US012394558B2

(12) United States Patent
Francis et al.

(10) Patent No.: US 12,394,558 B2
(45) Date of Patent: Aug. 19, 2025

(54) SURFACE-MOUNTED MAGNETIC-COMPONENT MODULE

(71) Applicant: **Murata Manufacturing Co., Ltd.**, Nagaokakyo (JP)

(72) Inventors: **Lee Francis**, Milton Keynes (GB); **William Jarvis**, Milton Keynes (GB); **Takayuki Tange**, Milton Keynes (GB); **Shouhei Hirose**, Milton Keynes (GB)

(73) Assignee: **MURATA MANUFACTURING CO., LTD.**, Kyoto (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **18/626,578**

(22) Filed: **Apr. 4, 2024**

(65) **Prior Publication Data**

US 2024/0249874 A1 Jul. 25, 2024

Related U.S. Application Data

(63) Continuation of application No. 16/924,666, filed on Jul. 9, 2020, now Pat. No. 11,978,581.

(60) Provisional application No. 62/871,849, filed on Jul. 9, 2019.

(51) **Int. Cl.**

H01F 27/28 (2006.01)
H01F 17/06 (2006.01)
H01F 27/255 (2006.01)

(52) **U.S. Cl.**

CPC ***H01F 27/2895*** (2013.01); ***H01F 17/062*** (2013.01); ***H01F 27/255*** (2013.01); ***H01F 27/2828*** (2013.01)

(58) **Field of Classification Search**

CPC .. H01F 27/2895; H01F 17/062; H01F 27/255; H01F 27/2828; H01F 27/022; H01F 2027/2814; H01F 27/2804

USPC 336/229, 221, 212

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,103,267	A *	7/1978	Olschewski	H05K 1/165	336/200
6,249,039	B1 *	6/2001	Harvey	H01F 17/0033	257/528
2008/0197956	A1 *	8/2008	Hasegawa	H01F 27/363	336/61
2009/0160595	A1 *	6/2009	Feng	H01L 23/49861	336/200
2015/0213938	A1 *	7/2015	Sakaguchi	H01F 27/28	206/408
2016/0181003	A1 *	6/2016	Li	H01F 17/062	336/200

OTHER PUBLICATIONS

Francis et al., "Surface-Mounted Magnetic-Component Module", U.S. Appl. No. 16/924,666, filed Jul. 9, 2020.

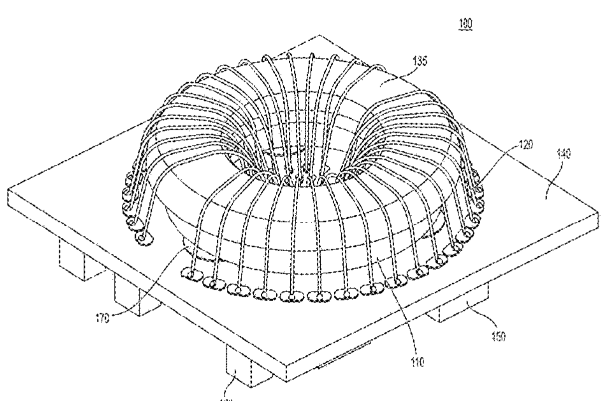
* cited by examiner

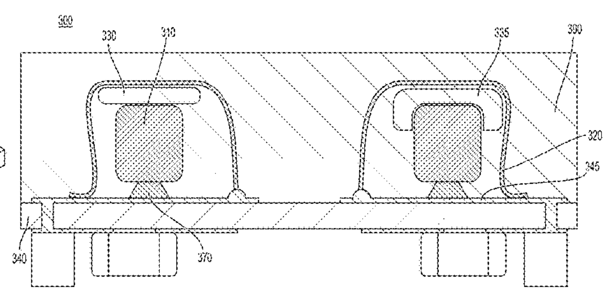
Primary Examiner — Shawki S Ismail
Assistant Examiner — Kazi S Hossain
(74) *Attorney, Agent, or Firm* — Keating & Bennett, LLP

(57) **ABSTRACT**

A magnetic-component module includes a substrate, a core on a first surface of the substrate, a spacer on the core, a gap between a bottom surface of the core and the first surface of the substrate, a winding including wire bonds extending over the core and electrically connecting a first portion of the substrate and a second portion of the substrate, and traces on and/or in the substrate, and an overmold material encapsulating the core, the spacer, and the wire bonds and filling the gap.

9 Claims, 22 Drawing Sheets





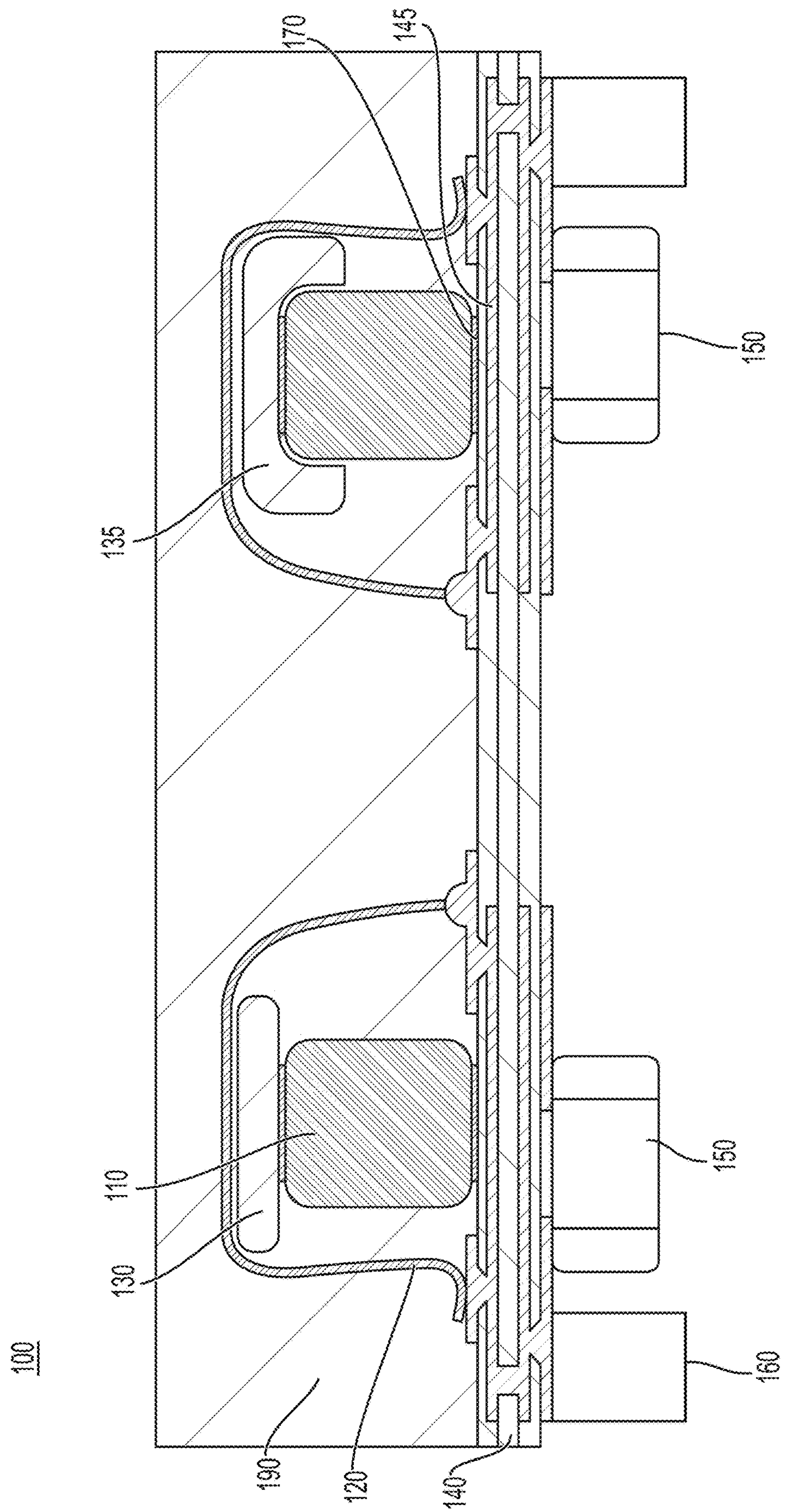


FIG. 1

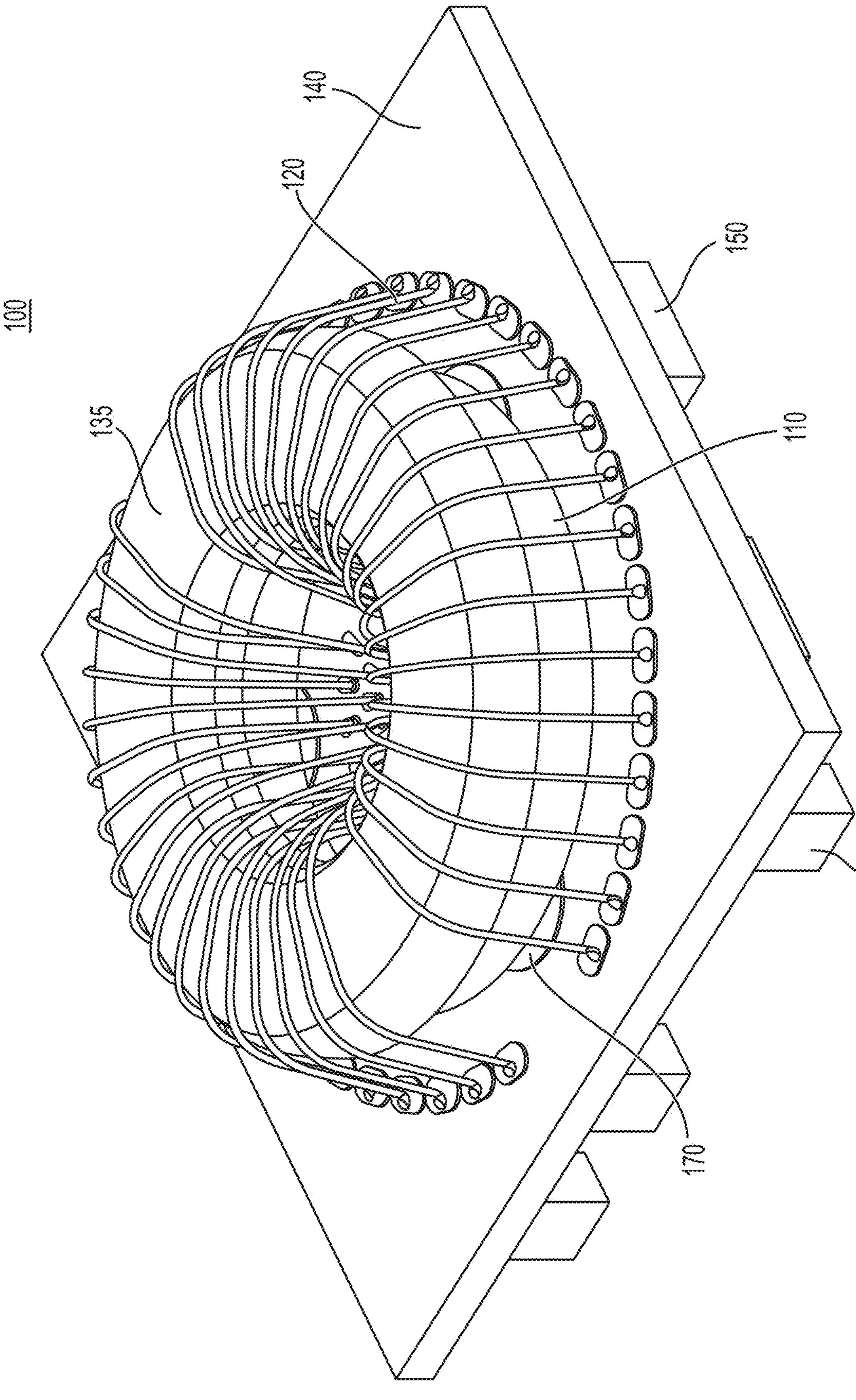


FIG. 2

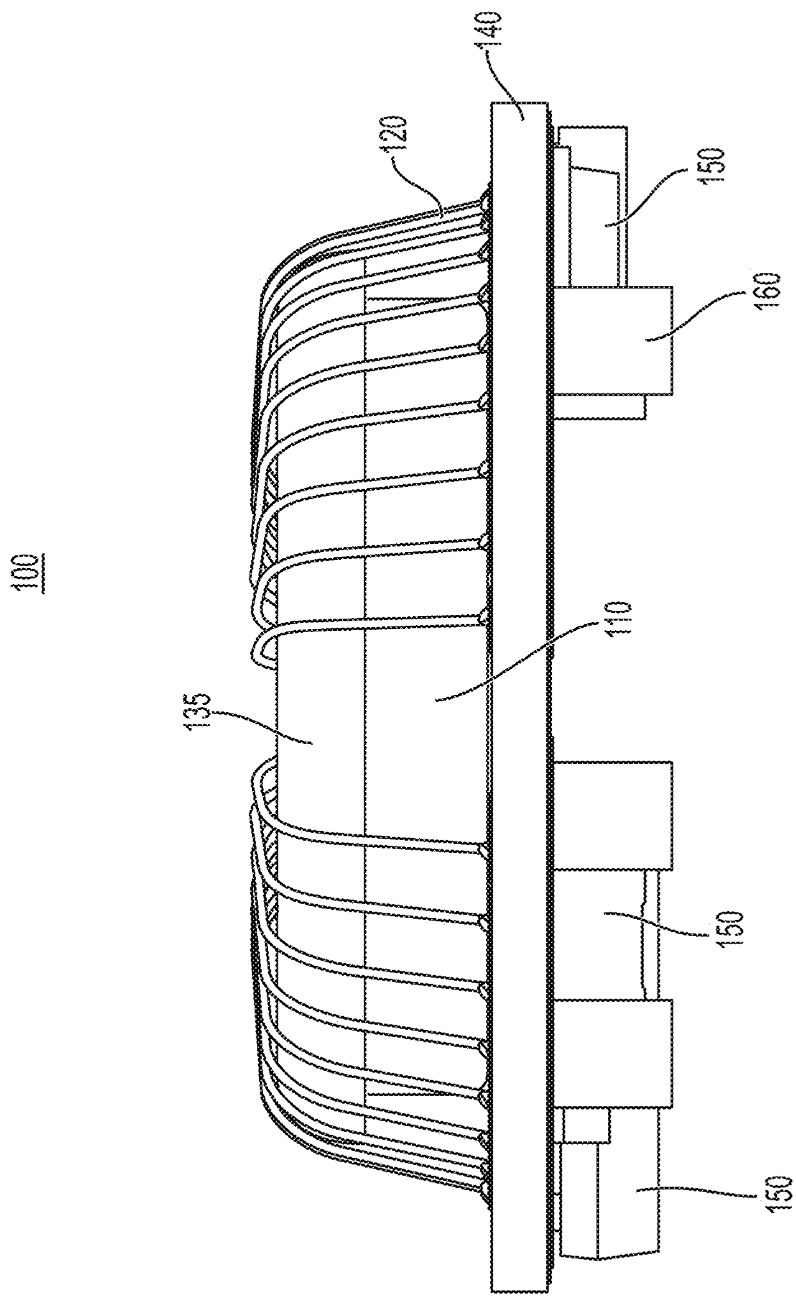


FIG. 3

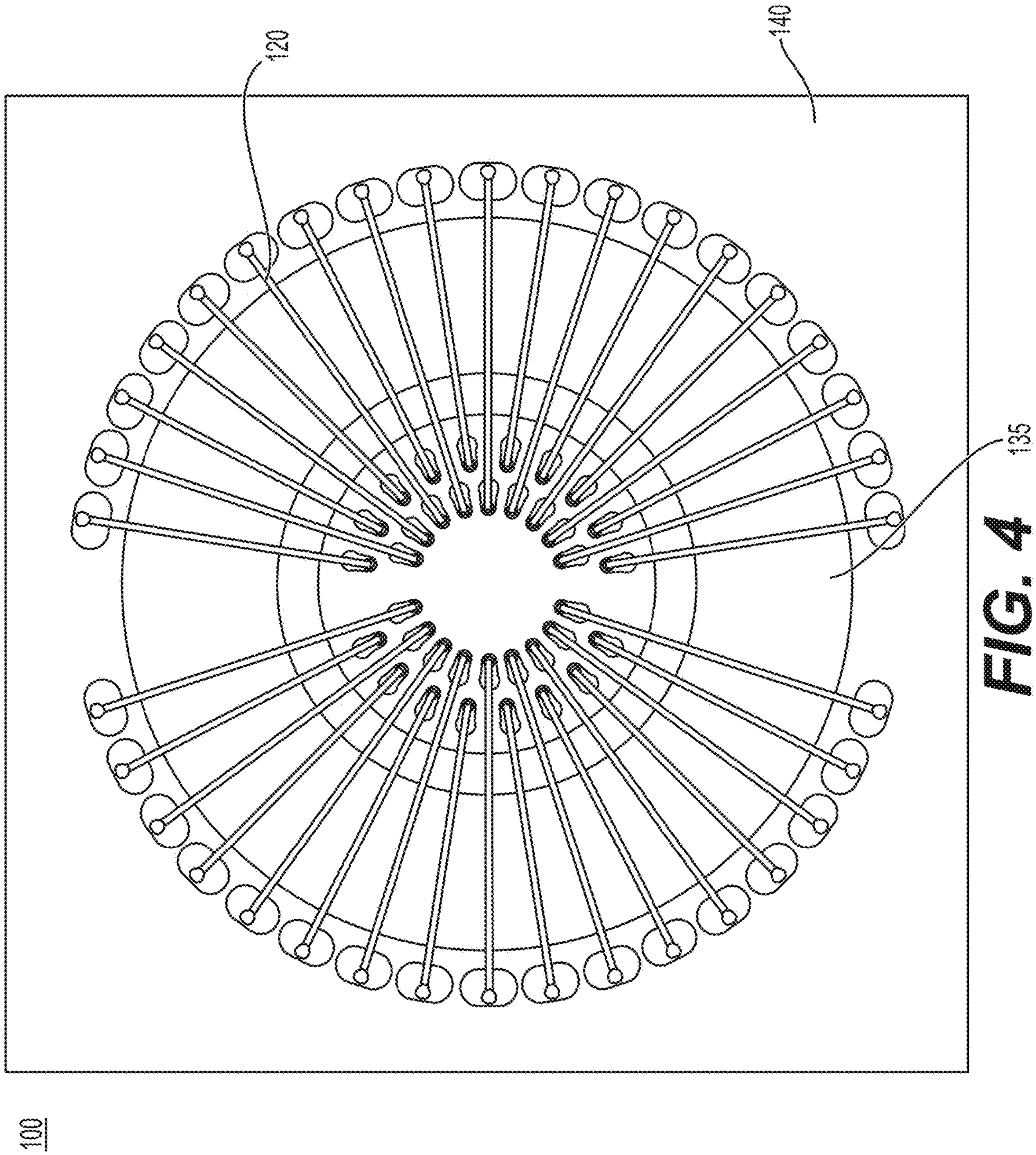


FIG. 4

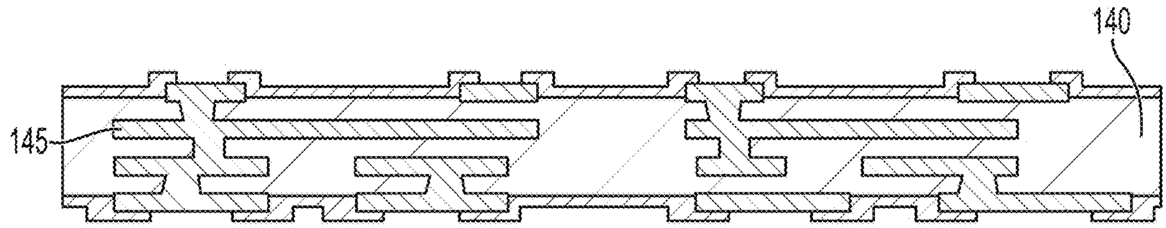


FIG. 5

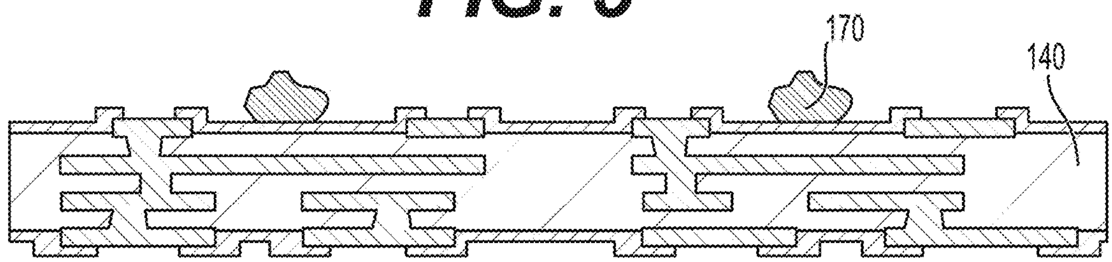


FIG. 6

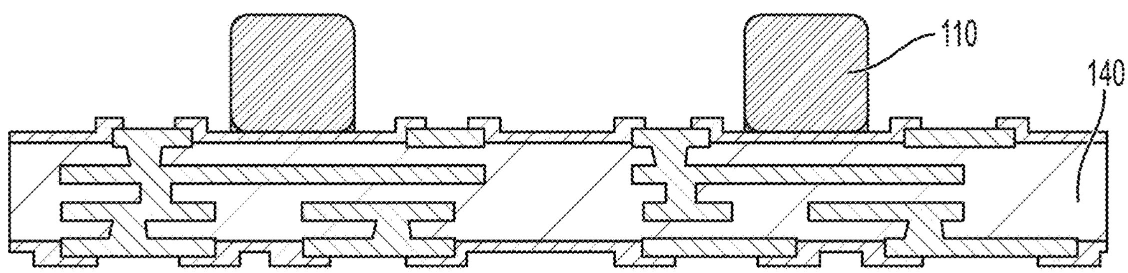


FIG. 7

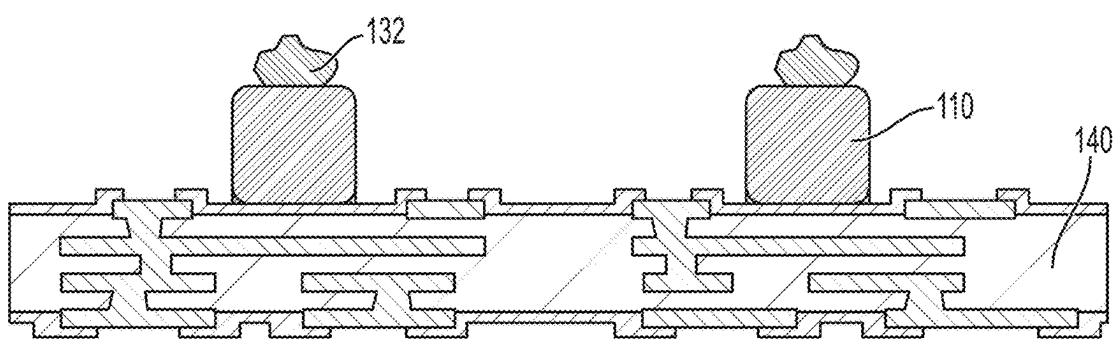


FIG. 8

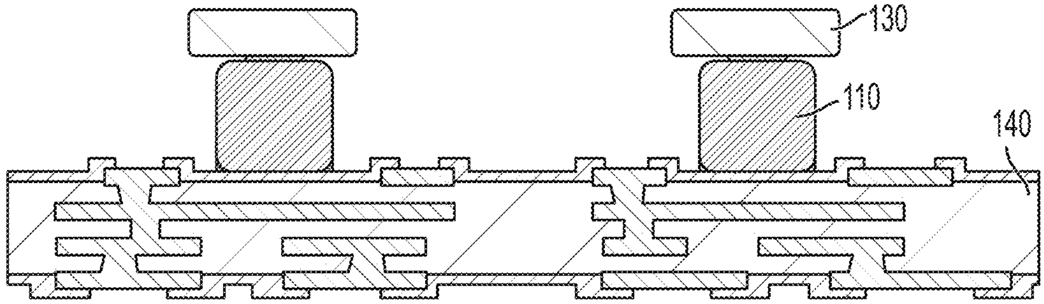


FIG. 9

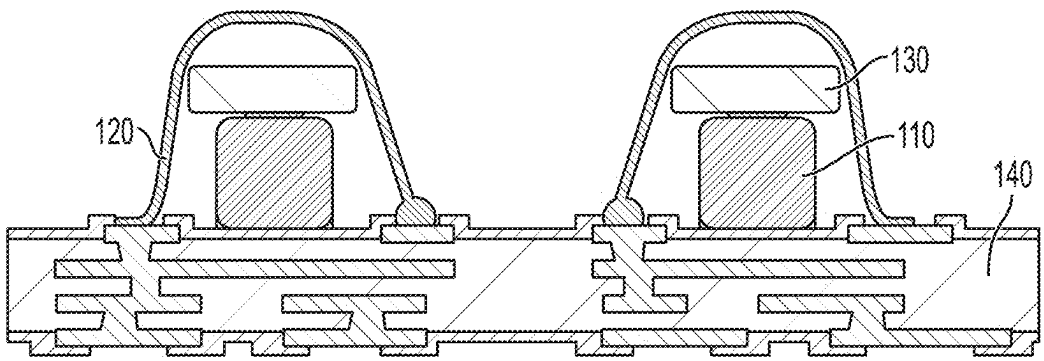


FIG. 10

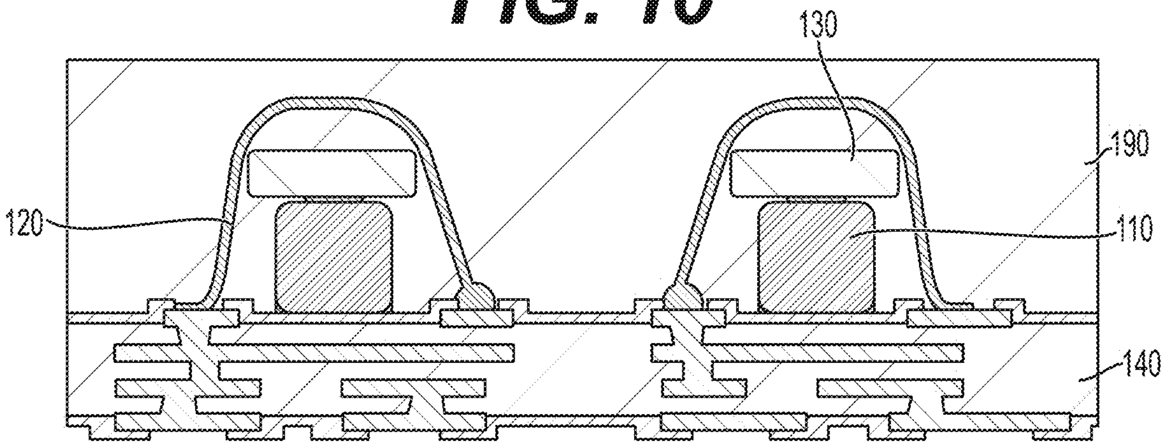


FIG. 11

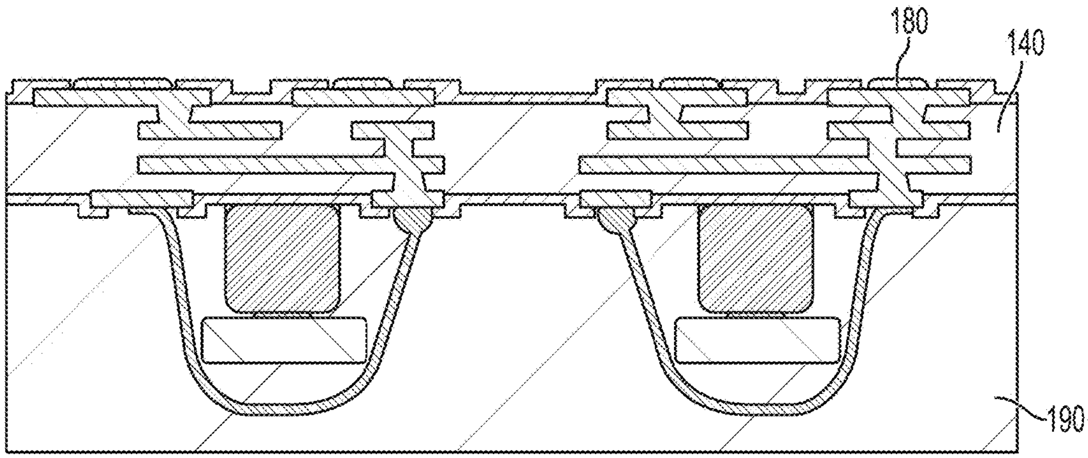


FIG. 12

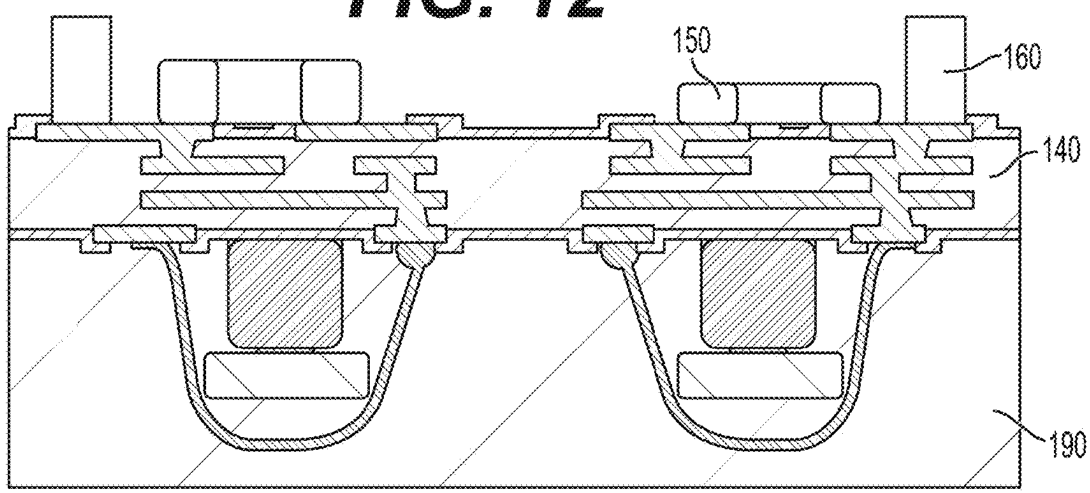


FIG. 13

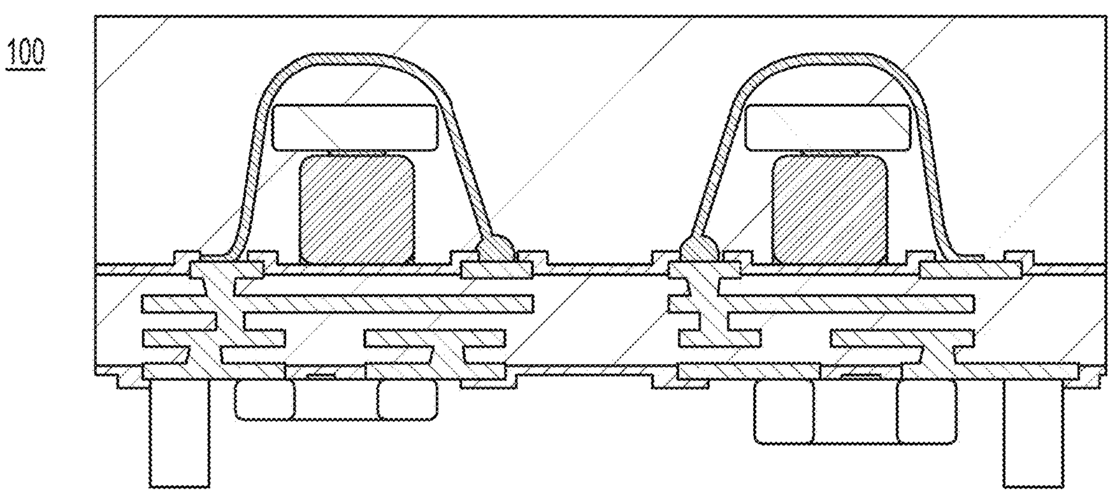


FIG. 14

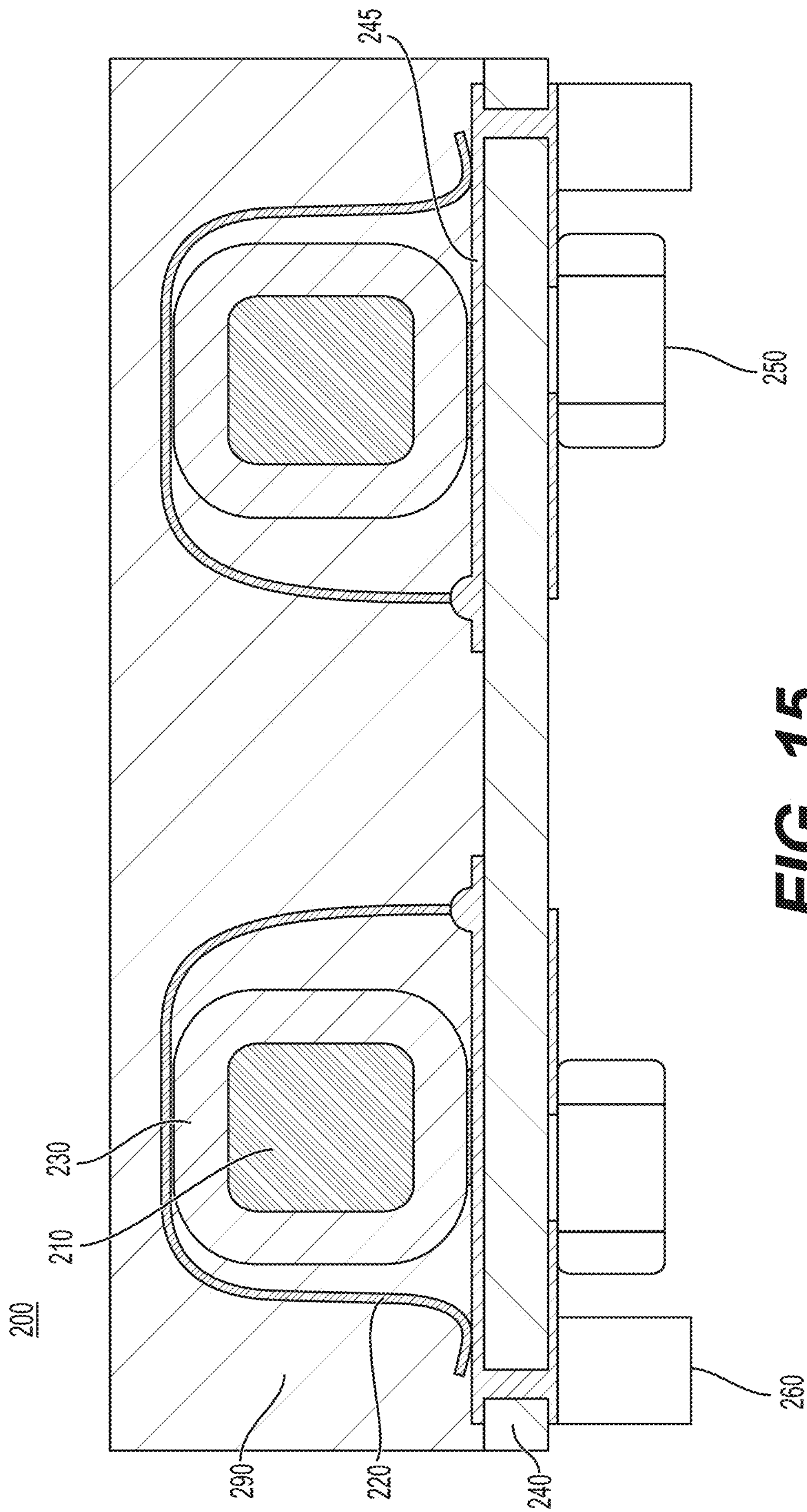


FIG. 15

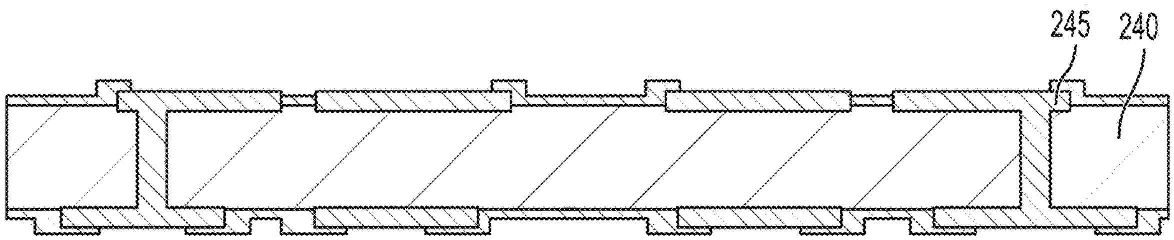


FIG. 16

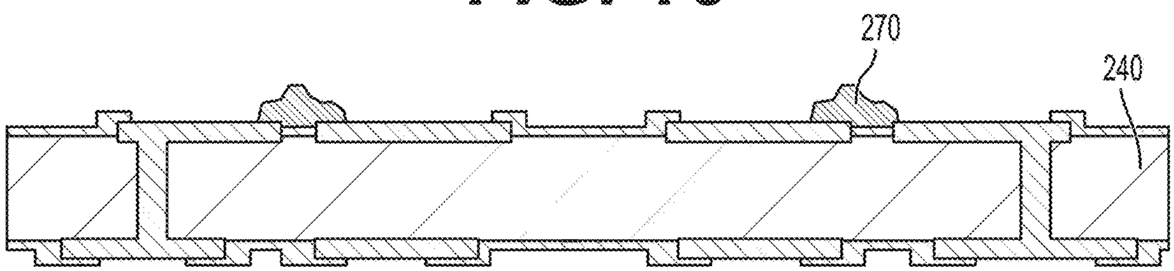


FIG. 17

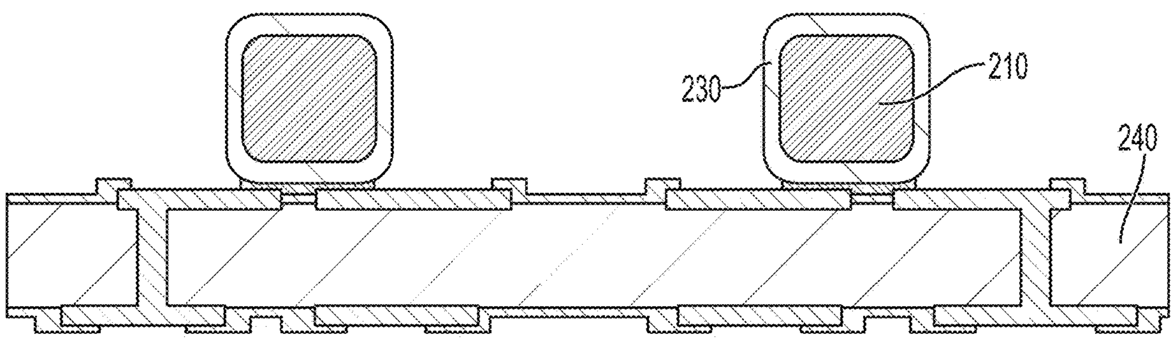


FIG. 18

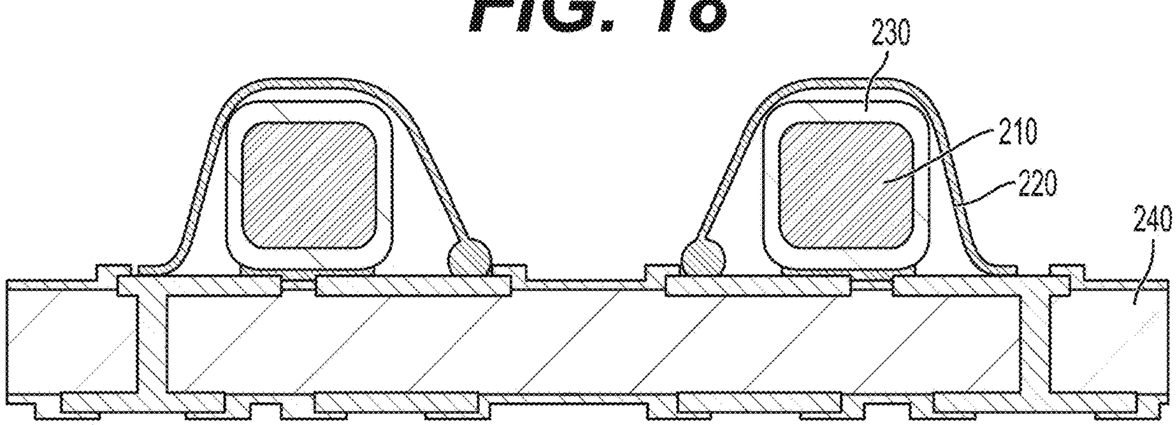


FIG. 19

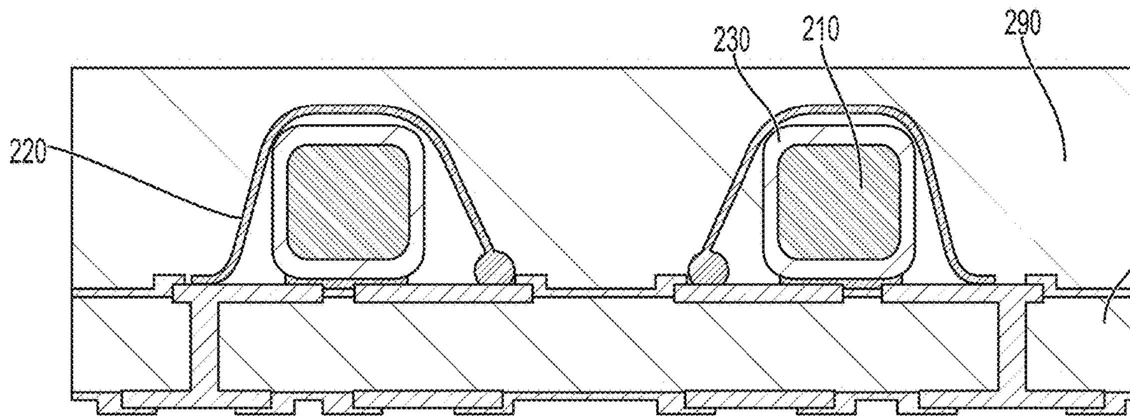


FIG. 20

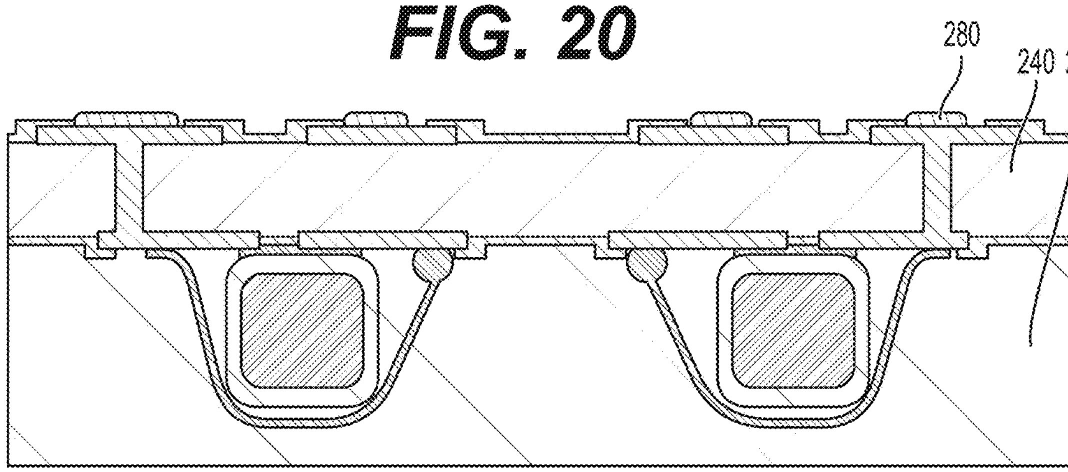


FIG. 21

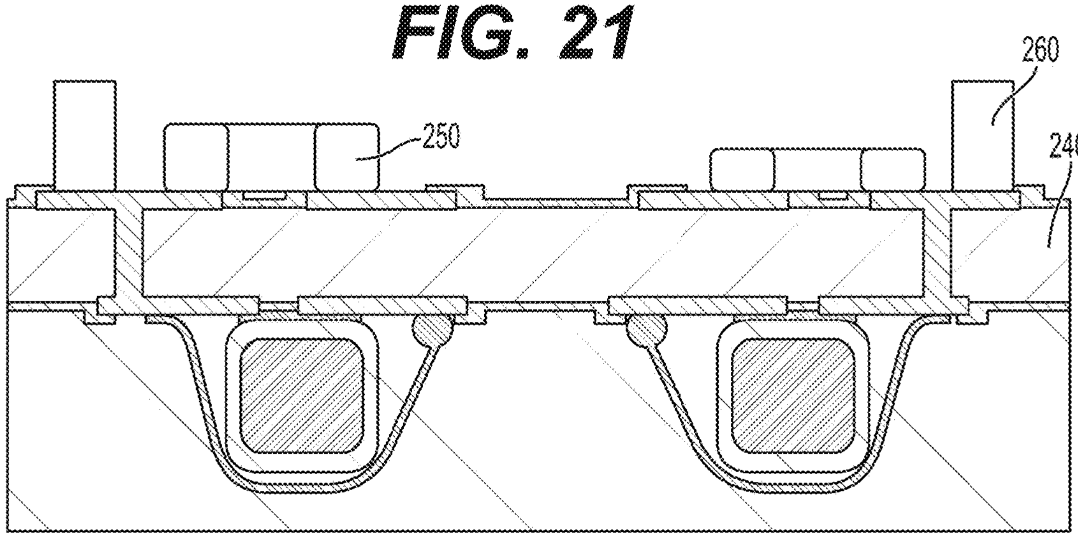


FIG. 22

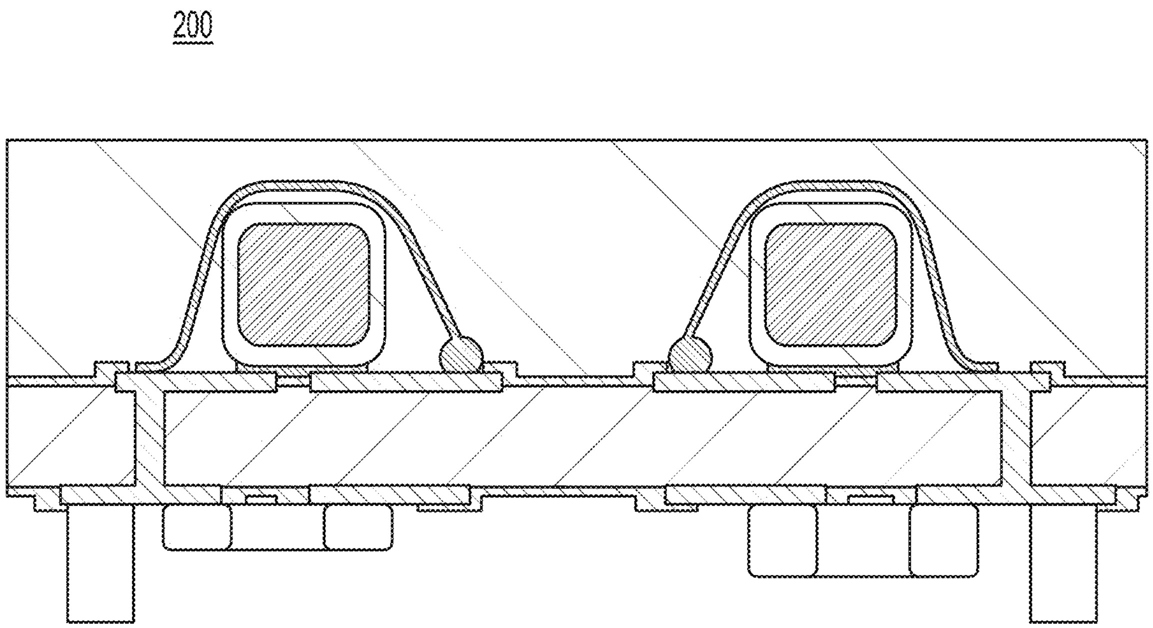


FIG. 23

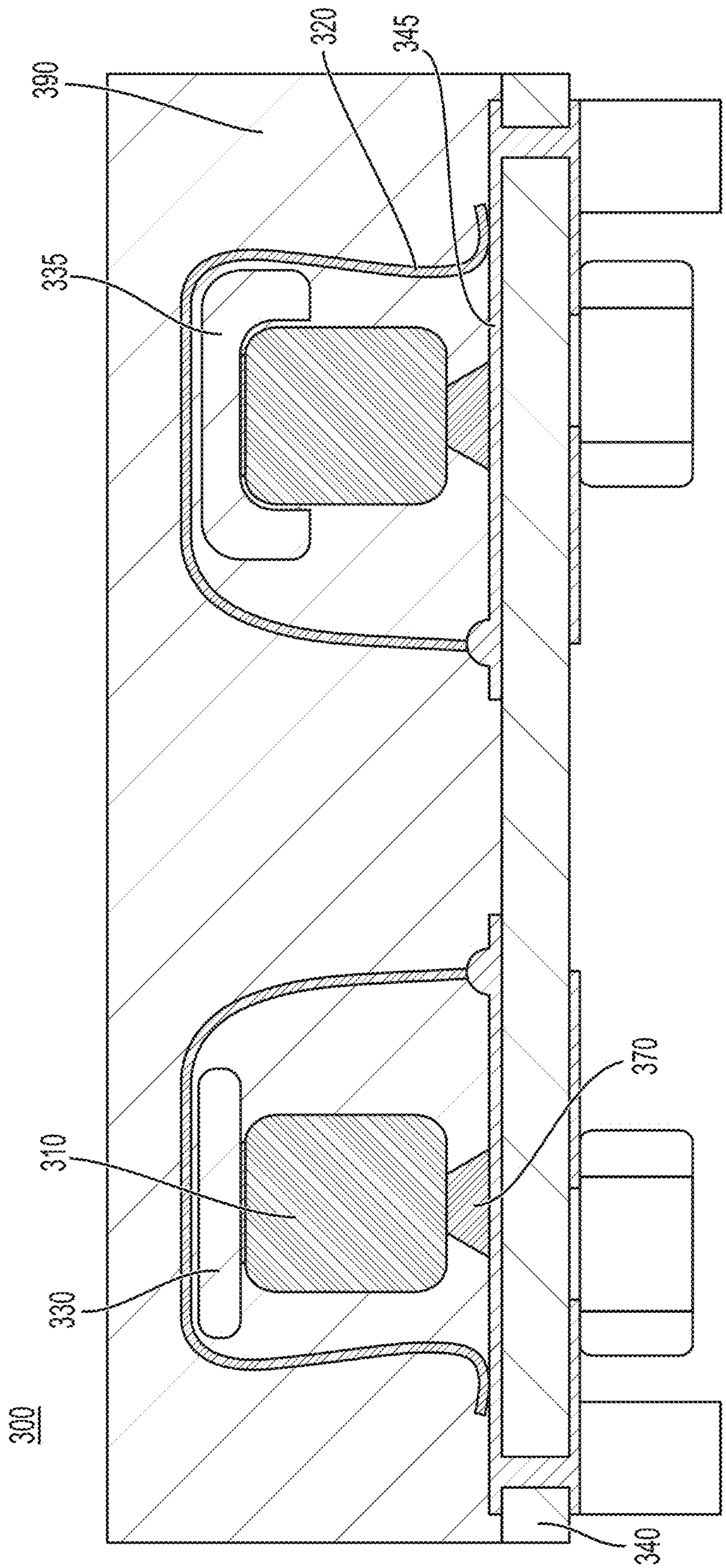


FIG. 24

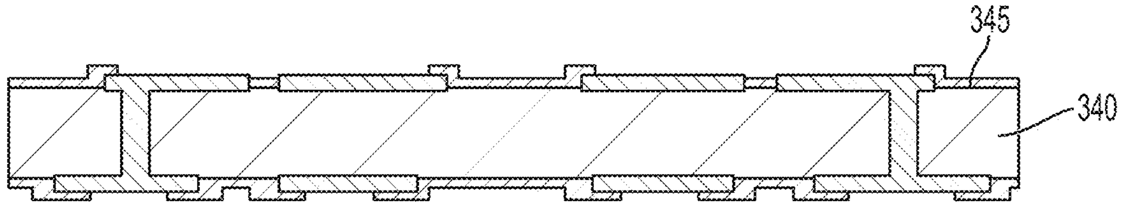


FIG. 25

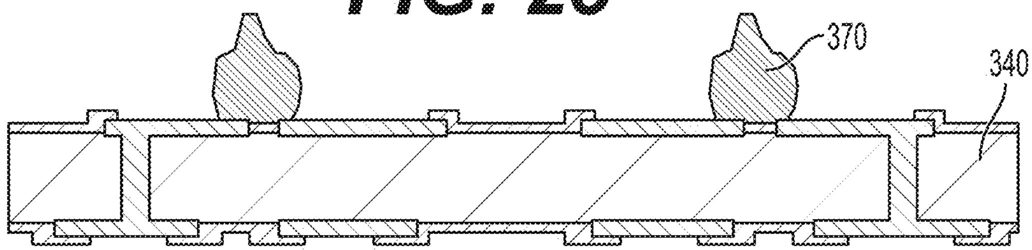


FIG. 26

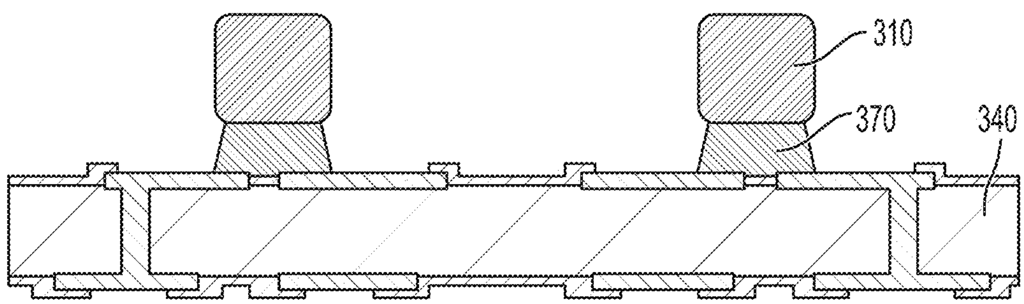


FIG. 27

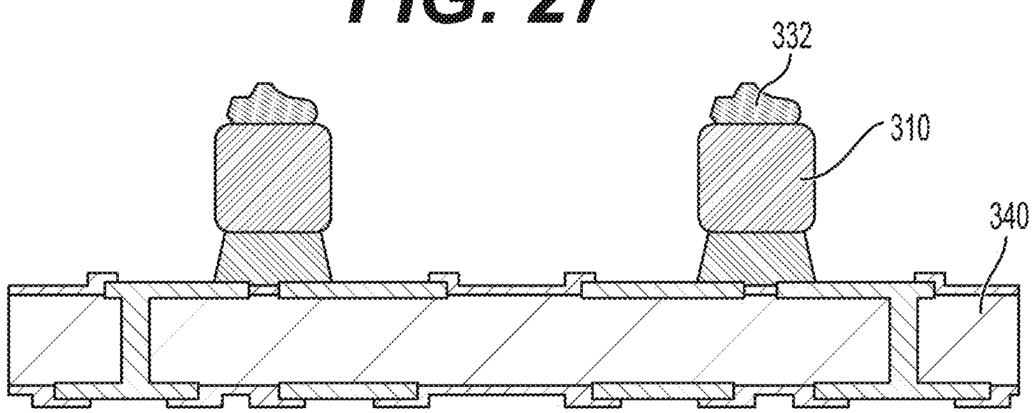


FIG. 28

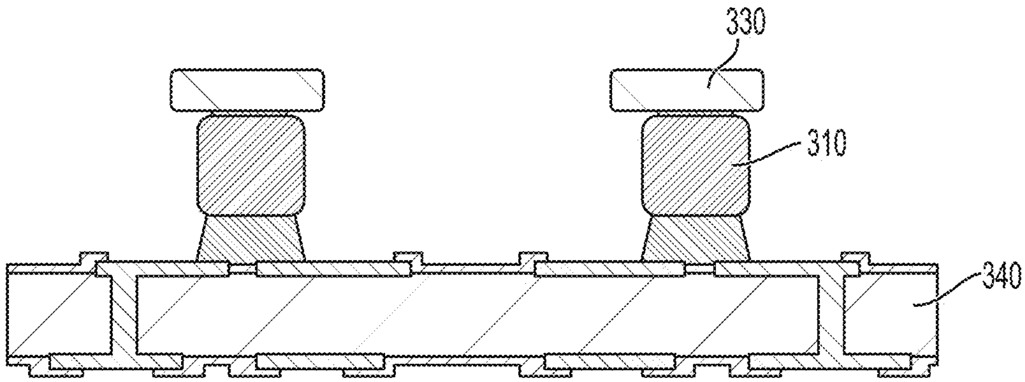


FIG. 29

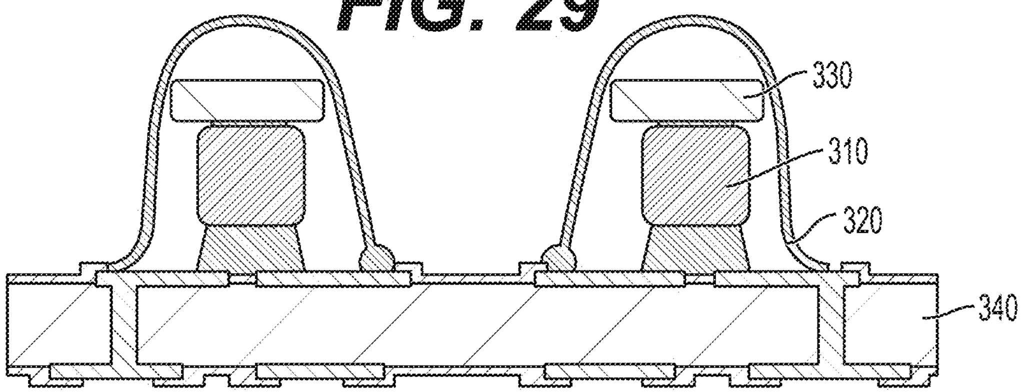


FIG. 30

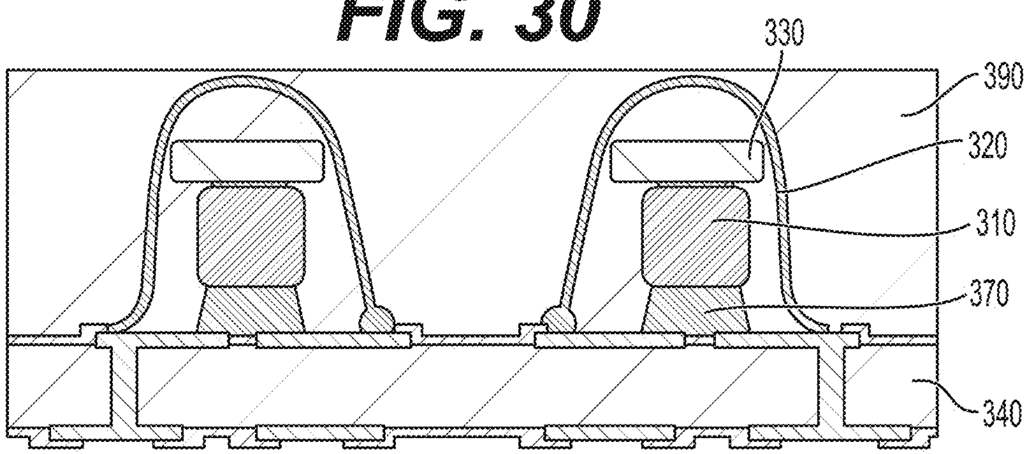


FIG. 31

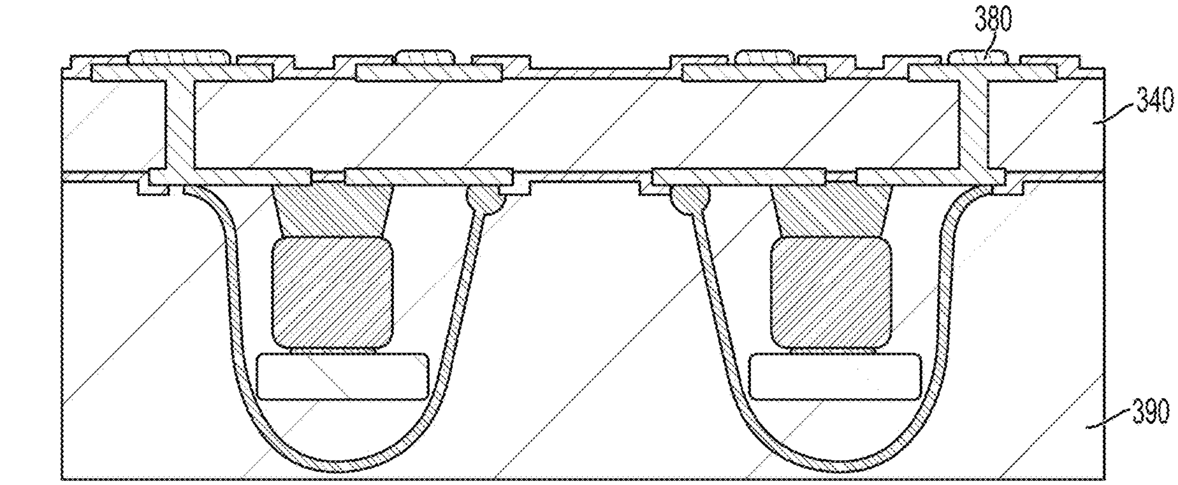


FIG. 32

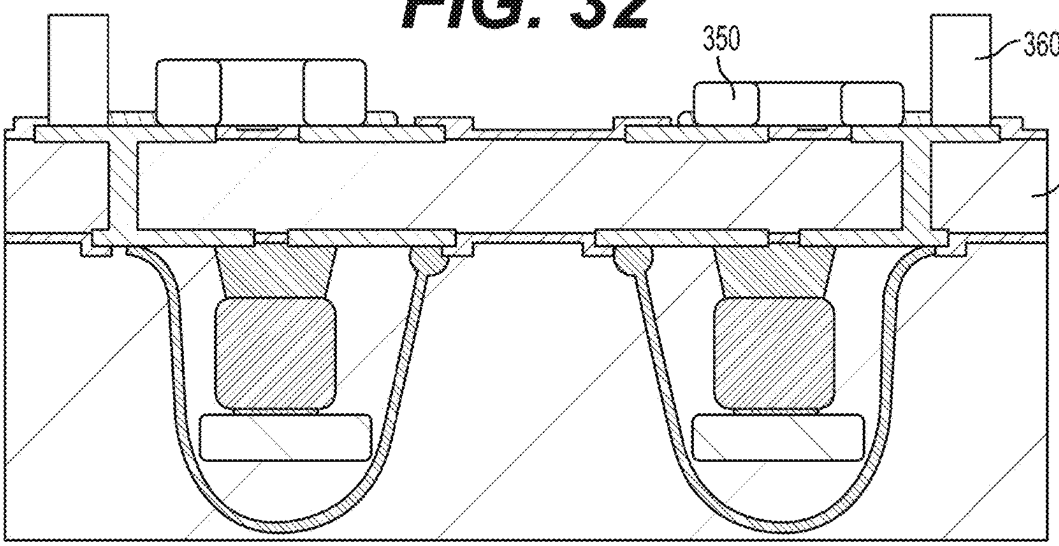


FIG. 33

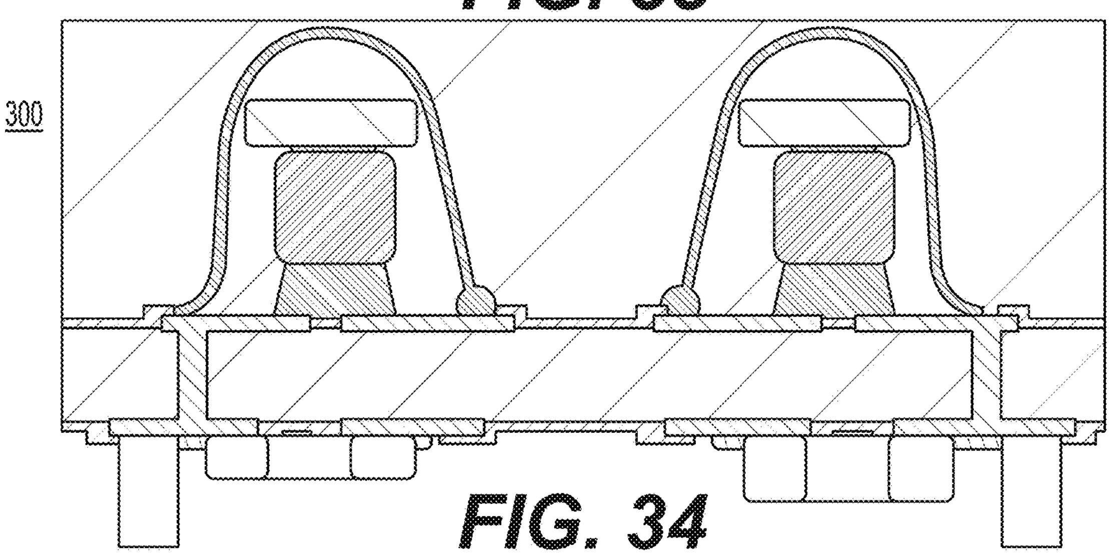


FIG. 34

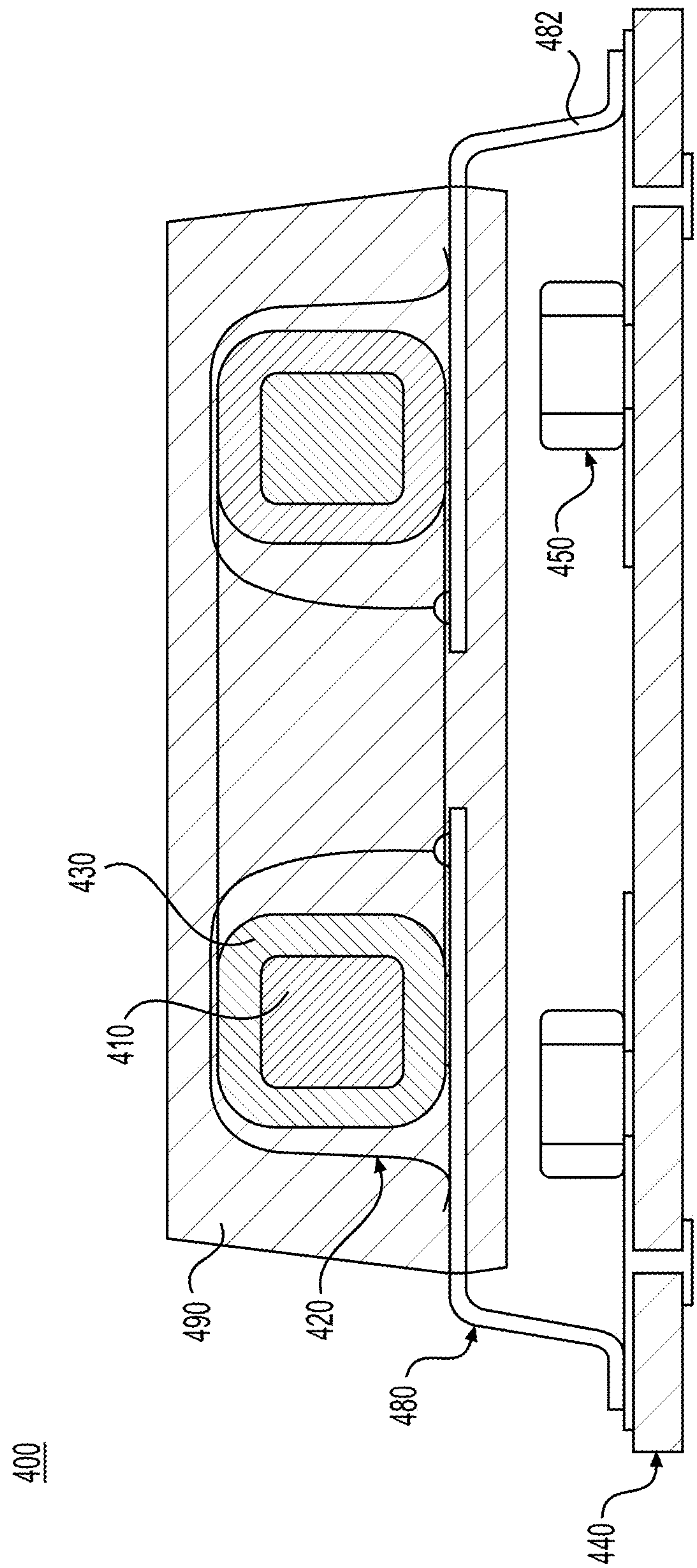


FIG. 35

FIG. 36

FIG. 37

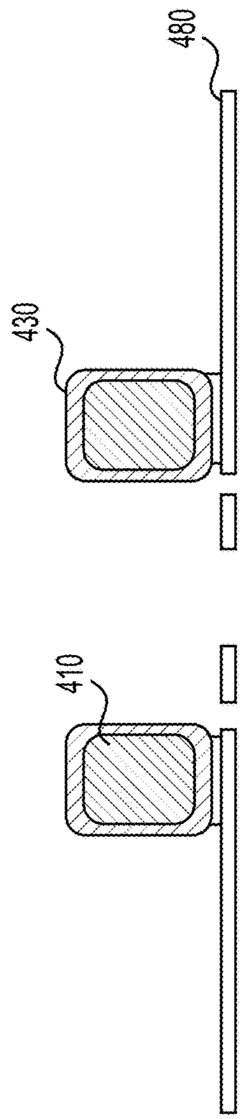


FIG. 38

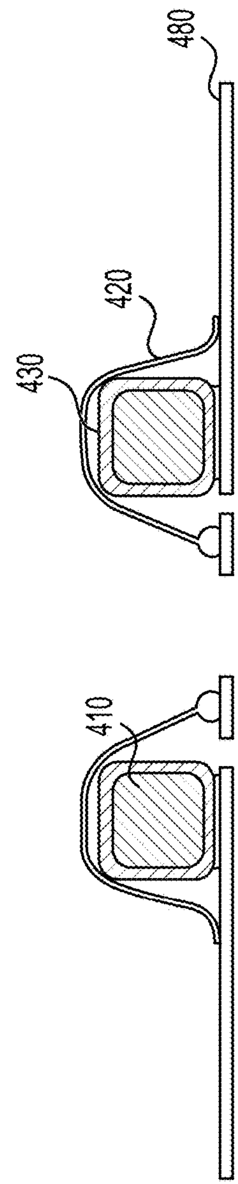


FIG. 39

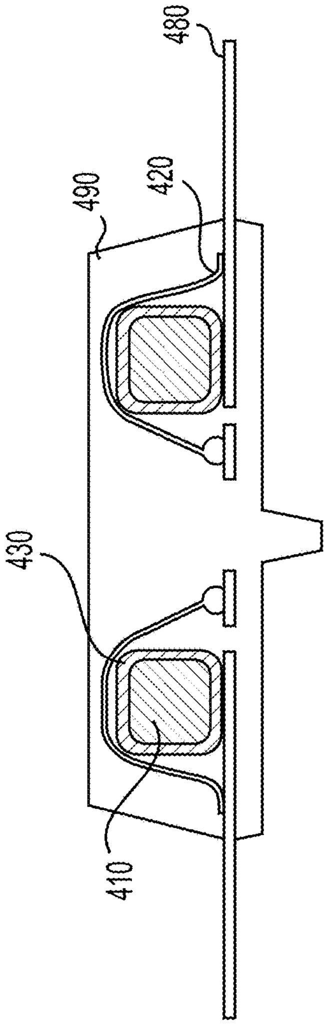


FIG. 40

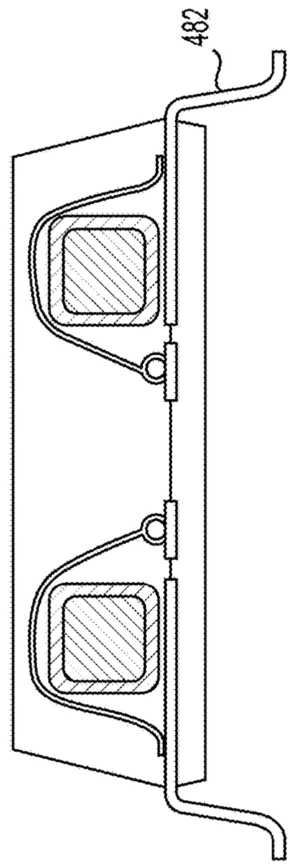


FIG. 41

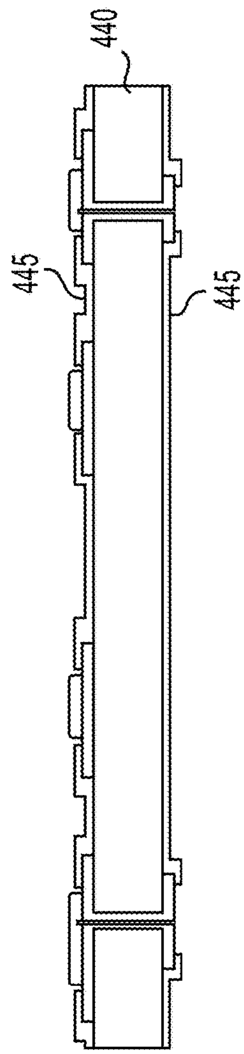


FIG. 42

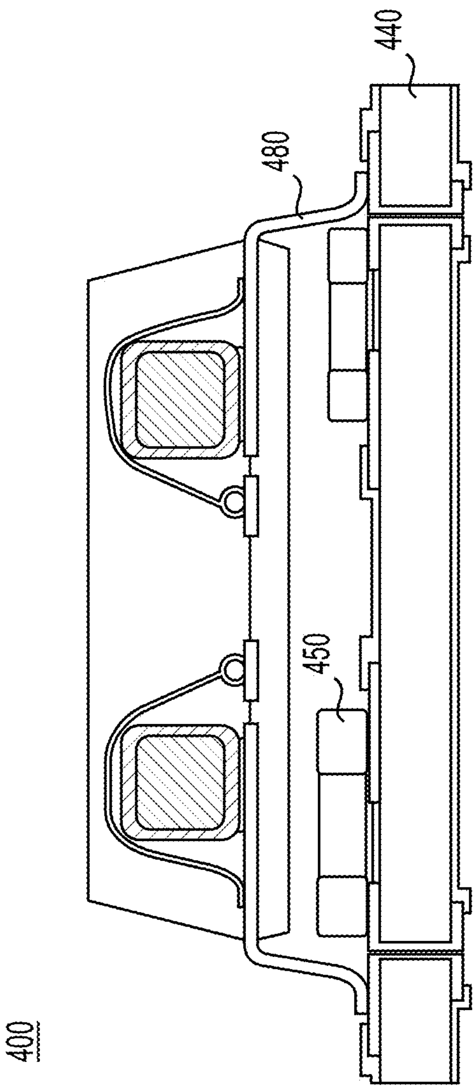


FIG. 43

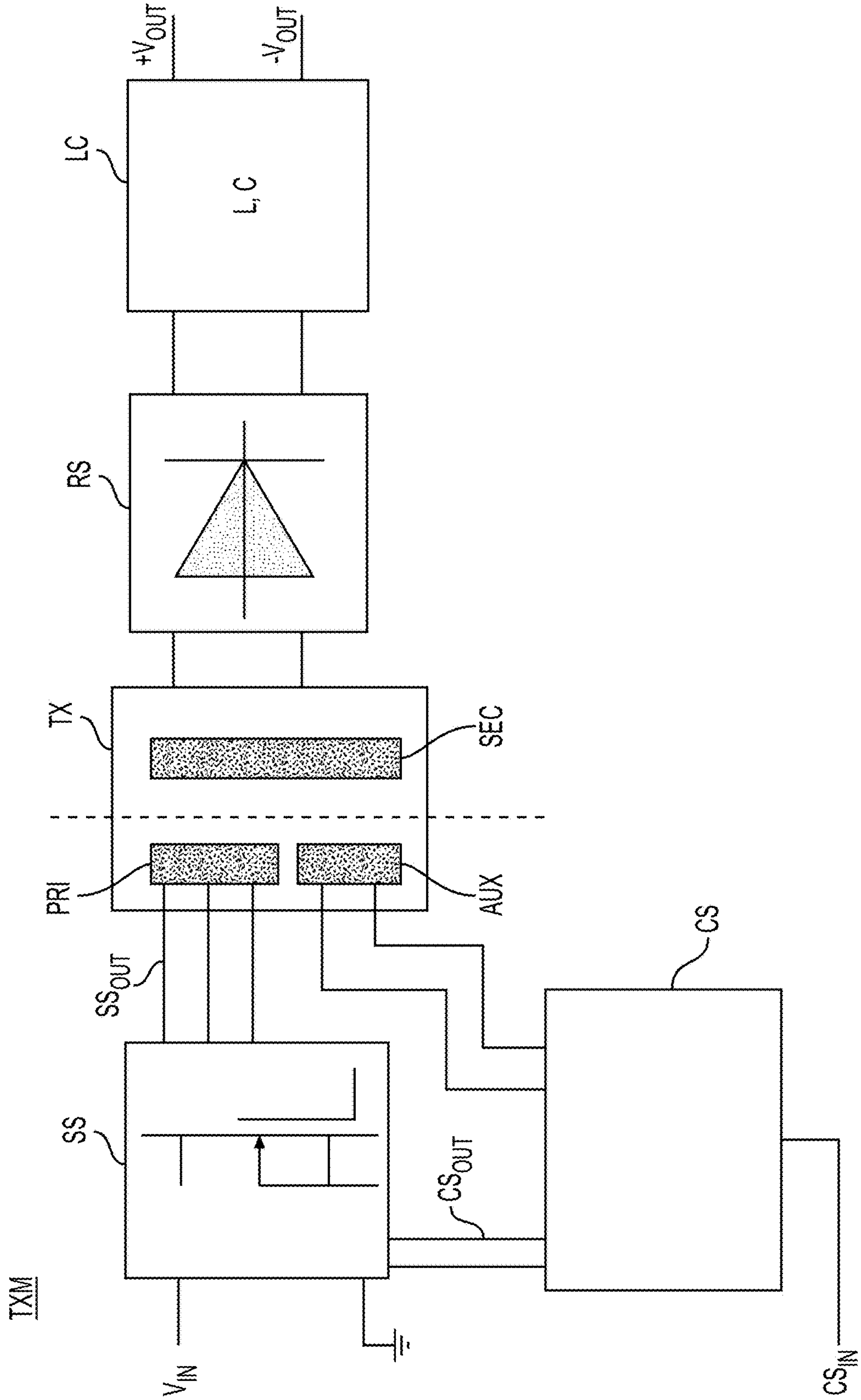


FIG. 44

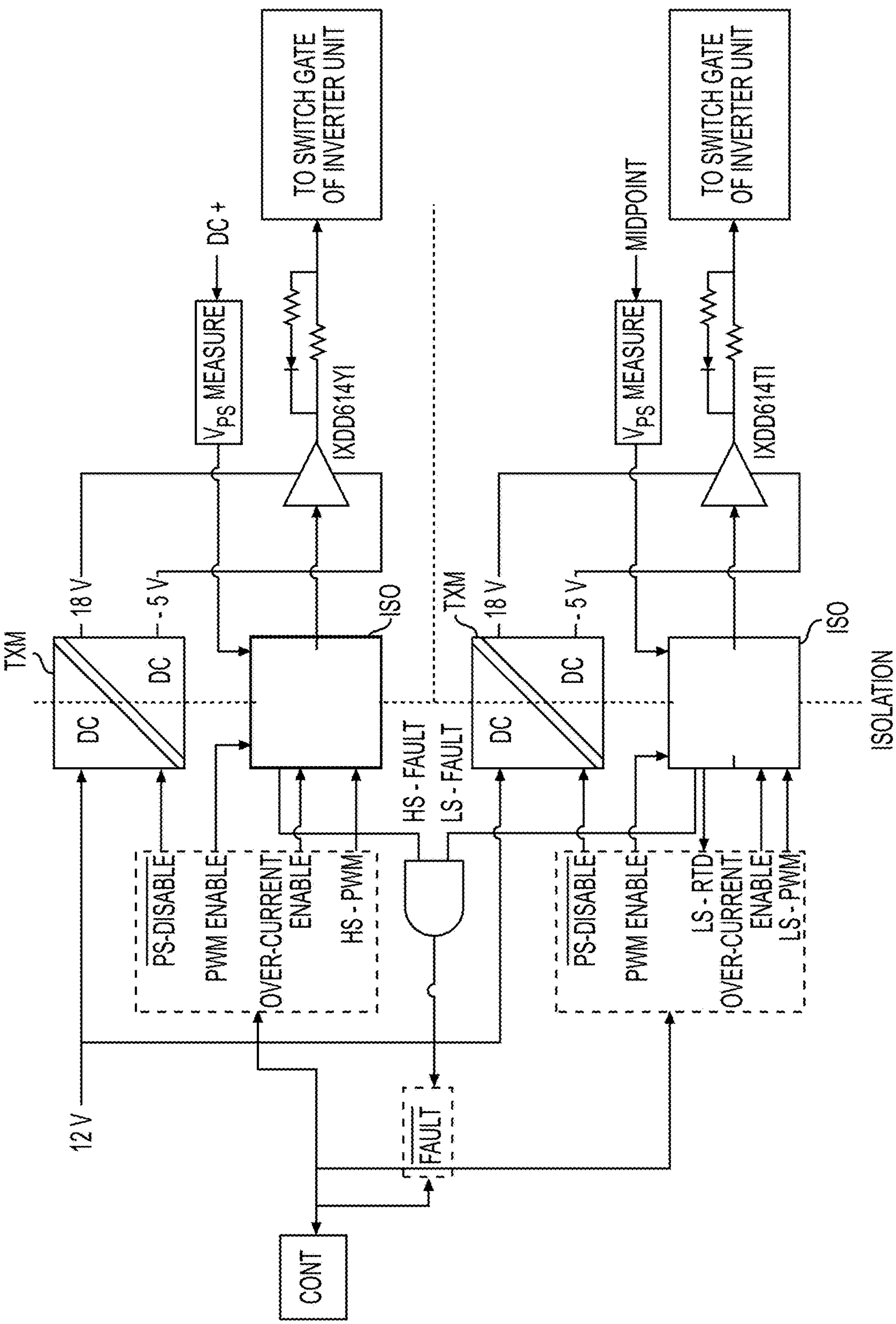

TO SWITCH GATE OF INVERTER UNIT
TO SWITCH GATE OF INVERTER UNIT
DC +
MIDPOINT
V_{PS} MEASURE
V_{PS} MEASURE
IXDD614YI
IXDD614TI
TXM
TXM
18 V
-5 V
18 V
-5 V
DC
DC
DC
DC
ISO
ISO
ISOLATION
HS - FAULT
LS - FAULT
PS-DISABLE
PWM ENABLE
OVER-CURRENT ENABLE
HS - PWM
PS-DISABLE
PWM ENABLE
LS - RTD
OVER-CURRENT ENABLE
LS - PWM
12 V
FAULT
CONT

FIG. 45

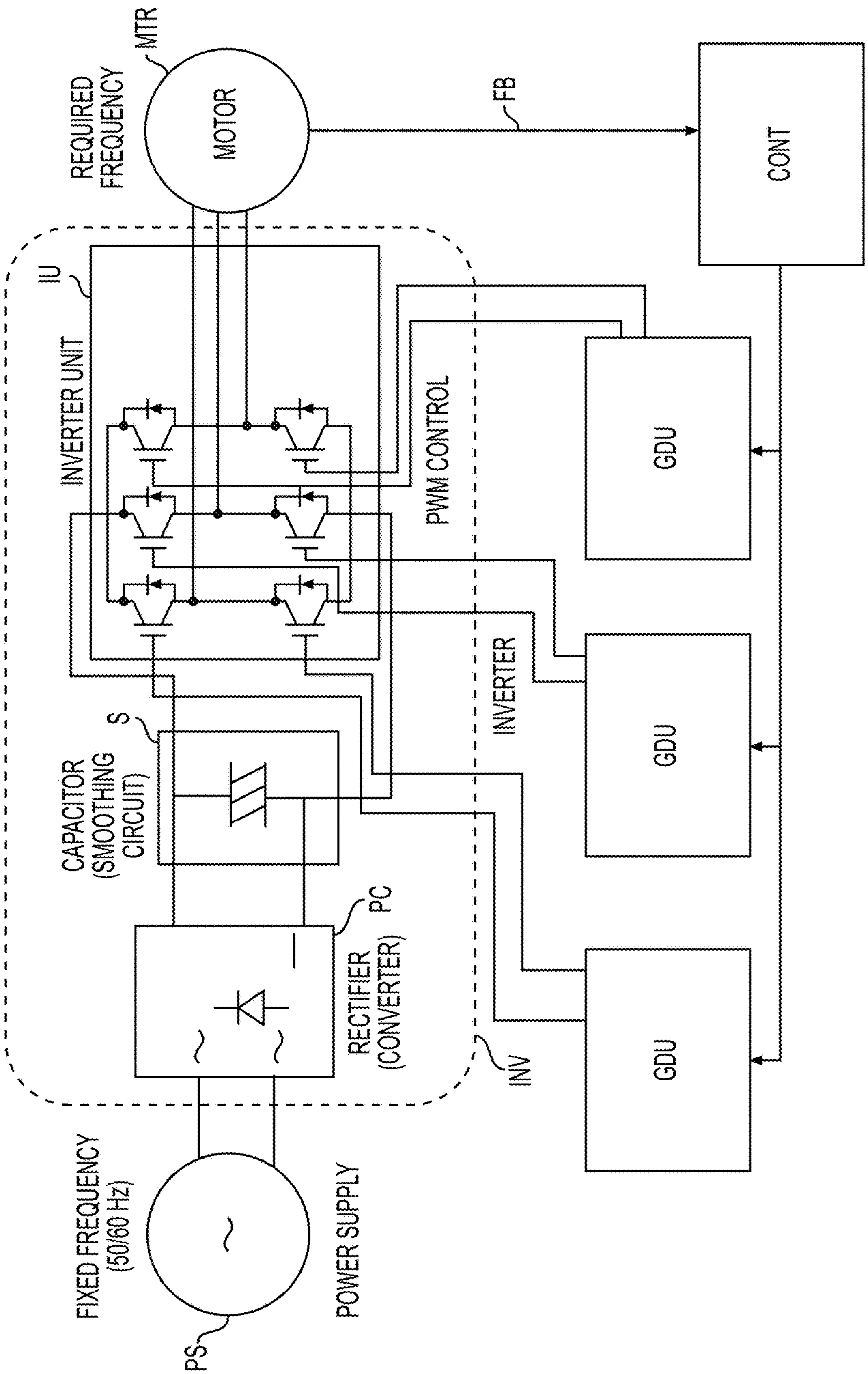

REQUIRED FREQUENCY
MTR
MOTOR
FB
CONT
IU
INVERTER UNIT
PWM CONTROL
GDU
GDU
GDU
INVERTER
S
CAPACITOR (SMOOTHING CIRCUIT)
PC
RECTIFIER (CONVERTER)
INV
FIXED FREQUENCY (50/60 Hz)
POWER SUPPLY
PS

FIG. 46

SURFACE-MOUNTED MAGNETIC-COMPONENT MODULE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Patent Application No. 62/871,849 filed on Jul. 9, 2019. The entire contents of this application are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to magnetic components and magnetic-component modules, and in particular, to transformers and surface-mounted transformer modules.

2. Background

Transformers are used in many applications, for example, to change the voltage of input electricity. A transformer has one or more primary windings and one or more secondary windings wound around a common core of magnetic material. The primary winding(s) receive electrical energy, such as from a power source, and couples this energy to the secondary winding(s) by a changing magnetic field. The energy appears as an electromagnetic force across the secondary winding(s). The voltage produced in the secondary winding(s) is related to the voltage in the primary winding(s) by the turns ratio between the primary and secondary windings. Typical transformers are implemented using an arrangement of adjacent coils. In a toroidal transformer, the windings wind around a toroid-shaped core.

Demands in many fields, including telecommunications, implantable medical devices, and battery-operated wireless devices, for example, have prompted design efforts to minimize the size of components with lower-cost solutions that exhibit the same or better performance but operate with reduced power consumption. The reduced power consumption is often prompted by further requirements in lowering supply voltages to various circuits. Accordingly, there is a continuing need to provide more efficient, smaller, and lower cost transformers.

SUMMARY OF THE INVENTION

To overcome the problems and satisfy the needs described above, preferred embodiments of the present invention provide magnetic-component modules each including a core on a substrate with a gap between the core and the substrate, a spacer arranged over the core, and wire bonds extending over the spacer and the core.

According to a preferred embodiment of the present invention, a magnetic-component module includes a substrate; a core on a first surface of the substrate; a spacer on the core; a gap between a bottom surface of the core and the first surface of the substrate; a winding including wire bonds extending over the core and electrically connecting a first portion of the substrate and a second portion of the substrate, and traces on and/or in the substrate; and an overmold material encapsulating the core, the spacer, and the wire bonds and filling the gap.

Electrical components can be attached to a second surface of the substrate that is opposite to the first surface of the substrate. The spacer can conform to a top of the core. An edge of the spacer can overhang the core. The spacer can extend over an entire outer surface of the core or over substantially the entire outer surface of the core.

The magnetic-component module can further include a lead frame that supports the core and that electrically connects the winding to the substrate, where the overmold material encapsulates a portion of the lead frame. The lead frame can be configured such that electrical components are located on the substrate under the lead frame.

The magnetic-component module can further include an adhesive to mount the core to the substrate. The adhesive can be in the gap between the core and the substrate, and the overmold material can encapsulate the adhesive. The spacer can include a polyethylene terephthalate (PET) resin.

According to a preferred embodiment of the present invention, a voltage converter circuit includes the magnetic-component module according to one of the various preferred embodiments of the present invention.

According to a preferred embodiment of the present invention, a gate drive switching circuit includes the voltage converter circuit according to one of the various preferred embodiments of the present invention.

According to a preferred embodiment of the present invention, a motor control circuit includes the gate drive switching circuit according to one of the various preferred embodiments of the present invention.

The above and other features, elements, characteristics, steps, and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments of the present invention with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a magnetic-component module with a spacer attached to a core.

FIG. **2** is a top perspective view of the magnetic-component module of FIG. **1**.

FIG. **3** is a side view of the magnetic-component module of FIG. **1**.

FIG. **4** is a top view of the magnetic-component module of FIG. **1**.

FIGS. **5-14** show steps of a method of manufacturing the magnetic-component module of FIG. **1**.

FIG. **15** shows a magnetic-component module with a spacer surrounding a core.

FIGS. **16-23** show steps of a method of manufacturing the magnetic-component module of FIG. **15**.

FIG. **24** shows a magnetic-component module with a core and a standoff.

FIGS. **25-34** show steps of a method of manufacturing the magnetic-component module of FIG. **24**.

FIG. **35** shows a magnetic-component module with a lead frame.

FIGS. **36-43** show steps of a method of manufacturing the magnetic-component module of FIG. **35**.

FIG. **44** is a block diagram of an example of an implementation of a magnetic-component module.

FIG. **45** is a block diagram of a gate-drive-circuit application including a magnetic-component module shown in FIG. **44**.

FIG. **46** shows circuitry for a motor control application.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. **1** shows a magnetic-component module **100** with a core **110**, winding(s) that are defined by wire bonds **120** and traces **145**, a spacer **130**, and a substrate **140**, such as a multilayer printed circuit board (PCB). An overmold material **190** can cover or encapsulate the core **110**, the wire bonds **120**, and the spacer **130**. The magnetic-component module **100** can be a transformer with primary and secondary windings that extend around the core **110**, as shown in FIG. **1**. Although FIG. **1** shows a transformer with two windings, other magnetic components can also be used, including, for example, an inductor with a single winding or a transformer with three or more windings. Circuitry components and/or connectors can be located on the bottom surface of the substrate. As shown in FIG. **1**, the magnetic-component module **100** can include surface-mount (SM) or input/output (I/O) pins **160** that are located on the bottom surface of the substrate **140**. The magnetic-component module **100** can include electrical components **150** mounted on the bottom surface of the substrate **140**. The electrical components **150** can include passive components, such as, capacitors, resistors, etc. and can include active components, such as transistors.

The core **110** can be an uninsulated core and can be fixed (i.e., adhered) to the multilayer substrate **140** with adhesive **170**. The adhesive **170** can include spaced apart portions along the bottom of the core **110** as shown in FIG. **2** or can extend along the entire bottom of the core **110**. The spacer **130** can be an insulated spacer and can be fixed (i.e., adhered) to a top of the core **140**. The spacer **130** can be made by an injection molding process. The spacer **130** can be made with any suitable material that can be injection molded, including polyethylene terephthalate (PET) resin. The spacer **130** can help ensure that the wire bonds **120** do not contact the core **110**, which would cause the magnetic-component module to short circuit. Although the spacer is shown as a single unitary body in the figures, the spacer can include two or more bodies arranged around the core.

The windings are disposed around the core **110** and include wire bonds **120** that extend over the core **110** and traces **145** on or in the substrate **140** that extend under the core **110**. The wire bonds **120** include two ends that are bonded to different portions of the substrate **140**. As shown in FIG. **4**, the wire bonds **120** can be attached to the substrate **140** in a single row outside of the spacer **135** and in two rows in the interior of the spacer **135**. Other arrangements are also possible, including two or more rows outside of the spacer **135** and one row or more than two rows in the interior of the spacer **135**. The wire bonds **120** define a top half of a winding. The wire bonds **120** can include copper wires, gold wires, aluminum wires, or any other suitable conductive material. The wire bonds **120** can be attached to the substrate **140** by ball bonding, wedge bonding, compliant bonding, or any other suitable attachment method. The traces **145** can be located on inner or outer layers of the substrate **140** and define a bottom half of the winding. If the core **110** is uninsulated, then the traces **145** can be located on an inner layer or the bottom surface of the substrate **140**. If the core **110** is insulated or if the spacer **130** completely surrounds the outer surface of the core **110** as shown in FIG. **15**, then the traces **145** can also be on the top surface of the substrate **140**.

The left side of FIG. **1** shows an example of a spacer **130** between the top of the core **110** and the wire bonds **120** to prevent the wire from touching the core **110** and being short-circuited. As shown, the spacer **130** is wider than a width of the core **110** to create an overhang that maintains a predetermined distance between the wire bond **120** and the core **110**. The right side of FIG. **1** shows an alternative configuration of the spacer **135** in which the spacer **135** conforms to the top portion of the core **110** and partially covers the side walls of the core **110**. It should be understood that, typically, the spacer will have a single cross-sectional shape throughout the spacer and that the two different cross-sectional shapes shown in FIG. **1** are examples of possible cross-sectional shapes. FIGS. **2-4** show a magnetic-component module **100** that uses the spacer **135** that conforms to the top portion of the core **110** and that partially covers the side walls of the core **110**, and FIGS. **9-14** show a magnetic-component module that uses the spacer **130** that is wider than the width of the core **110** to create an overhang.

FIG. **1** also shows that the core **110**, the spacer **130**, and wire bonds **120** can be overmolded with an overmold material **190** to stabilize and protect the components of the magnetic-component module. Instead of overmolding, it is also possible to use a potting method or an encapsulation method to stabilize and protect the components of the magnetic-component module.

FIGS. **2-4** show an example of magnetic-component module **100** with the spacer **135** and without the overmold material **190**. FIG. **2** is a top perspective view, FIG. **3** is a side view, and FIG. **4** is a top view. FIGS. **2-4** show views of the spacer **135** having a single cross-sectional shape and conforming to the top portion of the core **110**. FIGS. **2-4** show the core **110**, the wire bonds **120**, the substrate **140**, the components **150**, the I/O pins **150**, and the adhesive **170**.

FIGS. **5-14** show steps of a method of manufacturing the magnetic-component module **100** with the spacer **130**. FIG. **5** shows that the substrate **140**, such as a PCB, can be provided with traces **145** according to conventional techniques. FIG. **6** shows that the adhesive **170** can be deposited on portions of the surface of the substrate **140** on which the core **110** is to be mounted. FIG. **7** shows that the core **110** can be adhered to the substrate **140** where the adhesive **170** was deposited. FIG. **8** shows that an adhesive **132** can be deposited on a top surface of the core **110**. FIG. **9** shows that the spacer **130** can be adhered on the top surface of the core **110**. FIG. **10** shows that the wire bonds **120** can be formed such that the wire bonds **120** are attached to the substrate **140**, extend over the core **110** and the spacer **130**, and do not contact the core **110**. FIG. **11** shows that an overmold material **190** can be overmolded to cover or encapsulate the core **110**, the wire bonds **120**, and the **130** spacer. FIG. **12** shows that solder **180** can be deposited on the substrate **140** on the surface opposite to the overmold material **190**. FIG. **13** shows that the components **150** and the I/O pins **160** can be mounted on the substrate **140** using the solder **180**. FIG. **14** shows the finished magnetic-component module **100** shown in the left side of FIG. **1**.

FIG. **15** shows a magnetic-component module **200** with a core **210** that is fixed (i.e., adhered) to a substrate **240**. The magnetic-component module **200** includes the core **210**, winding(s) that are defined by wire bonds **220** and traces **245**, a spacer **230**, and a substrate **240**. The core **210** is covered on all sides by the spacer **230**. As in FIG. **1**, wire bonds **220** define the top half of the windings. Traces **245** on the top surface of substrate **240** define the bottom half of the windings. Because the spacer **230** covers the entire outer surface of the core **210**, it is not necessary to use a more-expensive multilayer substrate, and it is possible to use a less-expensive substrate **240** with no internal layers. But it is also possible to use a multilayer substrate in which the traces **245** defining the bottom half of the windings are located on the top surface or an internal layer of the multilayer substrate. Circuitry components and/or connectors can be located on the bottom surface of the substrate **240**. FIG. **2** also shows that the core **210**, the spacer **230**, and the wire bonds **220** can be overmolded with overmold material **290**. Instead of the spacer **230** extending over the entire outer surface of the core **210**, it is also possible that the spacer **230** only extends over substantially the entire outer surface of the core **210**. For example, the spacer **230** can extend over substantially the entire outer surface of the core **210** by having a C-shape such that the top and bottom and either the inner or outer side of the core **210** are covered, while either the outer or inner side of the core **210** is exposed. Alternatively, the spacer **230** can extend over substantially the entire outer surface of the core **210** by using two spacers, one that extends over the top of the core **210** and one that extends over the bottom of the core **210**.

As shown in FIG. **15**, the magnetic-component module **200** can include surface-mount (SM) or input/output (I/O) pins **260** that are located on the bottom surface of the substrate **240**. The magnetic-component module **200** can include electrical components **250** mounted on the bottom surface of the substrate **240**. The electrical components **250** can include passive components, such as, capacitors, resistors, etc. and can include active components, such as transistors.

FIGS. **16-23** show steps of a method of manufacturing the magnetic-component module **200** shown in FIG. **15**. FIG. **16** shows that the substrate **240**, such as a PCB, can be provided with traces **245** on two opposing outer surfaces according to conventional techniques. FIG. **17** shows that an adhesive **270** can be deposited on portions of the surface of the substrate **240** on which the core **210** is to be mounted. FIG. **18** shows the core **210** that is covered on all sides by the spacer **230** can be adhered to the substrate **240** where the adhesive **270** was deposited. FIG. **19** shows that the wire bonds **220** can be formed such that the wire bonds **220** are attached to the substrate **240**, extend over the core **210** covered by the spacer **230**, and do not contact the core **210**. FIG. **20** shows that an overmold material **290** can be overmolded to cover or encapsulate the core **210**, the wire bonds **220**, and the **230** spacer. FIG. **21** shows that solder **280** can be deposited on the substrate **240** on the opposite surface to the overmold material **290**. FIG. **22** shows that the components **250** and the I/O pins **260** can be mounted on the substrate **240** using the solder **280**. FIG. **23** shows the finished magnetic-component module **200** shown in FIG. **15**.

As described above with respect to FIGS. **1** and **15**, the core can be fixed to the top surface of the substrate. FIG. **24** shows an alternate arrangement of a magnetic-component module **300** in which an adhesive or glue layer **370** is thick enough to create a gap between the core **310** and the substrate **340** to allow the overmold material **390** to extend under the core **310** after bonding the wire bonds **320**. The magnetic-component module **300** includes a core **310**, winding(s) that are defined by wire bonds **320** and traces **345**, a spacer **330**, and a substrate **340**. FIG. **24** shows a truncated conical shaped adhesive layer **370** provided under the core **310** that creates the gap between the core **310** and the substrate **340**. The overmold material **390** can extend into the gap between the core **310** and the substrate **340**, providing an additional insulation layer to strengthen the isolation barrier between the core **310** and the traces **345** on the top surface of the substrate **340**. Because the overmold material **390** fills the gap between the core **310** and the substrate **340**, it is not necessary to use a more expensive multilayer substrate, and it is possible to use a less expensive substrate **340** with no internal layers. But it is also possible to use a multilayer substrate in which the traces **345** defining the bottom half of the windings are located on the top surface or an internal layer of the multilayer substrate.

The left side of FIG. **24** shows an example of a spacer **330** between the top of the core **310** and the wire bonds **320** to prevent the wire from touching the core **310** and being short-circuited. As shown, the spacer **330** is wider than a width of the core **310** to create an overhang that maintains a predetermined distance between the wire bond **320** and the core **310**. The right side of FIG. **24** shows an alternative configuration of the spacer **335** in which the spacer **335** conforms to the top portion of the core **310** and partially covers the side walls of the core **310**. It should be understood that, typically, the spacer will have a single cross-sectional shape throughout the spacer and that the two different cross-sectional shapes shown in FIG. **24** are examples of possible cross-sectional shapes. FIGS. **29-34** show a magnetic-component module that uses the spacer **130** that is wider than the width of the core **110** to create an overhang.

As shown in FIG. **24**, the magnetic-component module **300** can include surface-mount (SM) or input/output (I/O) pins **360** that are located on the bottom surface of the substrate **340**. The magnetic-component module **300** can include electrical components **350** mounted on the bottom surface of the substrate **340**. The electrical components **350** can include passive components, such as, capacitors, resistors, etc. and can include active components, such as transistors.

FIGS. **25-34** show steps of a method of manufacturing the magnetic-component module **300** shown in FIG. **24**. FIG. **25** shows that the substrate **340**, such as a PCB, can be provided with traces **345** on two opposing outer surfaces according to conventional techniques. FIG. **26** shows that an adhesive **370** can be deposited on portions of the surface of the substrate **340** on which the core **310** is to be mounted. FIG. **27** shows the core **310** can be adhered to the substrate **340** where the adhesive **370** was deposited. FIG. **28** shows that an adhesive **332** can be deposited on a top surface of the core **310**. FIG. **29** shows that a spacer **330** can be adhered on the top surface of the core **310**. FIG. **30** shows that the wire bonds **320** can be formed such that the wire bonds **220** are attached to the substrate **340**, extend over the core **310** and the spacer **330**, and do not contact the core **310**. FIG. **31** shows that an overmold material **390** can be overmolded to cover or encapsulate the core **310**, the wire bonds **320**, the **330** spacer, and the adhesive **370**. FIG. **32** shows that solder **380** can be deposited on the substrate **340** on the opposite surface to the overmold material **390**. FIG. **33** shows that the components **350** and the I/O pins **360** can be mounted on the substrate **340** using the solder **380**. FIG. **34** shows the finished magnetic-component module **300** shown in FIG. **24**.

FIG. **35** shows a magnetic-component module **400** with an overmolded core **410** and wire bonds **420** connected to a lead frame **480** instead of a substrate. FIG. **35** shows that the spacer **430** can surround the core **410**, but other arrangements, as shown in the previous figures, are also possible. The lead frame **480** can be made from any suitable conductive material. The core **410** is supported by legs **482** of the lead frame **480**. FIG. **35** also shows that the core **410**, the wire bonds **420**, and supporting portions of the lead frame **480** can all be overmolded. The legs **482** of the lead frame **480** can be mounted on a substrate **440** with a space created between the bottom of the overmold material **490** and the top surface of the substrate **440**. The space between the overmold material **490** and the substrate **440** can be used to mount circuitry components **450** and other electronic components and to increase the surface area of the magnetic-component module **400** to facilitate cooling. Using the lead frame **480** can save space and increase circuit density. Although FIG. **35** shows a substrate **440** with no internal layers, it is also possible to use a multilayer substrate.

FIGS. **36**-**43** show steps of a method of manufacturing the magnetic-component module **400** shown in FIG. **35**. FIG. **36** shows that a lead frame panel can be punched to form an unbent lead frame **480**. FIG. **37** shows that an adhesive **485** can be deposited on portions of the surface of the lead frame **480** on which the core **410** is to be mounted. FIG. **38** shows the core **410** with surrounding spacer **430** can be adhered to the lead frame **480** where the adhesive **485** was deposited. FIG. **39** shows that the wire bonds **420** can be formed such that the wire bonds **420** are attached to the lead frame **480**, extend over the core **410** and the spacer **430**, and do not contact the core **410** but may contact the spacer **430**. FIG. **40** shows that an overmold material **490** can be overmolded to cover or encapsulate the core **410**, the wire bonds **420**, the **430** spacer, and portions of the lead frame **480**. FIG. **41** shows that portions of the lead frame **480** can be bent to form the legs **482**. FIG. **42** shows that the two-layer substrate **440**, such as a PCB, can be provided with traces **445** according to conventional techniques. FIG. **43** shows that circuitry components **450** and the overmolded transformer with lead frame **480** can be mounted on the substrate **440** using conventional soldering techniques to complete fabrication of the magnetic-component module **400**.

FIG. **44** is a block diagram of an example of an implementation of a magnetic-component module TXM. In FIG. **44**, the magnetic-component module TXM is implemented as an isolated converter with the dashed line through the transformer TX showing the isolation boundary. The primary side that is on the left side of FIG. **44** and that is connected to the primary winding PR is isolated from the secondary side that is on the right side of FIG. **44** and that is connected to the secondary winding SEC. For example, FIG. **44** shows that the electronic module TXM can include a switching stage SS, a control stage CS, a transformer TX, a rectifier stage RS, and an output filter LC. The transformer TX can include the core and windings that are defined by wire bonds and traces as previously described. The circuitry and components other than the transformer TX can include other electronic components that are attached to the substrate or PCB on which the transformer TX is mounted, as previously described.

As shown in FIG. **44**, the switching stage SS receives an input voltage Vin and outputs a voltage SSout to at least one primary winding PRI of the transformer TX. The switching stage can include switches or transistors that control the flow of power. The control stage CS includes an input control signal CSin. The control stage CS can control the switching of the switches in the switching stage SS and can monitor the transformer TX via an auxiliary winding AUX. The dotted vertical line through the transformer TX represents the galvanic isolation between the primary winding PRI and the auxiliary winding AUX from the secondary winding SEC. The secondary winding of the transformer TX can be connected to a rectifier stage RS that in turn is connected to an output filter LC that outputs a DC voltage between +Vout and −Vout. The rectifier stage can include diodes and/or synchronous rectifiers that rectify the voltage at the secondary winding SEC. The output filter LC can include an arrangement of inductor(s) and capacitor(s) to filter unwanted frequencies.

FIG. **45** is a block diagram of a gate-drive-circuit application that can include one or more of the magnetic-component modules TXM shown in FIG. **44**. The vertical and horizontal dotted lines represent galvanic isolation. FIG. **45** shows that the magnetic-component modules TXM can include, for example, a +12 Vdc input and −5 Vdc and +18 Vdc outputs, which could be used, for example, to drive metal-oxide-semiconductor field-effect transistor (MOSFETs) or insulated-gate bipolar transistors (IGBTs). The outputs of the magnetic-component modules TXM can be connected to gate driver IXDD614YI. A controller CONT can transmit and receive control signals represented by those control signals shown in the dotted-line boxes, including, for example, power-supply disable, pulse-width modulation PWM enable, low-side and high-side PWM, over-current detection, etc. The control signals can be transmitted and received between the controller CONT and the isolation circuitry ISO and between the controller CONT and the magnetic-component modules TXM. The isolation circuitry ISO can receive and transmit feedback signals V_{DS} Measure. The isolation circuitry can include a transformer, a capacitor, an opto-coupler, a digital isolator, and the like. The output of the gate drive circuit can be connected to a gate of a switch located in an inverter-unit circuitry as a portion of an inverter for a motor control application as shown in FIG. **46**.

FIG. **46** shows circuitry for a motor control application that can include a power supply PS running at a fixed frequency of 50 Hz or 60 Hz, for example, an inverter INV, and a motor MTR running at its required frequency. As shown, the inverter INV can include a power converter PC, a smoothing circuit S, and inverter unit circuitry IU controlled with PWM control. FIG. **46** shows that a controller CONT can be included to control the gate drive units GDU of FIG. **45**. The gate drive units GDU can control the gates of the switches within the inverter unit circuitry IU. Feedback FB can be provided to the controller CONT from the motor MTR to stabilize control of the gate drive units GDU.

A package including the magnetic-component module can be any size. For example, the package can be about 12.7 mm by about 10.4 mm by about 4.36 mm. A package with these dimensions can provide higher isolation. The magnetic-component module can be used in many different applications, including, for example, industrial, medical, and automotive applications. For example, as explained above, the magnetic-component module can be included in a gate drive. The magnetic-component module can provide 1 W-2 W of power with an efficiency of greater than 80% and can provide 3 kV or 5 kV breakdown rating depending on the footprint of the magnetic-component module, for example. The magnetic-component module can include UL-required reinforced isolation and can operate at temperatures between about −40° C. and about 105° C. or between about −40° C. and about 125° C., for example. The magnetic-component module can have a moisture sensitivity level (MSL) of 1 or 2, for example, depending on the application. The magnetic component module can be used in battery management systems or programmable logic controller and data acquisition and communication compliant with RS484/232.

If the magnetic-component module includes a transformer, then, for example, the primary winding can include at least 20 turns and the secondary winding can include 12 turns. The coupling factor of the transformer can be 0.99, for example. The primary windings can have a direct-current resistance (DCR) of about 17.8 Ω/turn, and the secondary windings can have DCR of about 16.9 Ω/turn, for example. The maximum current can be 600 mA (over-current protection) with typical current being 300 mA, for example, to ensure that the magnetic-component module is not damaged in such over-current situations. The core can have an inner diameter of about 5.4 mm, an outer diameter of about 8.8

mm, and a height of about 1.97 mm, for example. The spacer can have an inner diameter of about 5.1 mm, an outer diameter of about 8.8 mm, and a height of about 0.2 mm, for example. The transformer can have size of about 12.7 mm by about 10.4 mm by about 2.5 mm, for example. The core can be made of any suitable material, including, for example, Mn—Zn, Ni—Zn, FeNi, and the like. The spacer can be made of any suitable material, including, for example, an epoxy adhesive. The wire bonds can be made of any suitable material, including, for example, Al or Cu. The pins can be made of any suitable material, including, for example, Cu with Ni—Sn coating. The overmold material can be made of any suitable material, including, for example, epoxy resin.

It should be understood that the foregoing description is only illustrative of the present invention. Various alternatives and modifications can be devised by those skilled in the art without departing from the present invention. Accordingly, the present invention is intended to embrace all such alternatives, modifications, and variances that fall within the scope of the appended claims.

What is claimed is:

1. A magnetic-component module comprising:

a substrate;

a core on a first surface of the substrate;

a spacer that conforms to a top of the core;

a gap between a bottom surface of the core and the first surface of the substrate;

an adhesive in the gap to mount the core to the substrate;

a winding including:

wire bonds extending over the core and electrically connecting a first portion of the substrate and a second portion of the substrate; and

traces on and/or in the substrate; and

an overmold material encapsulating the core, the spacer, the wire bonds, and the adhesive and filling the gap.

2. A voltage converter circuit comprising the magnetic-component module according to claim **1**.

3. A gate drive switching circuit comprising the voltage converter circuit of claim **2**.

4. A magnetic-component module comprising:

a substrate;

a core on a first surface of the substrate;

a spacer extending over an entire outer surface of the core or over substantially the entire outer surface of the core;

a gap between a bottom surface of the core and the first surface of the substrate;

an adhesive in the gap to mount the core to the substrate;

a winding including:

wire bonds extending over the core and electrically connecting a first portion of the substrate and a second portion of the substrate; and

traces on and/or in the substrate; and

an overmold material encapsulating the core, the spacer, the wire bonds, and the adhesive and filling the gap.

5. A voltage converter circuit comprising the magnetic-component module according to claim **4**.

6. A gate drive switching circuit comprising the voltage converter circuit of claim **5**.

7. A magnetic-component module comprising:

a substrate;

a core on a first surface of the substrate;

a spacer on the core such that an edge of the spacer overhangs the core;

a gap between a bottom surface of the core and the first surface of the substrate;

an adhesive in the gap to mount the core to the substrate;

a winding including:

wire bonds extending over the core and electrically connecting a first portion of the substrate and a second portion of the substrate; and

traces on and/or in the substrate; and

an overmold material encapsulating the core, the spacer, the wire bonds, and the adhesive and filling the gap.

8. A voltage converter circuit comprising the magnetic-component module according to claim **7**.

9. A gate drive switching circuit comprising the voltage converter circuit of claim **8**.

* * * * *