiment, substrate **1** includes a metal plate and an insulation layer deposited on a surface of the metal plate. Semiconductor device **21** is fixed on a surface of the insulation layer.

[0035] In the present embodiment the cooler includes a heat radiating member fixed to a surface of substrate **1** that is opposite to that having semiconductor device **21** disposed thereon. In the present embodiment the heat radiating member includes a plate member **2**. Plate member **2** is for example a straight fin. Plate member **2** is provided at at least one of a region opposite to that having semiconductor device **21** disposed therein and a region surrounding the region opposite to that having semiconductor device **21** disposed therein. Plate member **2** is provided at a back surface of substrate **1**. Plate member **2** is disposed to have a major surface substantially perpendicular to a major surface of substrate **1**.

[0036] FIG. **2** is a first general cross section of the semiconductor apparatus in the present embodiment. FIG. **2** is a general cross section thereof cut at a plane parallel to the major surface of the substrate. The semiconductor apparatus's cooler includes a plurality of plate members **2** disposed in alignment. Plate members **2** are disposed to have their respective major surfaces substantially parallel to one another. Plate member **2** is spaced from one another. Plate member **2** has a cutout portion **2***a* formed in a region having a secondary pipe **12**, which will be described later.

[0037] FIG. **3** is a second general cross section of the semiconductor apparatus in the present embodiment. FIG. **4** is a third general cross section of the semiconductor apparatus in the present embodiment. FIG. **3** is a cross section taken along a line III-III in FIG. **2** and FIG. **4** is a cross section taken along a line IV-IV in FIG. **2**.

[0038] In the present embodiment, plate member **2** is formed to be rectangular as seen in a plane. Cutout portion **2***a* is formed to provide a gap between secondary pipe **12** and an end of plate member **2**. An arrow **51** indicates a direction in which a coolant medium flows. Plate member **2** is disposed to have the major surface substantially parallel to the direction in which the coolant flows. Plate member **2** is formed to be substantially equal in height to a first flow path described later.

[0039] With reference to FIGS. **1** to **4**, in the present embodiment the cooler includes first flow path configuring means formed to allow a coolant to contact a heat radiating member. The first flow path configuring means is formed to configure the first flow path for the coolant. In the present embodiment the first flow path configuring means includes substrate **1** and a primary pipe **11** facing that side of substrate **1** which has plate member **2**. A first flow path configuring member includes a wall member **5** provided sideways of substrate **1** and primary pipe **11**. The first flow path is defined by a space surrounded by substrate **1**, primary pipe **11** and wall member **5**.

[0040] In the present embodiment the cooler is formed to pass a first coolant through the first flow path sandwiched between substrate **1** and primary pipe **11**. In the present embodiment a coolant supply device (not shown) is provided for supplying the first flow path of the cooler with a coolant.

[0041] In the present embodiment the cooler includes second flow path configuring means formed to cause a second coolant to impinge on the back surface of substrate **1** at a region opposite to that having the electric power converter disposed therein. The second flow path configuring means is formed to jet the second coolant directly to the portion opposite to that having the electric power converter disposed thereon.

[0042] In the present embodiment the second flow path configuring means is formed to configure a second flow path for a coolant. The second flow path configuring member includes primary pipe **11** spaced from the back surface of substrate **1**. Primary pipe **11** includes a flow path configuring plate **11***a* and a flow path configuring plate **11***b* spaced from each other and having their respective major surfaces parallel to each other. Sideways of flow path configuring plates **11***a* and **11***b*, wall member **5** is provided. A space surrounded by flow path configuring plates **11***a*, **11***b* and wall member **5** defines a portion of the second flow path.

[0043] In the present embodiment the second flow path configuring means includes secondary pipe **12** projecting from primary pipe **11** toward substrate **1**. Secondary pipe **12** is disposed opposite to the region of substrate **1** that has semiconductor device **21** disposed therein. In the present embodiment, secondary pipe **12** is formed to be cylindrical. Secondary pipe **12** is formed to project from flow path configuring plate **11***a*. Secondary pipe **12** is formed to communicate with primary pipe **11**. Secondary pipe **12** and primary pipe **11** configure the second flow path. In the present embodiment a coolant supply device (not shown) is provided to supply the second flow path with a second coolant.

[0044] In the present embodiment the first and second flow paths pass the first and second coolants, respectively, of water. The first and second flow paths are supplied with the coolant water by a common coolant supply device.

[0045] With reference to FIGS. **1** and **3**, in the present embodiment, secondary pipe **12** has an end surface **12***a* opposite to substrate **1**. End surface **12***a* inclines to provide a larger flow path in the direction in which the first flow path passes the first coolant, as indicated by arrow **51**. More specifically, end surface **12***a* is formed to have a larger distance from substrate **1** in the direction in which the first coolant flows. End surface **12***a* is formed to have the inclined surface facing downstream of the first coolant.

[0046] With reference to FIGS. **2** to **4**, semiconductor device **21** generates heat, which is transferred to substrate **1** and plate member **2**. A coolant supply device supplies the first coolant, which is introduced into the first flow path. The first coolant flows through a space sandwiched by substrate **1** and primary pipe **11**, as indicated by arrow **51**. The first coolant flows through the first flow path between plate members **2**. The first coolant flows in contact with plate member **2** and substrate **1**. As the first coolant contacts plate member **2** and substrate **1**, plate member **2** and substrate **1** are cooled. Subsequently, the first coolant is exhausted.

[0047] Semiconductor device **21** is cooled via substrate **1** as plate member **2** is cooled. The heat of semiconductor device **21** is transferred to substrate **1** and plate member **2**, and radiated from substrate **1** and plate member **2** to the first coolant.

[0048] The coolant supply device supplies the second coolant, which is introduced into the second flow path configured by the second flow path configuring member. The second coolant is introduced into primary pipe **11**, as indicated by an arrow **52**. A portion of the second coolant flowing through primary pipe **11** flows into secondary pipe **12**, as indicated by an arrow **53**.

[0049] The second coolant flowing into secondary pipe **12** is discharged through secondary pipe **12** at end surface **12***a*, as indicated by arrow **53**. In the present embodiment the second coolant supplied through the second flow path and thus separated from the first coolant does not contribute to cooling semiconductor device **21** before the second coolant is jetted out of secondary pipe **12**. Before the second coolant is jetted out of secondary pipe **12**, the second coolant does not contact plate member **2** provided at the second flow path, and thus does not have its ability as a coolant impaired. The second coolant jetted out of secondary pipe **12** impinges on the back surface of substrate **1** at the region opposite to that having semiconductor device **21** disposed therein. More specifically, the second coolant cools by an impinging jet stream the region of substrate **1** opposite to that having semiconductor device **21** disposed therein. The second coolant that impinges on substrate **1** allows semiconductor device **21** to be effectively cooled.

[0050] The second coolant impinging on substrate **1** flows through the first flow path together with the first coolant, when the second coolant contacts and thus cools substrate **1** and plate member **2** as the second coolant proceeds. Subsequently the second coolant is exhausted together with the first coolant.

[0051] The present embodiment includes first flow path configuring means formed to allow a coolant to contact a heat radiating member, and second flow path configuring means for causing an impinging jet stream to impinge on a region opposite to that having a semiconductor device disposed therein, and a first flow path and a second flow path are separated. In the first flow path, the heat radiating member can be disposed to radiate heat across an increased area to efficiently remove heat. In the second flow path, a second coolant is supplied such that it is separated from a first coolant until the second coolant is jetted out of a secondary pipe. The first coolant, which flows through the first flow path, gradually increases in temperature as it approaches downstream of the first coolant. In contrast, the second coolant downstream is substantially the same in temperature as that upstream. Thus the second coolant can impinge on semiconductor device **21** at low temperature and thus efficiently cool semiconductor device **21**. Furthermore, the coolant can be prevented from having its ability as a coolant impaired as it proceeds through a flow path and approaches downstream. Semiconductor device **21** can be cooled substantially uniformly.

[0052] Thus, in the present embodiment, an impinging jet stream, and the cooling by convection of a heat transfer member can be provided substantially separately, and an object to be cooled can be cooled effectively.

[0053] In the present embodiment the second flow path configuring means includes a primary pipe and a secondary pipe. A first flow path includes a space sandwiched between the primary pipe and a substrate. A plate member is disposed to surround a region opposite to that having a semiconductor device disposed therein. This configuration facilitates forming the first flow path configuring means and the second flow path configuring means. Furthermore a cooler having a simplified configuration can be provided.

[0054] With reference to FIGS. **1** and **3**, in the present embodiment, secondary pipe **12** has end surface **12***a* inclined to provide a larger path in a direction in which the first coolant flows. This configuration allows an impinging jet stream jetted from secondary pipe **12** to be guided downstream of the first coolant.

[0055] In the present embodiment the cooler includes a substrate having a surface with a semiconductor device disposed thereon, that faces vertically upward. Alternatively, the cooler may have a substrate having a surface with a semiconductor device disposed thereon, that faces vertically downward. This configuration allows bubbles generated in the first flow path or the second flow path to be guided to a side that is opposite to that having the substrate, and can thus prevent the bubbles from staying at the back surface of the substrate and removing a layer of liquid on the back surface of the substrate, and thus contributing to inefficient heat transfer.

[0056] Alternatively, the cooler may have the substrate disposed such that the surface of the substrate that has a semiconductor device disposed thereon extends in a vertical direction or a direction inclined relative the vertical direction. This configuration allows bubbles caused in the first flow path or the second flow path to be moved vertically upward. This can prevent the bubbles from staying at the back surface of the substrate. If bubbles are generated in the first flow path or the second flow path, a layer of liquid can be ensured at the back surface of the substrate.

[0057] In particular, if the coolant is liquid and a large heat flux is provided, vapors may be generated in the coolant. Any of the above configurations can expel such vapors from the cooler or move the vapors to a periphery of the cooler. This can prevent an object to be cooled from being cooled inefficiently as bubbles are generated.

[0058] In the present embodiment a plate member serving as a heat radiating member is formed to be substantially equal in height to the first flow path. This configuration allows the plate member to be provided along the entire height of the first flow path to transfer heat across an increased area. This allows the first coolant to effectively cool an object to be cooled.

[0059] In the present embodiment a plurality of semiconductor devices are disposed in a direction in which a coolant flows, and for the semiconductor devices, secondary pipes identical in geometry are provided. However, the secondary pipes are not limited thereto, and may be different from each other in size and geometry. Furthermore while in the present embodiment the secondary pipe is cylindrical, it is not limited thereto and may have any form.

[0060] For example, if different types of objects are to be cooled, then for an object generating a large quantity of heat, a secondary pipe of a large diameter may be provided, and for an object generating a small quantity of heat, a secondary pipe of a small diameter may be provided. Thus in the present embodiment the cooler can facilitate adjusting a quantity of heat to be removed in accordance with each object to be cooled.

[0061] Furthermore, the secondary pipe or the primary pipe may be provided with a valve adjusting a flow rate of a coolant jetted through a particular secondary pipe, a valve interrupting a flow through a particular secondary pipe, and the like. This configuration allows an impinging jet stream to be adjusted in flow rate to correspond to a quantity of heat generated by an object to be cooled, and an impinging jet stream to intermittently cool an object to be cooled. Furthermore, if an object to be cooled generates heat in a quantity varying in time series, then an impinging jet stream having a flow rate changed in accordance with such variation in the quantity of heat generated can be provided to optimally cool the object.

[0062] Furthermore in the present embodiment a plate member serving as a heat radiating member has a cutout portion. However, the plate member is not limited thereto and may not have a cutout portion. For example, the plate member may penetrate the secondary pipe. Furthermore, the plate member is not limited to having a flat surface. It may be formed to have a curved surface.

[0063] In the present embodiment the first coolant and the second coolant are identical. Alternatively, they may be different coolants. Furthermore, they are not limited to liquid and may contain gas.

[0064] Furthermore in the present embodiment the cooler is formed to have the first flow path and the second flow path passing the first coolant and the second coolant, respectively, in a single direction. However, it is not limited thereto, and may be formed to have the first flow path and the second flow path passing the first coolant and the second coolant in different directions, respectively.

[0065] Furthermore the coolant supply device may be a coolant supply device for supplying the first coolant and that for supplying the second coolant. Alternatively, it may include a circulation device circulating a coolant while cooling it.

[0066] In the present embodiment the object to be cooled is an electric power converter of large electric power by way of example. However, it is not limited thereto, and the present invention is applicable to a cooler for any object to be cooled.

For example, the present invention is also applicable for example to coolers for an electric power converter of small electric power and other objects to be cooled.

Second Embodiment

[0067] With reference to FIGS. **5** to **7**, the present invention in a second embodiment provides a cooler, as will now be described hereinafter. In the present embodiment the cooler is a cooler for cooling an electric power converter. The cooler includes first flow path configuring means and second flow path configuring means, similarly as described in the first embodiment. The present embodiment differs from the first embodiment by a heat radiating member for radiating the heat of an object to be cooled.

[0068] FIG. **5** is a general exploded perspective view of a semiconductor apparatus in the present embodiment. In the present embodiment the heat radiating member includes a bar member **3** fixed to and projecting from the back surface of substrate **1**. In the present embodiment, bar member **3** has a longitudinal direction substantially perpendicular to the back surface of substrate **1**.

[0069] FIG. **6** is a first general cross section of the semiconductor apparatus in the present embodiment. FIG. **6** is a general cross section as cut at a plane parallel to the major surface of the substrate. Bar member **3** surrounds secondary pipe **12**. Bar member **3** surrounds a region opposite to that having semiconductor device **21** disposed therein. Bar member **3** is disposed in a vicinity of the region opposite to that having semiconductor device **21** disposed therein. In the present embodiment, four bar members **3** are provided for a single semiconductor device **21**. The first coolant flows in direction **51**.

[0070] FIG. **7** is a second general cross section of the semiconductor apparatus in the present embodiment. FIG. **7** is a cross section taken along a line VII-VII in FIG. **6**. Bar member **3** is formed to have a length substantially equal to the height of the first flow path sandwiched between primary pipe **11** and substrate **1**.

[0071] In the present embodiment the heat radiating member includes a bar member. The bar member can be varied in position, length, number, and the like to allow the heat radiating member to remove heat at a different position and contact a coolant at a different area.

[0072] In the present embodiment bar members surround a region opposite to that having disposed therein an object to be cooled. Alternatively, the bar member may be provided at any position and in any number that do not prevent the second coolant having impinged on a surface of the substrate to be cooled from radically spreading and do not prevent the first coolant from flowing.

[0073] In the present embodiment the bar member is substantially equal in height to the first flow path passing the first coolant. This configuration allows the bar member to be disposed along substantially the entire height of the first flow path to allow the first coolant to effectively cool it.

[0074] The remainder in configuration, and function and effect is similar to that of the first embodiment. Accordingly it will not be described repeatedly.

Third Embodiment

[0075] With reference to FIG. **8**, the present invention in a third embodiment provides a cooler, as will be described hereinafter. The cooler includes first flow path configuring means and second flow path configuring means, similarly as described in the first embodiment. The cooler of the present embodiment is different from that of the first embodiment in the geometry of the heat radiating member and that of the secondary pipe of the second flow path configuring means.

[0076] FIG. **8** is a general cross section of the cooler in the present embodiment. FIG. **8** is a general cross section as cut at a plane perpendicular to the major surface of the substrate. In the present embodiment the cooler includes a secondary pipe **13** formed to project from a surface of primary pipe **11**. Secondary pipe **13** is formed to have a cross section in the form of a mountain. Secondary pipe **13** is tapered to provide a narrower flow path toward substrate **1**. In the present embodiment, secondary pipe **13** is formed to have an end surface substantially parallel to substrate **1**.

[0077] In the present embodiment the cooler includes a plate member **4**. Plate member **4** has a cutout portion **4***a*. Cutout portion **4***a* is formed to incline along the geometry of secondary pipe **13**. Cutout portion **4***a* inclines to have a cross section narrower toward substrate **1**. Cutout portion **4***a* is formed to space plate member **4** from secondary pipe **13**.

[0078] In the present embodiment the second coolant flowing in as indicated by arrow **52** is discharged from secondary pipe **13**, as indicated by an arrow **55**. When the second coolant is discharged from secondary pipe **13**, it is discharged along the flow of the first coolant as indicated by arrow **51**. Secondary pipe **13** that is tapered allows an impinging jet stream of the second coolant to smoothly join the first coolant. Furthermore, the secondary pipe can be tapered variously to facilitate adjusting the impinging jet stream in pressure and flow rate.

[0079] Furthermore, secondary pipe **13**, configuring the second flow path, that is tapered as seen in cross section can help the first coolant of the first flow path to approach substrate **1** and the second coolant having impinged on substrate **1** can be collected to substrate **1**. This allows the second coolant to cool substrate **1** more effectively. Furthermore in the first flow path the first coolant and the second coolant can flow in different layers and thus be prevented from being mixed together. Small pressure loss can thus be achieved.

[0080] The remainder in configuration, and function and effect is similar to that of the first embodiment. Accordingly it will not be described repeatedly.

Fourth Embodiment

[0081] With reference to FIGS. **9** and **10**, the present invention in a fourth embodiment provides a cooler, as will be described hereinafter. In the present embodiment the cooler includes the first flow path configuring means and the second flow path configuring means, and in addition, third flow path configuring means. More specifically in the present embodiment the cooler has the first flow path and the second flow path, and in addition, a third flow path. The third flow path is formed to communicate with the second flow path.

[0082] FIG. **9** is a first general cross section of the cooler in the present embodiment. FIG. **9** is a general cross section as cut at a plane parallel to the major surface of the substrate. FIG. **10** is a second general cross section of the cooler in the present embodiment. FIG. **10** is a cross section taken along a line X-X in FIG. **9**.

[0083] With reference to FIGS. **9** and **10**, in the present embodiment the cooler includes third flow path configuring means for configuring a third flow path for discharging a coolant flowing through the second flow path. The third flow path configuring means includes a diaphragm **6**. Diaphragm **6**

is disposed between primary pipe **11** and substrate **1**. Diaphragm **6** is in the form of a flat plate. Diaphragm **6** is disposed to have a major surface substantially parallel to the back surface of substrate **1**. Diaphragm **6** is disposed to divide the first flow path into two flow paths.

[0084] In the present embodiment the second flow path configuring member includes a secondary pipe **14**. Secondary pipe **14** penetrates diaphragm **6**. Secondary pipe **14** has a jet outlet in a space sandwiched between substrate **1** and diaphragm **6**. Secondary pipe **14** is fixed to diaphragm **6** without a gap. More specifically, there is no gap between secondary pipe **14** and diaphragm **6**.

[0085] In the present embodiment the cooler includes the heat radiating member that is implemented by a plate member **7**. Plate member **7** is formed to penetrate diaphragm **6**. Plate member **7** has a cutout portion **7***a*. Cutout portion **7***a* is formed to be circular as seen in a plane. Cutout portion **7***a* is formed along the geometry of secondary pipe **14**.

[0086] In the present embodiment, the first flow path is defined by a space sandwiched by primary pipe **11** and diaphragm **6**. Furthermore, the third flow path is defined by a space sandwiched by substrate **1** and diaphragm **6**. Primary pipe **11** and secondary pipe **14** define the second flow path.

[0087] In the present embodiment the coolant supply device is formed to supply a coolant directly to the first flow path and the second flow path and avoid supplying a coolant directly to the third flow path.

[0088] In the present embodiment the first flow path and the second flow path are isolated from each other. The first coolant cools plate member **7** as the first coolant proceeds through the first flow path, as indicated by arrow **51**. The second coolant flows through the second flow path and is jetted from secondary pipe **14**, as indicated by arrow **53**. The second coolant forms an impinging jet stream and thus cools the back surface of substrate **1**.

[0089] After the second coolant impinges on substrate **1**, the second coolant flows through the third flow path. In the third flow path the coolant flows toward an exhaust port, as indicated by an arrow **56**. In the third flow path the second coolant cools substrate **1** and plate member **7** as the second coolant proceeds. The first path is completely separated from the second and third paths.

[0090] In the present embodiment the cooler has a path cooling an object by an impinging jet stream and a path cooling the heat radiating member, separated from each other. The cooler is formed to prevent the second coolant forming an impinging jet stream and the first coolant cooling the heat radiating member from being mixed together. This can reduce or prevent the interference of the first coolant cooling the heat radiating member with the second coolant forming the impinging jet stream, to allow the impinging jet stream to more effectively cool the object.

[0091] Alternatively, in the present embodiment, the cooler can avoid the first coolant and the second coolant mixed together. For example, the first coolant and the second coolant can be different coolants, respectively. In that case the coolant supply device can be a coolant supply device including a circulation device for the first coolant and that for the second coolant different than the first coolant.

[0092] Furthermore in the present embodiment a plate member has a cutout portion and the cutout portion is formed along the geometry of a secondary pipe. The secondary pipe jets out the second coolant, which spreads radially along the geometry of the secondary pipe. This configuration can prevent the plate member from significantly preventing the second coolant from spreading.

[0093] The remainder in configuration, and function and effect is similar to that of the first embodiment. Accordingly it will not be described repeatedly.

[0094] The present invention can thus provide a cooler providing excellent performance to cool an electric power converter.

[0095] In the above described figures, identical or like potions are identically denoted.

[0096] It should be understood that the embodiments disclosed herein are illustrative and non-restrictive in any respect. The scope of the present invention is defined by the terms of the claims, rather than the description above, and is intended to include any modifications within the scope and meaning equivalent to the terms of the claims.

Industrial Applicability

[0097] The present invention is applicable to a cooler. In particular, it is advantageously applicable to a cooler for an electric power converter.

1. A cooler comprising:
- a substrate for disposing a heat generating element on one surface thereof;
- a heat radiating member fixed to an other surface of said substrate;
- a first flow path configuring member configuring a first flow path formed to allow a coolant to contact said heat radiating member; and
- a second flow path configuring member configuring a second flow path formed to jet a coolant toward said other surface at a region opposite to a region having said heat generating element disposed therein, said second flow path being separated from said first flow path.

2. The cooler according to claim **1**, wherein said heat radiating member includes at least one of a plate member and a bar member.

3. The cooler according to claim **1**, wherein:
- said heat radiating member surrounds said region opposite to said region having said heat generating element disposed therein;
- said second flow path configuring member includes a primary pipe remote from said other surface of said substrate, and a secondary pipe projecting from said primary pipe toward said substrate;
- said secondary pipe is opposite to said region of said substrates having said heat generating element disposed therein; and
- said first flow path includes a space sandwiched between said primary pipe and said substrate.

4. The cooler according to claim **3**, wherein:
- said secondary pipe has an end surface opposite to said substrate; and
- said end surface inclines to provide a larger flow path in a direction in which said coolant flows along said first flow path configuring member.

5. The cooler according to claim **3**, wherein said secondary pipe is tapered to be narrower toward said substrate.

6. The cooler according to claim **3**, further comprising a third flow path configuring member for discharging said coolant flowing through said second flow path, wherein:
- said third flow path configuring member includes a diaphragm between said primary pipe and said substrate;

said secondary pipe penetrates said diaphragm; and

said secondary pipe is fixed to said diaphragm without a gap.

7. The cooler according to claim **1**, wherein said substrate has said one surface extending in one of a vertical direction and a direction inclined relative to said vertical direction.

8. The cooler according to claim **1**, wherein said substrate has said one surface facing downward in a vertical direction.

9. A cooler comprising:

a substrate for disposing a heat generating element on one surface thereof;

a heat radiating member fixed to an other surface of said substrate;

first flow path configuring means for configuring a first flow path formed to allow a coolant to contact said heat radiating member; and

second flow path configuring means for configuring a second flow path formed to jet a coolant toward said other surface at a region opposite to a region having said heat generating element disposed therein, said second flow path being separated from said first flow path.

10. The cooler according to claim **9**, wherein said heat radiating member includes at least one of a plate member and a bar member.

11. The cooler according to claim **9**, wherein:

said heat radiating member surrounds said region opposite to said region having said heat generating element disposed therein;

said second flow path configuring means includes a primary pipe remote from said other surface of said substrate, and a secondary pipe projecting from said primary pipe toward said substrate;

said secondary pipe is opposite to said region of said substrate having said heat generating element disposed therein; and

said first flow path includes a space sandwiched between said primary pipe and said substrate.

12. The cooler according to claim **11**, wherein:

said secondary pipe has an end surface opposite to said substrate; and

said end surface inclines to provide a larger flow path in a direction in which said coolant flows along said first flow path configuring means.

13. The cooler according to claim **11**, wherein said secondary pipe is tapered to be narrower toward said substrate.

14. The cooler according to claim **11**, further comprising third flow path configuring means for discharging said coolant flowing through said second flow path, wherein:

said third flow path configuring means includes a diaphragm between said primary pipe and said substrate;

said secondary pipe penetrates said diaphragm; and

said secondary pipe is fixed to said diaphragm without a gap.

15. The cooler according to claim **9**, wherein said substrate has said one surface extending in one of a vertical direction and a direction inclined relative to said vertical direction.

16. The cooler according to claim **9**, wherein said substrate has said one surface facing downward in a vertical direction.

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