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### Radio-frequency module and communication device

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#### Abstract

A radio-frequency module includes a module substrate having main surfaces facing each other, a first base material at least partially formed of a first semiconductor material, and a second base material at least partially formed of a second semiconductor material having thermal conductivity higher than that of the first semiconductor material and in which a power amplifier circuit is formed. The first base material and the second base material are arranged on the main surface, the second base material is arranged between the module substrate and the first base material, bonded to the first base material, and connected to the main surface with an electrode interposed therebetween, one of the first base material and the second base material is connected to the main surface with an electrode interposed therebetween, and in plan view of the module substrate, an area of the electrode is larger than an area of the electrode.

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## Background/Summary

CROSS REFERENCE TO RELATED APPLICATION (1) This is a continuation of International Application No. PCT/JP2021/036698 filed on Oct. 4, 2021, which claims priority from Japanese Patent Application No. 2020-206538 filed on Dec. 14, 2020. The contents of these applications are incorporated herein by reference in their entireties.

## BACKGROUND OF THE DISCLOSURE

### Field of the Disclosure

(1) The present disclosure relates to a radio-frequency module and a communication device.

### Description of the Related Art

(2) In a mobile communication device such as a cellular phone, an arrangement configuration of circuit elements constituting a radio-frequency front-end circuit has become complicated particularly along with development of multiband technology.

(3) Patent Document 1 discloses a radio-frequency module including a power amplifier and a controller arranged on a package substrate. In the radio-frequency module in Patent Document 1, the power amplifier and the controller are arranged in a stacked manner to achieve a reduction in size of the radio-frequency module.

(4) Patent Document 1: U.S. Patent Application Publication No. 2017/0338847

## BRIEF SUMMARY OF THE DISCLOSURE

(5) However, in the radio-frequency module disclosed in Patent Document 1, it is necessary to dissipate the heat generated in the power amplifier through a module substrate (the package substrate), but it may be difficult to ensure sufficient heat dissipation properties.

(6) Thus, the present disclosure provides a radio-frequency module and a communication device with improved heat dissipation properties.

(7) A radio-frequency module according to an aspect of the present disclosure includes a module substrate having a first main surface and a second main surface facing each other, a first base material at least partially formed of a first semiconductor material, and a second base material that is at least partially formed of a second semiconductor material having thermal conductivity higher than that of the first semiconductor material and in which a power amplifier circuit is formed. The first base material and the second base material are arranged on the first main surface, the second base material is arranged between the module substrate and the first base material, bonded to the first base material, and connected to the first main surface with a first metal member interposed therebetween, one of the first base material and the second base material is connected to the first main surface with a second metal member interposed therebetween, and in plan view of the module substrate, an area of the first metal member is larger than an area of the second metal member.

(8) According to the present disclosure, it is possible to provide a radio-frequency module and a communication device with improved heat dissipation properties.

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## Description

### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

(1) FIG. 1 is a circuit configuration view of a radio-frequency module and a communication device according to an embodiment.

(2) Each of FIGS. 2A and 2B is a planar configuration schematic view of a radio-frequency module according to an example.

(3) FIG. 3 is a sectional configuration schematic view of the radio-frequency module according to the example.

(4) FIG. 4 is a sectional configuration view of a semiconductor IC according to the example.

(5) FIG. 5 is a sectional configuration view of a second base material according to the example.

(6) FIG. 6 is a circuit configuration view of a power amplifier circuit according to the example.

(7) FIG. 7 is a planar configuration schematic view of the semiconductor IC according to the example.

(8) FIG. 8A is a planar configuration schematic view of a semiconductor IC according to Modification 1.

(9) FIG. 8B is a planar configuration schematic view of a semiconductor IC according to Modification 2.

(10) FIG. 9 is a circuit configuration view of a power amplifier circuit according to Modification 3.

(11) FIG. 10 is a planar configuration schematic view of a semiconductor IC according to Modification 3.

(12) FIG. 11 is a planar configuration schematic view of a semiconductor IC according to Modification 4.

## DETAILED DESCRIPTION OF THE DISCLOSURE

(13) Hereinafter, an embodiment of the present disclosure will be described in detail. Note that, any of the embodiments described below illustrates a comprehensive or specific example. Numerical values, shapes, materials, components, arrangements and connection forms of the components, and the like illustrated in the following embodiment are mere examples and are not intended to limit the present disclosure. Among the components in the following examples, components not recited in the independent claims are described as optional components. In addition, sizes or size ratios of the components illustrated in the figures are not necessarily precise. In each figure, substantially the same components are denoted by the same reference numerals, and redundant description may be omitted or simplified.

(14) In addition, in the following description, each of a term indicating a relationship between elements such as parallel and perpendicular, a term indicating a shape of an element such as a rectangular shape, and a numerical range not only represents a strict meaning, but also means that a substantially equivalent range, for example, a difference of about several % is included.

(15) Further, in the following embodiment, “A is arranged on a first main surface of a substrate” means not only that A is directly mounted on the first main surface, but also that, out of a space on a side of the first main surface and a space on a side of the second main surface separated by the substrate, A is arranged in the space on the first main surface side. That is, a case where A is mounted on the first main surface with another circuit element, electrode, or the like interposed therebetween is included.

(16) In addition, in the following embodiment, “A and B are connected to each other” means not only that A and B contact each other but is defined to include a case where A and B are electrically connected to each other with a conductor electrode, a conductor terminal, a wiring line, another circuit component, or the like interposed therebetween. In addition, “connected between A and B” means being connected to both A and B between A and B.

(17) In addition, in the following embodiment, “A and B are bonded to each other” means a state where A and B are mechanically (physically) bonded to each other and is particularly defined to include a case where one surface included in A and one surface included in B are bonded to each other.

(18) In each of the following figures, an x-axis and a y-axis are axes orthogonal to each other on a plane parallel to a main surface of a module substrate. In addition, a z-axis is an axis perpendicular to the main surface of the module substrate, and a positive direction thereof indicates an upward direction, and a negative direction thereof indicates a downward direction.

(19) In addition, in a module configuration of the present disclosure, “in plan view” means that an object is viewed from a positive side of the z-axis by orthographic projection onto an xy plane. “A component is arranged on a main surface of a substrate” includes not only a case where the component is arranged on the main surface in a state of being in contact with the main surface of the substrate, but also a case where the component is arranged above the main surface without being in contact with the main surface, and a case where a part of the component is arranged so as

to be embedded in the substrate from a side of the main surface.

(20) Further, in the following, in A, B, and C mounted on a substrate, “C is arranged between A and B in plan view of the substrate (or a main surface of the substrate)” means that at least one of a plurality of line segments linking any point in A to any point in B in plan view of the substrate passes through a region of C. Further, in plan view of a substrate means that the substrate and a circuit element mounted on the substrate are viewed by orthographic projection onto a plane parallel to a main surface of the substrate.

(21) In addition, in the following, a “transmission path” means a transmission line constituted by a wiring line through which a radio-frequency transmission signal propagates, an electrode directly connected to the wiring line, a terminal directly connected to the wiring line or the electrode, and the like. In addition, a “reception path” means a transmission line constituted by a wiring line through which a radio-frequency reception signal propagates, an electrode directly connected to the wiring line, a terminal directly connected to the wiring line or the electrode, and the like.

(22) (Embodiment) [1. Circuit Configuration of Radio-Frequency Module **1** and Communication Device **5**]

(23) FIG. **1** is a circuit configuration view of a radio-frequency module **1** and a communication device **5** according to an embodiment. As illustrated in the figure, the communication device **5** includes the radio-frequency module **1**, an antenna **2**, an RF signal processing circuit (RFIC) **3**, and a baseband signal processing circuit (BBIC) **4**.

(24) The RFIC **3** is an RF signal processing circuit that processes a radio-frequency signal transmitted and received by the antenna **2**. To be specific, the RFIC **3** signal-processes a reception signal inputted via a reception path of the radio-frequency module **1** by down-conversion or the like, and outputs the reception signal generated by being signal-processed to the BBIC **4**. Further, the RFIC **3** signal-processes a transmission signal inputted from the BBIC **4** by up-conversion or the like, and outputs the transmission signal generated by being signal-processed to a transmission path of the radio-frequency module **1**.

(25) The BBIC **4** is a circuit that performs signal processing using an intermediate-frequency band lower than a radio-frequency signal transmitted through the radio-frequency module **1**. A signal processed in the BBIC **4** is used, for example, as an image signal for image display or as an audio signal for a call via a speaker.

(26) Further, the RFIC **3** also has a function as a control unit that controls the connections of switches **52**, **53**, and **54** included in the radio-frequency module **1**, based on a communication band (frequency band) to be used. To be specific, the RFIC **3** switches the connections of the switches **52** to **54** included in the radio-frequency module **1** according to a control signal (not illustrated). To be specific, the RFIC **3** outputs a digital control signal for controlling the switches **52** to **54** to a PA control circuit **11**. The PA control circuit **11** outputs digital control signals to the switches **52** to **54** according to the digital control signal inputted from the RFIC **3**, thereby controlling the connections and the disconnections of the switches **52** to **54**.

(27) Further, the RFIC **3** also has a function as a control unit that controls the gain of a power amplifier circuit **21** included in the radio-frequency module **1**, and a power supply voltage  $V_{cc}$  and a bias voltage  $V_{bias}$  supplied to the power amplifier circuit **21**. To be specific, the RFIC **3** outputs a digital control signal to a control signal terminal **110** of the radio-frequency module **1**. The PA control circuit **11** adjusts the gain of the power amplifier circuit **21** by outputting a control signal, the power supply voltage  $V_{cc}$ , or the bias voltage  $V_{bias}$  to the power amplifier circuit **21** according to the digital control signal inputted via the control signal terminal **110**. Note that, a control signal terminal for receiving a digital control signal for controlling the gain of the power amplifier circuit **21** from the RFIC **3** may be different from a control signal terminal for receiving a digital control signal for controlling the power supply voltage  $V_{cc}$  and the bias voltage  $V_{bias}$  supplied to the power amplifier circuit **21** from the RFIC **3**. Note that, the control unit may be provided outside the RFIC **3** and, for example, may be provided in the BBIC **4**.

(28) The antenna **2** is connected to an antenna connection terminal **100** of the radio-frequency module **1**, radiates a radio-frequency signal outputted from the radio-frequency module **1**, and receives a radio-frequency signal from outside and outputs the radio-frequency signal to the radio-frequency module **1**.

(29) Note that, in the communication device **5** according to the present embodiment, the antenna **2** and the BBIC **4** are not essential components.

(30) Next, a detailed configuration of the radio-frequency module **1** will be described.

(31) As illustrated in FIG. **1**, the radio-frequency module **1** includes the antenna connection terminal **100**, the power amplifier circuit **21**, the PA control circuit **11**, a low-noise amplifier circuit **31**, duplexers **61** and **62**, matching circuits **42**, **43**, **44**, and **45**, the switches **52**, **53**, and **54**, a diplexer **73**, the control signal terminal **110**, a transmission input terminal **120**, and a reception output terminal **130**.

(32) The antenna connection terminal **100** is an example of an input/output terminal and is an antenna common terminal connected to the antenna **2**.

(33) The power amplifier circuit **21** is an amplifier circuit that amplifies radio-frequency signals in a first communication band and a second communication band inputted from the transmission input terminal **120**. The power amplifier circuit **21** is included in a second base material **20**. For example, the second base material **20** is at least partially formed of GaAs. The power amplifier circuit **21** includes, for example, a heterojunction bipolar transistor (HBT).

(34) The low-noise amplifier circuit **31** is an amplifier circuit that amplifies radio-frequency signals in the first communication band and the second communication band with low noise and outputs the amplified radio-frequency signals to the reception output terminal **130**.

(35) The PA control circuit **11** is an example of a control circuit that adjusts the gain of the power amplifier circuit **21**, according to a digital control signal or the like inputted via the control signal terminal **110**. The PA control circuit **11** is included in a first base material **10**, and is constituted by, for example, a complementary metal oxide semiconductor (CMOS). Specifically, the PA control circuit **11** is formed by a silicon on insulator (SOI) process. This makes it possible to manufacture the PA control circuit **11** at low cost. Note that, for example, the first base material **10** is at least partially formed of Si.

(36) The duplexer **61** is constituted by a transmission filter **61T** and a reception filter **61R**. The duplexer **62** is constituted by a transmission filter **62T** and a reception filter **62R**.

(37) The transmission filter **61T** is connected to an output terminal of the power amplifier circuit **21** with the switch **52** and the matching circuit **42** interposed therebetween and passes a transmission signal in the first communication band therethrough. The transmission filter **61T** is arranged on a transmission path linking the transmission input terminal **120** to the antenna connection terminal **100**. Further, the transmission filter **62T** is connected to the output terminal of the power amplifier circuit **21** with the switch **52** and the matching circuit **42** interposed therebetween and passes a transmission signal in the second communication band therethrough. The transmission filter **62T** is connected to the transmission path linking the transmission input terminal **120** to the antenna connection terminal **100**.

(38) The reception filter **61R** is connected to a reception path linking the reception output terminal **130** to the antenna connection terminal **100** and passes a reception signal in the first communication band therethrough. Further, the reception filter **62R** is connected to the reception path linking the reception output terminal **130** to the antenna connection terminal **100** and passes a reception signal in the second communication band therethrough.

(39) Note that, each of the duplexers **61** and **62** may be a single filter that performs transmission by a time division duplex (TDD) method. In this case, a switch for switching between the transmission and the reception is arranged in at least one of a preceding stage and a subsequent stage of the above-described single filter.

(40) The switch **52** has a common terminal and two selection terminals. The common terminal of

the switch **52** is connected to the output terminal of the power amplifier circuit **21** with the matching circuit **42** interposed therebetween. One selection terminal of the switch **52** is connected to the transmission filter **61T**, and the other selection terminal of the switch **52** is connected to the transmission filter **62T**. In this connection configuration, the switch **52** switches between the connection between the power amplifier circuit **21** and the transmission filter **61T** and the connection between the power amplifier circuit **21** and the transmission filter **62T**. The switch **52** is constituted by, for example, a single-pole double-throw (SPDT) type switch circuit.

(41) The switch **53** has a common terminal and two selection terminals. The common terminal of the switch **53** is connected to an input terminal of the low-noise amplifier circuit **31** with the matching circuit **43** interposed therebetween. One selection terminal of the switch **53** is connected to the reception filter **61R**, and the other selection terminal of the switch **53** is connected to the reception filter **62R**. In this connection configuration, the switch **53** switches between the connection and the disconnection between the low-noise amplifier circuit **31** and the reception filter **61R** and switches between the connection and the disconnection between the low-noise amplifier circuit **31** and the reception filter **62R**. The switch **53** is constituted by, for example, an SPDT type switch circuit.

(42) The switch **54** is an example of an antenna switch, is connected to the antenna connection terminal **100** with the diplexer **73** interposed therebetween, and switches (1) between the connection and the disconnection between the antenna connection terminal **100** and the duplexer **61** and (2) between the connection and the disconnection between the antenna connection terminal **100** and the duplexer **62**.

(43) The matching circuit **42** is connected between the power amplifier circuit **21** and the transmission filters **61T** and **62T**, and achieves the impedance matching between the power amplifier circuit **21** and the transmission filter **61T** and the impedance matching between the power amplifier circuit **21** and the transmission filter **62T**.

(44) The matching circuit **43** is connected between the low-noise amplifier circuit **31** and the reception filters **61R** and **62R**, and achieves the impedance matching between the low-noise amplifier circuit **31** and the reception filter **61R** and the impedance matching between the low-noise amplifier circuit **31** and the reception filter **62R**.

(45) The matching circuit **44** is arranged on a path linking the switch **54** to the duplexer **61**, and achieves the impedance matching between the antenna **2** and the switch **54**, and the duplexer **61**. The matching circuit **45** is arranged on a path linking the switch **54** to the duplexer **62**, and achieves the impedance matching between the antenna **2** and the switch **54**, and the duplexer **62**.

(46) The diplexer **73** is an example of a multiplexer and constituted by filters **73L** and **73H**. The filter **73L** is a filter that has a frequency range of a first frequency-band group including the first communication band and the second communication band as a pass band, and the filter **73H** is a filter that has a frequency range of another frequency-band group having frequencies different from those of the first frequency-band group as a pass band. One terminal of the filter **73L** and one terminal of the filter **73H** are commonly connected to the antenna connection terminal **100**. Each of the filters **73L** and **73H** is, for example, an LC filter constituted by at least one of a chip-shaped inductor and capacitor.

(47) Note that, the radio-frequency module **1** according to the present embodiment only needs to have the power amplifier circuit **21** among the circuit components illustrated in FIG. **1**.

(48) Further, the low-noise amplifier circuit **31** and the switches **52** to **54** may be formed in a single semiconductor integrated circuit (IC). The above-described semiconductor IC is constituted by, for example, a CMOS. Specifically, the semiconductor IC is formed by an SOI process. Thus, the semiconductor IC can be manufactured at low cost. Note that, the semiconductor IC may be formed of at least one of GaAs, SiGe, and GaN. Thus, it is possible to output a radio-frequency signal having high-quality amplification performance and noise performance.

(49) Here, in the radio-frequency module having the above-described circuit configuration, it is

necessary to dissipate the heat generated in the power amplifier circuit, but it is difficult to ensure sufficient heat dissipation properties.

(50) On the other hand, a configuration of the radio-frequency module **1** for which sufficient heat dissipation properties can be ensured will be described below.

(51) [2. Arrangement Configuration of Circuit Elements of Radio-frequency Module **1A** According to Example]

(52) Each of FIGS. **2A** and **2B** is a planar configuration schematic view of a radio-frequency module **1A** according to an example. Further, FIG. **3** is a sectional configuration schematic view of the radio-frequency module **1A** according to the example, and specifically is a sectional view taken along a line III-III in FIGS. **2A** and **2B**. Note that, FIG. **2A** illustrates a layout of circuit components when, out of main surfaces **80a** and **80b** facing each other of a module substrate **80**, the main surface **80a** is viewed from a positive direction side of the z-axis. On the other hand, FIG. **2B** is a perspective view illustrating an arrangement of circuit components when the main surface **80b** is viewed from the positive direction side of the z-axis. In addition, in FIGS. **2A** and **2B**, each circuit component is provided with a mark representing a function thereof so that an arrangement relationship among the circuit components can be easily understood, but the radio-frequency module **1A** is not provided with the marks actually.

(53) The radio-frequency module **1A** according to the example specifically illustrates the arrangement configuration of the circuit elements constituting the radio-frequency module **1** according to the embodiment.

(54) As illustrated in FIGS. **2A** and **2B** and FIG. **3**, the radio-frequency module **1A** according to the present example further has, in addition to the circuit configuration illustrated in FIG. **1**, the module substrate **80**, resin members **81** and **82**, an external connection terminal **150**, a metal shield layer **85**, and a semiconductor IC **70**.

(55) The power amplifier circuit **21** and the PA control circuit **11** illustrated in FIG. **1** are included in the semiconductor IC **70**.

(56) The module substrate **80** is a substrate having the main surface **80a** and the main surface **80b** facing each other, and mounted with the circuit components constituting the radio-frequency module **1A**. As the module substrate **80**, for example, a low temperature co-fired ceramics (LTCC) substrate having stacked structure of a plurality of dielectric layers, a high temperature co-fired ceramics (HTCC) substrate, a component built-in substrate, a substrate having a redistribution layer (RDL), a printed circuit board, or the like is used.

(57) Note that, in the present example, the main surface **80a** corresponds to a first main surface, and the main surface **80b** corresponds to a second main surface.

(58) Note that, as illustrated in FIG. **2B**, the antenna connection terminal **100**, the control signal terminal **110**, the transmission input terminal **120**, and the reception output terminal **130** may be formed on the main surface **80b**.

(59) The resin member **81** is arranged on the main surface **80a**, and covers some of the circuit components constituting the radio-frequency module **1A** and the main surface **80a**. The resin member **82** is arranged on the main surface **80b**, and covers some of the circuit components constituting the radio-frequency module **1A** and the main surface **80b**. The resin members **81** and **82** have a function of ensuring reliability such as mechanical strength and moisture resistance of the circuit components constituting the radio-frequency module **1A**. Note that, the resin members **81** and **82** are not components essential for the radio-frequency module **1** according to the present embodiment.

(60) The metal shield layer **85** is formed on a surface of the resin member **81** and is set to a ground potential. The metal shield layer **85** is, for example, a metal thin film formed by a sputtering method and is copper, an alloy containing copper, or a stacked body containing copper.

(61) As illustrated in FIGS. **2A** and **2B** and FIG. **3**, in the radio-frequency module **1A** according to the present example, the semiconductor IC **70**, the duplexers **61** and **62**, and the matching circuits



**42, 43, 44, and 45** are arranged on the main surface **80a**. On the other hand, the low-noise amplifier circuit **31** and the switches **52 to 54** are arranged on the main surface **80b**.

(62) Note that, although not illustrated in FIGS. **2A** and **2B**, wiring lines for connecting the circuit components illustrated in FIG. **1** to each other are formed in the inside of the module substrate **80** and on the main surfaces **80a** and **80b**. Further, as the above-described wiring line, a bonding wire whose both ends are each bonded to any one of the main surfaces **80a** and **80b** and the circuit component constituting the radio-frequency module **1A** may be used, or a terminal, an electrode, or a wiring line formed on a surface of the circuit component constituting the radio-frequency module **1A** may be used.

(63) In addition, in the radio-frequency module **1A** according to the present example, a plurality of external connection terminals **150** is arranged on the main surface **80b**. The radio-frequency module **1A** exchanges electric signals with an external substrate arranged on a negative direction side of the z-axis of the radio-frequency module **1A** via the plurality of external connection terminals **150**. Further, some of the plurality of external connection terminals **150** are set to a ground potential of the external substrate. On the main surface **80b** facing the external substrate, out of the main surfaces **80a** and **80b**, a circuit component that is difficult to be reduced in height is not arranged, and the low-noise amplifier circuit **31** and the switches **52 to 54** that are easily reduced in height are arranged.

(64) Note that, as illustrated in FIGS. **2A** and **2B** and FIG. **3**, the external connection terminal **150** may be a columnar electrode penetrating the resin member **82** in a z-axis direction, or the external connection terminal **150** may be a bump electrode formed on the main surface **80b**. In this case, the resin member **82** on the main surface **80b** need not be present.

(65) Further, in the radio-frequency module **1A** according to the present example, it is essential that the semiconductor IC **70** is arranged on either of the main surfaces **80a** and **80b**, and the other circuit components may be arranged on either of the main surfaces **80a** and the **80b**.

(66) Further, although not illustrated in FIGS. **2A** and **2B** or FIG. **3**, the diplexer **73** may be surface-mounted on either of the main surfaces **80a** and **80b** or may be built in the module substrate **80**.

(67) The semiconductor IC **70** includes the first base material **10** and the second base material **20**.

(68) The first base material **10** is at least partially formed of a first semiconductor material. Examples of the first semiconductor material include an elemental semiconductor and, in particular, silicon (Si) or gallium nitride (GaN). That is, in the present example, the first base material **10** is at least partially formed of Si or GaN. Note that, the first semiconductor material is not limited to silicon or gallium nitride. For example, as the first semiconductor material, a material including any one of gallium arsenide, aluminum arsenide (AlAs), indium arsenide (InAs), indium phosphide (InP), gallium phosphide (GaP), indium antimonide (InSb), gallium nitride, indium nitride (InN), aluminum nitride (AlN), silicon, germanium (Ge), silicon carbide (SiC), and gallium oxide (III) (Ga.sub.2O.sub.3) or a multi-component mixed crystal material formed of two or more of these materials can be used, but the first semiconductor material is not limited thereto. Note that, in the present example, the PA control circuit **11** is formed in the first base material **10**.

(69) The second base material **20** is at least partially formed of a second semiconductor material having thermal conductivity higher than that of the first semiconductor material, and the power amplifier circuit **21** is formed therein. Examples of the second semiconductor material include a compound semiconductor and, in particular, gallium arsenide (GaAs) or silicon germanium (SiGe). That is, in the present example, the second base material **20** is at least partially formed of GaAs or SiGe, and the power amplifier circuit **21** is formed therein. Note that, the second semiconductor material is not limited to gallium arsenide or silicon germanium. For example, as the second semiconductor material, a material including any one of gallium arsenide, aluminum arsenide, indium arsenide, indium phosphide, gallium phosphide, indium antimonide, gallium nitride, indium nitride, aluminum nitride, silicon germanium, silicon carbide, gallium oxide (III), and gallium bismuth (GaBi), or a multi-component mixed crystal material formed of two or more of these

materials can be used, but the second semiconductor material is not limited thereto.

(70) As illustrated in FIG. 3, the second base material **20** is arranged between the module substrate **80** and the first base material **10**, bonded to the first base material **10**, and connected to the main surface **80a** with an electrode **23** (first metal member) interposed therebetween.

(71) Hereinafter, the semiconductor IC **70** will be described in detail. As described above, the semiconductor IC **70** includes the first base material **10** and the second base material **20**.

(72) FIG. 4 is a sectional configuration view of the semiconductor IC **70** according to the example. Further, FIG. 5 is a sectional configuration view of the second base material **20** according to the example.

(73) As illustrated in FIG. 4, the first base material **10** and the second base material **20** are stacked in the z-axis direction (a direction perpendicular to the main surface **80a**).

(74) The first base material **10** includes, for example, a Si substrate **12**, an insulating layer **13**, a Si layer **14**, a wiring layer **15**, and a SiN layer **17**. The SiN layer **17**, the wiring layer **15**, the Si layer **14**, the insulating layer **13**, and the Si substrate **12** are stacked in this order on the main surface **80a**.

(75) The Si substrate **12** is formed of, for example, silicon single crystal.

(76) The Si layer **14** is, for example, a layer made of silicon and is a layer on which circuit elements constituting the PA control circuit **11** are formed.

(77) The wiring layer **15** is a layer which is made of, for example, silicon oxide and in which a via wiring line **16** for transmitting a control signal from the PA control circuit **11** to the second base material **20** and the module substrate **80** is formed.

(78) The SiN layer **17** is, for example, a protective layer made of silicon nitride and is a layer for ensuring reliability such as moisture resistance of the first base material **10**.

(79) The first base material **10** is connected to the main surface **80a** with an electrode **24** (second metal member) extending from the first base material **10** toward the main surface **80a** interposed therebetween. The electrode **24** is, for example, constituted by a columnar conductor **24a** and a bump electrode **24b**, one end of the columnar conductor **24a** is bonded to an electrode **18** formed on the SiN layer **17**, and the other end is bonded to the bump electrode **24b**. The bump electrode **24b** is connected to an electrode formed on the main surface **80a**.

(80) Accordingly, since the PA control circuit **11** of the first base material **10** can directly exchange radio-frequency signals and digital signals with the module substrate **80**, it is possible to reduce a signal transmission loss.

(81) Note that, the first base material **10** only needs to include the Si substrate **12**, and the other layers need not be present. Further, the switches **53** and **54** may be included in the first base material **10**.

(82) Additionally, as illustrated in FIG. 4, the first base material **10** has main surfaces **10a** and **10b** facing each other. Note that, the main surface **10b** may be in contact with the metal shield layer **85**.

(83) Accordingly, the heat generated in the power amplifier circuit **21** of the second base material **20** can be dissipated outside through the first base material **10** and the metal shield layer **85**. Thus, the heat dissipation properties of the radio-frequency module **1A** are improved.

(84) Additionally, a resin member **71** is arranged on the main surface **10a** of the first base material **10**. Further, the resin member **71** covers the second base material **20**.

(85) Next, as illustrated in FIG. 5, the second base material **20** includes, for example, a GaAs base material layer **20n** and an epitaxial layer **20d**.

(86) The GaAs base material layer **20n** is, for example, a single crystal substrate made of gallium arsenide.

(87) The epitaxial layer **20d** is, for example, a layer formed by GaAs being epitaxially grown on the GaAs base material layer **20n**.

(88) The power amplifier circuit **21** is formed on, for example, the epitaxial layer **20d**.

(89) The GaAs base material layer **20n** is bonded to the SiN layer **17** of the first base material **10**. That is, the second base material **20** is bonded to the first base material **10**.

(90) The second base material **20** is connected to the main surface **80a** with the electrode **23** (first metal member) extending from the second base material **20** toward the main surface **80a** interposed therebetween. The electrode **23** is constituted by, for example, a columnar conductor **23a** and a bump electrode **23b**, one end of the columnar conductor **23a** is bonded to an electrode **22** formed on a main surface of the second base material **20**, and the other end is bonded to the bump electrode **23b**. The bump electrode **23b** is connected to an electrode formed on the main surface **80a**.

(91) Accordingly, since the power amplifier circuit **21** of the second base material **20** can directly exchange signals with the module substrate **80**, it is possible to reduce a signal transmission loss.

(92) Further, the power amplifier circuit **21** of the second base material **20** may receive a digital control signal, a DC signal, and the like from the PA control circuit **11** of the first base material **10** via the via wiring line **16**.

(93) FIG. **6** is a circuit configuration view of the power amplifier circuit **21** according to the example. As illustrated in the figure, the power amplifier circuit **21** includes an amplifier transistor **210**, capacitors **213** and **214**, a bias circuit **215**, a collector terminal **212**, an emitter terminal **211**, an input terminal **230**, and an output terminal **220**.

(94) The amplifier transistor **210**, for example, has a collector, an emitter, and a base, is a common-emitter type bipolar transistor, and is an amplifier element that amplifies a radio-frequency current inputted to the base and outputs the amplified current from the collector. Note that, the amplifier transistor **210** may be a field-effect type transistor having a drain (corresponding to the collector), a source (corresponding to the emitter), and a gate (corresponding to the base).

(95) The capacitor **214** is a DC cut capacitance element and has a function of preventing a DC current from leaking to the input terminal **230** due to a DC bias voltage applied from the bias circuit **215** to the base.

(96) The capacitor **213** is a DC cut capacitance element and has a function of removing a DC component of a radio-frequency amplified signal on which a DC bias voltage is superimposed, and the radio-frequency amplified signal from which the DC component is removed is outputted from the output terminal **220**.

(97) The bias circuit **215** is connected to the base of the amplifier transistor **210** and has a function of optimizing an operating point of the amplifier transistor **210** by applying the bias voltage to the base.

(98) The emitter terminal **211** is connected to the electrode **23** (first metal member) and is connected to a ground.

(99) According to the above-described circuit configuration of the power amplifier circuit **21**, a radio-frequency signal RFin inputted from the input terminal **230** becomes a base current Ib flowing from the base to the emitter of the amplifier transistor **210**. The base current Ib is amplified by the amplifier transistor **210** to become a collector current Icc, and a radio-frequency signal RFout corresponding to the collector current Icc is outputted from the output terminal **220**. At this time, a large current in which the base current Ib and the collector current Icc are added flows from the emitter terminal **211** to the ground. Thus, in order to improve the heat dissipation properties of the power amplifier circuit **21**, it is necessary to improve the heat dissipation properties from the emitter terminal **211** which needs to function as a heat dissipation portion of the amplifier transistor **210**.

(100) FIG. **7** is a planar configuration schematic view of the semiconductor IC **70** according to the example. Note that, FIG. **7** is a perspective view illustrating an arrangement of the first base material **10**, the second base material **20**, the PA control circuit **11**, the electrodes **23** and **24**, and electrodes **25** and **26**, when the main surface **80a**, out of the main surfaces **80a** and **80b** facing each other of the module substrate **80**, is viewed from the positive direction side of the z-axis. Note that, FIG. **4** is a sectional view taken along a line IV-IV in FIG. **7**.

(101) The electrode **26** is an example of the second metal member and connects the second base material **20** and the main surface **80a** to each other. The electrode **26** is, for example, the input

terminal **230** or the output terminal **220** of the power amplifier circuit **21** and is a signal electrode through which a radio-frequency signal flows.

(102) The electrode **23** is an example of the first metal member and connects the second base material **20** and the main surface **80a** to each other. The electrode **23** is, for example, a ground electrode connected to the emitter terminal **211** of the power amplifier circuit **21**.

(103) The electrode **24** is an example of the second metal member and connects the first base material **10** and the main surface **80a** to each other. The electrode **24** is, for example, an input terminal or an output terminal of the PA control circuit **11**, or a ground electrode.

(104) The electrode **25** is an example of a third metal member and connects the first base material **10** and the main surface **80a** to each other. The electrode **25** is, for example, a ground electrode of an electronic component formed on the first base material **10**.

(105) Here, in plan view of the module substrate **80**, an area of the electrode **23** is larger than an area of the electrode **26**. Further, the area of the electrode **23** is larger than an area of the electrode **24**.

(106) According to the above-described configuration, the heat generated in the power amplifier circuit **21** is promoted to be transferred to the first base material **10** having thermal conductivity higher than that of the second base material **20**. At the same time, the heat generated in the power amplifier circuit **21** is dissipated from the second base material **20** to the module substrate **80** through the electrode **23** having a large heat dissipation area. Thus, the heat generated in the power amplifier circuit **21** can be dissipated with high efficiency. Furthermore, since the first base material **10** and the second base material **20** are stacked in the direction perpendicular to the main surface **80a**, while the radio-frequency module **1A** is reduced in size, the heat dissipation properties can be improved.

(107) Additionally, as illustrated in FIG. 7, the electrode **23** has an elongated shape in plan view of the module substrate **80**. Accordingly, since electrode density can be increased with the electrode **23**, a region on the second base material **20** can be effectively utilized, as compared to a case, for example, where a large area is ensured by discretely arranging a plurality of electrodes, the electrodes having a circular shape like the electrode **26**.

(108) Note that, an elongated shape is a shape elongated in one direction, and a longitudinal direction indicates the one direction. More specifically, an elongated shape is a shape in which a length in the one direction is longer than a length in another direction intersecting with the one direction.

(109) Further, in plan view of the module substrate **80**, an area of the electrode **25** is larger than the area of the electrode **26**. Further, the area of the electrode **25** is larger than the area of the electrode **24**.

(110) According to the above-described configuration, the heat of the power amplifier circuit **21** transferred to the first base material **10** is dissipated to the module substrate **80** through the electrode **25** having a large heat dissipation area. Thus, the heat generated in the power amplifier circuit **21** can be dissipated with higher efficiency.

(111) Additionally, as illustrated in FIG. 7, the electrode **25** has an elongated shape in plan view of the module substrate **80**. Accordingly, since electrode density can be increased with the electrode **25**, a region on the first base material **10** can be effectively utilized, as compared to a case, for example, where a large area is ensured by discretely arranging a plurality of electrodes, the electrodes having a circular shape like the electrode **24**.

(112) Additionally, although not illustrated in FIG. 7, the amplifier transistor **210** and the electrode **23** may overlap each other, in plan view of the module substrate **80**.

(113) Accordingly, since a heat dissipation path linking the amplifier transistor **210** to the electrode **23** can be shortened, the thermal conductance of the heat dissipation path can be increased, and the heat dissipation properties can be improved.

(114) Additionally, as illustrated in FIG. 5, the amplifier transistor **210** of the power amplifier

circuit **21** has, for example, a collector layer **21C**, a base layer **21B**, and an emitter layer **21E**. The collector layer **21C**, the base layer **21B**, and the emitter layer **21E** are stacked in this order on the epitaxial layer **20d**. That is, in the amplifier transistor, the collector layer **21C**, the base layer **21B**, and the emitter layer **21E** are stacked in this order from a side of the first base material **10**.

(115) Additionally, as illustrated in FIG. **4**, the second base material **20** may be thinner than the first base material **10**. In other words, a thickness of the second base material **20** in a thickness direction (the z-axis direction) may be less than a thickness of the first base material **10** in the thickness direction (z-axis direction).

(116) Accordingly, since the second base material **20** having low thermal conductivity is relatively thin and the first base material **10** having high thermal conductivity is relatively thick, the heat transfer from the second base material **20** to the first base material **10** is promoted and the heat dissipation properties are improved.

(117) In addition, in the radio-frequency module **1A** according to the example, the low-noise amplifier circuit **31** and the switches **52** to **54** may be included in a semiconductor IC **75**.

(118) Accordingly, the radio-frequency module **1A** can be reduced in size.

(119) In addition, in the radio-frequency module **1A** according to Example 1, in plan view of the module substrate **80**, the low-noise amplifier circuit **31** does not overlap the first base material **10** and the second base material **20**.

(120) Accordingly, the power amplifier circuit **21** and the low-noise amplifier circuit **31** are distributed to both sides with the module substrate **80** interposed therebetween, and a large distance can be ensured between the power amplifier circuit **21** and the low-noise amplifier circuit **31**. Thus, the isolation between the transmission and the reception can be improved.

(121) [3. Electrode Arrangement Configuration of Semiconductor IC According to Modifications 1 and 2]

(122) Next, an arrangement configuration of the electrodes **23** and **25** will be described.

(123) FIG. **8A** is a planar configuration schematic view of a semiconductor IC **70A** according to Modification 1. Note that, FIG. **8A** is a perspective view illustrating an arrangement of a first base material **10A**, a second base material **20A**, the electrodes **23** to **25**, when the main surface **80a**, out of the main surfaces **80a** and **80b** facing each other of the module substrate **80**, is viewed from the positive direction side of the z-axis. The semiconductor IC **70A** according to Modification 1 is different from the semiconductor IC **70** according to the example only in an arrangement configuration of the electrodes **23** and **25**. Hereinafter, regarding the semiconductor IC **70A** according to the present modification, description of the same configuration as that of the semiconductor IC **70** according to the example will be omitted, and a different configuration will be mainly described.

(124) The electrode **23** is an example of the first metal member and connects the second base material **20A** and the main surface **80a** to each other.

(125) The electrode **25** is an example of the third metal member and connects the first base material **10A** and the main surface **80a** to each other.

(126) Here, as illustrated in FIG. **8A**, in plan view of the module substrate **80**, the second base material **20A** is included in the first base material **10A**, and the first base material **10A** has a central region C and an outer peripheral region P located on an outer periphery of the central region C. The electrode **23** is arranged in a region where the second base material **20A** and the outer peripheral region P overlap each other such that a longitudinal direction of the electrode **23** is parallel to an outer side L2 closest to the electrode **23** among outer sides of the first base material **10A**. Further, the electrode **25** is arranged in the outer peripheral region P such that a longitudinal direction of the electrode **25** is parallel to an outer side L1 closest to the electrode **25** among the outer sides of the first base material **10A**.

(127) Note that, in the present embodiment, “A is included in B in predetermined plan view” means that when an object is projected in a direction perpendicular to a predetermined plane, an entire

projection region of A overlaps a projection region of B.

(128) In a manufacturing process of mounting the semiconductor IC **70A** on the module substrate **80**, when the areas of the electrodes **23**, **24**, and **25** are different from each other, the amounts of solder applied to the electrodes are different from each other, and thus, a distance between each of the electrodes and the main surface **80a** increases as the area of the electrode increases. Thus, when the electrodes **23** and **25** having a large area are arranged in the central region C of the semiconductor IC **70A**, the semiconductor IC **70A** cannot be stably arranged on the module substrate **80**.

(129) On the other hand, according to the above-described arrangement configuration of the electrodes **23** and **25**, since the electrodes **23** and **25** are arranged in the outer peripheral region P and are each arranged along the closest outer side, it is possible to stably arrange the semiconductor IC **70A** on the module substrate **80** in the manufacturing process of mounting the semiconductor IC **70A** on the module substrate **80**.

(130) Note that, the outer sides to which the electrodes **23** and **25** are closest are not limited to the combination of the outer sides L2 and L1. The outer sides to which the electrodes **23** and **25** are closest may be a combination of the outer side L2 and an outer side L4 facing each other or a combination of L1 and L3.

(131) FIG. **8B** is a planar configuration schematic view of a semiconductor IC **70B** according to Modification 2. Note that, FIG. **8B** is a perspective view illustrating an arrangement of a first base material **10B**, a second base material **20B**, the electrodes **23** to **25**, when the main surface **80a**, out of the main surfaces **80a** and **80b** facing each other of the module substrate **80**, is viewed from the positive direction side of the z-axis. The semiconductor IC **70B** according to Modification 2 is different from the semiconductor IC **70** according to the example only in an arrangement configuration of the electrodes **23** and **25**. Hereinafter, regarding the semiconductor IC **70B** according to the present modification, description of the same configuration as that of the semiconductor IC **70** according to the example will be omitted, and a different configuration will be mainly described.

(132) The electrode **23** is an example of the first metal member and connects the second base material **20B** and the main surface **80a** to each other.

(133) The electrode **25** is an example of the third metal member and connects the first base material **10B** and the main surface **80a** to each other.

(134) Here, as illustrated in FIG. **8B**, in plan view of the module substrate **80**, the second base material **20B** is included in the first base material **10B**, and the first base material **10B** has the central region C and the outer peripheral region P located on the outer periphery of the central region C. The electrode **23** is arranged in a region where the second base material **20B** and the outer peripheral region P overlap each other such that the longitudinal direction of the electrode **23** is parallel to an outer side L3 closest to the electrode **23** among outer sides of the first base material **10B**. Further, the electrode **25** is arranged in the outer peripheral region P such that the longitudinal direction of the electrode **25** is parallel to the outer side L3 closest to the electrode **25** among the outer sides of the first base material **10A**.

(135) In the semiconductor IC **70B** according to the present modification, unlike the semiconductor IC **70A** according to Modification 1, the electrodes **23** and **25** are arranged along the same outer side L3. Also in this configuration, since the electrodes **23** and **25** are arranged in the outer peripheral region P and are arranged along the closest outer side, the semiconductor IC **70B** can be stably arranged on the module substrate **80**, in a manufacturing process of mounting the semiconductor IC **70B** on the module substrate **80**.

(136) Note that, in Modification 1 and Modification 2, the electrode arrangement in the case where the electrodes **23** and **25** have an elongated shape has been described. In a case where only the electrode **23** has an elongated shape and the electrode **25** has a circular shape having the same size as the electrode **24**, the following arrangement configuration may be employed.

(137) That is, in plan view of the module substrate **80**, the second base material **20** is included in the first base material **10**, the first base material **10** has the central region C and the outer peripheral region P located on the outer periphery of the central region C, and the electrode **23** is arranged in a region where the second base material **20** and the outer peripheral region P overlap each other such that a longitudinal direction of the electrode **23** is parallel to an outer side closest to the electrode **23** among outer sides of the first base material **10**.

(138) Also in this configuration, since the electrode **23** is arranged in the outer peripheral region P and is arranged along the closest outer side, the semiconductor IC **70** can be stably arranged on the module substrate **80** in a manufacturing process of mounting the semiconductor IC **70** on the module substrate **80**.

(139) [4. Electrode Arrangement Configuration of Semiconductor IC According to Modifications 3 and 4]

(140) Note that, the power amplifier circuit **21** may have a plurality of amplifier transistors that are cascade-connected to each other.

(141) FIG. **9** is a circuit configuration view of a power amplifier circuit **21M** according to Modification 3. The power amplifier circuit **21M** according to the present modification is configured to include amplifier transistors at two stages that are cascade-connected to each other. As illustrated in FIG. **9**, the power amplifier circuit **21M** has a power amplifier **21P** and a power amplifier **21D**.

(142) The power amplifier **21P** includes an amplifier transistor **210P**, capacitors **214P** and **213P**, a bias circuit **215P**, a collector terminal **212P**, an emitter terminal **211P**, a terminal **225**, and the output terminal **220**.

(143) The amplifier transistor **210P** is a first amplifier transistor arranged at a last stage (power stage) of the plurality of amplifier transistors and has, for example, a collector, an emitter, and a base. The amplifier transistor **210P** is a common-emitter type bipolar transistor, amplifies a radio-frequency current inputted to the base, and outputs the amplified radio-frequency current from the collector. Note that, the amplifier transistor **210P** may be a field-effect type transistor having a drain (corresponding to the collector), a source (corresponding to the emitter), and a gate (corresponding to the base).

(144) The power amplifier **21D** includes an amplifier transistor **210D**, capacitors **214D** and **213D**, a bias circuit **215D**, a collector terminal **212D**, an emitter terminal **211D**, the input terminal **230**, and the terminal **225**.

(145) The amplifier transistor **210D** is a second amplifier transistor arranged at a stage (drive stage) preceding the amplifier transistor **210P** arranged at the last stage and has, for example, a collector, an emitter, and a base. The amplifier transistor **210D** is a common-emitter type bipolar transistor, amplifies a radio-frequency current inputted to the base, and outputs the amplified radio-frequency current from the collector. Note that, the amplifier transistor **210D** may be a field-effect type transistor having a drain (corresponding to the collector), a source (corresponding to the emitter), and a gate (corresponding to the base).

(146) The capacitors **214P** and **214D** have a function similar to that of the capacitor **214**. The capacitors **213P** and **213D** have a function similar to that of the capacitor **213**. The bias circuits **215P** and **215D** are connected to the bases of the amplifier transistors **210P** and **210D**, respectively, and have a function similar to that of the bias circuit **215**.

(147) The emitter terminal **211P** is connected to an electrode **23P** (the first metal member) and is connected to the ground. Further, the emitter terminal **211D** is connected to an electrode **23D** (the second metal member) and is connected to the ground.

(148) According to the above-described circuit configuration of the power amplifier circuit **21M** according to the present modification, the radio-frequency signal RFin inputted from the input terminal **230** becomes a base current Ib1 flowing from the base to the emitter of the amplifier transistor **210D**. The base current Ib1 is amplified by the amplifier transistor **210D** to become a

collector current  $I_{cc1}$ , and a radio-frequency signal corresponding to the collector current  $I_{cc1}$  is outputted from the terminal **225**. Further, the radio-frequency signal amplified by the amplifier transistor **210D** becomes a base current  $I_{b2}$  flowing from the base to the emitter of the amplifier transistor **210P** via the terminal **225**. The base current  $I_{b2}$  is amplified by the amplifier transistor **210P** to become a collector current  $I_{cc2}$ , and a radio-frequency signal corresponding to the collector current  $I_{cc2}$  is outputted from the output terminal **220**. At this time, a large current in which the base current  $I_{b2}$  and the collector current  $I_{cc2}$  are added flows from the emitter terminal **211P** to the ground. Thus, in order to improve the heat dissipation properties of the power amplifier circuit **21M**, it is necessary to improve the heat dissipation properties from the emitter terminal **211P** which needs to function as a heat dissipation portion of the amplifier transistor **210P**.

(149) FIG. **10** is a planar configuration schematic view of a semiconductor IC **70C** according to Modification 3. Note that, FIG. **10** is a perspective view illustrating an arrangement of a first base material **10C**, a second base material **20C**, the PA control circuit **11**, and the electrodes **23D**, **23P**, **24** and **25**, when the main surface **80a**, out of the main surfaces **80a** and **80b** facing each other of the module substrate **80**, is viewed from the positive direction side of the z-axis.

(150) The electrode **23D** is an example of the second metal member and connects the second base material **20C** and the main surface **80a** to each other. The electrode **23D** is, for example, a ground electrode connected to the emitter terminal **211D** of the power amplifier circuit **21M**.

(151) The electrode **23P** is an example of the first metal member and connects the second base material **20C** and the main surface **80a** to each other. The electrode **23P** is, for example, a ground electrode connected to the emitter terminal **211P** of the power amplifier circuit **21M**.

(152) The electrode **24** is an example of the second metal member and connects the first base material **10C** and the main surface **80a** to each other. The electrode **24** is, for example, an input terminal or an output terminal of the PA control circuit **11**, or a ground electrode.

(153) The electrode **25** is an example of the third metal member and connects the first base material **10C** and the main surface **80a** to each other. The electrode **25** is, for example, a ground electrode of an electronic component formed on the first base material **10C**.

(154) Here, in plan view of the module substrate **80**, an area of the electrode **23P** is larger than the area of the electrode **24**. Further, the area of the electrode **23P** is larger than an area of the electrode **23D**.

(155) According to the above-described configuration, the heat generated in the power amplifier circuit **21M** is promoted to be transferred to the first base material **10C** having thermal conductivity higher than that of the second base material **20C**. At the same time, the heat generated in the power amplifier circuit **21M** is promoted to be dissipated from the second base material **20C** to the module substrate **80** through the electrode **23P** having a large heat dissipation area. Thus, the heat generated in the power amplifier circuit **21M** can be dissipated with high efficiency. Furthermore, since the first base material **10C** and the second base material **20C** are stacked in the direction perpendicular to the main surface **80a**, while a radio-frequency module is reduced in size, the heat dissipation properties can be improved.

(156) Additionally, as illustrated in FIG. **10**, the electrode **23P** has an elongated shape in plan view of the module substrate **80**. Accordingly, since electrode density can be increased with the electrode **23P**, a region on the second base material **20C** can be effectively utilized, as compared to a case, for example, where a large area is ensured by discretely arranging a plurality of electrodes, the electrodes having a circular shape like the electrode **24**.

(157) In addition, as illustrated in FIG. **10**, in plan view of the module substrate **80**, the amplifier transistor **210P** and the electrode **23P** may overlap each other, and the amplifier transistor **210D** and the electrode **23D** may overlap each other.

(158) Accordingly, since a heat dissipation path linking the amplifier transistor **210P** to the electrode **23P** can be shortened and a heat dissipation path linking the amplifier transistor **210D** to the electrode **23D** can be shortened, the thermal conductance of these heat dissipation paths can be



increased and the heat dissipation properties can be improved.

(159) FIG. **11** is a planar configuration schematic view of a semiconductor IC **70D** according to Modification 4. The semiconductor IC **70D** according to the present modification is different from the semiconductor IC **70C** according to Modification 3 in that the second base material **20** is constituted by two base materials that are arranged to be spaced apart from each other, that is, a third base material **20D** and a fourth base material **20P**. Hereinafter, the semiconductor IC **70D** according to the present modification will be described focusing on a configuration different from that of the semiconductor IC **70C** according to Modification 3.

(160) The semiconductor IC **70D** includes the third base material **20D** and the fourth base material **20P**. A first base material **10D** and the third base material **20D** are stacked in the z-axis direction (direction perpendicular to the main surface **80a**). Further, the first base material **10D** and the fourth base material **20P** are stacked in the z-axis direction (direction perpendicular to the main surface **80a**).

(161) The third base material **20D** is at least partially formed of the second semiconductor material having the thermal conductivity higher than that of the first semiconductor material, and the power amplifier circuit **21D** is formed therein. The fourth base material **20P** is at least partially formed of the second semiconductor material having the thermal conductivity higher than that of the first semiconductor material, and the power amplifier circuit **21P** is formed therein.

(162) The third base material **20D** is arranged between the module substrate **80** and the first base material **10D**, bonded to the first base material **10D**, and connected to the main surface **80a** with the electrode **23D** (second metal member) interposed therebetween.

(163) The fourth base material **20P** is arranged between the module substrate **80** and the first base material **10D**, bonded to the first base material **10D**, and connected to the main surface **80a** with the electrode **23P** (first metal member) interposed therebetween.

(164) According to the above-described configuration, the heat generated in the power amplifier circuit is promoted to be transferred to the first base material **10D** having thermal conductivity higher than that of the third base material **20D**. At the same time, the heat generated in the power amplifier circuit is promoted to be dissipated from the third base material **20D** to the module substrate **80** through the electrode **23P** having a large heat dissipation area. Thus, the heat generated in the power amplifier circuit can be dissipated with high efficiency. Further, since the second base material **20** is constituted by the third base material **20D** and the fourth base material **20P** that are arranged to be spaced apart from each other, the heat generated in one of the power amplifiers **21D** and **21P** can be dissipated to the module substrate **80** without being transmitted to the other of the power amplifiers **21D** and **21P**, and thus the heat dissipation efficiency is improved.

(165) [5. Effects and the Like]

(166) As described-above, the radio-frequency module **1A** according to the example includes the module substrate **80** having the main surfaces **80a** and **80b** facing each other, the first base material **10** at least partially formed of the first semiconductor material, and the second base material **20** that is at least partially formed of the second semiconductor material having the thermal conductivity higher than that of the first semiconductor material and in which the power amplifier circuit **21** is formed. The first base material **10** and the second base material **20** are arranged on the main surface **80a**, the second base material **20** is arranged between the module substrate **80** and the first base material **10**, bonded to the first base material **10**, and connected to the main surface **80a** with the electrode **23** interposed therebetween, one of the first base material **10** and the second base material **20** is connected to the main surface **80a** with the electrode **24** interposed therebetween, and in plan view of the module substrate **80**, the area of the electrode **23** is larger than the area of the electrode **24**.

(167) Additionally, the radio-frequency module **1A** according to the example includes the module substrate **80** having the main surfaces **80a** and **80b** facing each other, the first base material **10** at least partially formed of silicon or gallium nitride, and the second base material **20** that is at least

partially formed of gallium arsenide or silicon germanium and in which the power amplifier circuit **21** is formed. The first base material **10** and the second base material **20** are arranged on the main surface **80a**, the second base material **20** is arranged between the module substrate **80** and the first base material **10**, bonded to the first base material **10**, and connected to the main surface **80a** with the electrode **23** interposed therebetween, one of the first base material **10** and the second base material **20** is connected to the main surface **80a** with the electrode **24** interposed therebetween, and in plan view of the module substrate **80**, the area of the electrode **23** is larger than the area of the electrode **24**.

(168) Accordingly, the heat generated in the power amplifier circuit **21** is promoted to be transferred to the first base material **10** having the thermal conductivity higher than that of the second base material **20**. At the same time, the heat generated in the power amplifier circuit **21** is dissipated from the second base material **20** to the module substrate **80** through the electrode **23** having a large heat dissipation area. Thus, the heat generated in the power amplifier circuit **21** can be dissipated with high efficiency. Furthermore, since the first base material **10** and the second base material **20** are stacked in the direction perpendicular to the main surface **80a**, while the radio-frequency module **1A** is reduced in size, the heat dissipation properties can be improved.

(169) In addition, in the radio-frequency module **1A**, the electrode **23** may have an elongated shape in plan view of the module substrate **80**.

(170) Accordingly, since electrode density can be increased with the electrode **23**, a region on the second base material **20** can be effectively utilized, as compared to a case, for example, where a large area is ensured by discretely arranging a plurality of electrodes, the electrodes having a circular shape like the electrode **24**.

(171) In addition, in the semiconductor IC **70A** according to Modification 1, in plan view of the module substrate **80**, the second base material **20A** may be included in the first base material **10A**, the first base material **10A** may have the central region C and the outer peripheral region P, and the electrode **23** may be arranged in the region where the second base material **20A** and the outer peripheral region P overlap each other such that the longitudinal direction of the electrode **23** is parallel to the outer side L2 closest to the electrode among the outer sides of the first base material **10A**.

(172) Accordingly, since the electrode **23** is arranged in the outer peripheral region P and is arranged along the closest outer side L2, the semiconductor IC **70A** can be stably arranged on the module substrate **80** in the manufacturing process of mounting the semiconductor IC **70A** on the module substrate **80**.

(173) In addition, in the radio-frequency module **1A**, the first base material **10** may be connected to the main surface **80a** with the electrode **25** interposed therebetween, and in plan view of the module substrate **80**, the area of the electrode **25** may be larger than the area of the electrode **24**.

(174) Accordingly, the heat of the power amplifier circuit **21** transferred to the first base material **10** is dissipated to the module substrate **80** through the electrode **25** having a large heat dissipation area. Thus, the heat generated in the power amplifier circuit **21** can be dissipated with higher efficiency.

(175) In addition, in the radio-frequency module **1A**, the electrodes **23** and **25** may have an elongated shape in plan view of the module substrate **80**.

(176) Accordingly, since electrode density can be increased with the electrodes **23** and **25**, a region on the second base material **20** can be effectively utilized, as compared to a case, for example, where a large area is ensured by discretely arranging a plurality of electrodes, the electrodes having a circular shape like the electrode **24**.

(177) In addition, in the semiconductor IC **70A** according to Modification 1 or the semiconductor IC **70B** according to Modification 1, in plan view of the module substrate **80**, the second base material **20A** (or **20B**) may be included in the first base material **10A** (or **10B**), the first base material **10A** (or **10B**) may have the central region C and the outer peripheral region P, the

electrode **23** may be arranged in the region where the second base material **20A** (or **20B**) and the outer peripheral region **P** overlap each other such that the longitudinal direction of the electrode **23** is parallel to the outer side **L2** (or **L3**) closest to the electrode **23** among the outer sides of the first base material **10A** (or **10B**), and the electrode **25** may be arranged in the outer peripheral region **P** such that the longitudinal direction of the electrode **25** is parallel to the outer side **L1** (or **L3**) closest to the electrode **25** among the outer sides of the first base material **10A** (or **10B**).

(178) Accordingly, since the electrodes **23** and **25** are arranged in the outer peripheral region **P** and are each arranged along the closest outer side, the semiconductor IC **70A** (or **70B**) can be stably arranged on the module substrate **80** in the manufacturing process of mounting the semiconductor IC **70A** (or **70B**) on the module substrate **80**.

(179) In addition, in the radio-frequency module **1A**, the power amplifier circuit **21** may include the amplifier transistor **210**, and the amplifier transistor **210** may be connected to the electrode **23**.

(180) Accordingly, since the heat generated in the amplifier transistor **210** is dissipated from the second base material **20** to the module substrate **80** through the electrode **23** having a large heat dissipation area, the heat generated in the power amplifier circuit **21** can be dissipated with high efficiency.

(181) In addition, in the radio-frequency module **1A**, the amplifier transistor **210** and the electrode **23** may overlap each other, in plan view of the module substrate **80**.

(182) Accordingly, since a heat dissipation path linking the amplifier transistor **210** to the electrode **23** can be shortened, the thermal conductance of the heat dissipation path can be increased, and the heat dissipation properties can be improved.

(183) In addition, in the radio-frequency module **1A**, the amplifier transistor **210** may have the collector layer **21C**, the base layer **21B**, and the emitter layer **21E**. The collector layer **21C**, the base layer **21B**, and the emitter layer **21E** may be stacked in this order from the first base material **10** side.

(184) In addition, in the radio-frequency module according to Modification 3, the power amplifier circuit **21M** may include the plurality of amplifier transistors that are cascade-connected to each other, the plurality of amplifier transistors may have the amplifier transistor **210P** arranged at the last stage and the amplifier transistor **210D** arranged at the stage preceding the amplifier transistor **210P**, and the electrode **23** may be connected to the amplifier transistor **210P**.

(185) Accordingly, the heat generated in the power amplifier circuit **21M** is promoted to be transferred to the first base material **10C** having thermal conductivity higher than that of the second base material **20C**. At the same time, the heat generated in the power amplifier circuit **21M** is promoted to be dissipated from the second base material **20C** to the module substrate **80** through the electrode **23P** having a large heat dissipation area. Thus, the heat generated in the power amplifier circuit **21M** can be dissipated with high efficiency.

(186) In addition, in the radio-frequency module according to Modification 3, the electrode **25** may be connected to the amplifier transistor **210D**.

(187) In addition, in the radio-frequency module according to Modification 3, in plan view of the module substrate **80**, the amplifier transistor **210P** and the electrode **23** may overlap each other and the amplifier transistor **210D** and the electrode **25** may overlap each other.

(188) Accordingly, since a heat dissipation path linking the amplifier transistor **210P** to the electrode **23P** can be shortened, and a heat dissipation path linking the amplifier transistor **210D** to the electrode **23D** can be shortened, the thermal conductance of these heat dissipation paths can be increased and the heat dissipation properties can be improved.

(189) In addition, in the semiconductor IC **70D** according to Modification 4, the second base material may be constituted by the third base material **20D** and the fourth base material **20P** that are arranged to be spaced apart from each other, the amplifier transistor **210D** may be included in the third base material **20D**, and the amplifier transistor **210P** may be included in the fourth base material **20P**.

(190) Accordingly, since the second base material **20** is constituted by the third base material **20D** and the fourth base material **20P** that are arranged to be spaced apart from each other, the heat generated in one of the power amplifiers **21D** and **21P** can be dissipated to the module substrate **80** without being transmitted to the other of the power amplifiers **21D** and **21P**, and thus the heat dissipation efficiency is improved.

(191) In addition, in the radio-frequency module **1A**, the first base material **10** may include the PA control circuit **11** that controls the power amplifier circuit **21**.

(192) Accordingly, it is possible to shorten a control wiring line connecting the power amplifier circuit **21** and the PA control circuit **11** to each other.

(193) Further, the radio-frequency module **1A** may further include the plurality of external connection terminals **150** arranged on the main surface **80b**.

(194) Further, the radio-frequency module **1A** may further include the low-noise amplifier circuit **31** arranged on the main surface **80b**, and the first base material **10** and the second base material **20** need not overlap the low-noise amplifier circuit **31**, in plan view of the module substrate **80**.

(195) Accordingly, the power amplifier circuit **21** and the low-noise amplifier circuit **31** are distributed to both sides with the module substrate **80** interposed therebetween, and a large distance can be ensured between the power amplifier circuit **21** and the low-noise amplifier circuit **31**. Thus, the isolation between the transmission and the reception can be improved.

(196) Further, the communication device **5** includes the RFIC **3** that processes radio-frequency signals transmitted and received by the antenna **2**, and the radio-frequency module **1** that transmits the radio-frequency signals between the antenna **2** and the RFIC **3**.

(197) Accordingly, it is possible to provide the communication device **5** with improved heat dissipation properties.

(198) (Other Embodiments and the Like)

(199) Although the radio-frequency module and the communication device according to the embodiment of the present disclosure have been described above with reference to the embodiment, the example, and the modifications, the radio-frequency module and the communication device according to the present disclosure are not limited to the embodiment, the example, and the modifications described above. Other embodiments realized by combining any components in the above-described embodiment, example, and modifications, modifications obtained by applying various modifications conceived by a person skilled in the art to the above-described embodiment, example, and modifications without departing from the gist of the present disclosure, and various devices including the above-described radio-frequency module and communication device are also included in the present disclosure.

(200) For example, in the radio-frequency modules and the communication device according to the above-described embodiment, example, and modifications, another circuit element, wiring line, or the like may be inserted between paths connecting the circuit elements and the signal paths disclosed in the figures to each other.

(201) The present disclosure can be widely used in communication devices such as mobile phones as a radio-frequency module arranged in a multiband front end unit. **1, 1A RADIO-FREQUENCY MODULE 2 ANTENNA 3 RF SIGNAL PROCESSING CIRCUIT (RFIC) 4 BASEBAND SIGNAL PROCESSING CIRCUIT (BBIC) 5 COMMUNICATION DEVICE 10, 10A, 10B, 10C, 10D FIRST BASE MATERIAL 10a, 10b, 80a, 80b MAIN SURFACE 11 PA CONTROL CIRCUIT 12 Si SUBSTRATE 13 INSULATING LAYER 14 Si LAYER 15 WIRING LAYER 16 VIA WIRING LINE 17 SiN LAYER 18, 22, 23, 23D, 23P, 24, 25, 26 ELECTRODE 20, 20A, 20B, 20C SECOND BASE MATERIAL 20d EPITAXIAL LAYER 20D THIRD BASE MATERIAL 20n GaAs BASE MATERIAL LAYER 20P FOURTH BASE MATERIAL 21, 21M POWER AMPLIFIER CIRCUIT 21B BASE LAYER 21C COLLECTOR LAYER 21D, 21P POWER AMPLIFIER 21E EMITTER LAYER 23a, 24a COLUMNAR CONDUCTOR 23b, 24b BUMP ELECTRODE 31 LOW-NOISE AMPLIFIER CIRCUIT 42, 43, 44, 45 MATCHING CIRCUIT 52,**

53, 54 SWITCH 61, 62 DUPLEXER 61R, 62R RECEPTION FILTER 61T, 62T TRANSMISSION FILTER 70, 70A, 70B, 70C, 70D, 75 SEMICONDUCTOR IC 71, 81, 82 RESIN MEMBER 73 DIPLEXER 73H, 73L FILTER 80 MODULE SUBSTRATE 85 METAL SHIELD LAYER 100 ANTENNA CONNECTION TERMINAL 110 CONTROL SIGNAL TERMINAL 120 TRANSMISSION INPUT TERMINAL 130 RECEPTION OUTPUT TERMINAL 150 EXTERNAL CONNECTION TERMINAL 210, 210D, 210P AMPLIFIER TRANSISTOR 211, 211D, 211P EMITTER TERMINAL 212, 212D, 212P COLLECTOR TERMINAL 213, 213D, 213P, 214, 214D, 214P CAPACITOR 215, 215D, 215P BIAS CIRCUIT 220 OUTPUT TERMINAL 225 TERMINAL 230 INPUT TERMINAL

## Claims

1. A radio-frequency module, comprising: a module substrate having a first main surface and a second main surface facing each other; a first base material at least partially comprised of a first semiconductor material having a first thermal conductivity; and a second base material at least partially comprised of a second semiconductor material having a second thermal conductivity higher than the first thermal conductivity, wherein a power amplifier circuit is provided in the second base material, wherein the first base material and the second base material are arranged on the first main surface, the second base material is arranged between the module substrate and the first base material, bonded to the first base material, and connected to the first main surface with a first metal member interposed therebetween, one of the first base material and the second base material is connected to the first main surface with a second metal member interposed therebetween, and in plan view of the module substrate, a first area of the first metal member is larger than a second area of the second metal member.
2. A radio-frequency module, comprising: a module substrate having a first main surface and a second main surface facing each other; a first base material at least partially comprised of silicon or gallium nitride; and a second base material at least partially comprised of gallium arsenide or silicon germanium, wherein a power amplifier circuit is provided in the second base material, wherein the first base material and the second base material are arranged on the first main surface, the second base material is arranged between the module substrate and the first base material, bonded to the first base material, and connected to the first main surface with a first metal member interposed therebetween, one of the first base material and the second base material is connected to the first main surface with a second metal member interposed therebetween, and in plan view of the module substrate, a first area of the first metal member is larger than a second area of the second metal member.
3. The radio-frequency module according to claim 1, wherein the first metal member has an elongated shape in plan view of the module substrate.
4. The radio-frequency module according to claim 3, wherein in plan view of the module substrate, the second base material is included in the first base material, and the first base material has a central region and an outer peripheral region located on an outer periphery of the central region, and the first metal member is arranged in a region where the second base material and the outer peripheral region overlap each other such that a longitudinal direction of the first metal member is parallel to an outer side closest to the first metal member among outer sides of the first base material.
5. The radio-frequency module according to claim 1, wherein the first base material is connected to the first main surface with a third metal member interposed therebetween, and in plan view of the module substrate, a third area of the third metal member is larger than the second area of the second metal member.
6. The radio-frequency module according to claim 5, wherein in plan view of the module substrate, each of the first metal member and the third metal member has an elongated shape.

7. The radio-frequency module according to claim 6, wherein in plan view of the module substrate, the second base material is included in the first base material, and the first base material has a central region and an outer peripheral region located on an outer periphery of the central region, the first metal member is arranged in a region where the second base material and the outer peripheral region overlap each other such that a longitudinal direction of the first metal member is parallel to an outer side closest to the first metal member among outer sides of the first base material, and the third metal member is arranged in the outer peripheral region such that a longitudinal direction of the third metal member is parallel to an outer side closest to the third metal member among the outer sides of the first base material.
  8. The radio-frequency module according to claim 1, wherein the power amplifier circuit includes an amplifier transistor, and the amplifier transistor is connected to the first metal member.
  9. The radio-frequency module according to claim 8, wherein in plan view of the module substrate, the amplifier transistor and the first metal member overlap each other.
  10. The radio-frequency module according to claim 8, wherein the amplifier transistor has a collector layer, a base layer, and an emitter layer, and the collector layer, the base layer, and the emitter layer are stacked in an order of the collector layer, the base layer, and the emitter layer from a side of the first base material.
  11. The radio-frequency module according to claim 1, wherein the power amplifier circuit includes a plurality of amplifier transistors cascade-connected to each other, the plurality of amplifier transistors have a first amplifier transistor arranged at a last stage of the plurality of amplifier transistors, and a second amplifier transistor arranged at a stage preceding the first amplifier transistor, and the first metal member is connected to the first amplifier transistor.
  12. The radio-frequency module according to claim 11, wherein the second metal member is connected to the second amplifier transistor.
  13. The radio-frequency module according to claim 12, wherein in plan view of the module substrate, the first amplifier transistor and the first metal member overlap each other, and the second amplifier transistor and the second metal member overlap each other.
  14. The radio-frequency module according to claim 11, wherein the second base material is constituted by a third base material and a fourth base material, the third base material and the fourth base material being arranged to be spaced apart from each other, the first amplifier transistor is included in the fourth base material, and the second amplifier transistor is included in the third base material.
  15. The radio-frequency module according to claim 1, wherein the first base material includes a control circuit configured to control the power amplifier circuit.
  16. The radio-frequency module according to claim 1, further comprising: a plurality of external connection terminals arranged on the second main surface.
  17. The radio-frequency module according to claim 1, further comprising: a low-noise amplifier circuit arranged on the second main surface, wherein in plan view of the module substrate, the first base material and the second base material do not overlap the low-noise amplifier circuit.
  18. A communication device, comprising: an RF signal processing circuit configured to process a radio-frequency signal transmitted by an antenna; and the radio-frequency module according to claim 1 configured to transmit the radio-frequency signal between the antenna and the RF signal processing circuit.
  19. The radio-frequency module according to claim 2, wherein the first metal member has an elongated shape in plan view of the module substrate.
  20. The radio-frequency module according to claim 2, wherein the first base material is connected to the first main surface with a third metal member interposed therebetween, and in plan view of the module substrate, a third area of the third metal member is larger than the second area of the second metal member.
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