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Switching module including heat radiation member and inverter including the same

Abstract

A switching module **120** includes a positive-side conductor **51** in contact with an input-side electrode **30***a* provided on each upper arm switching element **30**U, a negative-side conductor **52** connected to an output-side electrode **30***b* of each lower arm switching element **30**L, and an electric insulating member **140** in contact with, at its upper surface, each output conductor **53** in contact with the input-side electrode **30***a* of each lower arm switching element **30**L and in contact with, at its lower surface, an electric conductive heat radiation member **42**. Each positive-side electric conductive layer **61** connected to the positive-side conductor **51** faces a corresponding one of negative-side electric conductive layers **62** connected to the negative-side conductor **52** via the electric insulating layer **60** such that a storage structure **63** interposed between the positive-side main line **21** and the negative-side main line **22** to store charge is inside the electric insulating member **140.**

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

(1) The present application claims priority to Japanese Patent Application No. 2022-154433, filed on Sep. 28, 2022, the entire contents of which are incorporated herein by reference.

BACKGROUND

(2) The technique disclosed herein relates to a switching module and an inverter, on which switching control is performed, and particularly relates to a switching module and an inverter suitable for use on a vehicle.

BACKGROUND

(3) In recent years, vehicles have been increasingly motorized. The vehicles are motorized in such a manner that an inverter is controlled using DC power supplied from a high-voltage battery for drive and a motor is driven accordingly. In this case, a power loss is caused in the inverter.
(4) Reduction in the power loss is a significant challenge in vehicle motorization. That is, there has been a demand for improvement in the efficiency of a switching module used for the inverter.
(5) For this reason, an improved semiconductor device of, e.g., silicon carbide (SiC) has been employed for the switching module. This has improved switching control to be performable at high speed.
(6) However, when the switching control is performed at high speed, there is a problem that harmonic noise is caused due to a high-frequency current flow caused by a periodic voltage change associated with such high-speed switching control.
(7) As the harmonic noise, current (normal mode current) flowing to the battery via an electric line and current (common mode current) flowing not only via an electric line but also via a stray capacitance (parasitic capacitance) and the ground (earth) are well-known. Due to these types of current, electromagnetic noise (normal mode noise and common mode noise) is caused.
(8) These types of electromagnetic noise would cause malfunction of electric devices located nearby, communication disturbance, etc. For this reason, in order to speed up the switching control, it is inevitable to suppress these types of electromagnetic noise.
(9) A smoothing capacitor that suppresses the normal mode noise is placed in a DC link of the inverter.
(10) That is, the smoothing capacitor supplies stored power to the switching module. Accordingly, a high-frequency impedance between positive and negative supply powers from the battery can be reduced. High-frequency current flowing to the battery substantially flows via the smoothing capacitor. Thus, the smoothing capacitor can suppress the normal mode noise.
(11) A technique of suppressing the common mode noise has also been proposed. For example, Japanese Unexamined Patent Publication No. 2018-195694 discloses a technique of reducing common mode noise caused in a half-bridge circuit (circuit configured such that two switching elements are connected in series).
(12) In the case of the half-bridge circuit, a voltage change is great at a midpoint between the two switching elements. Thus, in the technique of Japanese Unexamined Patent Publication No. 2018-195694, a heat sink (second heat sink 19) facing a conductive plate (midpoint conductive plate 15) at the midpoint via an insulating layer 31 is insulated from a ground terminal 24 (for the sake of easy explanation, reference numerals in Japanese Unexamined Patent Publication No. 2018-195694 are used herein for explaining Japanese Unexamined Patent Publication No. 2018-195694).
(13) With this configuration, common mode current flowing from the midpoint conductive plate 15 is reduced, and accordingly, common mode noise accompanying the common mode current is reduced.

SUMMARY

Technical Problems

(14) When the switching control is performed, resonance occurs between the DC link and each switching element. Accordingly, small vibration (ringing) occurs in the waveforms of the operating current and voltage of each switching element (see a reference numeral Y**1** in FIG. **1**).
(15) As the switching control is speeded up, the amplitude of the ringing increases. Thus, the ringing is a cause for the normal mode noise and the common mode noise because the ringing includes a high frequency component.
(16) Further, the ringing causes surge voltage (instantaneously-caused excessive voltage). When such surge voltage exceeds the withstand voltage limit of the switching element, a semiconductor of the switching element is damaged. Thus, for each switching element, a withstand voltage property sufficiently higher than the voltage of the battery with a sufficient allowance against such voltage is required. As a result, the switching element is inevitably expensive, and is a cause for an

increase in the cost of the switching module and therefore the cost of the inverter.
(17) That is, current (ripple current) flows in the smoothing capacitor when the motor is driven under inverter control. Accordingly, the smoothing capacitor generates heat due to a power loss caused by the ripple current and internal resistance.
(18) However, a film capacitor configured such that a plurality of films are stacked on each other is generally employed as the smoothing capacitor. Thus, heat radiation from the smoothing capacitor is difficult. Particularly, in the case of an in-vehicle inverter, in which the smoothing capacitor is large, the heat radiation from the smoothing capacitor is difficult.
(19) For these reasons, avoidance of the temperature increase in the smoothing capacitor for attaining reliability requires suppressing heat generation therein by reduction in the internal resistance thereof. Thus, the capacitance of the smoothing capacitor needs to be an excessive value more than necessary. For this reason, the smoothing capacitor is also expensive, and is a great cause for an inverter cost increase.
(20) Thus, the technique disclosed herein has an object of attaining a switching module capable of reducing the inverter cost by miniaturizing or omitting a smoothing capacitor, even though the function that the smoothing capacitor provides is still maintained in the switching module. The technique also has an object of attaining a switching module in which common mode noise can be reduced.
Solution to the Problems
(21) The technique disclosed herein relates to a switching module, on which switching control is performed, and which includes positive and negative-side main lines each connected respectively to positive and negative electrodes of a battery, a plurality of half-bridge circuits each of which includes upper and lower arm switching elements connected in series in an order from a positive-side main line side between the positive and negative-side main lines, and a plurality of output lines each of which is connected between the upper and lower arm switching elements in a corresponding one of the half-bridge circuits, switching control being performed on the switching module.
(22) The switching module includes a positive-side conductor in contact with an input-side electrode provided on the lower surface of each upper arm switching element and forming the positive-side main line, a negative-side conductor connected to an output-side electrode of each lower arm switching element and forming the negative-side main line, an output conductor in contact with an input-side electrode provided on the lower surface of each lower arm switching element and forming each output line, and an electric insulating member being in contact with, at an upper surface thereof, each of the positive-side conductor, the negative-side conductor, and the output conductor and being in contact with, at a lower surface thereof, a heat radiation member having electrical conductivity.
(23) The electric insulating member includes a plurality of positive-side electric conductive layers connected to the positive-side conductor, and a plurality of positive-side electric conductive layers connected to the negative-side conductor. Each positive-side electric conductive layer faces a corresponding one of the positive-side electric conductive layers via an electric insulating layer such that a storage structure interposed between the positive-side main line and the negative-side main line to store charge is provided inside the electric insulating member.
(24) That is, according to the switching module, the electric insulating member contacts the heat radiation member, and therefore, heat of the electric insulating member can be radiated to the heat radiation member. Thus, even when heat is generated, due to the switching control, on a circuit provided on, e.g., the lower arm switching element, such heat can be radiated via the electric insulating member.
(25) Each positive-side electric conductive layer faces a corresponding one of the negative-side electric conductive layers via the electric insulating layer such that the particular storage structure interposed between the positive-side main line and the negative-side main line is provided inside

the electric insulating member. When the switching module is placed in the inverter, this storage structure is connected in parallel with a smoothing capacitor.
(26) That is, the storage structure can function as the smoothing capacitor, and therefore, be used as a replacement for the smoothing capacitor. As a result, the smoothing capacitor can be miniaturized or be omitted, while the function of the smoothing capacitor is maintained. In this way, such a switching module that can reduce an inverter cost can be realized.
(27) In addition, the storage structure is provided inside the electric insulating member, and therefore, heat can be easily radiated. Thus, an excessive capacitance is not necessary for, e.g., a film capacitor, and therefore, such a switching module can be realized with the electric insulating member with a small size and a small capacitance.
(28) Further, since the storage structure and each switching element are substantially integrated, a parasitic inductance caused due to connection of the smoothing capacitor via an electric line can be eliminated. Accordingly, ringing of the waveforms of current and voltage flowing in the half-bridge circuit due to the switching control can be suppressed. Moreover, surge voltage can also be suppressed, and therefore, an excessive withstand voltage of the switching element is not necessary and the switching module can be inexpensive.
(29) The storage structure may be such that positive-side electric conductive layers and the positive-side electric conductive layers are alternately formed so as to extend in parallel with the upper and lower surfaces of the electric insulating member, and each positive-side electric conductive layer faces a corresponding one of the positive-side electric conductive layers via the electric insulating layer in the thickness direction of the electric insulating member.
(30) With this configuration, the storage structure can be efficiently arranged inside the electric insulating member. Accordingly, the thickness of the electric insulating member can be decreased while a high capacitance of the storage structure is ensured. As a result, heat radiation of the electric insulating member can be enhanced in terms of structure.
(31) The upper arm switching elements and the lower arm switching elements may be concentratedly arranged in a center portion on the upper surface of the electric insulating member, and the storage structure may be provided in an outer edge portion of the electric insulating member.
(32) With this configuration, the group of the switching elements and the storage structure do not overlap with each other. When the switching control is performed, each of the storage structure and the switching elements generates heat, but such heat can be efficiently transferred to the heat radiation member and be radiated from the heat radiation member.
(33) The storage structure may be interposed between the heat radiation member and a midpoint portion where at least each lower arm switching element is positioned.
(34) With this configuration, the flow of common mode current can be prevented, and occurrence of common mode noise can be prevented. That is, when the switching control is performed, voltage periodically greatly changes at the midpoint portion where each lower arm switching element is positioned. In a conventional case, the common mode current flows, and the common mode noise occurs accordingly.
(35) On the other hand, the potential of each of the positive and negative-side electric conductive layers of the storage structure does not change even when the switching control is performed. Thus, no current flows in a current path passing through the electric insulating member and the heat radiation member. Almost entire common mode current can be eliminated, and almost entire common mode noise can be eliminated accordingly.
(36) The storage structure may be provided over the entire area of the electric insulating member.
(37) With this configuration, the current path passing through the electric insulating member and the heat radiation member can be reliably blocked. Therefore, the common mode noise can be stably suppressed. In addition, the shape of each of the positive and negative-side electric conductive layers is simplified to facilitate formation thereof. Thus, the electric insulating member

can be easily manufactured.
(38) The positive-side electric conductive layers and the positive-side electric conductive layers may include: positive and negative-side parallel layers extending so as to face the upper and lower surfaces of the electric insulating member via the electric insulating layer; and a plurality of positive-side orthogonal layers and a plurality of negative-side orthogonal layers which are orthogonal to the positive-side parallel layer and the negative-side parallel layer and are alternately formed so as to extend in parallel with either one of end surfaces of the electric insulating member. The storage structure may be such that positive-side orthogonal layers and the negative-side orthogonal layers may face each other via the electric insulating layer in a side direction orthogonal to the thickness direction of the electric insulating member.
(39) This configuration is another aspect of the above-described storage structure. The storage structure can be selected in accordance with the specifications of the electric insulating member, and therefore, has excellent versatility.
(40) The storage structure may be interposed between the heat radiation member and a midpoint portion where at least each lower arm switching element is positioned.
(41) With this configuration, the common mode noise can be suppressed as described above.
(42) The midpoint portion may face the positive-side parallel layer or the negative-side parallel layer via the electric insulating layer.
(43) With this configuration, the current path passing through the electric insulating member and the heat radiation member can be easily blocked. Therefore, the common mode noise can be stably suppressed.
(44) The storage structure may be provided over the entire area of the electric insulating member.
(45) With this configuration, the current path passing through the electric insulating member and the heat radiation member can be reliably blocked. The common mode noise can be more stably suppressed. In addition, the shape of each of the positive and negative-side electric conductive layers is simplified to facilitate formation thereof. Thus, the electric insulating member can be easily manufactured.
(46) The electric insulating member may be made of such a ceramic material that a high permittivity material having a higher relative permittivity than that of aluminum oxide and a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide are mixed at a predetermined ratio.
(47) In the case of this switching module, the storage structure is provided in the electric insulating member, and therefore, high thermal conductivity and capacitance are required for the electric insulating member. The above-described configuration can adjust both the thermal conductivity and permittivity of the electric insulating member. Thus, the thermal conductivity and the capacitance can be optimized in accordance with the specifications of the electric insulating member.
(48) The high thermal conductive material may be aluminum nitride, and the high permittivity material may be barium titanate.
(49) Barium titanate has an extremely-high relative permittivity, and aluminum nitride has an extremely-high thermal conductivity. Thus, both the thermal conductivity and permittivity of the electric insulating member can be easily adjusted and enhanced.
(50) The electric insulating member may have a first portion made of a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide, and a second portion made of a high permittivity material having a higher relative permittivity than that of aluminum oxide.
(51) With this configuration, the electric insulating member can be formed without degradation of the properties of both the high thermal conductive material and the high permittivity material. Thus, both high thermal conductivity and capacitance of the electric insulating member can be obtained.
(52) Particularly, this configuration is advantageous in manufacturing when applied to the above-

described another form of the storage structure because the electric insulating member can be manufactured by a combination of existing methods even if different materials are used.
(53) The high thermal conductive material may be aluminum nitride, and the high permittivity material may be barium titanate.
(54) With this configuration, both the thermal conductivity and capacitance of the electric insulating member can be obtained at a high level.
(55) The above-described switching module is preferably applicable to an inverter for being interposed between a battery and a motor to drive the motor with power supplied from the battery.
(56) That is, the inverter may include the above-described switching module, and a DC link interposed between the battery and each of the positive-side main line and the negative-side main line. The DC link may have a positive-side junction line interposed between the positive-side main line and the positive electrode of the battery, a negative-side junction line interposed between the negative-side main line and the negative electrode of the battery, and a smoothing capacitor bridging between the positive-side junction line and the negative-side junction line. the storage structure also functioning as a smoothing capacitor in addition to the smoothing capacitor.
(57) With this configuration, the large and expensive smoothing capacitor can be miniaturized, and therefore, the inverter can be inexpensive.
(58) The inverter may include the above-described switching module, and a DC link interposed between the battery and each of the positive-side main line and the negative-side main line. The DC link may have a positive-side junction line interposed between the positive-side main line and the positive electrode of the battery, and a negative-side junction line interposed between the negative-side main line and the negative electrode side of the battery. the DC link including no smoothing capacitor, the storage structure functioning as a smoothing capacitor in replacement of the smoothing capacitor.
(59) With this configuration, the smoothing capacitor can be omitted, and therefore, the inverter can be much less expensive.
Advantages of the Invention
(60) The application of the technique disclosed herein to the switching module makes it possible that the smoothing capacitor can be miniaturized or be omitted even though the function that the smoothing capacitor provides is maintained and thus the inverter cost can be reduced. Further, the common mode noise can also be suppressed, thereby facilitating speeding-up of the switching control.

Description

BRIEF DESCRIPTION OF DRAWINGS
(1) FIG. **1** is a circuit diagram for describing an inverter (unimproved inverter) and a switching module (unimproved module) before application of the technique disclosed herein.
(2) FIG. **2** is a schematic view illustrating the inside of the unimproved module viewed from above.
(3) FIG. **3** is a schematic cross-sectional view taken along the arrow A**1**-A**1** of FIG. **2**.
(4) FIG. **4** is a view illustrating a switching module (improved module) to which the technique disclosed herein is applied and corresponding to FIG. **2**.
(5) FIG. **5** is a view illustrating the improved module and corresponding to FIG. **3**.
(6) FIG. **6** is a view for describing the configuration of an improved substrate.
(7) FIG. **7** is a view for describing a method for manufacturing the improved substrate.
(8) FIG. **8** illustrates circuit diagrams of improved inverters, illustrating examples of a case where a smoothing capacitor is miniaturized and a case where no smoothing capacitor is provided.
(9) FIG. **9** is a view illustrating a second improved module and corresponding to FIG. **5**.
(10) FIG. **10** is a circuit diagram of the second improved inverter.

(11) FIG. **11** is a schematic view illustrating a modification (first modified substrate) of the improved substrate.
(12) FIG. **12** is a view for describing another configuration of the first modified substrate.
(13) FIG. **13** is a schematic view illustrating a modification (second modified substrate) of the improved substrate.
(14) FIG. **14** is a view for describing a method for manufacturing the second modified substrate.
DESCRIPTION OF EMBODIMENTS
(15) Hereinafter, embodiments of the technique disclosed herein will be described. It should be noted that the following description is merely illustrative in nature.
(16) <Unimproved Inverter, Unimproved Module>
(17) For the sake of easy understanding of the technique disclosed herein, an inverter (unimproved inverter **1**) and a switching module (unimproved module **20**) before application of the technique disclosed herein will be described as a comparative example.
(18) <Circuit Structures of Unimproved Inverter **1** and Unimproved Module **20**>
(19) FIG. **1** illustrates an example of the in-vehicle unimproved inverter **1** equipped with the unimproved module **20**. The unimproved inverter **1** is for being mounted on a hybrid vehicle or an electric vehicle. The unimproved inverter **1** is interposed between a high-voltage battery **2** as a power source for the unimproved inverter **1** and a motor **3** that rotates wheels.
(20) A circuit of the unimproved module **20** includes a positive-side main line **21**, a negative-side main line **22**, three half-bridge circuits **23**, and three output lines **24**. The positive-side main line **21** is an electric line connected to the positive electrode of the battery **2**. The negative-side main line **22** is an electric line connected to the negative electrode of the battery **2**.
(21) The half-bridge circuits **23** are provided in parallel between the positive-side main line **21** and the negative-side main line **22**. Each half-bridge circuit **23** has two switching elements **30** (an upper arm switching element **30**U and a lower arm switching element **30**L). Here, the switching elements **30** are IGBTs.
(22) The upper arm switching element **30**U and the lower arm switching element **30**L are connected in series in this order from the positive-side main line **21** side. Each switching element **30** is connected in anti-parallel with a free wheel diode **25**. These half-bridge circuits **23** form an inverter circuit.
(23) Each output line **24** is connected to a portion between the upper arm switching element **30**U and the lower arm switching element **30**L in a corresponding one of the half-bridge circuits **23**. These output lines **24** are connected to the motor **3**.
(24) The unimproved inverter **1** includes a control circuit (not shown) that performs switching control. The control circuit is connected to each switching element **30**. The control circuit turns on or off each switching element **30** at a predetermined drive frequency (e.g., 10 kHz) by the switching control. Accordingly, the control circuit converts DC power supplied from the battery **2** into three-phase AC power of U, V, and W phases, and supplies the AC power to the motor **3** via each output line **24**.
(25) The unimproved module **20** is connected to the battery **2** via a DC link **10**. The DC link **10** is a circuit interposed between the battery **2** and each of the positive-side main line **21** and the negative-side main line **22**.
(26) The DC link **10** includes a positive-side junction line **11** interposed between the positive-side main line **21** and the positive electrode of the battery **2**, a negative-side junction line **12** interposed between the negative-side main line **22** and the negative electrode of the battery **2**, and a smoothing capacitor **13** bridging between the positive-side junction line **11** and the negative-side junction line **12**.
(27) The smoothing capacitor **13** is a large film capacitor. That is, a plastic film is used as a dielectric of the smoothing capacitor **13**. The plastic film is in the form of lamination, which is formed by winding or layering the plastic film together with metal foil. In this manner, the

smoothing capacitor **13** is formed.
(28) (Concreate Structure of Unimproved Module **20**)
(29) FIGS. **2** and **3** illustrate a concrete structure of the unimproved module **20**. FIG. **2** is a schematic view illustrating the inside of the unimproved module **20** viewed from above. FIG. **3** is a schematic cross-sectional view taken along the arrow A**1**-A**1** of FIG. **2**.
(30) The unimproved module **20** includes a substrate **40** (electric insulating member), a case cover **41**, and a heat sink **42** (heat radiation member). On the substrate **40**, the three half-bridge circuits **23** including the six switching elements **30** (three upper arm switching elements **30**U and three lower arm switching elements **30**L) are provided.
(31) Here, the switching elements **30** are the IGBTs as described above. A character "C" in the figure indicates a collector electrode **30***a* (input-side electrode), and a character "E" indicates an emitter electrode **30***b* (output-side electrode). A character "B" indicates a base electrode **30***c* (control electrode).
(32) The collector electrode **30***a* connected to the positive side having a higher voltage generates a greater amount of heat than the emitter electrode **30***b* connected to the negative side having a lower voltage. The collector electrode **30***a* is provided over the entirety of the lower surface of the switching element **30**.
(33) The emitter electrode **30***b* and the base electrode **30***c* are provided on the upper surfaces of the switching elements **30**. The emitter electrode **30***b* is greater in area than the base electrode **30***c* used for control. Although each switching element **30** is connected in anti-parallel with the free wheel diode **25** (see FIG. **1**), illustration thereof is omitted.
(34) The heat sink **42** is a metal member having excellent thermal conductivity and electrical conductivity. The heat sink **42** is formed, for example, in a rectangular plate shape from copper. The heat sink **42** is screwed to an in-vehicle cooler **43**. The cooler **43** is preferably of such a water-cooling type that coolant flows inside.
(35) The substrate **40** is formed in a rectangular plate shape from a material having electrical insulation properties, such as aluminum oxide (ceramic material) (that is, the substrate is a so-called alumina substrate). The lower surface of the substrate **40** contacts the upper surface of the heat sink **42**. With this configuration, the substrate **40** radiates heat to the cooler **43** via the heat sink **42**. The substrate **40** is cooled by the heat sink **42**.
(36) The case cover **41** is made of plastic and is formed in the shape of a box opened at bottom. The upper surface of the heat sink **42** is covered with the case cover **41**. With this configuration, the periphery of the substrate **40** is covered with the case cover **41**, and the substrate **40** is protected by the case cover **41**. The inside of the case cover **41** is filled with electric insulating resin.
(37) On the upper surface of the substrate **40**, a conductor having a predetermined pattern corresponding to electric wiring is formed. More specifically, copper forming the conductor is joined onto the upper surface of the substrate **40** by a well-known direct bonded copper (DBC) method.
(38) More specifically, as shown in FIG. **2**, a positive-side conductor **51** constituting the positive-side main line **21**, a negative-side conductor **52** constituting the negative-side main line **22**, three output conductors **53** constituting the output lines **24** respectively corresponding to the U, V, and W phases, and six switching conductors **54** constituting switching lines connected to the base electrodes **30***c* of the switching elements **30** are provided in contact with the upper surface of the substrate **40**.
(39) Each of the positive-side conductor **51**, the negative-side conductor **52**, and the output conductors **53** is provided so as to extend in parallel with the long sides (first sides **40***a*) of the substrate **40**.
(40) More specifically, the positive-side conductor **51** is provided so as to extend along one first side **40***a*. The negative-side conductor **52** is provided so as to extend along the other first side **40***a*. Each of the output conductors **53** is formed so as to extend between the positive-side conductor **51**

and the negative-side conductor **52** along these conductors **51**, **52**.
(41) The positive-side conductor **51** has a first extending portion **51***a* extending in a band shape along the adjacent first side **40***a* and three first element joint portions **51***b* formed at intervals and projecting from the inner edge of the first extending portion **51***a* toward the center of the substrate **40**. The negative-side conductor **52** has a second extending portion **52***a* extending in a band shape along the adjacent first side **40***a*.
(42) Each of the output conductors **53** has a third extending portion **53***a* extending in a band shape along the first side **40***a* and a third element joint portion **53***b* provided at one end of the third extending portion **53***a*. The third element joint portions **53***b* are arranged in parallel with the first side **40***a* at a center portion of the substrate **40**, and each third extending portion **53***a* is formed with a length according to arrangement of the third element joint portions **53***b*.
(43) Each of the first extending portion **51***a*, the second extending portion **52***a*, and the third extending portions **53***a* extends outward of the substrate **40** from one of the short sides (second sides **40***b*) of the substrate **40**. With this configuration, these end portions on one side protrude from the substrate **40** to form connection terminals.
(44) Three switching conductors **54** on each first side **40***a* are formed at intervals at the edge of the substrate **40**.
(45) The lower surface of each upper arm switching element **30**U is soldered onto a corresponding one of the first element joint portions **51***b* of the positive-side conductor **51**. In this way, the collector electrode **30***a* of each upper arm switching element **30**U is connected to the positive-side main line **21**.
(46) The emitter electrode **30***b* of each upper arm switching element **30**U is connected to the output conductor **53** of the corresponding one of the phases via a first bonding wire **55***a*. In this way, the emitter electrode **30***b* of each upper arm switching element **30**U is connected to the output line **24**. The base electrode **30***c* of each upper arm switching element **30**U is connected to a corresponding one of the switching conductors **54** via a second bonding wire **55***b*.
(47) The lower surface of each lower arm switching element **30**L is soldered onto the third element joint portion **53***b* of the output conductor **53** of the corresponding one of the phases. In this way, the collector electrode **30***a* of each lower arm switching element **30**L is connected to the output line **24** of the corresponding one of the phases.
(48) The emitter electrode **30***b* of each lower arm switching element **30**L is connected to the negative-side conductor **52** via a third bonding wire **55***c*. In this way, the collector electrode **30***a* of each lower arm switching element **30**L is connected to the negative-side main line **22**.
(49) The base electrode **30***c* of each lower arm switching element **30**L is connected to a corresponding one of the switching conductors **54** via a fourth bonding wire **55***d*. Each switching conductor **54** is provided to switch whether to flow current in a current path between the collector electrode **30***a* and the emitter electrode **30***b*.
(50) As described above, a group of the first element joint portions **51***b* and the third element joint portions **53***b* is arranged at the center portion of the substrate **40**. Accordingly, the upper arm switching elements **30**U and the lower arm switching elements **30**L are concentratedly arranged in a center portion on the upper surface of the substrate **40**.
(51) (Problems in Unimproved Inverter)
(52) The unimproved inverter **1** has various problems such as common mode noise.
(53) The output conductor **53** of each phase (particularly, a portion of the output conductor **53** in which the collector electrode **30***a* of the lower arm switching element **30**L is present, and a midpoint portion **56**) faces the heat sink **42** via the substrate **40**. The heat sink **42** is grounded by being attached to the in-vehicle cooler **43**. Accordingly, as shown in FIG. **3** in close-up, a predetermined stray capacitance is formed at the midpoint portion **56** (for the sake of convenience, the stray capacitance is expressed as a first virtual capacitor C**1**).
(54) The in-vehicle battery **2** is supported in a floating state. Thus, a certain stray capacitance

(second virtual capacitor C**2**) exists between the battery **2** and the ground, as illustrated in FIG. **1**.
(55) When the unimproved inverter **1** operates, each switching element **30** is turned on or off at the predetermined drive frequency by the switching control. Accordingly, a rectangular-waved high voltage including a harmonic component is applied to the midpoint portion **56**, and therefore, voltage intermittently changes in the output conductor **53**.
(56) Accordingly, common mode current flows via a current path passing through the first virtual capacitor C**1** and the second virtual capacitor C**2**, as indicated by an arrow Ic in FIG. **1**. As a result, the common mode noise occurs.
(57) The rated voltage of the battery **2** is, for example, a high voltage of 40 V or more or 300 V or more. Thus, a voltage change at the midpoint portion **56** is great, and consequently, the common mode current and the common mode noise are also great.
(58) Great current periodically flows in the DC link **10** by the switching control. That is, such high-frequency great current generates normal mode current. As a result, normal mode noise occurs.
(59) The smoothing capacitor **13** suppresses such normal mode current. That is, great current (ripple current) flows in the smoothing capacitor **13** by the switching control. In this manner, a high-frequency impedance between positive and negative supply powers from the battery **2** can be reduced.
(60) Thus, it is inevitable that the smoothing capacitor **13** is increased in size in order to suppress the normal mode current.
(61) The smoothing capacitor **13** generates heat due to a power loss caused by the ripple current and internal resistance. However, it is difficult for the smoothing capacitor **13**, which is the large film capacitor, to radiate heat.
(62) For these reasons, heat generation needs to be suppressed by reduction in the internal resistance in order to suppress an increase in the temperature of the smoothing capacitor **13** for the sake of ensuring reliability. Thus, the capacitance of the smoothing capacitor **13** needs to be an excessive value more than necessary. For example, a capacitance of about 500 μF is required. For this reason, the smoothing capacitor **13** is expensive, and is a great cause for an inverter cost increase.
(63) Generally, the positive-side junction line **11** and the negative-side junction line **12** are bus bars (rod- or plate-shaped metal conductor for great current). Thus, parasitic inductances (indicated by virtual inductors L in FIG. **1**) in these bus bars are great. There is a junction capacitance in each switching element **30**.
(64) When the switching control is performed, resonance occurs among these inductors L and these junction capacitances. Accordingly, small vibration (ringing) occurs in the waveforms of the operating current and voltage of each switching element **30**, as indicated by the arrow Y**1** in FIG. **1**.
(65) As the switching control is speeded up, more specifically as the time of transition in switching is shortened, the amplitude of the ringing increases. The ringing includes a high frequency component. Thus, the ringing is a cause for the normal mode noise and the common mode noise.
(66) Further, the ringing causes surge voltage with great overshoot to the positive or negative side of the battery **2**. When such surge voltage exceeds the withstand voltage limit of the switching element **30**, the semiconductor of the switching element **30** is damaged.
(67) Thus, for each switching element **30**, a withstand voltage property sufficiently higher than the voltage of the battery **2** with a sufficient allowance against such voltage is required. For this reason, it is also inevitable that the switching element **30** is expensive.
(68) <Improved Inverter, Improved Module (First Embodiment)>
(69) FIGS. **4** and **5** illustrate, as an example, a switching module (improved module **120**) to which the technique disclosed herein is applied. FIG. **4** is a view corresponding to FIG. **2**. FIG. **5** is a view corresponding to FIG. **3**.
(70) A basic structure of the improved module **120** is the same as that of the unimproved module **20**. Thus, the like reference numerals are used to represent members having the like configurations,

and description thereof will be simplified or omitted.
(71) The improved module **120** is different from the unimproved module **20** particularly in that a storage structure **63** according to the present disclosure is provided in the substrate. Hereinafter, differences, which include the difference in the substrate (improved substrate **140**), from the unimproved module **20** will be described in detail.
(72) As illustrated in FIGS. **4** and **5**, the positive-side conductor **51** has, in addition to the first extending portion **51***a* and the first element joint portion **51***b*, four first outwardly-projecting portions **51***c* formed at intervals and projecting from the outer edge of the first extending portion **51***a* toward the adjacent first side **40***a* and a first side end portion **51***d* extending in contact with the end surface of the first side **40***a*, and bridging the projecting ends of the first outwardly-projecting portions **51***c*.
(73) The negative-side conductor **52** has, in addition to the second extending portion **52***a*, four second outwardly-projecting portions **52***b* formed at intervals and projecting from the outer edge of the second extending portion **52***a* toward the adjacent first side **40***a* and a second side end portion **52***c* extending in contact with the end surface of the first side **40***a* and bridging the projecting ends of the second outwardly-projecting portions **52***b*.
(74) (Improved Substrate **140**)
(75) The improved substrate **140** includes a plurality of electric insulating layers **60**, a plurality of positive-side electric conductive layers **61** connected to the positive-side conductor **51**, and a plurality of negative-side electric conductive layers **62** connected to the negative-side conductor **52**.
(76) Each positive-side electric conductive layer **61** and each negative-side electric conductive layer **62** face each other via the electric insulating layer **60**. With this configuration, the storage structure **63** interposed between the positive-side main line **21** and the negative-side main line **22** and capable of storing electric charges is provided inside the improved substrate **140**.
(77) More specifically, each of the positive-side electric conductive layers **61** and the negative-side electric conductive layers **62** is formed in a rectangular thin film shape having the substantially same size as that of the improved substrate **140**, as illustrated in FIG. **6**. Each of the positive-side electric conductive layers **61** and the negative-side electric conductive layers **62** has a rectangular opening **64** in a center portion thereof. The opening **64** is formed such that the group of the first element joint portions **51***b* and the third element joint portions **53***b* is accommodated inside the opening **64**.
(78) The improved substrate **140** in this case includes two positive-side electric conductive layers **61** and three negative-side electric conductive layers **62**. The positive-side electric conductive layers **61** and the negative-side electric conductive layers **62** are alternately formed in parallel with the upper and lower surfaces of the improved substrate **140**.
(79) More specifically, the improved substrate **140** is configured such that the electric insulating layer **60**, the negative-side electric conductive layer **62**, the electric insulating layer **60**, the positive-side electric conductive layer **61**, the electric insulating layer **60**, the negative-side electric conductive layer **62**, the electric insulating layer **60**, the positive-side electric conductive layer **61**, the electric insulating layer **60**, the negative-side electric conductive layer **62**, and the electric insulating layer **60** are stacked in this order. With this configuration, each positive-side electric conductive layer **61** and each negative-side electric conductive layer **62** face each other in the thickness direction of the improved substrate **140** via the electric insulating layer **60** at an outer edge portion of the improved substrate **140**.
(80) As illustrated in FIG. **5** in close-up, each positive-side electric conductive layer **61** is connected to a positive-side conductive end **65** provided at the end surface of one first side **40***a*. Each negative-side electric conductive layer **62** is connected to a negative-side conductive end **66** provided at the end surface of the other first side **40***a*. The positive-side conductive end **65** is soldered to the first side end portions **51***d*. The negative-side conductive end **66** is soldered to the second side end portions **52***c*.

(81) The size of the short side of each of the positive-side electric conductive layers **61** and the negative-side electric conductive layers **62** is slightly smaller than the size of the short side (second side **40***b*) of the improved substrate **140**. Thus, the protruding end of each positive-side electric conductive layer **61** is positioned with a margin from the end surface of the other first side **40***a*. The protruding end of each negative-side electric conductive layer **62** is positioned with a margin from the end surface of the one first side **40***a*.
(82) With this configuration, the storage structure **63** interposed between the positive-side main line **21** and the negative-side main line **22** and capable of storing electric charges is provided inside the improved substrate **140**. More specifically, a group of positive-side electric conductive layers **61** and a group of negative-side electric conductive layers **62** formed with the electric insulating layers **60** interlayered therebetween form a structure having a certain capacitance and functioning as a smoothing capacitor.
(83) (Details of Improved Substrate **140**)
(84) Each switching element **30** generates heat due to the switching control. The improved substrate **140** transfers such heat to the heat sink **42**, and the heat sink **42** radiates the heat. Thus, it is preferable that the improved substrate **140** have excellent thermal conductivity. For this reason, it is preferable that the thickness of the improved substrate **140** be thin. For example, the thickness may be preferably 1 mm or less.
(85) On the other hand, it is preferable that the capacitance of the electric insulating layer **60** be high, for the sake of the storage structure **63**. For this reason, the material of the improved substrate **140** may be preferably one having a high permittivity.
(86) The improved substrate **140** is made of a ceramic material. Generally, aluminum oxide is used as the ceramic material. The thermal conductivity of aluminum oxide is approximately 23 to 36 W/m.Math.k, and the relative permittivity of aluminum oxide is approximately 9.5 to 9.7.
(87) In the case of the improved substrate **140**, it is preferable that both the thermal conductivity and the permittivity thereof be high, as described above. Thus, the improved substrate **140** may be preferably made of such a ceramic material that a material (high permittivity material) having a higher relative permittivity than that of aluminum oxide and a material (high thermal conductive material) having a higher thermal conductivity than that of aluminum oxide are mixed at a predetermined ratio.
(88) Examples of the high permittivity material may include zirconia, titanium oxide, and barium titanate. Examples of the high thermal conductive material may include silicon carbide and aluminum nitride. Particularly, the high permittivity material may be preferably barium titanate having an extremely-high relative permittivity (with a relative permittivity of 1500), and the high thermal conductive material may be preferably aluminum nitride having an extremely-high thermal conductivity (with a thermal conductivity of 90 to 200).
(89) With the configuration in which the high thermal conductive material and the high permittivity material are mixed at the ratio suitable for the improved substrate **140**, the improved substrate **140** can be obtained with optimal thermal conductivity and permittivity.
(90) (Manufacturing of Improved Substrate **140**)
(91) Each of the positive-side electric conductive layers **61** and the negative-side electric conductive layers **62** is preferably made of silver paste. With this configuration, the improved substrate **140** can be manufactured by a well-known method for a laminated ceramic capacitor. FIG. **7** illustrates one example of such a method.
(92) As illustrated in (a) of FIG. **7**, a thin plate **70** in a paste form is formed from the predetermined ceramic material, which will be the electric insulating layer **60**. After that, as illustrated in (b) of FIG. **7**, a thin layer **71** made of silver paste, which will be the positive-side electric conductive layer **61**, is printed on the thin plate **70**. As illustrated in (c) of FIG. **7**, a thin plate **70** in a paste form is further formed thereon from the predetermined ceramic material, which will be the electric insulating layer **60**.

(93) As illustrated in (d) of FIG. **7**, a thin layer **71** made of silver paste, which will be the negative-side electric conductive layer **62**, is further printed on the thin plate **70**. After that, as illustrated in (e) of FIG. **7**, a thin plate **70** in a paste form is further formed on the thin layer **71** using the predetermined ceramic material for the electric insulating layer **60**.
(94) A predetermined laminated structure is formed by repetition of the above-described process. Thereafter, the laminated structure is solidified by pressing and sintering, and in this manner, an intermediate of the improved substrate **140** is formed. For example, each end surface of the first sides **40***a* of the formed intermediate of the improved substrate **140** is plated with nickel. After that, each of the positive-side conductive end **65** and the negative-side conductive end **66** is fabricated, and in this manner, the improved substrate **140** is completed.
(95) (Effects of Improved Substrate **140**)
(96) The storage structure **63**, i.e., the group of the positive-side electric conductive layers **61** and the negative-side electric conductive layers **62** facing each other via the electric insulating layers **60**, formed in the improved substrate **140** functions as a virtual capacitor Ci capable of replacing the smoothing capacitor **13** in the circuit of the improved module **120**.
(97) FIG. **8** illustrates, as an example, a circuit configuration of an improved inverter **100**. In the improved module **120**, the virtual capacitor Ci is equivalent to a group of element capacitors connected to both positive and negative-side end portions of each half-bridge circuit **23**. That is, the virtual capacitor Ci is connected in parallel with the smoothing capacitor **13** in the circuit of the improved inverter **100**, and the storage structure **63** of the improved substrate **140** fulfills the same function as that of the smoothing capacitor **13**.
(98) Thus, as illustrated in the upper view of FIG. **8**, the smoothing capacitor **13** can be miniaturized, and part thereof can be replaced with the storage structure **63**. Further, as illustrated in the lower view of FIG. **8**, the smoothing capacitor **13** can be omitted if the storage structure **63** fulfills all the functions of the smoothing capacitor **13**. As a result, the inverter cost can be reduced.
(99) Unlike the smoothing capacitor **13**, heat generated due to the ripple current can be transferred to the heat sink **42** and be radiated from the heat sink **42** in the case of the storage structure **63**. Thus, there is no necessity of excessively increasing the capacitance and decreasing an equivalent series resistance (ESR). A capacitance of approximately 500 uF is required for the smoothing capacitor **13** of the unimproved inverter **1**, but the capacitance can be approximately 10 μF to 50 μF in the case of the storage structure **63**.
(100) In the case of the improved substrate **140**, the storage structure **63** is provided at the outer edge portion of the improved substrate **140**, and the group of the switching elements **30** and the storage structure **63** do not overlap with each other. Thus, when the switching control is performed, heat from all the storage structure **63** and the switching elements **30** can be efficiently transferred to the heat sink **42** and radiated from the heat sink **42** although the storage structure **63** and the switching elements **30** generate the heat.
(101) In the case of the storage structure **63**, an electric connection length between the storage structure **63** and each switching element **30** is extremely shorter than that between the smoothing capacitor **13** and each switching element **30**. Thus, a parasitic inductance due to wiring at such a portion is also extremely low. As a result, almost no ringing and surge voltage as illustrated in FIG. **1** are caused.
(102) That is, in the improved inverter **100** employing the improved module **120**, the normal mode noise and the common mode noise can be effectively suppressed. The withstand voltage of each switching element **30** can also be lowered.
(103) <Improved Inverter, Improved Module (Second Embodiment)>
(104) FIG. **9** illustrates, as an example, a second embodiment (second improved module **220**) of the switching module to which the technique disclosed herein is applied. FIG. **9** is a view corresponding to FIG. **5**.
(105) A basic structure of the second improved module **220** is the same as that of the improved

module **120**. Thus, the like reference numerals are used to represent members having the like configurations, and description thereof will be simplified or omitted. The second improved module **220** is different from the improved module **120** in that no opening **64** is formed in the center portion of each of the positive-side electric conductive layers **61** and the negative-side electric conductive layers **62**.

(106) More specifically, each of the two positive-side electric conductive layers **61** and the three negative-side electric conductive layers **62** in the improved substrate **140** (second improved substrate **240**) of the second improved module **220** is formed in a rectangular thin film shape having the substantially same size as that of the improved substrate **140**, and is provided over the entire area of the second improved substrate **240**.

(107) The positive-side electric conductive layers **61** and the negative-side electric conductive layers **62** are alternately formed in parallel with the upper and lower surfaces of the second improved substrate **240**. With this configuration, each positive-side electric conductive layer **61** and each negative-side electric conductive layer **62** face each other in the thickness direction of the second improved substrate **240** via the electric insulating layer **60** over the substantially entirety of the second improved substrate **240**.

(108) In the case of the second improved module **220**, the storage structure **63** is provided over almost entirety of the second improved substrate **240**. Thus, the storage structure **63** is interposed between the heat sink **42** and a large portion of each output conductor **53** including the midpoint portion **56** where the input-side electrode of the lower arm switching element **30**L is positioned.

(109) Thus, the flow of common mode current can be prevented, and occurrence of the common mode noise can be prevented. Reasons are detailed as follows.

(110) When the switching control is performed, each switching element **30** is turned on or off at a predetermined timing. Accordingly, the voltage periodically greatly changes at each output conductor **53**, particularly at the midpoint portion **56** where the input-side electrode of the lower arm switching element **30**L is positioned. Thus, the common mode current flows in the unimproved inverter **1**, and the common mode noise occurs therein, as illustrated in FIG. **1**.

(111) On the other hand, in the case of the second improved module **220**, a first virtual capacitor C**11** including the electric insulating layer **60** as a dielectric is provided between the uppermost negative-side electric conductive layer **62** in the second improved substrate **240** and each output conductor **53**, as illustrated in FIG. **9** in close-up. Moreover, a second virtual capacitor C**21** including the electric insulating layer **60** as a dielectric is also provided between the lowermost negative-side electric conductive layer **62** in the improved substrate **140** and the heat sink **42**.

(112) FIG. **10** illustrates, as an example, a circuit diagram of an inverter (second improved inverter **200**) to which the second improved module **220** is applied. Here, one of the half-bridge circuits **23** will be described as an example, but the other half-bridge circuits **23** operate in the same manner, except that the phases thereof are shifted from those of the one described below.

(113) When the lower arm switching element **30**L is OFF, the upper arm switching element **30**U is ON. Accordingly, current flows as indicated by Ion, and the first virtual capacitor C**11** is supplied and charged with the voltage of the battery **2**. At this time, the uppermost negative-side electric conductive layer **62** forming the first virtual capacitor C**11** is electrically connected to the negative electrode side of the battery **2**. Thus, the uppermost negative-side electric conductive layer **62** is at the same potential as that at the negative electrode of the battery **2**.

(114) When the lower arm switching element **30**L is ON, the upper arm switching element **30**U is OFF. Accordingly, current flows as indicated by Ioff, and the charge accumulated in the first virtual capacitor C**11** is discharged through a current path passing through the uppermost negative-side electric conductive layer **62**. Thus, the uppermost negative-side electric conductive layer **62** is also at the same potential as that at the negative electrode of the battery **2**.

(115) The uppermost negative-side electric conductive layer **62** is held at the potential at the negative electrode of the battery **2** regardless of whether the switching element is turned on or off.

That is, the potential of the uppermost negative-side electric conductive layer **62** does not change even when the switching control is performed. There is no potential difference between the lowermost negative-side electric conductive layer **62** and the heat sink **42**.
(116) That is, since the midpoint portion **56** where a voltage change is great faces the negative-side electric conductive layer **62**, whose potential does not change, via the electric insulating layer **60**, no charge is accumulated in the second virtual capacitor C**21** even when the switching control is performed.
(117) On this point, the potential may only be required to be kept constant, and therefore, the midpoint portion **56** does not necessarily face the negative-side electric conductive layer **62**, but may face the uppermost positive-side electric conductive layer **61** via the electric insulating layer **60**.
(118) No current flows in a current path passing through the first virtual capacitor C**11** and the second virtual capacitor C**21**. A common mode current value is zero. Thus, according to the second improved inverter **200**, almost entire common mode noise can be eliminated.
(119) <Modifications of Improved Substrate>
(120) Next, modifications (modified substrates) of the improved substrate will be described as examples. The modified substrate may be applied to the above-described improved inverter **100** and improved module **120** or the above-described second improved inverter **200** and second improved module **220**.
(121) (First Modified Substrate)
(122) FIG. **11** illustrates, as an example, a first modified substrate **80**. The first modified substrate **80** illustrated therein is modified based on the second improved substrate **240**.
(123) The first modified substrate **80** is different from the second improved substrate **240** in the structure of the electric insulating layer **60**. The electric insulating layers **60** of the first modified substrate **80** are made of two different materials and are divided into a plurality of portions.
(124) That is, the first modified substrate **80** has portions (first portions **81**) made of a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide and portions (second portions **82**) made of a high permittivity material having a higher relative permittivity than that of aluminum oxide.
(125) The first portion **81** is made of aluminum nitride, for example. The second portion **82** is made of barium titanate, for example.
(126) The entirely-homogeneous electric insulating layers **60** (covering layers **83**) are formed as a pair of outermost layers forming both surfaces (front and back surfaces) of the first modified substrate **80**. The covering layer **83** may be made of aluminum oxide, but preferably has excellent thermal conductivity in preference to the permittivity. Thus, in the illustrated example, the same material as that of the first portion **81** is used.
(127) As each electric insulating layer **60** positioned between these covering layers **83**, the first portions **81** and the second portions **82** are separately formed in a mixed manner. For example, each of the first portions **81** and the second portions **82** illustrated in FIG. **11** is formed, as illustrated in (a) of FIG. **12**, in a linear shape when the first modified substrate **80** is viewed in plane, and these portions **81**, **82** are alternately arranged in a stripe pattern.
(128) The first portions **81** and the second portions **82** are not limited to arrangement in the stripe pattern, and arrangement thereof can be selected as necessary according to the specifications of the substrate **40**. For example, in a case where the first modified substrate **80** is the above-described improved substrate **140**, the second portion **82** having a high permittivity may be arranged at the outer edge portion, where the storage structure **63** is provided, of the improved substrate **140**, and the first portion **81** having a high thermal conductivity may be arranged at the center portion, where the group of the switching elements **30** is positioned, of the improved substrate **140**, as illustrated in (b) of FIG. **12**.
(129) The first portions **81** and the second portions **82** may be arranged in a checkerboard pattern,

as illustrated in (c) of FIG. **12**. As an alternative, many first portions **81** arranged in a circular pattern may be provided in the second portion **82** when the first modified substrate **80** is viewed in plane, or conversely, many second portions **82** arranged in a circular pattern may be provided in the first portion **81** when the first modified substrate **80** is viewed in plane.

(130) With the configuration in which the electric insulating layers **60** are made of the two materials having different properties as described above, a high thermal conductivity and a great capacitance value of the storage structure **63** can be ensured in the first modified substrate **80**.

(131) (Second Modified Substrate)

(132) FIG. **13** illustrates a second modified substrate **90**. The second modified substrate **90** is different from the improved substrate **140**, the second improved substrate **240**, and the first modified substrate **80** in terms of the structures of the positive-side electric conductive layer **61**, the negative-side electric conductive layer **62**, and the electric insulating layer **60**.

(133) As in the first modified substrate **80**, the second modified substrate **90** is also configured such that the electric insulating layers **60** are made of two different materials and are divided into a plurality of portions.

(134) That is, the second modified substrate **90** has portions (first portions **91**) made of a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide and portions (second portions **92**) made of a high permittivity material having a higher relative permittivity than that of aluminum oxide. The first portion **91** is made of aluminum nitride, for example. The second portion **92** is made of barium titanate, for example.

(135) Further, the entirely-homogeneous electric insulating layers **60** (covering layers **93**) are provided as a pair of outermost layers forming both surfaces (front and back surfaces) of the second modified substrate **90**. The covering layer **93** may be made of aluminum oxide, but may be preferably configured as having excellent thermal conductivity in preference to the permittivity. Thus, in the illustrated example, the same material as that of the first portion **91** is used.

(136) The positive-side electric conductive layer **61** and the negative-side electric conductive layer **62** include a positive-side parallel layer **61***a*, and a negative-side parallel layer **62***a*, respectively, and a plurality of positive-side orthogonal layers **61***b*, and a plurality of negative-side orthogonal layers **62***b*, respectively. In other words, the positive-side electric conductive layer **61** includes the positive-side parallel layer **61***a* and the plurality of positive-side orthogonal layers **61***b*, and the negative-side electric conductive layer **62** includes the negative-side parallel layer **62***a* and the plurality of negative-side orthogonal layers **62***b*.

(137) One positive-side parallel layer **61***a* and one negative-side parallel layer **62***a* are provided for the second modified substrate **90**. In the illustrated example, the positive-side parallel layer **61***a* extends so as to face the lower surface of the second modified substrate **90** via the outermost electric insulating layer **60** (covering layer **93**), and the negative-side parallel layer **62***a* extends so as to face the upper surface of the second modified substrate **90** via the outermost electric insulating layer **60** (covering layer **93**).

(138) The plurality of positive-side orthogonal layers **61***b* and the plurality of negative-side orthogonal layers **62***b* are orthogonal to the positive-side parallel layer **61***a* and the negative-side parallel layer **62***a*, and are alternately provided so as to extend in parallel with either one of the right and left end surfaces of the second modified substrate **90** (in the illustrated example, the end surface of the first side **40***a* as the long side).

(139) In other words, the plurality of positive-side orthogonal layers **61***b* is orthogonal to the positive-side parallel layer **61***a* and the negative-side parallel layer **62***a*, and is provided alternately with the negative-side orthogonal layers **62***b* so as to extend in parallel with the end surface of the first side **40***a* of the second modified substrate **90**. Similarly, the plurality of negative-side orthogonal layers **62***b* is orthogonal to the positive-side parallel layer **61***a* and the negative-side parallel layer **62***a*, and is provided alternately with the positive-side orthogonal layers **61***b* so as to extend in parallel with the end surface of the first side **40***a* of the second modified substrate **90**.

(140) These positive-side orthogonal layers **61***b* and negative-side orthogonal layers **62***b* face each other via the electric insulating layers **60** interlayered therebetween in a direction (side direction) orthogonal to the thickness direction of the second modified substrate **90**, thereby forming the storage structure **63**.
(141) One end of the positive-side parallel layer **61***a* extends to the end surface of the right first side **40***a*, but does not extend to the end surface of the left first side **40***a*. Similarly, one end of the negative-side parallel layer **62***a* extends to the end surface of the left first side **40***a*, but does not extend to the end surface of the right first side **40***a*. The protruding end of the positive-side orthogonal layer **61***b* and the negative-side parallel layer **62***a* are insulated from each other by an insulator **94**. The protruding end of the negative-side orthogonal layer **62***b* and the positive-side parallel layer **61***a* are also insulated from each other by an insulator **94**.
(142) The positive-side conductive end **65** covering the end surface of the right first side **40***a* is formed on such an end surface. The negative-side conductive end **66** covering the end surface of the left first side **40***a* is formed on such an end surface. The positive-side conductive end **65** is connected to the positive-side parallel layer **61***a*, and the negative-side conductive end **66** is connected to the negative-side parallel layer **62***a*.
(143) The electric insulating layers **60** are provided such that each of the first portions **91** and the second portions **92** is separately formed between the positive-side orthogonal layer **61***b* and the negative-side orthogonal layer **62***b* in a mixed manner. More specifically, the positive-side orthogonal layers **61***b* and the negative-side orthogonal layers **62***b* are alternately arranged in the side direction, and the first portion **91** or the second portion **92** is formed between the positive-side orthogonal layer **61***b* and the negative-side orthogonal layer **62***b* in an alternate manner.
(144) The storage structure **63** formed in the second modified substrate **90**, i.e., the group of the positive-side orthogonal layers **61***b* and the negative-side orthogonal layers **62***b* facing each other via the electric insulating layers **60**, functions as the above-described virtual capacitor Ci. In addition, as in the first modified substrate **80**, the electric insulating layers **60** are separately provided as the first portions **91** and the second portions **92**, and therefore, both a high thermal conductivity and a high capacitance can be ensured.
(145) In the case of the second modified substrate **90**, the storage structure **63** is preferably provided over the entire area of the second modified substrate **90**. Moreover, the midpoint portion **56** preferably faces the negative-side parallel layer **62***a* (may face the positive-side parallel layer **61***a*) via the electric insulating layer **60**.
(146) With this configuration, no charge is accumulated between the midpoint portion **56** and the negative-side parallel layer **62***a*, and therefore, the common mode noise can be prevented, as described above.
(147) FIG. **14** illustrates, as an example, a method for manufacturing the second modified substrate **90**. In the case of the first modified substrate **80**, the different materials need to be combined to form the single piece of thin plate **70**. However, the second modified substrate **90** can be manufactured by a combination of existing methods. The second modified substrate **90** can be relatively easily mass-produced.
(148) As illustrated in the upper view of (a) of FIG. **14**, a thin plate **70** in a paste form is formed from a high thermal conductive material. Silver paste is printed to form a thin layer **71** on the thin plate **70**. As illustrated in the lower view of (a) of FIG. **14**, a thin plate **70** in a paste form is further formed on the thin layer **71** from a high permittivity material. Silver paste is further printed to form a thin layer **71** on the thin plate **70**. This process is repeated a predetermined number of times. Thereafter, the resultant is solidified by pressing and sintering, and in this manner, a mass lamination is formed as illustrated in (b) of FIG. **14**.
(149) The mass lamination is sliced into a size corresponding to the thickness of the second modified substrate **90** along a direction orthogonal to a lamination direction, as indicated by the arrow Y**2** in (b) of FIG. **14**. Then, a first intermediate **72** of the second modified substrate **90** is

obtained as illustrated in (c) of FIG. **14**.

(150) Next, as illustrated in (d) of FIG. **14**, an insulator **94** is printed on both surfaces of the first intermediate **72** to cover the positive-side orthogonal layer **61***b* exposed on the upper side and cover the negative-side orthogonal layer **62***b* exposed on the lower side.

(151) Next, as illustrated in (e) of FIG. **14**, a thin layer **71** of silver paste is printed on both surfaces of the first intermediate **72** to form the negative-side parallel layer **62***a* on the upper side and form the positive-side parallel layer **61***a* on the lower side. Thereafter, as illustrated in (f) of FIG. **14**, a thin plate **70** in a paste form is formed on both sides of the first intermediate **72** from a high thermal conductive material. Then, the resultant is solidified by pressing and sintering, and in this manner, a second intermediate **73** is formed.

(152) Thereafter, each end surface of the first sides **40***a* of the second intermediate **73** is plated with nickel, for example. After that, each of the positive-side conductive end **65** and the negative-side conductive end **66** is fabricated, and in this manner, the second modified substrate **90** is completed.

(153) <Effects of Disclosed Technique, Application, Etc.>

(154) As described above, according to the technique disclosed herein, the large expensive smoothing capacitor **13** essential for the unimproved module **20** can be replaced with the storage structure **63** provided in the substrate **40**. In other words, the easily-coolable smoothing capacitor **13** can be formed using existing members. Thus, the smoothing capacitor can be miniaturized or be omitted, which the function that the smoothing capacitor provides is maintained. As a result, the inverter cost can be reduced, and the inverter can be less expensive.

(155) The parasitic inductance of the DC link **10** is eliminated, and the adversely-affecting ringing due to the switching control is reduced. Thus, the normal mode noise can be suppressed. Furthermore, with the configuration in which the midpoint portion **56** where a voltage change in the half-bridge circuit **23** is great and the heat sink **42** are blocked from each other via the conductive layer with the stable potential, the common mode current path can be blocked and, consequently, the common mode noise can be effectively suppressed. Thus, the function of the inverter can be improved.

(156) Furthermore, with the configuration in which the electric insulating layer **60** is configured with the high thermal conductive material and the high permittivity material in combination as above, both high thermal conductivity and capacitance of the substrate **40** can be attained. The function of the inverter can be further improved.

(157) The disclosed technique is not limited to the embodiments and also includes various other configurations. For example, a well-known semiconductor chip such as a MOSFET, a bipolar transistor, an IGBT, or GaN can be applied to the switching element **30**.

(158) The number of positive-side electric conductive layers **61** and the number of negative-side electric conductive layers **62** described or illustrated herein are merely examples. The number of formed positive-side orthogonal layers **61***b* and the number of formed negative-side orthogonal layers **62***b* described or illustrated herein are one example. The arrangement, shapes, etc. of the layers in the storage structure may be improved in accordance with specifications as required.

(159) The technique disclosed herein is suitably applicable to in-vehicle inverters, but is also applicable to other types of electric equipment.

DESCRIPTION OF REFERENCE CHARACTERS

(160) **1** Unimproved Inverter **2** Battery **3** Motor **10** DC Link **11** Positive-Side Junction Line **12** Negative-Side Junction Line **13** Smoothing Capacitor **20** Unimproved Module **21** Positive-Side Main Line **22** Negative-Side Main Line **23** Half-Bridge Circuit **24** Output Line **25** Free Wheel Diode **30** Switching Element **30***a* Collector Electrode (Input-Side Electrode) **30***b* Emitter Electrode (Output-Side Electrode) **30***c* Base Electrode (Control Electrode) **30**U Upper Arm Switching Element **30**L Lower Arm Switching Element **40** Substrate (Electric Insulating Member) **41** Case Cover **42** Heat Sink (Heat Radiation Member) **43** Cooler **51** Positive-Side Conductor **51***a* First Extending Portion **51***b* First Element Joint Portion **51***c* First Outwardly-Projecting Portion **51***d* First

Side End Portion **52** Negative-Side Conductor **52***a* Second Extending Portion **52***b* Second Outwardly-Projecting Portion **52***c* Second Side End Portion **53** Output Conductor **53***a* Third Extending Portion **53***b* Third Element Joint Portion **54** Switching Conductor **56** Midpoint Portion **60** Electric Insulating Layer **61** Positive-Side Electric Conductive Layer **61***a* Positive-Side Parallel Layer **61***b* Positive-Side Orthogonal Layer **62** Positive-Side electric conductive layer **62***a* Negative-Side Parallel Layer **62***b* Negative-Side Orthogonal Layer **63** Storage Structure **64** Opening **65** Positive-Side Conductive End **66** Positive-Side Conductive End **80** First Modified Substrate **81** First Portion **82** Second Portion **83** Covering Layer **90** Second Modified Substrate **91** First Portion **92** Second Portion **93** Covering Layer **94** Insulator **100** Improved Inverter **120** Improved Module **140** Improved Substrate **200** Second Improved Inverter **220** Second Improved Module **240** Second Improved Substrate

Claims

1. A switching module, on which switching control is performed, and which includes positive and negative-side main lines each connected respectively to positive and negative electrodes of a battery, a plurality of half-bridge circuits, each of which includes upper and lower arm switching elements connected in series in an order from a positive-side main line side between the positive and negative-side main lines, and a plurality of output lines, each of which is connected between the upper and lower arm switching elements in a corresponding one of the half-bridge circuits, the switching module comprising: a positive-side conductor in contact with an input-side electrode provided on a lower surface of each upper arm switching element and forming the positive-side main line; a negative-side conductor connected to an output-side electrode of each lower arm switching element and forming the negative-side main line; an output conductor in contact with the input-side electrode provided on the lower surface of each lower arm switching element and forming each output line; and an electric insulating member being in contact with, at an upper surface thereof, each of the positive-side conductor, the negative-side conductor, and the output conductor and being in contact with, at a lower surface thereof, a heat radiation member having electrical conductivity, wherein the electric insulating member includes: a plurality of positive-side electric conductive layers connected to the positive-side conductor; and a plurality of negative-side electric conductive layers connected to the negative-side conductor, wherein each positive-side electric conductive layer faces a corresponding one of the negative-side electric conductive layers via an electric insulating layer such that a storage structure capable of storing charges and interposed between the positive-side main line and the negative-side main line is provided inside the electric insulating member, wherein the positive-side electric conductive layers and the negative-side electric conductive layers include: positive and negative-side parallel layers extending so as to face the upper and lower surfaces of the electric insulating member via the electric insulating layer; and a plurality of positive-side orthogonal layers and a plurality of negative-side orthogonal layers, which are orthogonal to the positive-side parallel layer and the negative-side parallel layer and are alternately formed so as to extend in parallel with either one of end surfaces of the electric insulating member, and wherein the storage structure is such that the positive-side orthogonal layers and the negative-side orthogonal layers face each other via the electric insulating layer in a side direction orthogonal to a thickness direction of the electric insulating member.
2. The switching module of claim 1, wherein the storage structure is such that the positive-side electric conductive layers and the negative-side electric conductive layers are alternately formed so as to extend in parallel with the upper and lower surfaces of the electric insulating member, and the each positive-side electric conductive layer faces a corresponding one of the positive side negative-side electric conductive layers via the electric insulating layer in a thickness direction of the electric insulating member.

3. The switching module of claim 2, wherein the upper arm switching elements and the lower arm switching elements are concentratedly arranged in a center portion on the upper surface of the electric insulating member, and the storage structure is provided in an outer edge portion of the electric insulating member.
4. The switching module of claim 3, wherein the electric insulating member is made of such a ceramic material that a high permittivity material having a higher relative permittivity than that of aluminum oxide and a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide are mixed at a predetermined ratio.
5. The switching module of claim 2, wherein the storage structure is interposed between the heat radiation member and a midpoint portion where at least each lower arm switching element is positioned.
6. The switching module of claim 5, wherein the storage structure is provided over an entire area of the electric insulating member.
7. The switching module of claim 5, wherein the electric insulating member is made of such a ceramic material that a high permittivity material having a higher relative permittivity than that of aluminum oxide and a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide are mixed at a predetermined ratio.
8. The switching module of claim 2, wherein the electric insulating member is made of such a ceramic material that a high permittivity material having a higher relative permittivity than that of aluminum oxide and a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide are mixed at a predetermined ratio.
9. The switching module of claim 1, wherein the storage structure is interposed between the heat radiation member and a midpoint portion where at least each lower arm switching element is positioned.
10. The switching module of claim 9, wherein the midpoint portion faces the positive-side parallel layer or the negative-side parallel layer via the electric insulating layer.
11. The switching module of claim 10, wherein the storage structure is provided over an entire area of the electric insulating member.
12. The switching module of claim 1, wherein the electric insulating member is made of such a ceramic material that a high permittivity material having a higher relative permittivity than that of aluminum oxide and a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide are mixed at a predetermined ratio.
13. The switching module of claim 12, wherein the high thermal conductive material is aluminum nitride, and the high permittivity material is barium titanate.
14. The switching module of claim 1, wherein the electric insulating member has: a first portion made of a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide, and a second portion made of a high permittivity material having a higher relative permittivity than that of aluminum oxide.
15. The switching module of claim 14, wherein the high thermal conductive material is aluminum nitride, and the high permittivity material is barium titanate.
16. An inverter for being interposed between a battery and a motor to drive the motor with power supplied from the battery, comprising: the switching module of claim 1; and a DC link interposed between the battery and each of the positive-side main line and the negative-side main line, the DC link including: a positive-side junction line interposed between the positive-side main line and the positive electrode of the battery; and a negative-side junction line interposed between the negative-side main line and the negative electrode side of the battery; and a smoothing capacitor bridging between the positive-side junction line and the negative-side junction line, and the storage structure also functioning as a smoothing capacitor in addition to the smoothing capacitor.
17. An inverter for being interposed between a battery and a motor to drive the motor with power supplied from the battery, comprising: the switching module of claim 1; and a DC link interposed

between the battery and each of the positive-side main line and the negative-side main line, the DC link including a positive-side junction line interposed between the positive-side main line and the positive electrode of the battery, and a negative-side junction line interposed between the negative-side main line and the negative electrode side of the battery, and the DC link including no smoothing capacitor, the storage structure functioning as a smoothing capacitor in replacement of smoothing capacitors.

18. A switching module, on which switching control is performed, and which includes positive and negative-side main lines each connected respectively to positive and negative electrodes of a battery, a plurality of half-bridge circuits, each of which includes upper and lower arm switching elements connected in series in an order from a positive-side main line side between the positive and negative-side main lines, and a plurality of output lines, each of which is connected between the upper and lower arm switching elements in a corresponding one of the half-bridge circuits, the switching module comprising: a positive-side conductor in contact with an input-side electrode provided on a lower surface of each upper arm switching element and forming the positive-side main line; a negative-side conductor connected to an output-side electrode of each lower arm switching element and forming the negative-side main line; an output conductor in contact with the input-side electrode provided on the lower surface of each lower arm switching element and forming each output line; and an electric insulating member being in contact with, at an upper surface thereof, each of the positive-side conductor, the negative-side conductor, and the output conductor and being in contact with, at a lower surface thereof, a heat radiation member having electrical conductivity, wherein the electric insulating member includes: a plurality of positive-side electric conductive layers connected to the positive-side conductor; and a plurality of negative-side electric conductive layers connected to the negative-side conductor, wherein each positive-side electric conductive layer faces a corresponding one of the negative-side electric conductive layers via an electric insulating layer such that a storage structure capable of storing charges and interposed between the positive-side main line and the negative-side main line is provided inside the electric insulating member, and wherein the electric insulating member is made of such a ceramic material that a high permittivity material having a higher relative permittivity than that of aluminum oxide and a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide are mixed at a predetermined ratio.

19. A switching module, on which switching control is performed, and which includes positive and negative-side main lines each connected respectively to positive and negative electrodes of a battery, a plurality of half-bridge circuits, each of which includes upper and lower arm switching elements connected in series in an order from a positive-side main line side between the positive and negative-side main lines, and a plurality of output lines, each of which is connected between the upper and lower arm switching elements in a corresponding one of the half-bridge circuits, the switching module comprising: a positive-side conductor in contact with an input-side electrode provided on a lower surface of each upper arm switching element and forming the positive-side main line; a negative-side conductor connected to an output-side electrode of each lower arm switching element and forming the negative-side main line; an output conductor in contact with the input-side electrode provided on the lower surface of each lower arm switching element and forming each output line; and an electric insulating member being in contact with, at an upper surface thereof, each of the positive-side conductor, the negative-side conductor, and the output conductor and being in contact with, at a lower surface thereof, a heat radiation member having electrical conductivity, wherein the electric insulating member includes: a plurality of positive-side electric conductive layers connected to the positive-side conductor; and a plurality of negative-side electric conductive layers connected to the negative-side conductor, wherein each positive-side electric conductive layer faces a corresponding one of the negative-side electric conductive layers via an electric insulating layer such that a storage structure capable of storing charges and interposed between the positive-side main line and the negative-side main line is provided inside

the electric insulating member, and wherein the electric insulating member includes: a first portion made of a high thermal conductive material having a higher thermal conductivity than that of aluminum oxide, and a second portion made of a high permittivity material having a higher relative permittivity than that of aluminum oxide.