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Inventor(s)	Hori; Motohito et al.

Semiconductor device

Abstract

A semiconductor device includes a semiconductor module that includes: an insulating circuit board, a semiconductor chip provided on a main surface of the insulating circuit board, and an external connection terminals provided on the main surface of the insulating circuit board; an external printed circuit board provided so as to face a main surface of the semiconductor module, the external printed circuit board having a through hole into which the external connection terminal is inserted; and an elastic member provided between the main surface of the semiconductor module and the external printed circuit board so as to apply a pressing force to the main surface of the semiconductor module.

Inventors: **Hori; Motohito (Nagano, JP), Ikeda; Yoshinari (Nagano, JP), Hirao; Akira (Nagano, JP)**

Applicant: **Fuji Electric Co., Ltd.** (Kanagawa, JP)

Family ID: **1000008766414**

Assignee: **FUJI ELECTRIC CO., LTD. (Kanagawa, JP)**

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Primary Examiner: Gumedzoe; Peniel M

Attorney, Agent or Firm: CHEN YOSHIMURA LLP

Background/Summary

BACKGROUND OF THE INVENTION

Technical Field

(1) The present invention relates to a semiconductor device incorporating a power semiconductor element.

Background Art

(2) As a conventional semiconductor device, there is known a semiconductor module in which a power semiconductor chip (hereinafter simply referred to as a “semiconductor chip”) constituting a power semiconductor element, such as a switching element for power conversion, is mounted on an insulating circuit board. When the semiconductor module **101** has a configuration in which both ends are screwed, fixing spring plates are attached to both ends of a case that accommodates the semiconductor chip and the insulating circuit board inside. The semiconductor module is fixed to a cooler via a compound by fastening the fixing spring plate to the cooler with screws and washers.

(3) Patent Document 1 discloses a semiconductor module that includes a ceramic circuit board, a circuit pattern, and a sealing material, and that uses press-fit terminals as external connection terminals. Patent Document 2 discloses a configuration in which a spring holding bracket is arranged under a control circuit board, a leaf spring is arranged between the lower part of the spring holding bracket and the upper part of a semiconductor module, and the semiconductor module is

pressed from above.
RELATED ART DOCUMENT
Patent Document
(4) Patent Document 1: Japanese Patent Application Laid-Open Publication No, 2021-150468
Patent Document 2: Japanese Patent Application Laid-Open Publication No. 2014-225571
SUMMARY OF THE INVENTION
(5) In a conventional semiconductor device, when a current is applied to a semiconductor module and constituent members expand due to the heat generated by the current flowing through the semiconductor chips and the members, because the case is fixed at both ends, the central portion of the case is deformed upward. As the case deforms, the center of the compound is also pulled upward. After that, when the current to the semiconductor module is cut off, heat generation ceases, the members shrink, and the deformation of the case returns to its original state. As the above phenomenon is repeated, the compound is gradually pushed out and flows out. Such a phenomenon is called pump-out. As a result, there is a problem that heat dissipation is deteriorated due to depletion of the compound, causing an increase in the temperature of the semiconductor chip.
(6) In view of the above problems, an object of the present invention is to provide a semiconductor device capable of suppressing deformation of the semiconductor module when the current is turned on and off so as to reduce compound pump-out.
(7) Additional or separate features and advantages of the invention will be set forth in the descriptions that follow and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the invention will be realized and attained by the structure particularly pointed out in the written description and claims thereof as well as the appended drawings.
(8) To achieve these and other advantages and in accordance with the purpose of the present invention, as embodied and broadly described, in one aspect, the present disclosure provides a semiconductor device, comprising: a semiconductor module that includes: an insulating circuit board, a semiconductor chip provided on a main surface of the insulating circuit board, and an external connection terminals provided on the main surface of the insulating circuit board; an external printed circuit board provided so as to face a main surface of the semiconductor module, the external printed circuit board having a through hole into which the external connection terminal is inserted; and an elastic member provided between the main surface of the semiconductor module and the external printed circuit board so as to apply a pressing force to the main surface of the semiconductor module.
(9) According to the present invention, it is possible to provide a semiconductor device capable of suppressing the deformation of the semiconductor module when the current is turned on and off, thereby reducing the pump-out of a compound when the semiconductor device is mounted on a cooler via the compound.
(10) It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory, and are intended to provide further explanation of the invention as claimed.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a schematic cross-sectional view of a semiconductor device according to an embodiment.
(2) FIG. **2** is a side view of the semiconductor module according to the embodiment.
(3) FIG. **3** is a plan view of the semiconductor module and elastic members according to the embodiment.

(4) FIG. **4** is an equivalent circuit diagram of the semiconductor module according to the embodiment.
(5) FIG. **5** is a schematic cross-sectional view for explaining a method of assembling the semiconductor device according to the embodiment;
(6) FIG. **6** is a schematic cross-sectional view of a semiconductor device according to a comparative example;
(7) FIG. **7** is a plan view of a semiconductor module according to the comparative example.
(8) FIG. **8** is a schematic cross-sectional view of the semiconductor module according to the comparative example when deformed.

DETAILED DESCRIPTION OF EMBODIMENTS

(9) Embodiments will be described below with reference to the drawings. In the description of the drawings, the same or similar parts are denoted by the same or similar reference numerals, and overlapping descriptions are omitted. However, the drawings are schematic, and the relationship between the thickness and the planar dimensions, the ratio of the thickness of each layer, and the like may differ from the actual ones. In addition, portions having different dimensional relationships and ratios may also be included between drawings. Further, the embodiments shown below are examples of devices and methods for embodying the technical idea of the present invention, and the materials, shapes, structures, and arrangements, etc., of constituent elements are not particularly limited by these embodiments.
(10) In the following description, the “first main electrode” of the semiconductor chip means either the source electrode or the drain electrode in the case of a field effect transistor (FET) or static induction transistor (SIT). In the case of an insulated gate bipolar transistor (IGBT), it means either the emitter electrode or the collector electrode. In static induction thyristors (SI thyristors), gate turn-off thyristors (GTO), and diodes, it means either the anode electrode or the cathode electrode. Further, the “second main electrode” of the semiconductor element means either one of the source electrode and the drain electrode, which are not the first main electrode, in the case of FET and SIT. In the case of an IGBT, it means either an emitter electrode or a collector electrode that does not serve as the first main electrode. In the case of SI thyristors, GTOs, and diodes, it means either the anode electrode or the cathode electrode, which does not serve as the first main electrode. That is, if the “first main electrode” is the source electrode, the “second main electrode” means the drain electrode. If the “first main electrode” is the emitter electrode, the “second main electrode” means the collector electrode. If the “first main electrode” is the anode electrode, the “second main electrode” means the cathode electrode.
(11) In addition, the definitions of directions such as “up”, “down”, “up and down”, “left”, “right”, “left and right” in the following description are merely definitions for convenience of explanation, and do not limit the technical idea of the present invention. For example, if the object is rotated by 90° and observed, “up and down” will be converted to “left and right”, and if the object is rotated by 180° and observed, “up and down” will be reversed.
(12) <Semiconductor Device Configuration>
(13) FIG. **1** shows a schematic cross-sectional view of a semiconductor device according to an embodiment. In FIG. **1**, illustration of components appearing in a cross section of a semiconductor module (power semiconductor module) **1** of a semiconductor device of the embodiment is omitted, and a side surface of a case **8** on the front side of the semiconductor module **1** is illustrated. In the cross-sectional view shown in FIG. **1**, the horizontal direction in FIG. **1** is defined as the X-axis, and the rightward direction in FIG. **1** is defined as the positive direction of the X-axis. Further, the direction orthogonal to the X-axis, which is the direction toward the back side and the front side in FIG. **1**, is defined as the Y-axis, and the back side in FIG. **1** is defined as the positive direction of the Y-axis. A direction orthogonal to the X-axis and the Y-axis, which are vertical directions in FIG. **1**, is defined as the Z-axis, and the upward direction in FIG. **1** is defined as the positive direction of the Z-axis. The same applies to FIG. **2** and subsequent figures.

(14) As shown in FIG. **1**, the semiconductor device according to the embodiment includes a semiconductor module **1**, an external printed circuit board **20** provided facing one main surface (upper surface) of the semiconductor module **1**, elastic members **71** and **72** provided between the main surface of the semiconductor module **1** and the external printed circuit board **20**, and a cooler (heat sink) **32** provided on the main surface (lower surface) opposite to one main surface of the semiconductor module **1** via a compound (bonding material) **31**.
(15) The semiconductor module **1** is a semiconductor module called "2 in 1" that has the functions of two power semiconductor elements. FIG. **2** is a side view of the semiconductor module **1**. In FIG. **2**, the sealing member **7** is transparently shown, and the illustration of the portion of the case **8** that covers the front side of the sealing member **7** is omitted.
(16) As shown in FIG. **2**, the semiconductor module **1** includes an insulating circuit board **10** and semiconductor chips **2***a* and **2***b* provided on one main surface (upper surface) of the insulating circuit board **10**. An internal printed circuit board **4** is provided on the other main surface (upper surface) side opposite to the one main surface (lower surface) side facing the insulating circuit board **10** of the semiconductor chips **2***a* and **2***b*.
(17) The insulating circuit board **10** has, for example, a rectangular planar shape. The insulating circuit board **10** includes an insulating substrate **11**, upper conductor layers **12***a* and **12***b* provided on one main surface (upper surface) of the insulating substrate **11**, and a lower conductor layer **13** provided on the other main surface (lower surface) of the insulating substrate **11**. The insulating circuit board **10** may be, for example, a direct copper bond (DCB) board, an active braze (AMB) board, or the like. The insulating substrate **11** is composed of, for example, a ceramic substrate made of aluminum oxide (Al.sub.2O.sub.3), aluminum nitride (AlN), silicon nitride (Si.sub.3N.sub.4), boron nitride (BN), or the like, or a resin insulating substrate using a polymer material or the like. The upper conductor layers **12***a* and **12***b* and the lower conductor layer **13** are made of conductor foil made of, for example, copper (Cu) or aluminum (Al). A predetermined circuit pattern is formed on the upper conductor layers **12***a* and **12***b*.
(18) The semiconductor chips **2***a* and **2***b* may be made of, for example, a silicon (Si) material, or may be made of a wide bandgap semiconductor material such as silicon carbide (SiC), gallium nitride (GaN), or gallium oxide (Ga.sub.2O.sub.3). The types of the semiconductor chips **2***a* and **2***b* differ depending on the application, but for example, a power semiconductor element, such as metal oxide semiconductor field effect transistors (MOSFETs), insulated gate bipolar transistors (IGBTs), static induction (SI) thyristors, gate turn-off (GTO) thyristors, and the like, a rectifying element such as a freewheeling diode (FWD), or the like can be employed. Here, a case will be described where the semiconductor chips **2***a* and **2***b* are SiC MOSFETs, the semiconductor chip **2***a* is the semiconductor chip on the upper arm side, and the semiconductor chip **2***b* is the semiconductor chip on the lower arm side.
(19) FIG. **2** illustrates a case where the semiconductor module **1** has a single semiconductor chips **2***a* and a single semiconductor chip **2***b* as semiconductor chips on the upper arm side and the lower arm side, respectively. But the number of the semiconductor chips are not limited, and can be selected as appropriate. For example, the semiconductor module **1** may have two or more semiconductor chips each for the upper arm side and the lower arm side.
(20) The semiconductor chips **2***a* and **2***b* each have a first main electrode (drain electrode) on the lower surface side, and a control electrode (gate electrode) and a second main electrode (source electrode) on the upper surface side. The drain electrode of the semiconductor chip **2***a* is directly bonded to the upper conductor layer **12***a* of the insulating circuit board **10** via a bonding material (not shown) such as solder or sintered material, or directly using a direct bonding technique. The drain electrode of the semiconductor chip **2***b* is directly bonded to the upper conductor layer **12***b* of the insulating circuit board **10** via a bonding material such as solder or sintered material, or directly using a direct joining technique.
(21) The semiconductor chips **2***a*, **2***b* are electrically connected to the internal printed circuit board

4 via a plurality of bumps (post electrodes) **3***a*, **3***b*. The source electrode of the semiconductor chip **2***a* is joined to one or more of the plurality of bumps **3***a* via a joining material (not shown) such as solder or sintered material. The gate electrode of the semiconductor chip **2***a* is joined to another one or more of the plurality of bumps **3***a* via a joining material (not shown) such as solder or sintered material. The source electrode of the semiconductor chip **2***b* is joined to one or more of the plurality of bumps **3***b* via a joining material (not shown) such as solder or sintered material. The gate electrode of the semiconductor chip **2***b* is joined to another one or more of the plurality of bumps **3***b* via a joining material (not shown) such as solder or sintered material.

(22) The bumps **3***a* and **3***b* are, for example, rod-shaped, pin-shaped, or column-shaped, and specifically may be circular columns, elliptical columns, or polygonal columns such as, triangular columns, or square columns. Metal materials such as copper (Cu) can be used as materials for the bumps **3***a* and **3***b*. The bumps **3***a* and **3***b* may be bonded to the lower wiring layer **43** of the internal printed circuit board **4** or may be bonded to the upper wiring layer **42** through the internal printed circuit board **4**. The bumps **3***a* and **3***b* may be, for example, stud bumps made of gold (Au) or the like, or pillar electrodes or ball-shaped electrodes using various metal materials such as solder, metal sintered bodies such as nano-silver (Ag) paste, or the like.

(23) The internal printed circuit board **4** includes an insulating layer **41**, an upper wiring layer **42** provided on one main surface (upper surface) of the insulating layer **41**, and a lower wiring layer **43** provided on the other main surface (lower surface) of the insulating layer **41**. For example, the insulating layer **41** is made of a resin substrate made of polyimide resin, a combination of glass fiber and polyimide resin, or the like. The upper wiring layer **42** and the lower wiring layer **43** are made of conductor foil made of, for example, copper (Cu) or aluminum (Al). A predetermined circuit pattern is formed on the upper wiring layer **42** and the lower wiring layer **43**. For example, the same circuit pattern may be formed on the upper wiring layer **42** and the lower wiring layer **43**. The upper wiring layer **42** and the lower wiring layer **43** may be electrically connected to each other via a through hole penetrating the insulating layer **41**.

(24) The lower end of the drain-side connection terminal **6***a*, which is an external connection terminal for the main wiring on the positive electrode side, is joined to the upper conductor layer **12***a* of the insulating circuit board **10** via a joining material (not shown) such as solder or sintered material. The drain-side connection terminal **6***a* extends upward from the insulating circuit board **10**. The drain-side connection terminal **6***a* is made of a metal material such as copper (Cu). The drain-side connection terminal **6***a* supplies current to the drain electrode of the semiconductor chip **2***a* through the upper conductor layer **12***a* of the insulating circuit board **10**.

(25) To the upper wiring layer **42** of the internal printed circuit board **4**, the lower end of the source-side connection terminal **6***b*, which is an external connection terminal for the main wiring on the negative electrode side, is joined via a joining material (not shown) such as solder or sintered material. The source-side connection terminal **6***b* extends upward from the internal printed circuit board **4**. The source-side connection terminal **6***b* is made of a metal material such as copper (Cu). The source-side connection terminal **6***b* allows current from the source electrode of the semiconductor chip **2***b* to flow through the bumps **3***b* and the internal printed circuit board **4** to the external printed circuit board **20** shown in FIG. **1**.

(26) The lower end of the output terminal **6***c*, which is an external connection terminal for the main wiring on the output side, is joined to the upper conductor layer **12***b* of the insulating circuit board **10** via a joining material (not shown) such as solder or sintered material. The output terminal **6***c* extends upward from the insulating circuit board **10** and penetrates the internal printed circuit board **4**. The output terminal **6***c* is electrically connected to the upper wiring layer **42** and the lower wiring layer **43** of the internal printed circuit board **4**. The output terminal **6***c* is made of a metal material such as copper (Cu). The output terminal **6***c* allows current from the source electrode of the semiconductor chip **2***a* to flow through the bumps **3***a* and the internal printed circuit board **4** to the external printed circuit board **20** shown in FIG. **1** when the semiconductor chip **2***a* is ON. The

output terminal **6***c* supplies current from the external printed circuit board **20** shown in FIG. **1** to the drain electrode of the semiconductor chip **2***b* through the upper conductor layer **12***b* of the insulating circuit board **10** when the semiconductor chip **2***b* is ON.

(27) Although not shown in FIG. **2**, the internal printed circuit board **4** is electrically connected to a plurality of gate control terminals, which are external connection terminals for gate control. Respective gate control terminals apply control signals for controlling ON/OFF of the semiconductor chips **2***a* and **2***b* to the gate electrodes of the semiconductor chips **2***a* and **2***b* via the internal printed circuit board **4** and the bumps **3***a* and **3***b*, respectively.

(28) The insulating circuit board **10**, the semiconductor chips **2***a* and **2***b*, the bumps **3***a* and the internal printed circuit board **4** are sealed with a sealing member **7**. As the sealing member **7**, for example, a resin material such as a hard thermosetting resin having high heat resistance can be used. Specifically, an epoxy resin, a maleimide resin, a cyanate resin, or the like can be used. The lower conductor layer **13** of the insulating circuit board **10** is exposed on the lower surface side of the sealing member **7**.

(29) The upper portions of the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, and the output terminal **6***c* protrude from the upper surface side of the sealing member **7**. The drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, and the output terminal **6***c* are configured as press-fit terminals. The drain-side connection terminal **6***a* has a main portion **61** and a projecting portion (thick portion) **62** thicker than the main portion **61**. The source-side connection terminal **6***b* has a main portion **63** and a projecting portion **64** thicker than the main portion **63**. The output terminal **6***c* has a main portion **65** and a projecting portion **66** thicker than the main portion **65**. The plurality of gate control terminals, not shown in FIG. **2**, are also press-fit terminals.

(30) A case **8** is provided for housing the semiconductor chips **2***a* and **2***b*, the internal printed circuit board **4**, and the sealing member **7** inside. The case **8** is made of thermoplastic resin such as polyphenylene sulfide (PSS), polybutylene terephthalate (PBT), polybutylene succinate (PBS), polyamide, acrylonitrile butadiene styrene (ABS). The case **8** is provided so as to surround the side surfaces of the sealing member **7**.

(31) The outer shape of the sealing member **7** and the case **8** constitutes the outer shape of the semiconductor module **1** and has a substantially rectangular parallelepiped shape. The upper surfaces of the sealing member **7** and the case **8** correspond to the upper surface of the semiconductor module **1**, and the lower surfaces of the sealing member **7** and the case **8** correspond to the lower surface of the semiconductor module **1**. The case **8** may have not only the side wall portion covering the side surfaces of the sealing member **7** but also the lid portion covering the upper surface of the sealing member **7**. In this case, the upper surface of case **8** corresponds to the upper surface of semiconductor module **1**. Openings are provided in the lid of the case **8**, and the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, and the output terminal **6***c* pass through the openings of the lid.

(32) As shown in FIG. **1**, the lower surface side of the semiconductor module **1** is joined to the cooler **32** via the compound **31**. The compound **31** is composed of, for example, a thermal interface material (TIM) or the like. Thermally conductive materials such as thermally conductive greases, elastomer sheets, room temperature vulcanizing (RTV) rubbers, gels, phase change materials, solders, and silver solders can be used as the TIM. The cooler **32** is made of a metal material such as aluminum (Al).

(33) An external printed circuit board **20** is provided facing the upper surface side of the semiconductor module **1**. The external printed circuit board **20** has, for example, a rectangular planar shape. The external printed circuit board **20** includes an insulating layer **21**, an upper wiring layer **22** arranged on the upper surface of the insulating layer **21**, and a lower wiring layer **23** arranged on the lower surface of the insulating layer **21**. For example, the insulating layer **21** is made of a resin substrate made of polyimide resin or a combination of glass fiber and polyimide

resin, or the like. The upper wiring layer **22** and the lower wiring layer **23** are made of conductor foil made of, for example, copper (Cu) or aluminum (Al). A predetermined circuit pattern is formed on the upper wiring layer **22** and the lower wiring layer **23**.

(34) The external printed circuit board **20** is provided with a plurality of through holes (through holes) **20***a* and **20***b* penetrating the external printed circuit board **20**. The projecting portion **62** of the drain-side connection terminal **6***a* is press-fitted (press-contacted) into and jointed to the through-hole **20***a* of the external printed circuit board **20** so as to be electrically connected to at least one of the upper wiring layer **22** and the lower wiring layer **23**. The projecting portion **64** of the source-side connection terminal **6***b* is press-fitted into and jointed to the through-hole **20***b* of the external printed circuit board **20** so as to be electrically connected to at least one of the upper wiring layer **22** and the lower wiring layer **23**. The projecting portion **66** of the output terminal **6***c* positioned on a rear side with respect to the drain-side connection terminal **6***a* and the source-side connection terminal **6***b* is press-fitted into and jointed to a through-hole (not shown) of the external printed circuit board **20** so as to be electrically connected to at least one of the lower wiring layers **23** and the lower wiring layer **23**.

(35) Elastic members **71** and **72** are provided between the upper surface of the semiconductor module **1** and the external printed circuit board **20**. The outer peripheral surfaces of the elastic members **71** and **72** are in contact with the upper surface of the semiconductor module **1** and one main surface (lower surface) of the external printed circuit board **20**. The elastic members **71** and **72** are provided apart from the drain-side connection terminal **6***a*, the source-side connection terminal **6***b* and the output terminal **6***c*. The elastic members **71** and **72** may be in contact with at least one of the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, and the output terminal **6***c*. The elastic member **71** is provided between the drain-side connection terminal **6***a* and the output terminal **6***c*. The elastic member **72** is provided between the output terminal **6***c* and the source-side connection terminal **6***b*.

(36) FIG. **1** illustrates a case where the elastic members **71** and **72** are circular-cylindrical, but they may be cylindrical other than circular-cylindrical, columnar such as circular-columnar or prismatic columnar, or may be dot-shaped or a hollow ball shape. The elastic members **71** and **72** are composed of elastic and insulating members. As the material of the elastic members **71** and **72**, for example, an elastomer such as silicon rubber, fluororubber, or urethane rubber can be used.

(37) In FIG. **1**, the elastic members **71** and **72** are sandwiched between the semiconductor module **1** and the external printed circuit board **20** and are elastically deformed, and the cross-sectional shapes of the elastic members **71** and **72** are elliptic due to the elastic deformation. As schematically indicated by the arrows in FIG. **1**, the elastic members **71** and **72** apply pressing forces F**1** and F**2** due to elastic force to the upper surface of the sealing member **7**, which is the upper surface of the semiconductor module **1**. As a result, the semiconductor module **1** is pressed against the cooler **32** via the compound **31** so as to radiate heat. The elastic members **71** and **72** may be fixed in position by the pressing forces F**1** and F**2**, or may be adhered to the upper surface of the semiconductor module **1** and the lower surface of the external printed circuit board **20** with an adhesive or the like.

(38) A plan view of the semiconductor module **1** and elastic members **71** and **72** shown in FIG. **1** is shown in FIG. **3**. In FIG. **3**, outlines of planar patterns of the semiconductor chips **2***a* and **2***b* incorporated in the semiconductor module **1** are schematically shown by dashed lines. Also, the outer shape of the planar pattern of the internal printed circuit board **4** incorporated in the semiconductor module **1** is schematically shown by the one dot chain line. FIG. **3** also shows gate control terminals **9***a* to **9***f* electrically connected to the gate electrodes of the semiconductor chips **2***a* and **2***b*, respectively, through the internal printed circuit board **4**. Each of the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* is a press-fit terminal, which is schematically illustrated as a circle in FIG. **3**. Some of the gate control terminals **9***a* to **9***f* may constitute auxiliary source terminals for

detecting currents on the source sides of the semiconductor chips **2***a* and **2***b*.
(39) As shown in FIG. **3**, the semiconductor module **1** has a substantially rectangular planar shape. The horizontal direction of the X-axis in FIG. **3** is the longitudinal direction of the semiconductor module **1**, and the vertical direction of the Y-axis in FIG. **3** is the transverse direction of the semiconductor module **1**.
(40) The output terminal **6***c* is provided substantially at the center of the semiconductor module **1**. The drain-side connection terminal **6***a* and the source-side connection terminal **6***b* are arranged side by side at positions in the longitudinal direction of the semiconductor module **1** different from the position of the output terminal **6***c*. The gate control terminals **9***a* to **9***f* are arranged in a row in the longitudinal direction of the semiconductor module **1** on the opposite side of the output terminal **6***c* from the drain-side connection terminal **6***a* and the source-side connection terminal **6***b*. The arrangement positions of the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* are not particularly limited.
(41) The elastic members **71** and **72** are provided substantially in the center of the semiconductor module **1** in the longitudinal direction. The elastic members **71** and **72** are provided so as to extend parallel to the transverse direction of the semiconductor module **1** with the output terminal **6***c* interposed therebetween. The number of elastic members **71** and **72** is not limited, and either one of the elastic members **71** and **72** may be provided, or three or more elastic members may be provided. The elastic members **71** and **72** may be provided so as to extend parallel to the longitudinal direction of the semiconductor module **1** with the output terminal **6***c* interposed therebetween. The elastic member may be ring-shaped so as to surround the output terminal **6***c*.
(42) As shown in FIG. **1**, the external printed circuit board **20** is fixed to the cooler **32** by fixing portions (**24***a*, **25***a*, **26***a*), (**24***b*, **25***b*, **26***b*) at both ends in the longitudinal direction of the semiconductor module **1**. The fixed portions (**24***a*, **25***a*, **26***a*), (**24***b*, **25***b*, **26***b*) may be arranged at the four corners of the rectangular planar shape of the external printed circuit board **20**.
(43) The fixing portion (**24***a*, **25***a*, **26***a*) comprises screws **24***a*, a washer **25***a* and spacers **26***a*. The screw **24***a* is fastened to the cooler **32** via the washer **25***a* and the spacers **26***a*. The fixing portion (**24***b*, **25***b*, **26***b*) comprises a screw **24***b*, a washer **25***b* and spacers **26***b*. The screw **24***b* is fastened to the cooler **32** via the washer **25***b* and the spacers **26***b*.
(44) Next, the operation of the semiconductor module **1** of the semiconductor device according to the embodiment when the current is turned on will be described. Through the gate control terminals **9***a* to **9***f* shown in FIG. **3**, control signals for controlling the on/off of the semiconductor chips **2***a* and **2***b* shown in FIG. **2** are applied to the gate electrodes of the semiconductor chips **2***a* and **2***b* via the internal printed circuit board **4** and bumps **3***a*, **3***b*, so as to perform alternate switching operations of the semiconductor chips **2***a* and **2***b*.
(45) The arrows I**1** to I**6** in FIG. **2** schematically indicate current paths in the semiconductor module **1**. A current (arrow I**1**) entering from the drain-side connection terminal **6***a* passes through the upper conductor layer **12***a* of the insulating circuit board **10**, flows through the semiconductor chip **2***a* on the upper arm side to the bumps **3***a* (arrow I**2**), flows through the internal printed circuit board **4**, and flows through the output terminal **6***c* to the external printed circuit board **20** (arrow I**3**). Next, a current (arrow I**4**) that enters the output terminal **6***c* from the external printed circuit board **20** passes through the upper conductor layer **12***b* of the insulating circuit board **10**, flows through the semiconductor chip **2***b* on the lower arm side to the bumps **3***b* (arrow I**5**), flows through the internal printed circuit board **4**, and flows through the source-side connection terminal **6***b* to the external printed circuit board **20** (arrow I**6**).
(46) Next, FIG. **4** shows an example of an equivalent circuit of the semiconductor module **1** of the semiconductor device according to the embodiment. As shown in FIG. **4**, the semiconductor module **1** forms part of a three-phase bridge circuit. The drain-side connection terminal P is connected to the second main electrode (drain electrode) of the transistor T**1** on the upper arm side, and the source-side connection terminal N is connected to the first main electrode (source

electrode) of the transistor T**2** on the lower arm side. The source electrode of the transistor T**1** and the drain electrode of the transistor T**2** are connected to an output terminal U and an auxiliary source terminal S**1**. An auxiliary source terminal S**2** is connected to the source electrode of the transistor T**2**. Gate control terminals G**1** and G**2** are connected to the gate electrodes of the transistors T**1** and T**2**, respectively. In the transistors T**1** and T**2**, body diodes D**1** and D**2** serving as freewheeling diodes (FWD) are respectively connected in anti-parallel and incorporated.
(47) The drain-side connection terminal P, the source-side connection terminal N, and the output terminal U shown in FIG. **4** correspond to the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, and the output terminal **6***c* shown in FIG. **1**, respectively. The transistors T**1** and T**2** shown in FIG. **4** correspond to the semiconductor chips **2***a* and **2***b* shown in FIG. **1**, respectively. The gate control terminals G**1**, G**2** and the auxiliary source terminals S**1**, S**2** shown in FIG. **4** correspond to the gate control terminals **9***a*-**9***f* shown in FIG. **3**.
(48) <Manufacturing Method of Semiconductor Device>
(49) Next, an example of the manufacturing method (assembling method) of the semiconductor device according to the embodiment will be described. The insulating circuit board **10** shown in FIG. **2** is prepared, and the semiconductor chips **2***a* and **2***b* are mounted on the upper surfaces of the upper conductor layers **12***a* and **12***b* of the insulating circuit board **10** via a bonding material. Next, the bumps **3***a* and **3***b* are mounted on the upper surfaces of the semiconductor chips **2***a* and **2***b* via a bonding material, and the internal printed circuit board **4** is mounted on the bumps **3***a* and **3***b* via a bonding material.
(50) Next, the lower ends of the drain-side connection terminal **6***a* and the output terminal **6***c* are mounted on the upper surfaces of the upper conductor layers **12***a* and **12***b*, respectively, of the insulating circuit board **10** via a bonding material, and the lower end of the source-side connection terminal **6***b* is mounted on the upper surface of the upper wiring layer **42** of the internal printed circuit board **4** via a bonding material. The gate control terminals **9***a* to **9***f* shown in FIG. **3** are also mounted on the upper surface of the upper wiring layer **42** of the internal printed circuit board **4** via a bonding material. Next, by heat treatment, the insulating circuit board **10**, the semiconductor chips **2***a* and **2***b*, the bumps **3***a* and **3***b*, the internal printed circuit board **4**, the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* are joined with each other.
(51) Next, the insulating circuit board **10**, the semiconductor chips **2***a* and **2***b*, the bumps **3***a* and **3***b*, and the internal printed circuit board **4** are arranged inside the case **8**. The inside of the case **8** is filled with the sealing member **7**, and the insulating circuit board **10**, the semiconductor chips **2***a* and **2***b*, the bumps **3***a* and **3***b*, and the internal printed circuit board **4** are sealed with the sealing member **7**. Upper portions of the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* protrude from the upper surface side of the sealing member. As a result, the semiconductor module **1** is completed.
(52) Next, elastic members **71** and **72** are placed on the upper surface of the semiconductor module **1** as shown in FIG. **5**. Also, the external printed circuit board **20** is prepared, and arranged above and aligned with the semiconductor module **1**. Then, as shown in FIG. **1**, the external printed circuit board **20** is fastened and fixed to the cooler **32** by the fixing portions (**24***a*, **25***a*, **26***a*), (**24***b*, **25***b*, **26***b*) so that the drain-side connection terminal **6***a* and the source-side connection terminal **6***b* are press-fitted into the through holes **20***a* and **20***b*, respectively, of the external printed circuit board **20** and that the output terminal **6***c* and the gate control terminals **9***a* to **9***f* are press-fitted into other through holes (not shown) of the external printed circuit board **20**. At this time, the elastic members **71** and **72** are sandwiched between the semiconductor module **1** and the external printed circuit board **20** and are elastically deformed. Thus, the semiconductor device according to the embodiment is completed.
(53) Instead of placing the elastic members **71** and **72** on the upper surface of the semiconductor module **1** in advance and elastically deforming the elastic members **71** and **72** when fixing the

external printed circuit board **20** to the cooler **32**, the external printed circuit board **20** may be fixed to the cooler **32**, and the elastic members **71** and **72** may be inserted between the external printed circuit board **20** and the semiconductor module **1** in a state of being elastically deformed.

Comparative Example

(54) Here, a semiconductor device according to a comparative example will be described with reference to FIGS. **6** to **8**. FIG. **6** is a schematic cross-sectional view of a semiconductor device according to the comparative example, and FIG. **7** is a plan view of only a semiconductor module **101** of the semiconductor device according to the comparative example. In FIG. **6**, illustration of components appearing in the cross section of the semiconductor module **101** is omitted, and the side surface of the case **108** on the front side of the semiconductor module **101** is illustrated. As shown in FIG. **6**, the semiconductor device according to the comparative example differs from the semiconductor device according to the embodiment in that there is no elastic member between the external printed circuit board **20** and the semiconductor module **101**.

(55) Furthermore, as shown in FIGS. **6** and **7**, the semiconductor device according to the comparative example differs from the semiconductor device according to the embodiment in that the semiconductor module **101** is screwed at both ends. Fixing spring plates **102***a* and **102***b* are attached to the respective ends of the case **108** of the semiconductor module **101**. The fixing spring plates **102***a* and **102***b* are fixed to the cooler **32** by screws **104***a* and **104***b* via washers **103***a* and **103***b*, respectively.

(56) Further, in the semiconductor device according to the comparative example, as shown in FIGS. **6** and **7**, the drain-side connection terminal **106***a*, the source-side connection terminal **106***b*, the output terminal **106***c*, and the gate control terminals **107***a* to **107***f* are not press-fit terminals, but are terminals having a constant thickness. As shown in FIG. **6**, the drain-side connection terminal **106***a* and the source-side connection terminal **106***b* are joined to the external printed circuit board **20** via solders **105***a* and **105***b*, respectively. The output terminal **106***c* and the gate control terminals **107***a* to **107***f* are similarly joined to the external printed circuit board **20** via solders (not shown).

(57) In the semiconductor device according to the comparative example, since the semiconductor module **101** has a configuration in which both ends are screwed, pump-out is likely to occur. That is, when an electric current is applied to the semiconductor module **101** and the semiconductor chips and members contained in the semiconductor module **101** expand due to the heat generated by the electric current flowing through them, because the case **108** is fixed at both ends, as indicated schematically by the arrow **109** in FIG. **8**, the central portion of the case **108** is deformed upward. As the case **108** deforms, the compound **31** is also pulled upward at its central portion. After that, the current in the semiconductor module **101** is turned off, the heat is no longer generated, the member shrinks, and the deformation of the case **108** returns to its original state. By repeating the this phenomenon, the compound **31** is gradually pushed out and flows out. As a result, the compound **31** is depleted, deteriorating the heat dissipation and increasing the temperature of the semiconductor chip.

Effect

(58) On the other hand, according to the semiconductor device according to the embodiment, by inserting the elastic members **71** and **72** between the external printed circuit board **20** and the semiconductor module **1**, the central pressing forces F**1** and F**2** are directly transmitted to the semiconductor module **1**, and the semiconductor module **1** is pressed against the cooler **32** via the compound **31** with a stronger force. As a result, deformation of the semiconductor module **1** that would be caused when the current of the semiconductor module **1** is turned on and off can be suppressed, and pump-out can be reduced.

(59) Furthermore, according to the semiconductor device according to the embodiment, the elastic members **71** and **72** press the semiconductor module **1** through the compound **31** against the cooler **32** with a strong force. Therefore, it becomes unnecessary to fix the case **108** of the semiconductor module **101** to the cooler **32** using the fixing spring plates **102***a*, **102***b*, the washers **103***a*, **103***b*, and

the screws **104***a*, **104***b* at both ends of the case **108** as in the semiconductor device of the comparative example shown in FIGS. **6** and **7**. Therefore, compared with the semiconductor device of the comparative example, the space for arranging the fixing spring plates **102***a* and **102***b*, the washers **103***a* and **103***b*, and the screws **104***a* and **104***b* can be eliminated, and the semiconductor device of the embodiment can be miniaturized to that extent. Moreover, since the semiconductor module **1** can be freely deformed in the lateral direction when the current of the semiconductor module **1** is turned on or off, the upward deformation of the semiconductor module **1** can be suppressed.

(60) Furthermore, according to the semiconductor device according to the embodiment, the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* are configured as press-fit terminals. As a result, even if the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* move upward as the semiconductor module **1** deforms upward when the semiconductor module **1** is turned on and off, the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* can slide up and down inside the corresponding through holes (**20***a*, **20***b* and the others) of the external printed circuit board **20**. Therefore, the vertical movement of the external printed circuit board **20** can be suppressed, and the pressing forces F**1** and F**2** by the elastic members **71** and **72** can be maintained.

(61) Furthermore, by forming the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* as press-fit terminals, when the elastic members **71** and **72** are pressed and elastically deformed by the external printed circuit board **20** after the elastic members **71** and **72** are placed on the upper surface of the semiconductor module **1** during the assembly of the semiconductor device of the embodiment, the external printed circuit board **20** can be vertically moved by adjusting the degree of tightening the fixing portions (**24***a*, **25***a*, **26***a*) and (**24***b*, **25***b*, **26***b*). This way, the elastic deformation amounts of the elastic members **71** and **72** and the pressing forces F**1** and F**2** can be adjusted.

Other Embodiments

(62) As described above, the present invention has been described with reference to embodiments, but the statements and drawings forming part of this disclosure should not be understood to limit the present invention. Various alternative embodiments, implementations and operational techniques will become apparent to those skilled in the art from this disclosure.

(63) For example, as the semiconductor module **1** of the semiconductor device according to the embodiment, a “2-in-1” configuration having the functions of two power semiconductor elements has been exemplified. However, the present invention is applicable to a “1 in 1” configuration. Further, the semiconductor device according to the embodiment may have a plurality of semiconductor modules **1**. For example, three semiconductor modules **1** may be arranged side by side to form a “6-in-1” configuration.

(64) Further, in the embodiment above, the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* are press-fit terminals. But the drain-side connection terminal **6***a* and the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* may be terminals having a constant thickness instead of press-fit terminals. In this case, the drain-side connection terminal **6***a*, the source-side connection terminal **6***b*, the output terminal **6***c*, and the gate control terminals **9***a* to **9***f* may be joined to the external printed circuit board **20** via a joining material such as solder.

(65) Also, the configurations disclosed by the embodiments can be appropriately combined to the extent that the combination does not cause contradiction. Thus, the present invention naturally includes various embodiments and the like that are not described here. Therefore, the technical scope of the present invention is defined only by the matters specifying the invention according to the valid scope of claims based on the above description. It will be apparent to those skilled in the

art that various modifications and variations can be made in the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention cover modifications and variations that come within the scope of the appended claims and their equivalents. In particular, it is explicitly contemplated that any part or whole of any two or more of the embodiments and their modifications described above can be combined and regarded within the scope of the present invention.

Claims

1. A semiconductor device, comprising: a semiconductor module that includes: an insulating circuit board, a semiconductor chip provided on a main surface of the insulating circuit board, and an external connection terminal provided on the main surface of the insulating circuit board; an external printed circuit board provided so as to face a main surface of the semiconductor module, the external printed circuit board having a through hole into which the external connection terminal is inserted; and an elastic member provided between the main surface of the semiconductor module and the external printed circuit board so as to apply a pressing force to the main surface of the semiconductor module.
2. The semiconductor device according to claim 1, wherein the external connection terminal is a press-fit terminal, and is press-fitted into the through hole of the external printed circuit board.
3. The semiconductor device according to claim 1, wherein said elastic member is made of a circular-cylindrical elastomer.
4. The semiconductor device according to claim 1, wherein the main surface of the semiconductor module is rectangular in a plan view, and wherein the elastic member is provided in a central portion in a longitudinal direction of the semiconductor module in the plan view.
5. The semiconductor device according to claim 4, wherein the elastic member extends parallel to a transverse direction of the semiconductor module.
6. The semiconductor device according to claim 5, wherein the external connection terminal is provided in a central portion in the longitudinal direction of the semiconductor module, and wherein the elastic member is provided in a pair and the pair of the elastic members are provided so as to sandwich the external connection terminal in a plan view.
7. The semiconductor device according to claim 1, further comprising a cooler attached to another main surface of the semiconductor module that is opposite to said main surface via a compound.
8. The semiconductor device according to claim 7, further comprising a fixing portion that fixes the external printed circuit board to said cooler.
9. The semiconductor device according to claim 1, wherein the semiconductor module further comprises a sealing member that seals the semiconductor chip.
10. The semiconductor device according to claim 1, wherein the semiconductor module further comprises an internal printed circuit board so as to face the semiconductor chip on the main surface of the insulating circuit board, the internal printed circuit board being electrically connected to the semiconductor chip.
11. The semiconductor device according to claim 2, further comprising a cooler attached to another main surface of the semiconductor module that is opposite to said main surface via a compound.
12. The semiconductor device according to claim 11, further comprising a fixing portion that fixes the external printed circuit board to said cooler.
13. The semiconductor device according to claim 12, wherein the semiconductor module further comprises a sealing member that seals the semiconductor chip.
14. The semiconductor device according to claim 13, wherein the semiconductor module further comprises an internal printed circuit board so as to face the semiconductor chip on the main surface

of the insulating circuit board, the internal printed circuit board being electrically connected to the semiconductor chip and being sealed by the sealing member.