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(54) TRANSFORMER-BASED INTEGRATED CIRCUIT PACKAGES HAVING FRACTIONAL COIL STRUCTURES

(71) Applicant: **Allegro MicroSystems, LLC**, Manchester, NH (US)

(72) Inventors: **Paul A. David**, Bow, NH (US); **Vijay Mangtani**, Nashua, NH (US); **William P. Taylor**, Amherst, NH (US)

(73) Assignee: **Allegro MicroSystems, LLC**, Manchester, NH (US)

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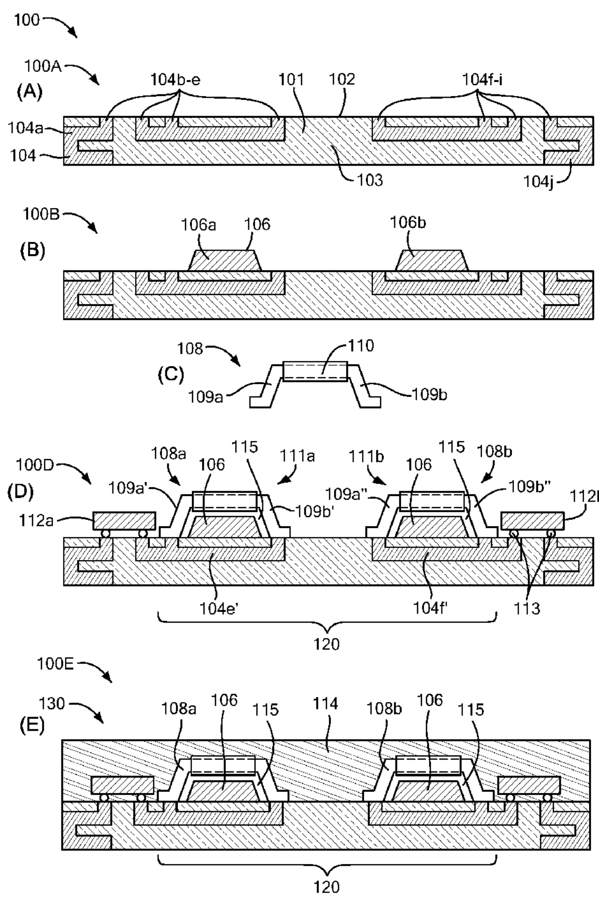
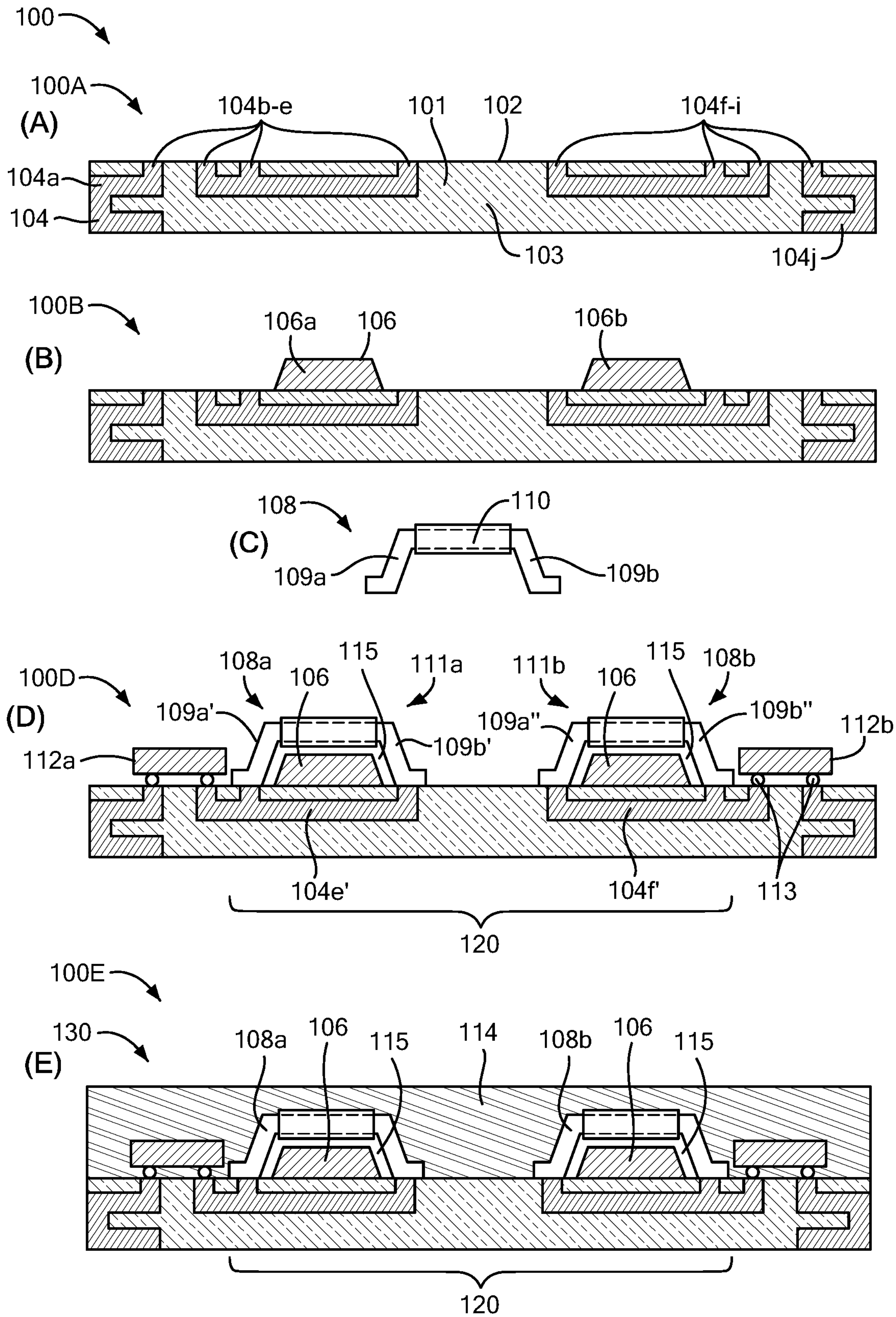
(57) **ABSTRACT**

Systems, structures, packages, circuits, and methods provide transformers having fractional coil structures. A first plurality of conductive traces in a substrate forms first portions of first and second transformer coils. Two or more fractional coil structures are provided, with each including a second plurality of conductive traces forming second portions of the transformer coils and configured to extend around a portion of a provided magnetic core. The fractional coil structures are configured such that first (primary) and second (secondary) transformer coils are formed when the second plurality of conductive traces is brought into contact with the first plurality of conductive traces. A transformer having one or more fractional coil structures can be included in integrated circuit (chip) packages or modules. The packages and modules may include various types of circuits; in some examples, chip packages or modules may include a galvanically isolated gate driver or other high voltage circuit.

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100A
(A)
104b-e
101
102
104f-i
104a
104
103
104j
100B
(B)
106a
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108
110
(C)
109a
109b
100D
(D)
108a
115
111a
111b
115
108b
106
106
109a'
109a''
109b''
112b
112a
109b'
104e'
104f'
113
120
100E
130
(E)
108a
106
115
114
108b
106
115
120

FIG. 1

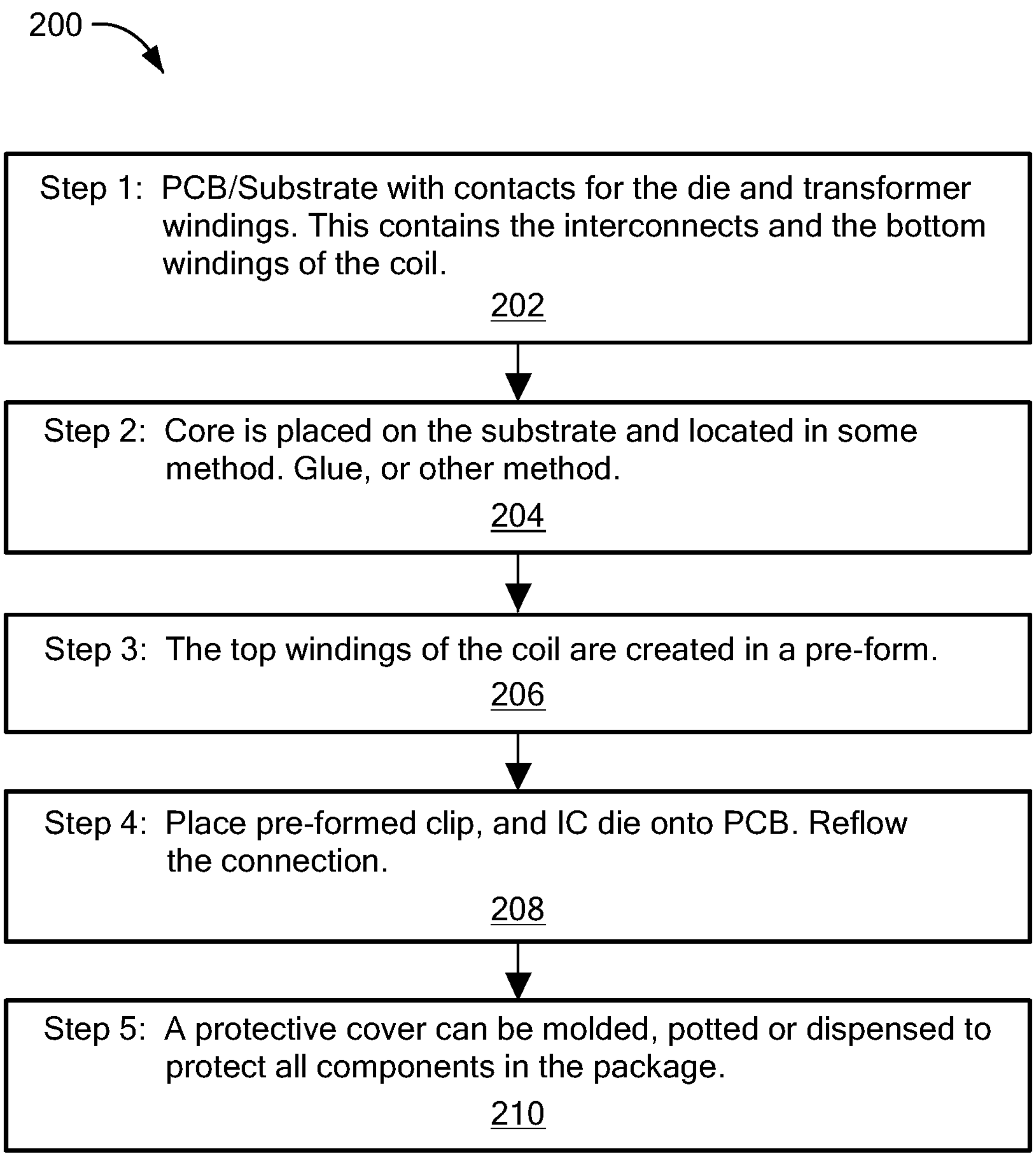
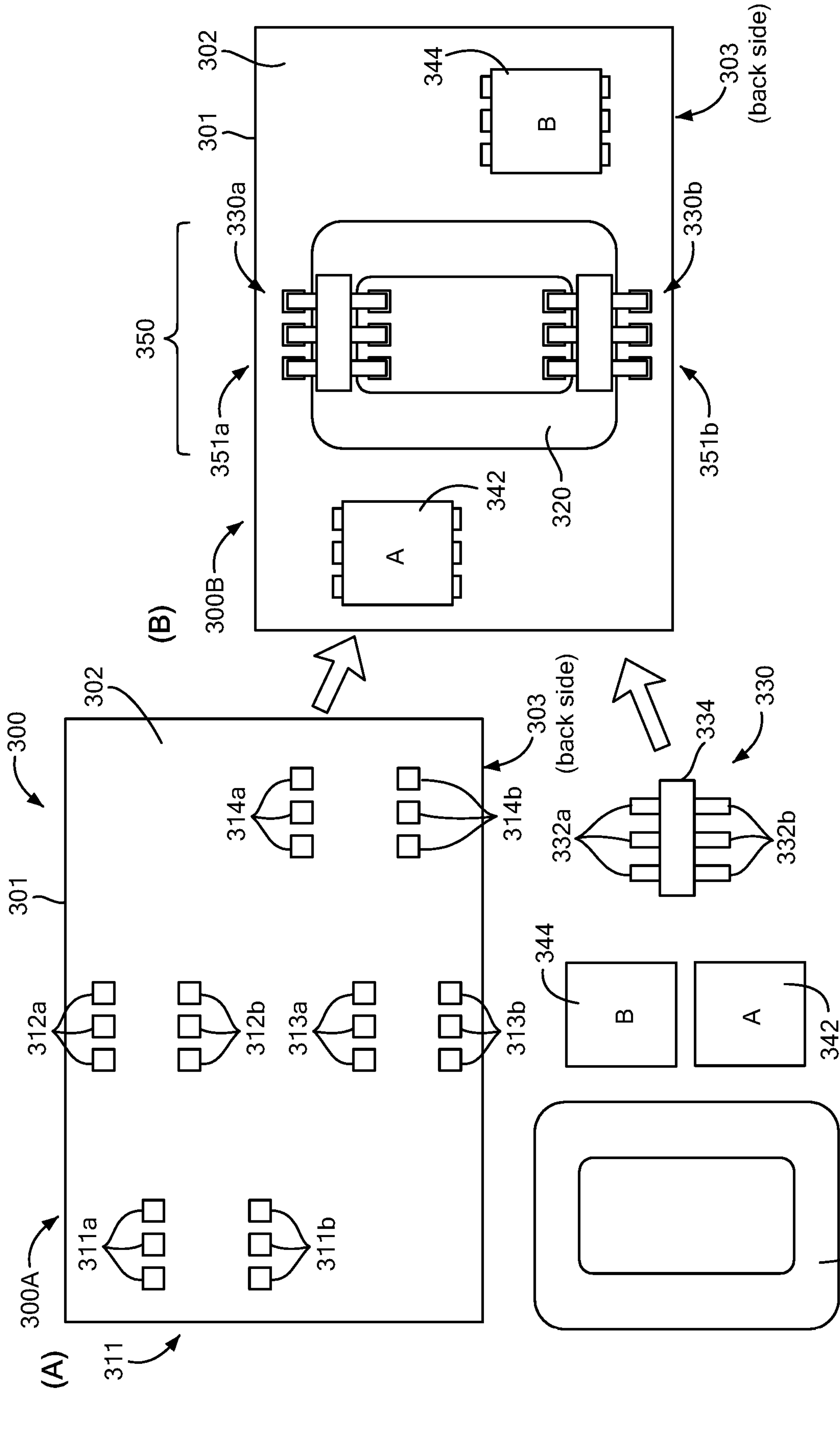

200
Step 1: PCB/Substrate with contacts for the die and transformer windings. This contains the interconnects and the bottom windings of the coil.
202
Step 2: Core is placed on the substrate and located in some method. Glue, or other method.
204
Step 3: The top windings of the coil are created in a pre-form.
206
Step 4: Place pre-formed clip, and IC die onto PCB. Reflow the connection.
208
Step 5: A protective cover can be molded, potted or dispensed to protect all components in the package.
210

FIG. 2



(A)
(B)
300
300A
300B
301
302
303
(back side)
311
311a
311b
312a
312b
313a
313b
314a
314b
320
330
330a
330b
332a
332b
334
342
344
A
B
350
351a
351b

FIG. 3

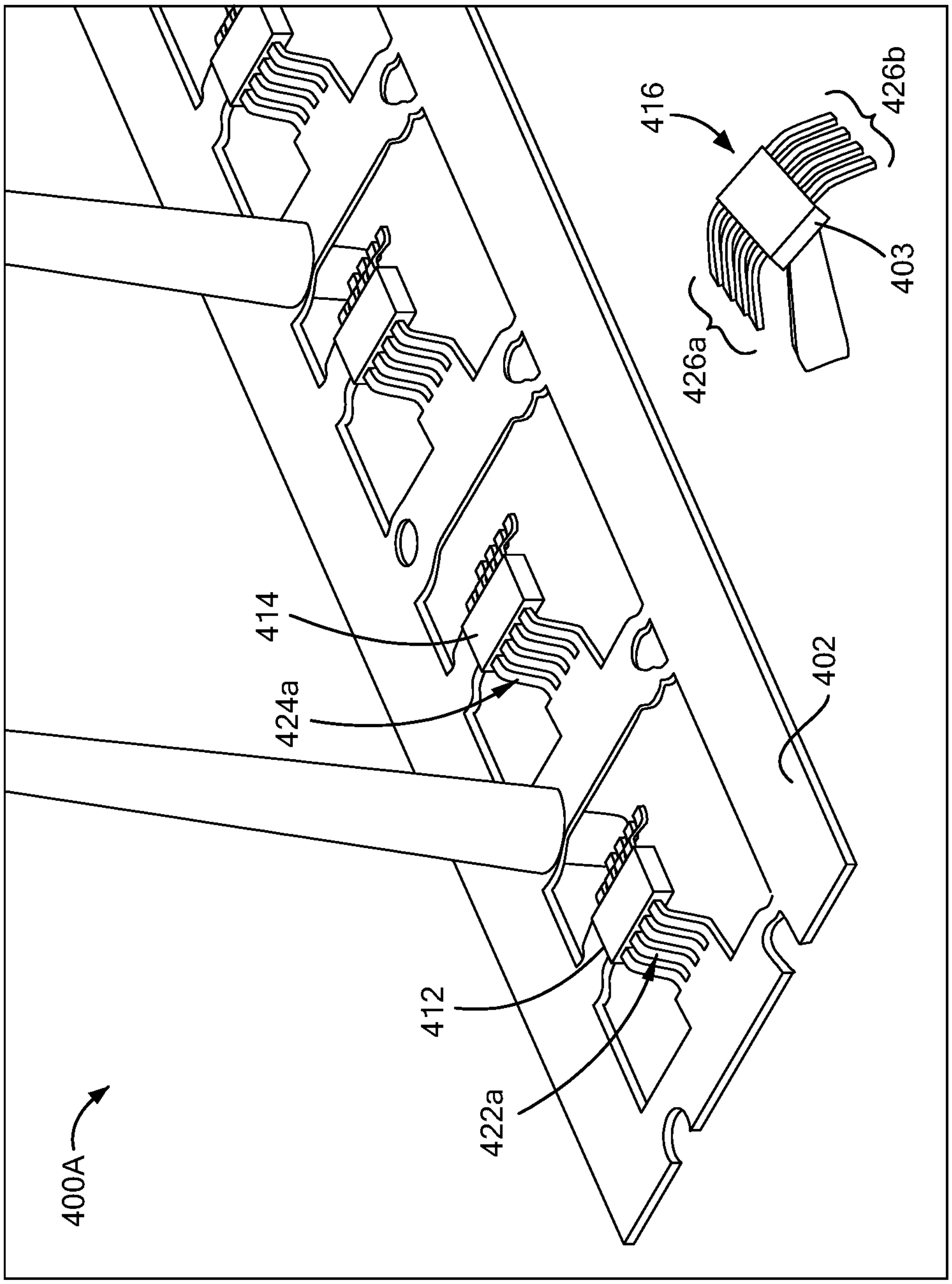


FIG. 4A

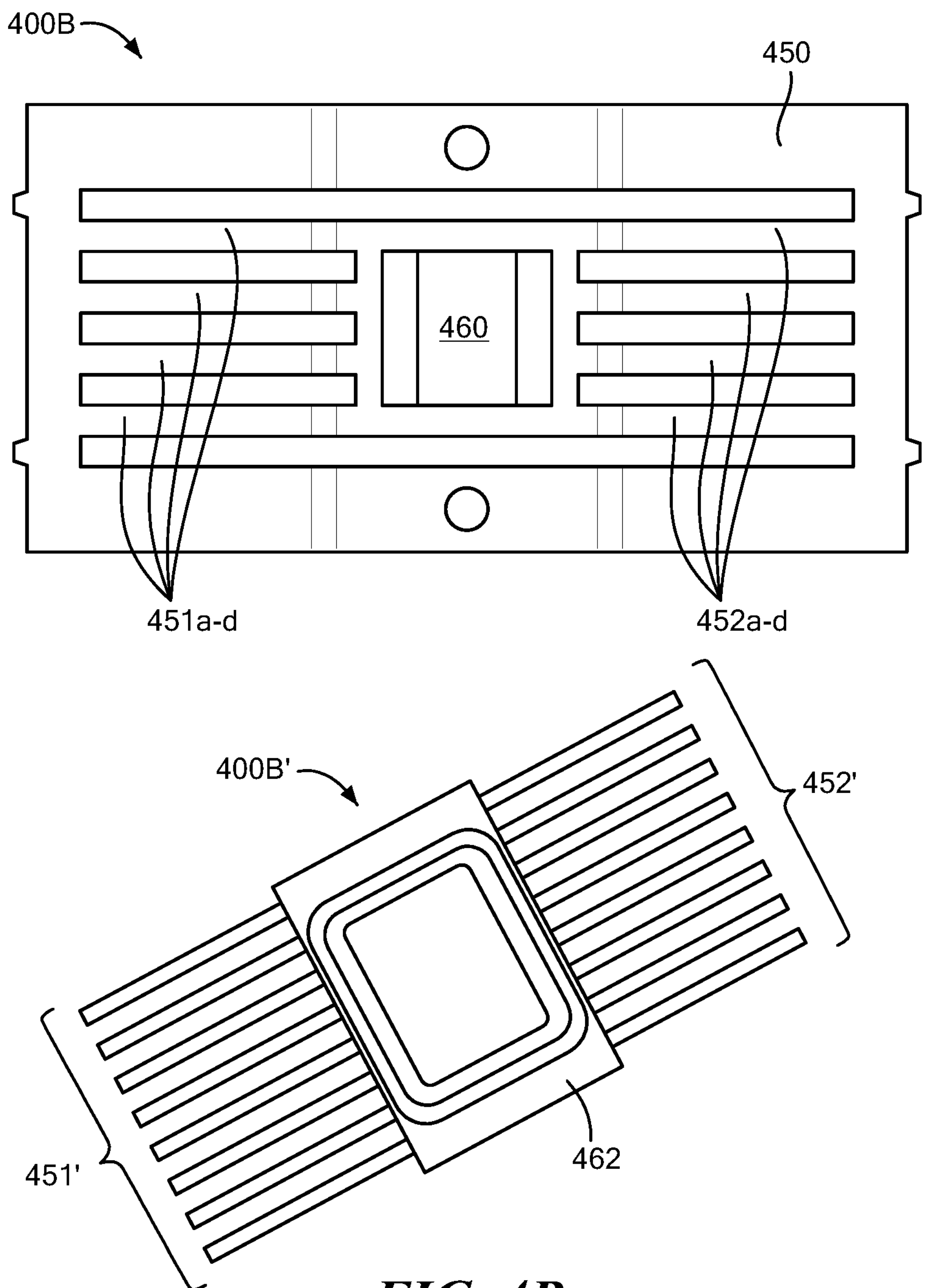
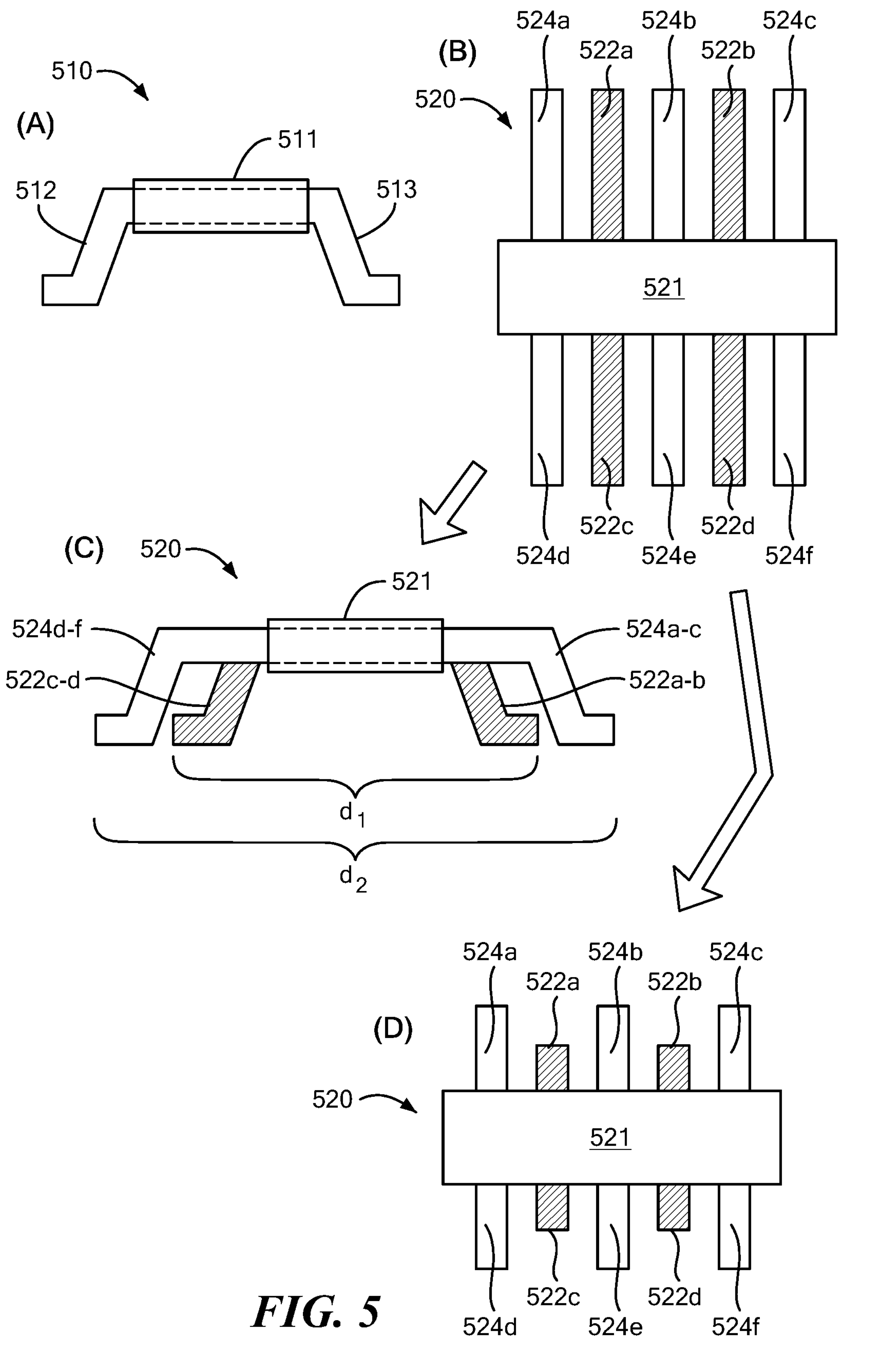


FIG. 4B



510
(A)
511
512
513
(B)
520
524a
522a
524b
522b
524c
521
522c
522d
524d
524e
524f
(C)
520
521
524d-f
524a-c
522c-d
522a-b
d 1
d 2
(D)
520
524a
522a
524b
522b
524c
521
522c
522d
524d
524e
524f

FIG. 5

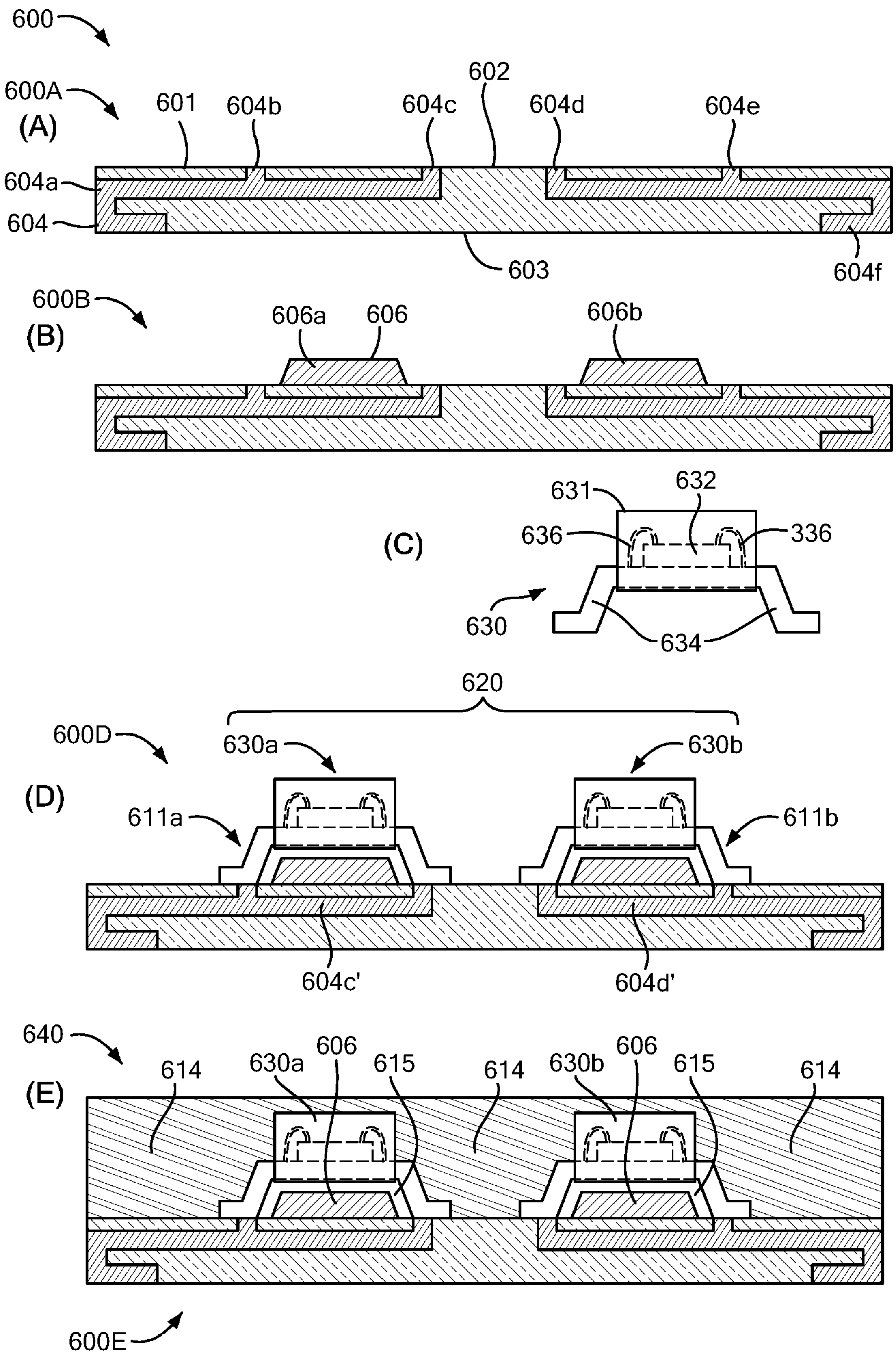

600
600A
(A)
601
604b
602
604c
604d
604e
604a
604
603
604f
600B
(B)
606a
606
606b
631
632
636
336
(C)
630
634
620
600D
630a
630b
(D)
611a
611b
604c'
604d'
640
(E)
614
630a
606
615
614
630b
606
615
614
600E

FIG. 6

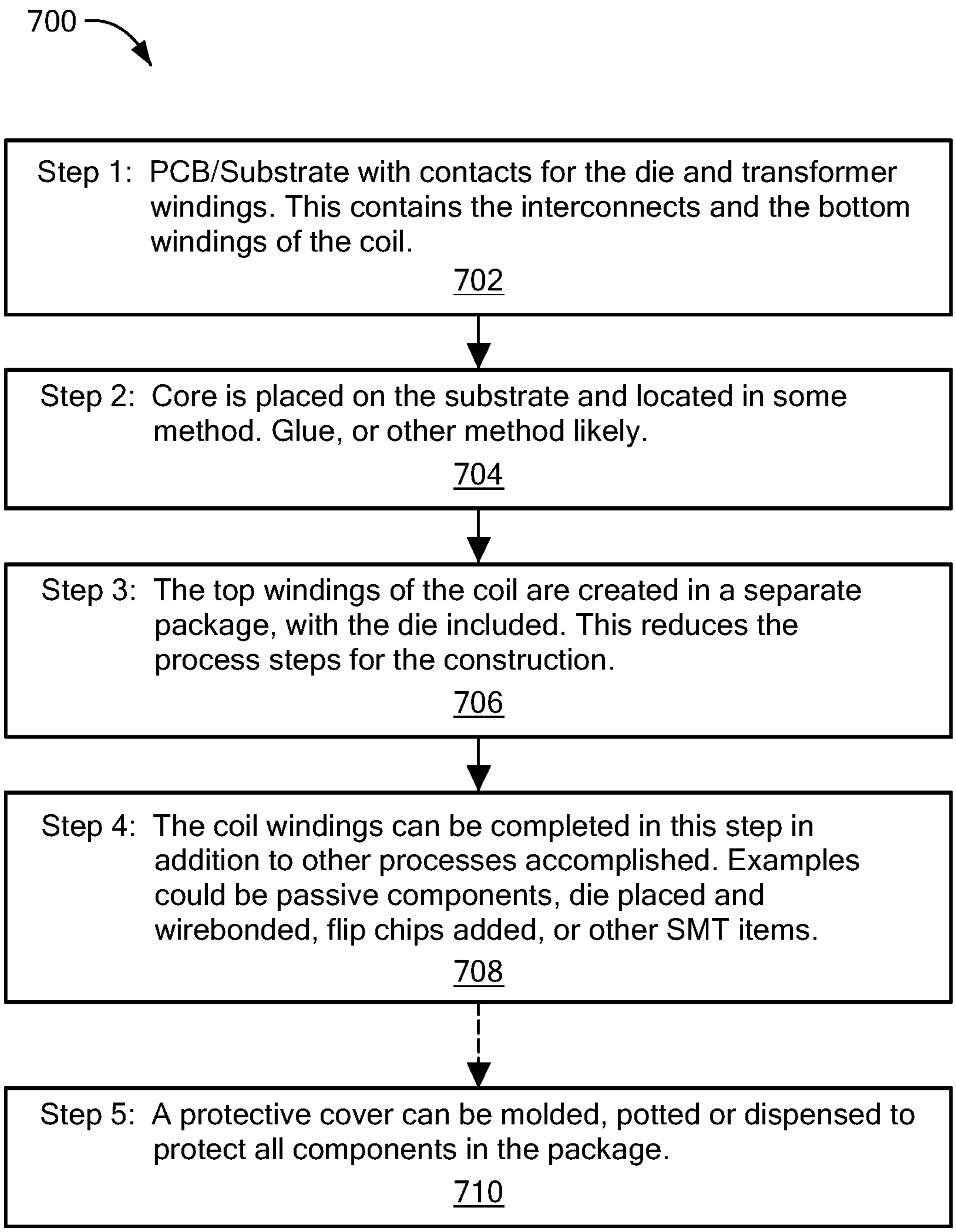

700
Step 1: PCB/Substrate with contacts for the die and transformer windings. This contains the interconnects and the bottom windings of the coil.
702
Step 2: Core is placed on the substrate and located in some method. Glue, or other method likely.
704
Step 3: The top windings of the coil are created in a separate package, with the die included. This reduces the process steps for the construction.
706
Step 4: The coil windings can be completed in this step in addition to other processes accomplished. Examples could be passive components, die placed and wirebonded, flip chips added, or other SMT items.
708
Step 5: A protective cover can be molded, potted or dispensed to protect all components in the package.
710

FIG. 7

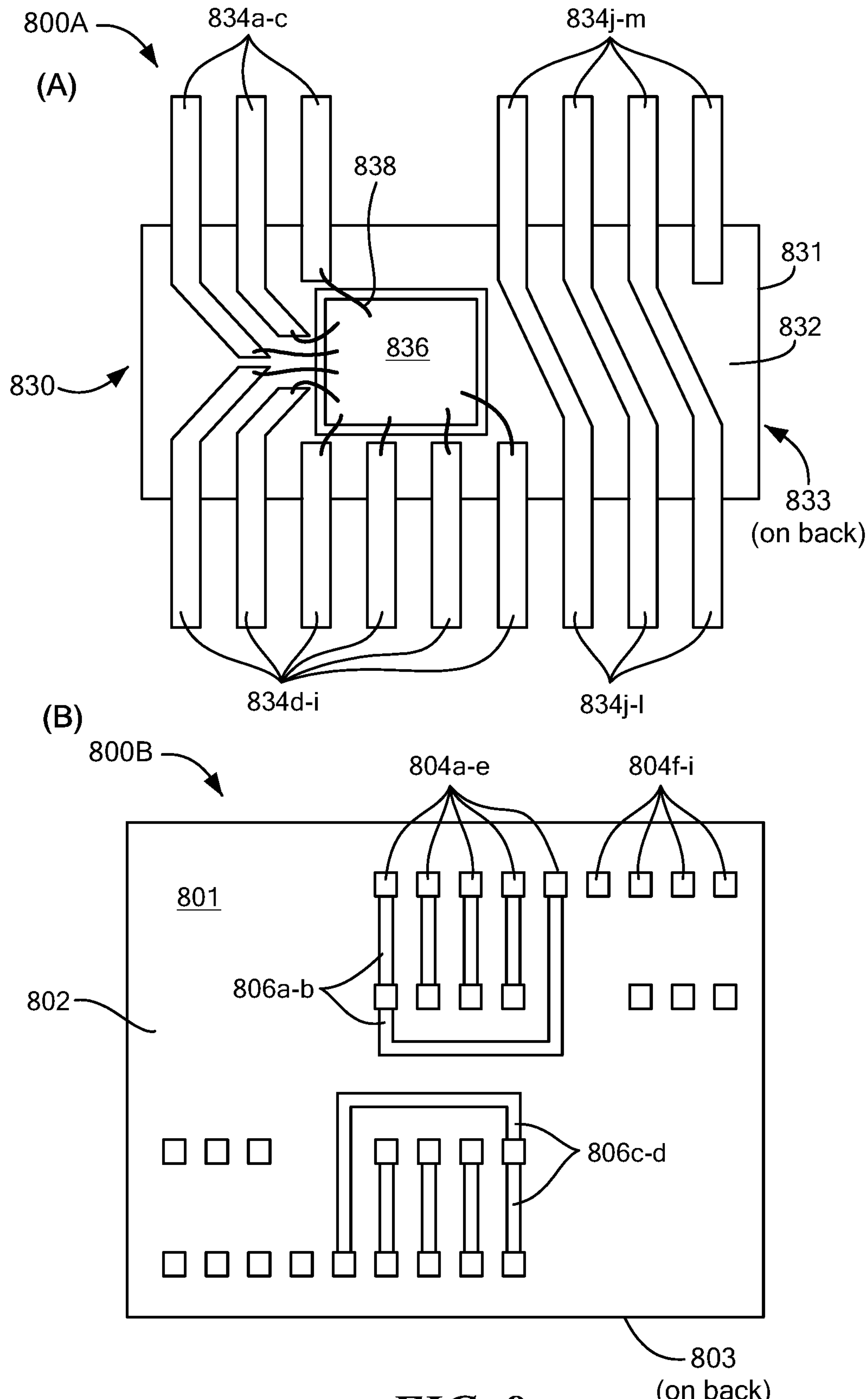

800A
(A)
834a-c
834j-m
838
831
832
836
830
833
(on back)
834d-i
834j-l
(B)
800B
804a-e
804f-i
801
806a-b
802
806c-d
803
(on back)

FIG. 8

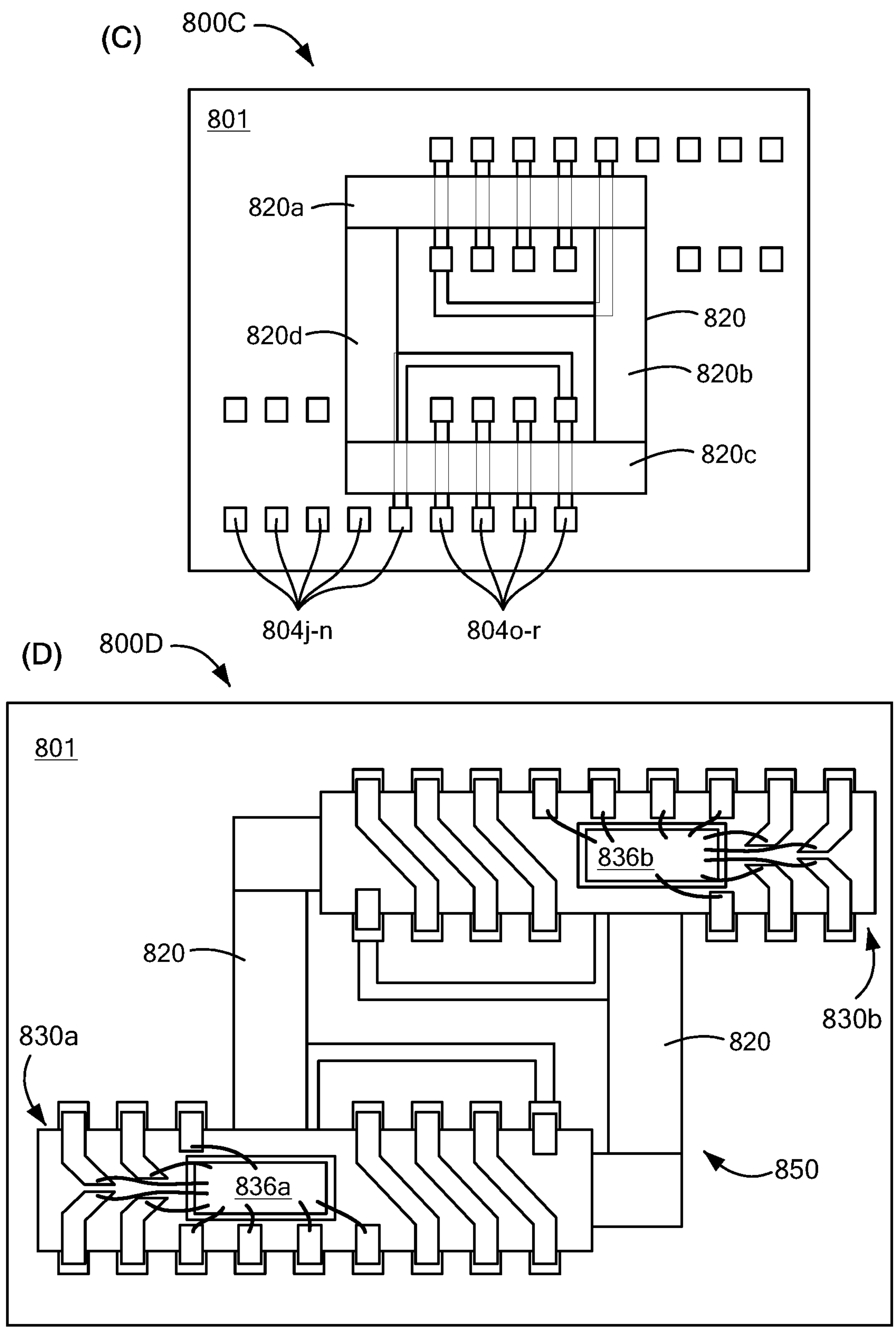


FIG. 8 (continued)

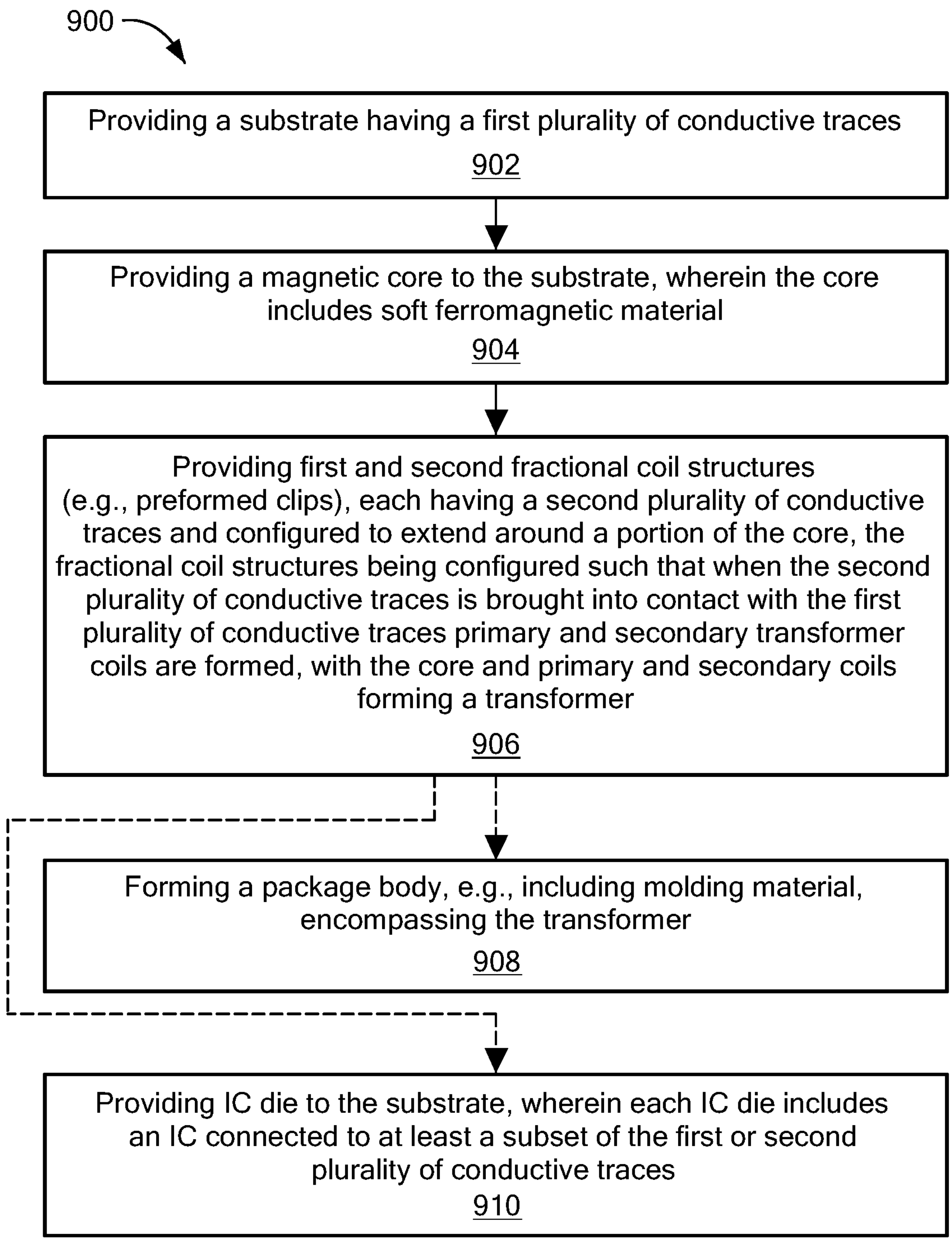

900
Providing a substrate having a first plurality of conductive traces
902
Providing a magnetic core to the substrate, wherein the core includes soft ferromagnetic material
904
Providing first and second fractional coil structures (e.g., preformed clips), each having a second plurality of conductive traces and configured to extend around a portion of the core, the fractional coil structures being configured such that when the second plurality of conductive traces is brought into contact with the first plurality of conductive traces primary and secondary transformer coils are formed, with the core and primary and secondary coils forming a transformer
906
Forming a package body, e.g., including molding material, encompassing the transformer
908
Providing IC die to the substrate, wherein each IC die includes an IC connected to at least a subset of the first or second plurality of conductive traces
910

FIG. 9

TRANSFORMER-BASED INTEGRATED CIRCUIT PACKAGES HAVING FRACTIONAL COIL STRUCTURES

BACKGROUND

[0001] Solid state switches typically include a transistor structure. The controlling electrode of the switch, usually referred to as its gate (or base), is typically controlled (driven) by a switch drive circuit, sometimes also referred to as gate drive circuit. Such solid state switches are typically voltage-controlled, turning on when the gate voltage exceeds a manufacturer-specific threshold voltage by a margin, and turning off when the gate voltage remains below the threshold voltage by a margin.

[0002] Switch drive circuits typically receive their control instructions from a controller such as a pulse-width-modulated (PWM) controller via one or more switch driver inputs. Switch drive circuits deliver their drive signals directly (or indirectly via networks of active and passive components) to the respective terminals of the switch (gate and source).

[0003] Some electronic systems, including ones with solid state switches, have employed galvanic isolation to prevent undesirable DC currents flowing from one side of an isolation barrier to the other. Such galvanic isolation can be used to separate circuits in order to protect users from coming into direct contact with hazardous voltages.

[0004] Various transmission techniques are available for signals to be sent across galvanic isolation barriers including optical, capacitive, and magnetic coupling techniques. Magnetic coupling typically relies on use of a transformer to magnetically couple circuits on the different sides of the transformer, typically referred to as the primary and secondary sides, while also providing galvanic separation of the circuits.

[0005] Transformers used for magnetic-coupling isolation barriers typically utilize a magnetic core to provide a magnetic path to channel flux created by the currents flowing in the primary and secondary sides of the transformer. Magnetic-coupling isolation barriers have been shown to have various drawbacks, including manufacturing problems, for integrated circuit (IC) packages due to the included magnetic core.

SUMMARY

[0006] Aspects of the present disclosure are directed to transformer-based circuits, circuit portions, and packages, including integrated circuit (IC) packages, having one or more fractional coil structures, and related manufacturing methods.

[0007] One general aspect of the present disclosure includes a transformer-based integrated circuit (IC) package. The transformer-based integrated circuit package can include: a substrate having a first plurality of conductive traces; a core disposed on the substrate, where the core includes a soft ferromagnetic material; and a pair of fractional coil structures, each having a second plurality of conductive traces and configured to extend around a portion of the core, where the pair of fractional coil structures is configured such that primary and secondary coils are formed when the second plurality of conductive traces is brought into contact with the first plurality of conductive traces; where the primary and secondary coils are configured with the core as a transformer. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

[0008] Implementations may include one or more of the following features. The IC package may include at least one semiconductor die disposed on the substrate. The at least one semiconductor die may include an integrated circuit (IC). The IC can be connected to the secondary coil. The transformer can be configured as a step-up transformer, a step-down transformer, or a power transformer. The IC may include a gate driver. The substrate may include a printed circuit board (PCB). The PCB may include suitable PCB material(s), e.g., FR4, FR5, etc. The core may include ferrite. The core may include iron powder. The core may include a laminated metal core or a laminated non-metal core, e.g., laminated ferrite. At least one fractional coil structure may include a semiconductor die disposed on a substrate, where the semiconductor die includes an integrated circuit (IC). The IC may be connected to a subset of the second plurality of conductive traces. The IC may include a gate driver, and where the second plurality of conductive traces is connected to the second (secondary) coil. At least one fractional coil structure may include a leadframe. The core may include a plurality of core portions. The plurality of core portions are connected at joints including ferrite-loaded epoxy. The IC package may include a package body including the substrate. The package body may include a molding material. The package body may include a potting material.

[0009] Another general aspect of the present disclosure includes a method of making a transformer-based integrated circuit (IC) package. The method can include: providing a substrate having a first plurality of conductive traces; providing a core disposed on the substrate, where the core includes a soft ferromagnetic material; and providing a pair of fractional coil structures, each having a second plurality of conductive traces and configured to extend around a portion of the core, where the pair of fractional coil structure is configured such that primary and secondary coils are formed when the second plurality of conductive traces is brought into contact with the first plurality of conductive traces; where the primary and secondary coils are configured with the core as a transformer.

[0010] Implementations may include one or more of the following features. The method may include providing at least one semiconductor die disposed on the substrate, where the at least one semiconductor die may include an integrated circuit (IC). The IC can be connected to the secondary coil. The transformer can be configured as a step-up transformer, a step-down transformer, or a power transformer. The IC may include a gate driver. The substrate may include a printed circuit board (PCB). The PCB may include suitable PCB material(s), e.g., FR4, FR5, etc. The core may include ferrite. The core may include iron powder. The core may include a laminated metal core or a laminated non-metal core, e.g., ferrite. At least one (e.g., of the pair) of fractional coil structures may include an IC die disposed on a substrate, where the IC die may include an IC. The IC can be connected to a subset of the second plurality of conductive traces. The IC may include a gate driver, and where the second plurality of conductive traces is connected to the secondary coil. At least one fractional coil structures may include a leadframe.

[0011] The features and advantages described herein are not all-inclusive; many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been selected principally for readability and instructional purposes, and not to limit in any way the scope of the present disclosure, which is susceptible of many embodiments. What follows is illustrative, but not exhaustive, of the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The manner and process of making and using the disclosed embodiments may be appreciated by reference to the figures of the accompanying drawings. In the figures like reference characters refer to like components, parts, elements, or steps/actions; however, similar components, parts, elements, and steps/actions may be referenced by different reference characters in different figures. It should be appreciated that the components and structures illustrated in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principals of the concepts described herein. Furthermore, embodiments are illustrated by way of example and not limitation in the figures, in which:

[0013] FIG. **1** is a diagram showing structure of an example transformer-based integrated circuit (IC) package having fractional coil structures at successive stages of fabrication, in accordance with the present disclosure;

[0014] FIG. **2** is a diagram showing an example method of fabricating a transformer-based integrated circuit (IC) package having fractional coil structures with steps corresponding to the structures shown in FIG. **1**;

[0015] FIG. **3** is a diagram showing Views A-B of an example transformer-based integrated circuit (IC) package structure having fractional coil structures in an unassembled state and an assembled state, respectively, in accordance with the present disclosure;

[0016] FIG. **4**A is a diagram of an example of structure for a contactor molding and leadforming process, in accordance with the present disclosure;

[0017] FIG. **4**B is a diagram of an example long-lead dual in-line-package (DIP), in accordance with the present disclosure;

[0018] FIG. **5** is a diagram with views showing different lead configurations, in accordance with example embodiments of the present disclosure;

[0019] FIG. **6** is a diagram showing structure of a further example transformer-based integrated circuit (IC) package having fractional coil structures at successive stages of fabrication, in accordance with the present disclosure;

[0020] FIG. **7** is a diagram showing an example method of fabricating a transformer-based integrated circuit (IC) package having fractional coil structures with steps corresponding to the structures shown in FIG. **6**;

[0021] FIG. **8** is a diagram showing Views A-D of an example transformer-based integrated circuit (IC) package having fractional coil structures with included ICs, in accordance with the present disclosure; and

[0022] FIG. **9** is a diagram showing an example method of fabricating a transformer-based integrated circuit (IC) package having fractional coil structures, in accordance with the present disclosure.

DETAILED DESCRIPTION

[0023] The features and advantages described herein are not all-inclusive; many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been selected principally for readability and instructional purposes, and not to limit in any way the scope of the inventive subject matter. The subject technology is susceptible of many embodiments. What follows is illustrative, but not exhaustive, of the scope of the subject technology.

[0024] Aspects of the present disclosure are directed to and include systems, structures, circuits, and methods providing transformers and transformer structures that can be used for galvanic isolation (a.k.a., voltage isolation). Embodiments and examples can include fractional (fractional) coil structures used with a core in a transformer configuration. In some embodiments, a transformer with fractional coil structures may have, e.g., a step up, a step down, or a power transformer configuration. Some embodiments and examples can include integrated circuit (IC) packages or modules with transformer having fractional coil structures. Some embodiments can include transformer packages having fractional coil structures, not necessarily including one or more ICs; other passive and/or active components may be included in such transformer packages.

[0025] The IC packages and modules may include various types of circuits; in some examples, IC packages or modules may include a galvanically isolated gate driver or other high voltage circuit, etc. First and second semiconductor die having one or more integrated circuits (a.k.a., "IC die") can be included in the packages. Such integrated circuits can include, e.g., but are not limited to, high-voltage circuits such as galvanically-isolated gate drivers configured to drive an external gate on a solid-state switch, e.g., a field effect transistor (FET), a metal oxide semiconductor FET (MOSFET), a metal semiconductor FET (MESFET), a gallium nitride FET (GaN FET), a high electron mobility transistor (HEMT), a silicon carbide FET (SIC FET), an insulated gate bipolar transistor (IGBT), or another load.

[0026] FIG. **1** is a diagram showing structure of an example transformer-based integrated circuit (IC) package **100** having fractional coil structures at successive stages of fabrication (shown in Views A-E), in accordance with the present disclosure.

[0027] As shown in View A, structure **100**A includes substrate **101** including opposed first and second sides (surfaces) **102**, **103** and a plurality of conductive traces/conductive structures **104**, which can be (reside) on a surface of or within substrate **101**. In some embodiments, substrate **101** may include or be formed from a molded lead frame, and conductive traces/structures **104** may include, but are not limited to, conductive lead frame regions, e.g., in an epoxy mold compound or other molded plastic body. As explained in further detail below, the plurality of conductive traces/structures **104** can include first and second groups (pluralities, sub-groups, subsets, or sub-pluralities) that are galvanically separated for use with an associated transformer. In the example shown, conductive traces **104** include conductive traces **104***a*-**104***j*. Some conductive traces, e.g., **104***a* and **104***j* can be used for input/output functionality. Some conductive traces, e.g., **104***b*-*c* and **104***h*-*l*, can be used for connections to active/passive components such as IC die, etc. Some conductive traces, e.g., **104***d*-*e* and **104***f*-*g*, can be used for connections to fractional coil structures as part of transformer coils, as described in further detail below. Of course, additional conductive structures/traces can be present for substrate **101** in addition to those shown, e.g., in or on one or more portions of substrate **101** extending into and/or out of the drawing plane.

[0028] View B shows structure **100**B including magnetic core **106**, shown with representative cross sections **106***a-b*, added to structure **100**A of View A. While cross sections **106***a-b* are shown as having certain shapes, those are merely provided for example; a person of ordinary skill in the art will understand that the magnetic core **106** may have any suitable cross section, e.g., circular, rectangular with rounded corners, etc. Core **106** can include soft ferromagnetic material, e.g., ferrite, a nickel alloy, or SiFe, and may have a closed shape, e.g., a toroidal or rectangular shape, as shown. In some embodiments, an insulator material can be provided to the magnetic core to provide isolation. In some embodiments, the core may be insulated with an insulating tape on the core side(s)/surface(s) facing an adjacent substrate.

[0029] View C shows an example fractional coil structure **108** (a.k.a., coil package or coil winding package) having one or more (e.g., a plurality of) fractional coil windings shown as **109***a-b* (e.g., as leads) that are held/pass through body **110**. The fractional coil windings **109***a-b* may made be made of or include any suitable conductive material. Body **110** can be made of or include any suitable material, e.g., an insulative or dielectric molding material. For example, in some embodiments, tape can be used to hold leadframes together.

[0030] View D shows structure **100**D including first and second fractional coil structures **108***a-b* and first and second integrated circuit (IC) die (a.k.a., semiconductor die) **112***a-b* added to structure B shown in View B. First and second fractional coil structures **108***a-b* are positioned adjacent respective cross sections **106***a-b* of core **106**. The plurality of conductive structures (e.g., leads) of first and second fractional coil structures **108***a-b* form respective portions of the galvanically separated first (primary) and second (secondary) coils **111***a*-**11***b* of transformer **120**. The fractional coil structures **108***a-b*, including respective leads **109***a'-b'* and **109***a"-b*," are preferably configured to avoid direct contact with core **106**, as indicated. Fractional coil structures **108***a-b* may be formed/configured as packaged leads (lead packages) in some embodiments. IC die **112***a-b* are shown connected to respective portions of conductive traces **104** by solder balls **113**.

[0031] Fractional coil structures **108***a-b* together with respective coil structures of the substrate **101**, shown as **104***e'* and **104***f'*, form separate first and second coils **111***a*-**111***b* (e.g., primary and secondary coils) of transformer **120**. Fractional coil structure **108***a* (e.g., with portions of multiple coil windings shown as leads **109***a'-b'*) together with portions of conductive traces, e.g., **104***e'*, form windings of first (primary) coil **111***a*. Fractional coil structure **108***b* (e.g., with portions of multiple coil windings shown as leads **109***a"-b"*) together with portions of conductive traces, e.g., **104***f'*, form windings of second (secondary) coil **111***b*. The first and second coils **111***a*, **111***b* (along with connected conductive structure) are galvanically separated on primary and secondary sides of transformer **120** and may each coil have a desired number of windings (coil loops) configured about core **106**, which can be a different number for each coil.

[0032] View D also shows the addition of first and second semiconductor die (a.k.a., IC die) **112***a*, **112***b*, which may be connected to first and second coils **111***a*, **111***b*, respectively. In some examples and embodiments, IC **100** package may include a gate driver (e.g., as an IC in die **112***b*) that is galvanically isolated by the transformer structure **120**. In some embodiments and examples, the secondary side of transformer **120** may be a high voltage side, e.g., with transformer **120** configured as a step up transformer. Other passive and/or active components (not shown) may also be provided for (e.g., place on) substrate **101** for IC package **100**. In some embodiments, dielectric material(s), e.g., one or more coatings and/or tape, may be placed over the core **106** prior to mounting fractional coil structures **108***a-b*, which may be formed/configured as packaged leads. In some embodiments, a space or region (spacing) **115** between core **106** and first and second fractional coil structures **108***a-b* can be occupied by mold material, e.g., shown as **114** in view (E) used as insulator. In some embodiment, leads **109***a'-b'* and/or leads **109***a"-b"* may be covered with suitable insulative material(s), e.g., a dielectric gel, an insulator, and/or a parylene coating, after attachment to substrate **101**.

[0033] View E shows structure **100**E including structure **100**D of View D covered by an optional encapsulant (encapsulate) material **114**. Any suitable material may be used for encapsulant **114**. In some embodiments, encapsulant **114** can include a silicone material. In some embodiments, encapsulant **114** can include a molding (mold) material. The encapsulated structure can form an IC package **130**, in some embodiments. Other embodiments can utilize the structure shown with less encapsulant than as shown or with no encapsulant. As noted previously, in some embodiments, a region or space **115** between the core **106** and first and second fractional coil structures **108***a-b* can be occupied by mold material **114**; in some embodiments, other materials may be used to fill space **115**. For example, in some embodiments, space **115** may be occupied by a dielectric gel, or a silicone based underfill type of material may be utilized to fill the space **115** and be more flexible than, e.g., epoxy mold compound.

[0034] FIG. **2** is a diagram showing an example method **200** of fabricating a transformer-based integrated circuit (IC) package having fractional coil structures with steps corresponding to the structures shown in FIG. **1**.

[0035] Method **200** can include providing a substrate (e.g., PCB) with conductive structure (e.g., contacts) for IC die and portions of transformer coil windings, as described at **202** (Step 1). A magnetic core can be provided to, e.g., placed or disposed on, the substrate, as described at **204** (Step 2). The magnetic core can include one or more soft (referring to magnetism property) ferromagnetic material(s). In some embodiments, glue or epoxy may be used for placement of the magnetic core. A fractional coil structure with portions of coil windings (e.g., supplementary to those described at **202**), may be provided, e.g., by preforming and/or molding, as described at **206** (Step 3). In some embodiments, the fractional coil structure may be or include a preformed structure, e.g., clip. The fractional coil structure (e.g., a preformed clip, or premolded lead frame structure) may be placed on the substrate and configured about the magnetic core, as described at **208** (Step 4). In some embodiments, the fractional coil structure may be subject to a reflow step/process for connection to the substrate. One or more IC die and/or other active/passive components may also be added. Any suitable mounting/bonding technique can be used for adding/mounting one or more ICs and/or other components. For example, wirebonds, flip chip connections, or tape-automated bonding (TAB) can be used for ICs in some embodiments. An optional protective cover may be added (e.g., molded, potted, dispensed, etc.) to protect components, as described at **210** (optional Step 5).

[0036] FIG. **3** is a diagram showing Views A-B of an example transformer-based integrated circuit (IC) package structure **300** having fractional coil structures in an unassembled state (**300**A) and an assembled state (**300**B), respectively, in accordance with the present disclosure.

[0037] As shown in View A, IC package structure **300**A can include a substrate **301** having opposed first and second sides **302**, **303**. Substrate **301** can include conductive traces **311** including multiple pluralities of conductive traces, e.g., **311***a-b*, **312***a-b*, **313***a-b*, **314***a-b*, which can include (but are not required to have) suitable connections (not visible) within substate **301**. Conductive traces **311** can be used for connections to and/or between active and/or passive components, as described in further detail below. A magnetic core **320** can be included. Magnetic core can include a soft ferromagnetic material. In some embodiment, e.g., for higher frequency operation, a laminated core **320** may be used. A laminated core may include metal or metallic material(s) in some embodiments. In some embodiments, a laminated core may include non-metallic materials, e.g., ferrite. For the configuration shown in views A and B, a laminated core **320** may have layers that are parallel to the plane of the figures. In other words, the magnetic flux paths would be broken in the vertical direction (perpendicular to the substrate), but not in the in-plane (in-substrate) direction. In some embodiment, the core layers may have a thickness (perpendicular to the plane of the substrate) in the range of about 50-250 microns; other thicknesses may be used in other embodiments. First and second IC die **340**, **342**, can be included as shown. First and/or second IC die **340**, **342** may be in a die package in some embodiments (e.g., as shown) or may be exposed in other embodiments.

[0038] As shown in View A, package structure **300** can include one or more fractional coil structures **330**. Each fractional coil structure **330** can include one or more (e.g., a plurality of) fractional coil windings shown as **332***a-b* that are held/pass through body **334**. The fractional coil windings **332***a-b* may made be of or include any suitable conductive material. Body **334** can be made of or include any suitable material, e.g., an insulative or dielectric molding material (which may include an epoxy mold compound).

[0039] View B shows the components of package structure **300**A of View A in an assembled state as an assembled package structure **300**B. In some embodiments, a package may be formed with or based on package structure **300**B, e.g., by applying a molding compound and application of a compression molding step. View B shows magnetic core **320** placed on substrate **301**. Die (die packages) **342** and **344** are placed on substrate **301** and received by conductive structures **311***a-b* and **314***a-b*, respectively. Die **340** and **342** may be connected to conductive structures **311***a-b* and **314***a-b* by any suitable means, e.g., solder or the like. In some alternative embodiments, the die **342** and/or **344** may be mounted to the substrate **301** (e.g., PCB) in a flip-chip configuration using conductive balls or bumps, or in a chip on board configuration using wire bonds to connect the die **342** and/or **344** to the substrate **301**. First and second fractional coil structures **330***a-b* are mounted to substrate **301** at conductive structures **312***a-b* and **313***a-b*, respectively. The fractional coil structures **330***a-b* and respective conductive structures **312***a-b* and **313***a-b* of substrate **301** are configured as first and second coils about **351***a-b* core **320** and operational as a transformer **350** (having primary and secondary sides) for IC package structure **300**. Transformer **350** can provide galvanic isolation of/between IC die **342** and **344** and other portions of primary and secondary sides of transformer **350**.

[0040] While two fractional coil structures **330***a-b* are shown for IC package structure **300**, other embodiments can have fewer or more fractional coil structures. For example, in some embodiments, a single fractional coil structure con be used for one coil of transformer **350** while a different coil structure is used for another coil of the transformer. In other embodiments, more than two fractional coil structures can be used, e.g., embodiments having a single primary coil and two or more secondary coils.

[0041] FIG. **4**A is a diagram of an example of structure **400**A for a contactor molding and leadforming process, in accordance with the present disclosure. Structure **400**A includes an outer (main) leadframe **402** with cutouts forming multiple smaller leadframes **412**, **414**, **416**, each having sets of leads (**422***a-b*, **424***a-b*, **426***a-b*) that can be used for fractional coil structures in accordance with the present disclosure. Contactor molding **403** can be applied as shown for each fractional coil structure. The leadframes **412**, **414**, **416** can have bodies (not shown) molded to produce individual fractional coil structures having leads/conductive traces with desired pitch and alignment, in accordance with the present disclosure.

[0042] FIG. **4**B is a diagram of an example long-lead dual in-line-package (DIP) **400**B that can be used for a fractional coil structure in some embodiments. An outer leadframe **450** can have material selectively removed by a suitable technique (e.g., by etching, laser cutting, etc.) to form a plurality of leads (conductive traces) **451***a-d* and **452***a-d*. In some embodiments, an optional die pad **460** may be present for receiving a semiconductor die (a.k.a., integrated circuit die) with an integrated circuit (IC). In some embodiments leads **451***a-d* are connected to leads **452***a-d*, respectively. In some embodiments, other configurations of connections may exist between leads **451***a-d* and **452***a-d* (see, e.g., FIG. **8**). Finished DIP **400**B' (at right) includes a package body (e.g., a molded body) **462**, which may encapsulate one or more semiconductor die (not shown). Finished DIP **400**B' includes two sets of leads **451'**, **452'** each having a desired number or leads and a desired pitch between the leads.

[0043] FIG. **5** is a diagram with Views A-D showing different lead configurations, in accordance with example embodiments of the present disclosure. View A shows fractional coil structure **510** with body **511** and lead sets **512**, **513**. As shown, the leads in lead sets **512** and **513** share a common configuration (bent shape).

[0044] Views B-D show an alternate embodiments of a fractional coil structure **520** with leads having different configurations. View B shows a top view fractional coil structure **520** having body **521** and lead sets **522***a-b* and **524***a-c* (at the top) and lead sets **522***c-d* and **524***d-f* (at the bottom), with the leads having straight configurations, prior to shaping for attachment.

[0045] View C shows a side view of fractional coil structure **520** with the lead sets configured for attachment, e.g., to a substrate. As shown, leads **522***a-b* have a different attachment location relative to body **521** compared to leads **524***a-c*; likewise, leads **522***c-d* have a different attachment location relative to body **521** compared to leads **524***d-f*. The difference in attachment locations is illustrated by comparing distance d_1 to distance d_2.

[0046] View D shows a top view of the fractional coil structure **520** shown in View C. As can be seen, the configuration of leads allows a higher density of leads (which can be used, e.g., as windings for a related transformer) for the given footprint of body **521**.

[0047] FIG. **6** is a diagram showing structure of a further example transformer-based integrated circuit (IC) package **600** having fractional coil structures with included IC die at successive stages of fabrication (shown in Views A-E), in accordance with the present disclosure.

[0048] As shown in View A, structure **600**A includes substrate **601** includes opposed first and second sides (surfaces) **602**, **603** and a plurality of conductive traces (conductive structures) **604**. In the example shown, substrate **601** includes conductive traces **604**, which include conductive trace **604***a*-**604***f*. Some conductive traces, e.g., **604***a* and **604***f*, can be used for input/output functionality. Some conductive traces (not shown) can be used for connections to active/passive components. Some conductive traces, e.g., **604***b-c* and **604***d-e*, can be used for connections to fractional coil structures as part of transformer coils, as described in further detail below. Additional conductive structures can be present for substrate **601** in addition to those shown, e.g., in or on one or more portions of substrate **601** extending into and/or out of the plane of the figure.

[0049] View B shows structure **600**B including magnetic core **606**, shown with cross sections **606***a-b*, added to structure **600**A of View A. Core **606** can include soft ferromagnetic material, e.g., ferrite, a nickel alloy, or SiFe, and may have a closed shape, e.g., a toroidal or rectangular shape, as shown. In some embodiments, an insulator material can be provided to the magnetic core **606** to provide isolation. In some embodiments, the core **606** may be insulated with an insulating tape on the core side(s)/surface(s) facing an adjacent substrate. IIn some embodiments, core **606** may be coated with one or more dielectric materials. As noted above, while core **606** is shown having a certain cross-sectional shape, core **606** may have any suitable cross-sectional shape, e.g., round, oval, rectangular, etc.

[0050] View C shows an example fractional coil structure **630** having an included IC die. Fractional coil structure **630** includes a body **631** and a plurality of conductive traces (leads) **634** that are held/pass through body **631**. Body **631** can also include an IC die **632**. Conductive traces **634** can include fractional coil windings (which can be used as part of a primary or secondary coil) as well as leads/traces for input/out functionality for IC die **632**. IC die **632** may be connected to one or more of the conductive traces/leads **634** by suitable connections, e.g., wire bonds, etc. Conductive traces **634** may made be made of or include any suitable conductive material, e.g., copper, etc. Body **631** can be made of or include any suitable material, e.g., an insulative or dielectric molding material.

[0051] View D shows structure **600**D with first and second fractional coil structures **630***a-b* (each similar to structure **630** of View C) added to structure **600**B shown in View B. Fractional coil structures **630***a-b* together with respective coil structures of the substrate **601** form separate first and second coils **611***a*-**611***b* (e.g., primary and secondary coils) of a transformer **620**. Fractional coil structure **630***a* (e.g., with portions of multiple coil windings) together with portions of conductive traces **604**, e.g., **604***c*', form windings of a first coil **611***a* (e.g., a primary coil) of transformer **620**. Fractional coil structure **630***b* (e.g., with portions of multiple coil windings) together with portions of conductive traces, e.g., **604***d*', form windings of a second coil **611***b* (e.g., a secondary coil) of transformer **620**. The first and second coils **611***a*, **611***b* may each have a desired number of windings (coil loops) configured about core **606**, which can be a different number for each coil. In some examples and embodiments, structure **600**D may include a gate driver (e.g., as an IC in die **632***b*) that is galvanically isolated from the IC die **632***a* by transformer structure **220**. In some embodiments and examples, the secondary side of transformer **620** may be a high voltage side, e.g., with transformer **620** configured as a step up transformer.

[0052] View E shows structure **600**E including the structure **600**D of View D covered by an optional encapsulant (encapsulate) material **614**. Any suitable material may be used for encapsulant **614**. In some embodiments, encapsulant **614** can include a silicone material. In some embodiments, encapsulant **614** can include a molding material. The encapsulated structure can form an IC package **640**, in some embodiments. Other embodiments can utilize the structure shown with less encapsulant than as shown or with no encapsulant. As noted previously for FIG. **1**, in some embodiments, a region or space **615** between the core **606** and first and second fractional coil structures **630***a-b* can be occupied by mold material **614**; in some embodiments, other materials may be used to fill space **615**. For example, in some embodiments, space **615** may be occupied by a dielectric gel, or a silicone based underfill type of material may be utilized to fill the space **615** and be more flexible than, e.g., epoxy mold compound.

[0053] FIG. **7** is a diagram showing an example method **700** of fabricating a transformer-based integrated circuit (IC) package having fractional coil structures with steps corresponding to the structures shown in FIG. **6**.

[0054] Method **700** can include providing a PCB/substrate with contacts for the die and portions (e.g., "lower winding" portions) of transformer windings, as shown at **702** ("Step 1"). The PCB/substrate can include the interconnects and portions (e.g., "bottom winding" portions) of the coils used for the transformer. A magnetic core can be placed on the substrate, as shown at **704** ("Step 2"). The magnetic core can include soft ferromagnetic material. Any suitable placement/location technique may be used. In some embodiments, a core may be affixed to or on the substrate by use of glue or epoxy. Other portions of the coils (e.g., "top winding" portions) can be formed in a separate package, as described at **706** ("Step 3"). In some embodiments, the separate package can include an IC die. The different winding portions can be joined, e.g., by placing the separate package(s) over the magnetic core, as described at **708** ("Step 4"). This can result in formation of complete first (primary) and second (secondary) coils of the transformer. Other active and passive components may be added during this step (or others). A protective later/cover can optionally be applied, as described at **710** (optional "Step 5"). In some embodiments, a protective cover/layer can be molded, potted, or dispensed.

[0055] FIG. **8** is a diagram showing Views A-D of an example transformer-based integrated circuit (IC) package

800 having fractional coil structures with included IC die, in accordance with the present disclosure.

[0056] View A shows a top section view of a fractional coil structure **800**A including an IC die **836**. Structure **800**A includes a body (e.g., substrate or molded body) **830**. Body **830** includes body material **831** with first side **832** and second side **833**. Structure **800**A includes a plurality of conductive traces **834***a-m*. In some embodiments, structure **800**A also includes an IC die **836**, which may be disposed on a die pad, e.g., shown as die pad connected to conductive trace **834***g*. As shown, some conductive traces **834***a-i* may be connected to IC die **836** by suitable connections, e.g., wire bonds **838**. As shown, other conductive traces **834***j-l* are not connected to IC die **836**. Some conductive traces can pass through body **830** without interruption, as shown by traces **834***j-m*, e.g., for use as one or more windings in a primary or secondary coil. Some conductive traces may originate/terminate at body **831**, e.g., as indicated by conductive trace **834***m*. IC die **836** may include an integrated circuit, e.g., control circuity and/or a gate driver. In some embodiments, fractional coil structure **800**A can include or be configured as a pre-formed clip.

[0057] View B shows structure **800**B includes a substrate **801** (e.g., PCB) used for an example transformer-based integrated circuit (IC) package, in accordance with the present disclosure. Substrate **801** includes a first side **802** and a second side **803**. Substrate **801** includes a plurality of conductive traces/structures including exposed pads **804** (e.g., including **804***a-i*) and buried traces **806** (e.g., including **806***a-d*). Substrate **801** and the included conductive traces/structures are configured to receive a magnetic core and a plurality (e.g., two) of fractional coil structures (such as **800**A shown in View A) that can form complete transformer coils when connected to conductive structures (e.g., certain of pads **804** and buried traces **806**) of substrate **801**.

[0058] View C shows structure **800**C, which includes structure **800**B of View B with the addition of magnetic core **820**. Magnetic core **820** can include one or more soft ferromagnetic materials. In some embodiments, magnetic core **820** may have a plurality of pieces/sections, which can be affixed or connected to one another (e.g., positioned next to and in contact) to facilitate flow of magnetic flux. For example, core **820** is shown with four component pieces **820***a-d*. Structure **800**C is configured to receive/support a plurality of fractional coil structures **800**A shown in View A, e.g., by connections at pads **804***j-r*.

[0059] View D shows structure **800**D which includes structure **800**C of View C along with two fractional coil structures **830***a* and **830***b* (each similar to structure **800**A shown in View A) mounted to substrate **801**. Structure **800**D can include suitable conductive structure for input/output functionality, e.g., conductive pads on the second side **803** (not shown) of substrate **801**. Conductive traces in substrate **801** are in contact with coil portions in fractional coil structures **830***a* and together can form a first (primary) coil about core **820**. Conductive traces in substrate **801** are in contact with coil portions in fractional coil structure **830***b* and together can form a second (secondary) coil about core **820**. The first and second coils and core **820** can be configured as a transformer **850** as shown. Each of fractional coil structures **830***a* and **830***b* can include a desired IC die **836***a*, **836***b*, which can be galvanically isolated from one another by the transformer **850**. In some embodiments, an IC in an IC die **836***b* on the secondary side of transformer **850** can include a gate driver, e.g., configured to drive a solid state power switch such as a FET (e.g., SiC FET or GaN FET) or IGBT, or some other load. In some embodiments, an optional protective layer, e.g., encapsulant, potting material, and/or molding material may be applied to structure **800**D to form an IC package.

[0060] FIG. **9** is a diagram showing an example method **900** of fabricating a transformer-based integrated circuit (IC) package having fractional coil structures, in accordance with the present disclosure.

[0061] Method **900** can include providing a substrate having a first plurality of conductive traces, as described at **902**. In some embodiments, the substrate may be or include a PCB. A magnetic core can be provided to the substrate, as described at **904**. First and second fractional coil structures (e.g., preformed clips) can be provided, each having a second plurality of conductive traces and configured to extend around a portion of the core, as described at **906**. In some embodiments, a single fractional transformer coil structure in accordance with the present disclosure may be used for one coil while a different coil construction may be used for another transformer coil. The fractional coil structures can be configured such that when the second plurality of conductive traces is brought into contact with the first plurality of conductive traces (of the substrate) first (primary) and second (secondary) transformer coils are formed, with the core and primary and secondary coils forming a transformer.

[0062] A package body can be formed as an optional step, as described at **908**. The package body may encapsulate or cover the core and fractional coil structures of the transformer. In some embodiments, one or more IC die (packaged or unpackaged) can be provided to the substrate, as described at **910**. For example, in some embodiments first and second IC die can be provided to the substrate prior to the optional encapsulation step. In some embodiments, one or more IC die (packaged or unpackaged) can be provided to one or more fractional coil structure. In some embodiments, the transformer may be configured as a step up transformer. In some embodiment, the second IC die can include a gate driver.

[0063] In some examples and/or embodiments, integrated circuits (ICs), e.g., in IC die **342** and **344** in FIG. **3** (View B), or other conductive features of the primary and secondary sides of a transformer structure in an IC or transformer package according to the present disclosure can be fabricated or configured to have a desired separation distance (d) between certain parts or features, e.g., to meet internal creepage or external clearance requirements for a given pollution degree rating as defined by certain safety standards bodies such as the Underwriters Laboratories (UL) and the International Electrotechnical Commission (IEC). For example, a separation distance may be between closest (voltage) points of the respective circuits, e.g., the low-voltage (primary) side and high-voltage (secondary) side. For further example, such a separation distance may be the distance between any two voltage points between the primary and secondary sides, e.g., distance between die **342** and die **344** in FIG. **3** (View B), or a distance between exposed leads connected to the die, may be or may be at least 1.2 mm, 1.4 mm, 1.5 mm, 3.0 mm, 4.0 mm, 5.5 mm, 7.2 mm, 8.0 mm, 10 mm, or 10+mm in respective examples. Such a distance between conductive portions or areas of die can include any insulation covering a conductor, e.g., such as plastic coating of a wire/lead. Other distances between conductive parts, components, and/or features of an IC/transformer package may also be designed and implemented, e.g., to meet desired internal creepage, voltage breakdown, or external clearance requirements, e.g., between external leads.

[0064] In some examples and embodiments, a dielectric material (e.g., gel) may be used for potting and/or protecting substrate (e.g., PCB) systems, assemblies, and/or packages, to protect die and/or interconnects from environment conditions and/or to provide dielectric insulation. In some examples, a dielectric material may include, but is not limited to, one or more of the following materials: DOWSIL™ EG-3810 Dielectric Gel (made available by The Dow Chemical Corporation, a.k.a., "Dow", and DOWSIL™ EG-3896 Dielectric Gel (made available by Dow), which has the ability to provide isolation greater than 20 kV/mm. Other suitable gel materials may also or instead be used, e.g., to meet or facilitate meeting/achieving voltage isolation specifications required by a given package design. DOWSIL™ EG-3810 is designed for temperature ranges from −60° C. to 200° C. and DOWSIL™ EG-3896 Dielectric Gel −40° C. to +185° C.; both of which can be used to meet typical temperature ranges for automotive applications.

[0065] Accordingly, embodiments and/or examples of the inventive subject matter can afford various benefits relative to prior art techniques. For example, embodiments and examples of the present disclosure can enable or facilitate use of smaller size packages for a given power, current. or voltage rating. Embodiments and examples of the present disclosure can enable or facilitate lower costs and higher scalability for manufacturing of IC packages/modules having voltage-isolated (galvanic isolation) IC die and transformers.

[0066] Various embodiments of the concepts, systems, devices, structures, and techniques sought to be protected are described above with reference to the related drawings. Alternative embodiments can be devised without departing from the scope of the concepts, systems, devices, structures, and techniques described. For example, in some embodiments, fractional coil structures (e.g., primary and secondary transformer coils) may have a whole number or fractional number of turns (loops about a related core), e.g., 1.5, 2.5, 1.75, 1.8, 2.25, 6.5, 8.8, etc.

[0067] It is noted that various connections and positional relationships (e.g., over, below, adjacent, etc.) may be used to describe elements and components in the description and drawings. These connections and/or positional relationships, unless specified otherwise, can be direct or indirect, and the described concepts, systems, devices, structures, and techniques are not intended to be limiting in this respect. Accordingly, a coupling of entities can refer to either a direct or an indirect coupling, and a positional relationship between entities can be a direct or indirect positional relationship.

[0068] As an example of an indirect positional relationship, positioning element "A" over element "B" can include situations in which one or more intermediate elements (e.g., element "C") is between elements "A" and elements "B" as long as the relevant characteristics and functionalities of elements "A" and "B" are not substantially changed by the intermediate element(s).

[0069] Also, the following definitions and abbreviations are to be used for the interpretation of the claims and the specification. The terms "comprise," "comprises," "comprising," "include," "includes," "including," "has," "having," "contains" or "containing," or any other variation are intended to cover a non-exclusive inclusion. For example, an apparatus, a method, a composition, a mixture, or an article, which includes a list of elements is not necessarily limited to only those elements but can include other elements not expressly listed or inherent to such apparatus, method, composition, mixture, or article.

[0070] Additionally, the term "exemplary" means "serving as an example, instance, or illustration." Any embodiment or design described as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments or designs. The terms "one or more" and "at least one" indicate any integer number greater than or equal to one, i.e., one, two, three, four, etc. The term "plurality" indicates any integer number greater than one. Those terms, however, may refer to fractional numbers/values where context admits, e.g., a number of loops in a transformer coil may be a plurality that includes a fractional value, e.g., 2.75, 3.5, 4.25, etc. The term "connection" can include an indirect connection and a direct connection.

[0071] References in the specification to "embodiments," "one embodiment, "an embodiment," "an example embodiment," "an example," "an instance," "an aspect," etc., indicate that the embodiment described can include a particular feature, structure, or characteristic, but every embodiment may or may not include the particular feature, structure, or characteristic. Moreover, such phrases do not necessarily refer to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it may affect such feature, structure, or characteristic in other embodiments whether explicitly described or not.

[0072] Relative or positional terms including, but not limited to, the terms "upper," "lower," "right," "left," "vertical," "horizontal, "top," "bottom," and derivatives of those terms relate to the described structures and methods as oriented in the drawing figures. The terms "overlying," "atop," "on top, "positioned on" or "positioned atop" mean that a first element, such as a first structure, is present on a second element, such as a second structure, where intervening elements such as an interface structure can be present between the first element and the second element. The term "direct contact" means that a first element, such as a first structure, and a second element, such as a second structure, are connected without any intermediary elements.

[0073] Use of ordinal terms such as "first," "second," "third," etc., in the claims to modify a claim element does not by itself connote any priority, precedence, or order of one claim element over another, or a temporal order in which acts of a method are performed but are used merely as labels to distinguish one claim element having a certain name from another element having a same name (but for use of the ordinal term) to distinguish the claim elements.

[0074] The terms "approximately" and "about" may be used to mean within ±20% of a target (or nominal) value in some embodiments, within plus or minus (±) 10% of a target value in some embodiments, within ±5% of a target value in some embodiments, and yet within ±2% of a target value in some embodiments. The terms "approximately" and "about" may include the target value. The term "substantially equal" may be used to refer to values that are within ±20% of one another in some embodiments, within ±10% of one another in some embodiments, within ±5% of one another in some embodiments, and yet within ±2% of one another in some embodiments.

[0075] The term "substantially" may be used to refer to values that are within ±20% of a comparative measure in some embodiments, within ±10% in some embodiments, within ±5% in some embodiments, and yet within ±2% in some embodiments. For example, a first direction that is "substantially" perpendicular to a second direction may refer to a first direction that is within ±20% of making a 90° angle with the second direction in some embodiments, within ±10% of making a 90° angle with the second direction in some embodiments, within ±5% of making a 90° angle with the second direction in some embodiments, and yet within ±2% of making a 90° angle with the second direction in some embodiments.

[0076] The disclosed subject matter is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The disclosed subject matter is capable of other embodiments and of being practiced and carried out in various ways.

[0077] Also, the phraseology and terminology used in this patent are for the purpose of description and should not be regarded as limiting. As such, the conception upon which this disclosure is based may readily be utilized as a basis for the designing of other structures, methods, and systems for carrying out the several purposes of the disclosed subject matter. Therefore, the claims should be regarded as including such equivalent constructions as far as they do not depart from the spirit and scope of the disclosed subject matter.

[0078] Although the disclosed subject matter has been described and illustrated in the foregoing exemplary embodiments, the present disclosure has been made only by way of example. Thus, numerous changes in the details of implementation of the disclosed subject matter may be made without departing from the spirit and scope of the disclosed subject matter.

[0079] Accordingly, the scope of this patent should not be limited to the described implementations but rather should be limited only by the spirit and scope of the following claims.

[0080] All publications and references cited in this patent are expressly incorporated by reference in their entirety.

What is claimed is:

1. A transformer-based integrated circuit (IC) package comprising:
- a substrate having a first plurality of conductive traces;
- a core disposed on the substrate, wherein the core includes a soft ferromagnetic material; and
- a pair of fractional coil structures, each having a second plurality of conductive traces and configured to extend around a portion of the core, wherein the pair of fractional coil structures is configured such that primary and secondary coils are formed when the second plurality of conductive traces is brought into contact with the first plurality of conductive traces;
- wherein the primary and secondary coils are configured with the core as a transformer.

2. The IC package of claim **1**, further comprising at least one semiconductor die disposed on the substrate.

3. The IC package of claim **2**, wherein the at least one semiconductor die comprises an integrated circuit (IC).

4. The IC package of claim **3**, wherein the IC is connected to the secondary coil.

5. The IC package of claim **4**, wherein the transformer is configured as a step-up transformer.

6. The IC package of claim **5**, wherein the IC comprises a gate driver.

7. The IC package of claim **1**, wherein the substrate comprises a printed circuit board (PCB).

8. The IC package of claim **7**, wherein the PCB comprises FR4.

9. The IC package of claim **1**, wherein the core comprises ferrite.

10. The IC package of claim **1**, wherein the core comprises iron powder.

11. The IC package of claim **1**, wherein the core comprised a laminated metal core.

12. The IC package of claim **1**, wherein at least one fractional coil structure comprises a semiconductor die disposed on a substrate, wherein the semiconductor die includes an integrated circuit (IC).

13. The IC package of claim **12**, wherein the IC is connected to a subset of the second plurality of conductive traces.

14. The IC package of claim **13**, wherein the IC comprises a gate driver, and wherein the second plurality of conductive traces is connected to the secondary coil.

15. The IC package of claim **1**, wherein at least one fractional coil structure comprises a leadframe.

16. The IC package of claim **1**, wherein the core comprises a plurality of core portions.

17. The IC package of claim **16**, wherein the plurality of core portions are connected at joints including ferrite-loaded epoxy.

18. The IC package of claim **1**, further comprising a package body including the substrate.

19. The IC package of claim **18**, wherein the package body includes a molding material.

20. The IC package of claim **18**, wherein the package body includes a potting material.

21. A method of making a transformer-based integrated circuit (IC) package, the method comprising:
- providing a substrate having a first plurality of conductive traces;
- providing a core disposed on the substrate, wherein the core includes a soft ferromagnetic material; and
- providing a pair of fractional coil structures, each having a second plurality of conductive traces and configured to extend around a portion of the core, wherein the pair of fractional-coil structure is configured such that primary and secondary coils are formed when the second plurality of conductive traces is brought into contact with the first plurality of conductive traces;
- wherein the primary and secondary coils are configured with the core as a transformer.

22. The method of claim **21**, further comprising providing at least one semiconductor die disposed on the substrate, wherein the at least one semiconductor die comprises an integrated circuit (IC).

23. The method of claim **22**, wherein the IC is connected to the secondary coil.

24. The method of claim **23**, wherein the transformer is configured as a step-up transformer.

25. The method of claim **24**, wherein the IC comprises a gate driver.

26. The method of claim **21**, wherein the substrate comprises a printed circuit board (PCB).

27. The method of claim **26**, wherein the PCB comprises FR4.

28. The method of claim **21**, wherein the core comprises ferrite.

29. The method of claim **21**, wherein the core comprises iron powder.

30. The method of claim **21**, wherein the core comprised a laminated metal core.

31. The method of claim **21**, wherein at least one of the pair of fractional coil structures comprises an IC die disposed on a substrate, wherein the IC die comprises an IC.

32. The method of claim **31**, wherein the IC is connected to a subset of the second plurality of conductive traces.

33. The method of claim **32**, wherein the IC comprises a gate driver, and wherein the second plurality of conductive traces is connected to the secondary coil.

34. The method of claim **21**, wherein at least one fractional coil structures comprises a leadframe.

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