



- (51) International Patent Classification:
H01F 17/00 (2006.01)
- (21) International Application Number:
PCT/US2014/048723
- (22) International Filing Date:
29 July 2014 (29.07.2014)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
61/872,342 30 August 2013 (30.08.2013) US
14/155,244 14 January 2014 (14.01.2014) US
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- (81) Designated States (*unless otherwise indicated, for every
kind of national protection available*): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM,
TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM,
ZW.

[Continued on next page]

(54) Title: VARYING THICKNESS INDUCTOR

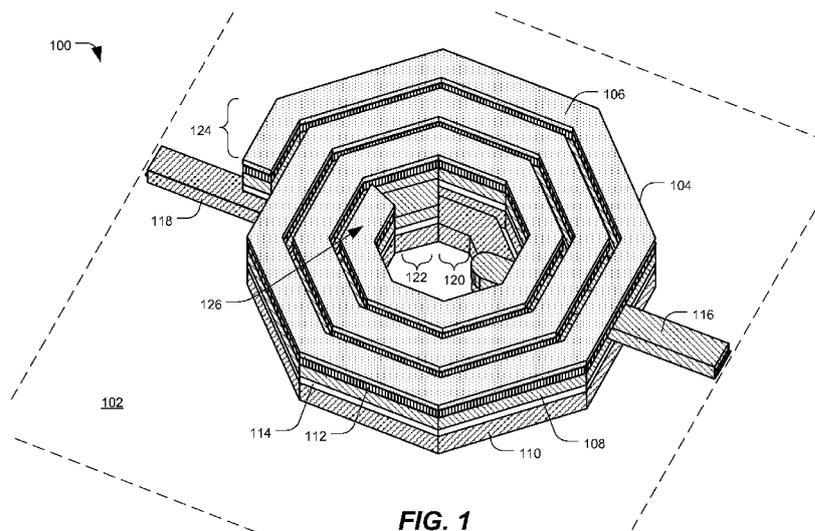


FIG. 1

(57) Abstract: A particular device includes a substrate and a spiral inductor coupled to the substrate. The spiral inductor includes a first conductive spiral and a second conductive spiral overlaying the first conductive spiral. A first portion of an innermost turn of the spiral inductor has a first thickness in a direction perpendicular to the substrate. The first portion of the innermost turn includes a first portion of the first conductive spiral and does not include the second conductive spiral. A second portion of the innermost turn includes a first portion of the second conductive spiral. A portion of an outermost turn of the spiral inductor has a second thickness in the direction perpendicular to the substrate that is greater than the first thickness. A portion of the outermost turn includes a second portion of the first conductive spiral and a second portion of the second conductive spiral.



WO 2015/030976 A1

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

- *with international search report (Art. 21(3))*

VARYING THICKNESS INDUCTOR

CLAIM OF PRIORITY

[0001] The present application claims priority from U.S. Provisional Patent Application No. 61/872,342, entitled "VARYING THICKNESS INDUCTOR," filed August 30, 2013 and U.S. Non-Provisional Patent Application No. 14/155,244, entitled "VARYING THICKNESS INDUCTOR," filed January 14, 2014, the contents of which are incorporated by reference in their entirety.

FIELD

[0002] The present disclosure is generally related to an inductor having a thickness that varies.

DESCRIPTION OF RELATED ART

[0003] Advances in technology have resulted in smaller and more powerful computing devices. For example, there currently exist a variety of portable personal computing devices, including wireless computing devices, such as portable wireless telephones, personal digital assistants (PDAs), and paging devices that are small, lightweight, and easily carried by users. More specifically, portable wireless telephones, such as cellular telephones and internet protocol (IP) telephones, can communicate voice and data packets over wireless networks. Further, many such wireless telephones include other types of devices that are incorporated therein. For example, a wireless telephone can also include a digital still camera, a digital video camera, a digital recorder, and an audio file player. Also, such wireless telephones can process executable instructions, including software applications, such as a web browser application, that can be used to access the Internet. As such, these wireless telephones can include significant computing capabilities.

[0004] Inductors are used in power regulation, frequency control and signal conditioning applications in many electronic devices (e.g., personal computers, tablet computers, wireless mobile handsets, and wireless telephones). An inductor with a higher electrical resistance may consume more power than an inductor with a lower electrical resistance.

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A spiral inductor may contribute a particular electrical resistance (e.g., a resistance associated with an eddy current loss) to an electrical system powered by an alternating current. The eddy current loss may be related to a quantity or a volume of conductive material present in an innermost turn of the spiral inductor. A trace width associated with the spiral inductor may be decreased to reduce the eddy current loss. However, process technology used to fabricate the spiral inductor may be unable to produce an inductor with a trace width smaller than a particular width.

SUMMARY

[0005] This disclosure presents embodiments of an inductor having a thickness that varies. The inductor may be a stepped layer stack spiral inductor or a gradient layer stack spiral inductor. For example, the inductor may be coupled to a substrate and a portion of an outermost turn of the inductor may be thicker than a portion of an innermost turn of the inductor. In the example, the thickness of the inductor may monotonically increase (e.g., consistently increasing without substantially decreasing) from the innermost turn of the inductor to the outermost turn of the inductor. The inductor may be configured to provide a similar inductance value as compared to a conventional spiral inductor of similar size (e.g., a spiral inductor having a uniform thickness). The reduced thickness of the innermost turn may cause the inductor to have a lower radio frequency (RF) resistance than the conventional spiral inductor due to reduced eddy current loss. An electronic device may use the inductor to provide inductance using less power, as compared to an electronic device that includes the conventional spiral inductor.

[0006] In a particular embodiment, an apparatus includes a substrate and a spiral inductor coupled to the substrate. The spiral inductor includes a first conductive spiral and a second conductive spiral overlaying the first conductive spiral. A first portion of an innermost turn of the spiral inductor has a first thickness in a direction perpendicular to the substrate. The first portion of the innermost turn includes a first portion of the first conductive spiral and does not include the second conductive spiral. A second portion of the innermost turn includes a first portion of the second conductive spiral. A portion of an outermost turn of the spiral inductor has a second thickness, in the direction perpendicular to the substrate, that is greater than the first thickness. A portion of the

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outermost turn includes a second portion of the first conductive spiral and a second portion of the second conductive spiral.

[0007] In another particular embodiment, a method includes forming a first conductive spiral of a spiral inductor coupled to a substrate. The method further includes forming a second conductive spiral of the spiral inductor that overlays the first conductive spiral. A first portion of an innermost turn of the spiral inductor has a first thickness in a direction perpendicular to the substrate. The first portion of the innermost turn includes a first portion of the first conductive spiral and does not include the second conductive spiral. A second portion of the innermost turn includes a first portion of the second conductive spiral. A portion of an outermost turn of the spiral inductor has a second thickness in the direction perpendicular to the substrate. The second thickness is greater than the first thickness. The portion of the outermost turn includes a second portion of the first conductive spiral and a second portion of the second conductive spiral.

[0008] In another particular embodiment, an apparatus includes a substrate and a spiral inductor coupled to the substrate. A first portion of an innermost turn of the spiral inductor has a first thickness in a direction perpendicular to the substrate. A second portion of the innermost turn of the spiral inductor has a second thickness in the direction perpendicular to the substrate. The second thickness is greater than the first thickness. A thickness of the spiral inductor in the direction perpendicular to the substrate increases according to a gradient from the first thickness to the second thickness.

[0009] In another particular embodiment, a method includes forming a conductive spiral of a spiral inductor coupled to a substrate. The method further includes forming a conductive layer of the spiral inductor above the conductive spiral. A first portion of an innermost turn of the spiral inductor has a first thickness in a direction perpendicular to the substrate. A second portion of the innermost turn has a second thickness in the direction perpendicular to the substrate. The second thickness is greater than the first thickness. A thickness of the spiral inductor in the direction perpendicular to the substrate increases according to a gradient from the first thickness to the second thickness.

[0010] One particular advantage provided by at least one of the disclosed embodiments is that a spiral inductor having a varying thickness provides a similar inductance as

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compared to a uniform thickness spiral inductor of similar dimensions. However, a reduced thickness of an innermost turn of the spiral inductor causes the inductor to have a lower electrical resistance due to a reduced eddy current loss. Thus, an electronic device may use the inductor having the varying thickness to provide inductance using less power, as compared to an electronic device that includes the uniform thickness spiral inductor.

[0011] Other aspects, advantages, and features of the present disclosure will become apparent after review of the entire application, including the following sections: Brief Description of the Drawings, Detailed Description, and the Claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a diagram depicting a particular embodiment of a system including a substrate and a stepped layer stack spiral inductor having a thickness that varies;

[0013] FIG. 2 is a diagram depicting a particular embodiment of a system including a substrate and a gradient layer stack spiral inductor having a thickness that varies;

[0014] FIG. 3 is a diagram depicting a comparison between a spiral inductor having a thickness that varies and a spiral inductor having a thickness that does not vary;

[0015] FIG. 4 is a flow chart that illustrates a particular embodiment of a method of forming a spiral inductor having a thickness that varies;

[0016] FIG. 5 is a flow chart that illustrates another particular embodiment of a method of forming a spiral inductor having a thickness that varies;

[0017] FIG. 6 is a block diagram that illustrates a communication device including a substrate and a spiral inductor having a thickness that varies; and

[0018] FIG. 7 is a data flow diagram that illustrates a particular illustrative embodiment of a manufacturing process to manufacture electronic devices that include a substrate and a spiral inductor having a thickness that varies.

DETAILED DESCRIPTION

[0019] Referring to FIG. 1, a particular illustrative embodiment of a system 100 including a substrate 102 and a spiral inductor 104 (e.g., a stepped layer stack inductor) coupled to the substrate 102 is shown. The spiral inductor 104 may include a first conductive spiral 106, a conductive layer 108, a second conductive spiral 110, a first passivation layer 112, and a second passivation layer 114. The spiral inductor 104 is connected to a first lead 116 and to a second lead 118. A trace width associated with the spiral inductor 104 may be a minimum trace width that can be manufactured using a particular process technology used to fabricate the spiral inductor 104. In a particular embodiment, the spiral inductor includes a layer with a thickness between 1 μm and 20 μm having a minimum trace width between 5 μm and 50 μm .

[0020] The conductive layer 108 may form a spiral (e.g., a conductive spiral) or may form a partial spiral or a discontinuous spiral (e.g., the conductive layer 108 may form a spiral shape, but the conductive layer 108 may not be present within a particular distance from the first lead 116 and from the second lead 118). A spiral may include a plurality of turns, where each beginning point of each turn has a different radius from a center point of the spiral.

[0021] The spiral inductor 104 includes a first portion 120 having a first thickness in a direction perpendicular to the substrate 102, a second portion 122 having a second thickness in the direction perpendicular to the substrate 102, a third portion 126 having a third thickness in the direction perpendicular to the substrate 102, and a fourth portion 124 having a fourth thickness in the direction perpendicular to the substrate 102. The fourth thickness may be greater than the third thickness (not shown), the third thickness may be greater than the second thickness, and the second thickness may be greater than the first thickness. The first portion 120, the second portion 122, and the third portion 126 may be part of an innermost turn of the spiral inductor 104 and the fourth portion 124 may be part of an outermost turn of the spiral inductor 104. In a particular embodiment, the first portion 120 includes a first portion of the second conductive spiral 110. The second portion 122 may include a first portion of the conductive layer 108 and a second portion of the second conductive spiral 110. The third portion 126 may include a first portion of the first conductive spiral 106, a second portion of the conductive layer

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108, and a third portion of the second conductive spiral 110. The fourth portion 124 may include a second portion of the first conductive spiral 106, a third portion of the conductive layer 108, and a fourth portion of the second conductive spiral 110.

[0022] Although FIG. 1 illustrates each spiral having a different length, in other embodiments, two or more spirals may have the same length. Although FIG. 1 illustrates the first portion 120, the second portion 122, and the third portion 126 as each having a different thickness, in other embodiments, the second thickness may be the same as the first thickness or the third thickness. Further, although FIG. 1 illustrates the third length of the second conductive spiral 110 being greater than the second length of the conductive layer 108 and the second length of the conductive layer 108 being greater than the first length of the first conductive spiral 106, in other embodiments, the conductive spirals and the conductive layer may have a different length relationship (e.g., the first length of the first conductive spiral 106 may be greater than the second length of the conductive layer 108 and the second length of the conductive layer 108 may be greater than the third length of the second conductive spiral 110). Thus, although FIG. 1 illustrates the first portion 120 including only the first portion of the second conductive spiral 110, in other embodiments, the first portion 120 may include portions of different conductive spirals or a portion of the conductive layer. For example, the first portion 120 may include only a first portion of the first conductive spiral 106.

[0023] The substrate 102 may be a dielectric substrate formed of a glass material, an alkaline earth boro-aluminosilicate glass, Silicon (Si), Gallium Arsenide (GaAs), Indium Phosphate (InP), Silicon Carbide (SiC), a glass-based laminate, sapphire (Al₂O₃), quartz, a ceramic, Silicon on Insulator (SOI), Silicon on Sapphire (SOS), high resistivity Silicon (HRS), Aluminum Nitride (AlN), a plastic, or a combination thereof. The conductive spirals 106 and 110 and the conductive layer 108 may be formed by depositing aluminum, copper, silver, gold, tungsten, molybdenum, an alloy of aluminum, silver, gold, tungsten, or molybdenum, or a combination thereof, above the substrate 102. The spiral inductor 104 may be fabricated using the same fabrication steps as an inductor having an outermost turn having a thickness that is not greater than a thickness of an innermost turn (e.g., additional deposition steps or etching steps may be unnecessary). Each passivation layer (e.g., the first passivation layer 112 and the second passivation layer 114) may be formed of a photo-definable polymer.

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[0024] In a particular embodiment, the first conductive spiral 106 overlays the conductive layer 108 and the conductive layer 108 overlays the second conductive spiral 110. The first passivation layer 112 may be formed between the first conductive spiral 106 and the conductive layer 108. The second passivation layer 114 may be formed between the conductive layer 108 and the second conductive spiral 110. One or more vias may be formed in the first passivation layer 112, the second passivation layer 114, or both. The one or more vias may electrically connect the first conductive spiral 106, the conductive layer 108, and the second conductive spiral 110, or a combination thereof. The one or more vias may further electrically connect the first conductive spiral 106, the conductive layer 108, the second conductive spiral 110, or a combination thereof, to the first lead 116, to the second lead 118, or to both.

[0025] A thickness of the spiral inductor 104 in the direction perpendicular to the substrate 102 may increase monotonically from an innermost portion of the spiral inductor 104 to an outermost portion of the spiral inductor 104. In a particular embodiment, the spiral inductor 104 may be a stepped layer stack inductor where a thickness of the spiral inductor 104 in the direction perpendicular to the substrate 102 increases in a step configuration. For example, a thickness of the first conductive spiral 106, the conductive layer 108, and the second conductive spiral 110 in the direction perpendicular to the substrate 102 may be substantially constant along the length of each conductive spiral. In this example, a second length of the conductive layer 108 may be greater than a first length of the first conductive spiral 106 and a third length of the second conductive spiral 110 may be greater than a second length of the conductive layer 108. The first portion 120 may include a first portion of the second conductive spiral 110. The first conductive spiral 106 and the conductive layer 108 may not extend to the first portion 120. The second portion 122 may include a second portion of the second conductive spiral 110 and a first portion of the conductive layer 108. The first conductive spiral 106 may not extend to the second portion 122. The fourth portion 124 may include a third portion of the second conductive spiral 110, a second portion of the conductive layer 108, and a portion of the first conductive spiral 106. As another example, the first conductive spiral 106 may be formed by depositing a first conductive layer with a first length and by depositing a second conductive layer with a second length

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directly above (e.g., with no intervening passivation layer) the first conductive layer. The first conductive layer and the second conductive layer may have different lengths.

[0026] When a current is applied to the first lead 116 or the second lead 118, a magnetic field is generated by the spiral inductor 104. An eddy current loss associated with the outermost turn of the spiral inductor 104 may be reduced, as compared to a uniform thickness spiral inductor, because the outermost turn of the spiral inductor 104 has a greater thickness than the innermost turn of the spiral inductor (i.e., because a conductive volume of the innermost turn of the spiral inductor 104 is smaller than a conductive volume of an innermost turn of the uniform thickness spiral inductor). Thus, a radio frequency (RF) resistance associated with the spiral inductor 104 may be reduced because eddy current loss contributes to RF resistance.

[0027] Although FIG. 1 illustrates the spiral inductor 104 including two conductive spirals, in other embodiments, the spiral inductor 104 may include one conductive spiral or more than two conductive spirals. Although FIG. 1 illustrates the spiral inductor 104 including one conductive layer, in other embodiments, the spiral inductor 104 may include more than one conductive layer. Although FIG. 1 illustrates the first passivation layer 112 and the second passivation layer 114 as overlaying the conductive layer 108 and the second conductive spiral 110 respectively, the first passivation layer 112, the second passivation layer 114, or both, may cover an area larger than an area associated with the spiral inductor 104 (e.g., the first passivation layer 112, the second passivation layer 114, or both, may fill a center of the spiral inductor 104 or the space between turns of the spiral inductor 104).

[0028] An electronic device that includes a varying thickness spiral inductor (e.g., the spiral inductor 104) may provide a similar inductance as compared to a uniform thickness spiral inductor of similar dimensions. However, a reduced thickness of an innermost turn of the varying thickness spiral inductor causes the varying thickness inductor to have a lower electrical resistance to an alternating current due to reduced eddy current loss. Thus, an electronic device may use the varying thickness inductor to provide inductance using less RF power, as compared to an electronic device that includes the uniform thickness spiral inductor.

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[0029] Referring to FIG. 2, a particular illustrative embodiment of a system 200 including a substrate 202 and a spiral inductor 204 (e.g., a gradient layer stack inductor) coupled to the substrate 202 is shown. The spiral inductor 204 may include a first conductive spiral 206, a conductive layer 208, and a second conductive spiral 210. A trace width associated with the spiral inductor 204 may be a minimum trace width that can be manufactured using a particular process technology used to fabricate the spiral inductor 204. The system 200 may be the same as the system 100, except one or more of the first conductive spiral 206, the conductive layer 208, the second conductive spiral 210 of the spiral inductor 204 may have a gradient thickness, as described below, as compared to a thickness that increases in the step configuration of FIG. 1. The system 200 may be fabricated using similar methods and materials as the system 100 of FIG. 1.

[0030] A thickness of the spiral inductor 204 in the direction perpendicular to the substrate 202 may increase monotonically from an innermost portion of the spiral inductor 204 to an outermost portion of the spiral inductor 204. In a particular embodiment, the spiral inductor 204 may be a gradient layer stack inductor where a thickness in the direction perpendicular to the substrate 202 increases from one point along an innermost turn to another point along the innermost turn. The thickness of a first portion of an innermost turn of the spiral inductor 204 may be greater than a thickness of a second portion of the innermost turn. For example, a particular portion of the conductive layer 208 corresponding to a portion 222 of the innermost turn of the spiral inductor 204 may have a gradient thickness (e.g., a thickness that varies proportionately to an incline along a portion 222 of the innermost turn of the spiral inductor 204) in the direction perpendicular to the substrate 202. A portion of the conductive layer 208 corresponding to the portion 222 may have a thickness in the direction perpendicular to the substrate 202 that increases from a first point 214 to a second point 212. A portion of the conductive layer 208 corresponding to the second point 212 may have a thickness in the direction perpendicular to the substrate 202 that is greater than a thickness of the first point 214. The first conductive spiral 106, the conductive layer 208, the second conductive spiral 110, or a combination thereof, may have a substantially constant thickness or may have a gradient thickness.

[0031] An electronic device that includes a varying thickness spiral inductor (e.g., the spiral inductor 204) may provide a similar inductance as compared to a uniform

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thickness spiral inductor of similar dimensions. However, a reduced thickness of an innermost turn of the varying thickness spiral inductor causes the varying thickness spiral inductor to have a lower electrical resistance due to reduced eddy current loss. Thus, an electronic device may use the varying thickness spiral inductor to provide inductance using less power, as compared to an electronic device that includes the uniform thickness spiral inductor.

[0032] Referring to FIG. 3, an illustrative diagram 300 of a comparison between a spiral inductor having a thickness that varies (e.g., a varying thickness spiral inductor 304), such as the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2, and a spiral inductor having a thickness that does not vary (e.g., a uniform thickness spiral inductor 302). In FIG. 3, a table 306 illustrates a percent change between the uniform (e.g., nonvarying) thickness spiral inductor 302 and the varying thickness spiral inductor 304, in a particular embodiment where the uniform thickness spiral inductor 302 and the varying thickness spiral inductor 304 are proportioned to have an inductance value (L) of 4.9851 nanohenries (nH). A quality factor (Q) associated with the varying thickness spiral inductor 304 is higher (e.g., 33.775) than a quality factor associated with the uniform thickness spiral inductor 302 (e.g., 32.974) (e.g., 2.43% in the particular embodiment shown). The varying thickness spiral inductor 304 may be associated with a lower electrical resistance as compared to the uniform thickness spiral inductor 302, and for an inductor, electrical resistance is inversely proportional to quality factor. In addition, an area (in square millimeters (mm^2)) of the varying thickness spiral inductor 304 (e.g., 0.571 mm^2) used to generate the inductance value (e.g., 4.9851 nH) is smaller than an area of the uniform thickness spiral inductor 302 (e.g., 0.575 mm^2) used to generate the inductance value (e.g., 0.72% in the particular embodiment shown). A quality factor per area (Q/Area) of the varying thickness spiral inductor 304 (e.g., 59.2) is higher than a quality factor per area of the uniform thickness spiral inductor 302 (e.g., 3.17% in the particular embodiment shown).

[0033] FIG. 4 is a flowchart illustrating a particular embodiment of a method 400 of forming an electronic device. The method includes, at 402, forming a first conductive spiral of a spiral inductor coupled to a substrate. For example, the second conductive spiral 110 of the spiral inductor 104 of FIG. 1 may be formed coupled to the substrate 102. The method further includes, at 404, forming a second conductive spiral of the

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spiral inductor. For example, the first conductive spiral 106 of the spiral inductor 104 of FIG. 1 may be formed. The second conductive spiral overlays the first conductive spiral. For example, the first conductive spiral 106 overlays the second conductive spiral 110. A first portion of an innermost turn of the spiral inductor has a first thickness in a direction perpendicular to the substrate. For example, the first portion 120 of the spiral inductor 104 of FIG. 1 has a first thickness in a direction perpendicular to the substrate 102. The first portion of the innermost turn includes a first portion of the first conductive spiral and does not include the second conductive spiral. For example, the first portion 120 of the spiral inductor 104 of FIG. 1 includes a portion of the second conductive spiral 110 and does not include the first conductive spiral 106. A second portion of the innermost turn includes a first portion of the second conductive spiral. For example, the third portion 126 of the spiral inductor 104 of FIG. 1 includes a portion of the first conductive spiral 106. A portion of an outermost turn of the spiral inductor has a second thickness in the direction perpendicular to the substrate, where the second thickness is greater than the first thickness. For example, the fourth portion 124 of the spiral inductor 104 of FIG. 1 has a second thickness in a direction perpendicular to the substrate 102, and the second thickness is greater than the first thickness. The portion of the outermost turn includes a second portion of the first conductive spiral and a second portion of the second conductive spiral. For example, the fourth portion 124 includes a portion of the second conductive spiral 110 and a portion of the first conductive spiral 106.

[0034] The method of FIG. 4 may be initiated by a processing unit such as a central processing unit (CPU), a field-programmable gate array (FPGA) device, an application-specific integrated circuit (ASIC), a controller, another hardware device, firmware device, or any combination thereof. As an example, the method of FIG. 4 can be initiated by fabrication equipment, such as a processor within or coupled to fabrication equipment and that executes instructions stored at a memory (e.g., a non-transitory computer-readable medium), as described further with reference to FIG. 7. Integrated circuit manufacturing processes may be used to fabricate the system 100 of FIG. 1 and the system 200 of FIG. 2, such as wet etching, dry etching, deposition, planarization, lithography, or a combination thereof.

[0035] An electronic device formed according to the method 400 may include a varying thickness spiral inductor that provides a similar inductance as compared to a uniform

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thickness spiral inductor of similar dimensions. However, a reduced thickness of an innermost turn of the varying thickness spiral inductor causes the varying thickness inductor to have a lower electrical resistance due to reduced eddy current loss. Thus, an electronic device may use the varying thickness inductor to provide inductance using less power, as compared to an electronic device that includes the uniform thickness spiral inductor.

[0036] FIG. 5 is a flowchart illustrating a particular embodiment of a method 500 of forming an electronic device. The method includes, at 502, forming a conductive spiral of a spiral inductor coupled to a substrate. For example, the second conductive spiral 210 of the spiral inductor 204 of FIG. 2 may be formed and coupled to the substrate 202. The method further includes, at 504, forming a conductive layer of the spiral inductor above the conductive spiral. For example, the conductive layer 208 of the spiral inductor 204 of FIG. 2 may be formed above the second conductive spiral 210. A first portion of an innermost turn of the spiral inductor has a first thickness in a direction perpendicular to the substrate. For example, the portion of the spiral inductor 204 of FIG. 2 corresponding to the first point 214 has a first thickness in a direction perpendicular to the substrate 202. A second portion of the innermost turn has a second thickness in the direction perpendicular to the substrate, where the second thickness is greater than the first thickness. For example, the portion of the spiral inductor 204 of FIG. 2 corresponding to the second point 212 has a second thickness in a direction perpendicular to the substrate 202, and the second thickness is greater than the first thickness. A thickness of the spiral inductor in the direction perpendicular to the substrate increases according to a gradient from the first thickness to the second thickness. For example, the thickness of the spiral inductor 204 of FIG. 2 increases according to a gradient from the first point 214 to the second point 212.

[0037] The method of FIG. 5 may be initiated by a processing unit such as a central processing unit (CPU), a field-programmable gate array (FPGA) device, an application-specific integrated circuit (ASIC), a controller, another hardware device, firmware device, or any combination thereof. As an example, the method of FIG. 5 can be initiated by fabrication equipment, such as a processor within or coupled to fabrication equipment and that executes instructions stored at a memory (e.g., a non-transitory computer-readable medium), as described further with reference to FIG. 7.

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[0038] An electronic device formed according to the method 500 may include a varying thickness spiral inductor that provides a similar inductance as compared to a uniform thickness spiral inductor of similar dimensions. However, a reduced thickness of an innermost turn of the varying thickness spiral inductor causes the varying thickness inductor to have a lower electrical resistance due to reduced eddy current loss. Thus, an electronic device may use the varying thickness inductor to provide inductance using less power, as compared to an electronic device that includes the uniform thickness spiral inductor.

[0039] Referring to FIG. 6, a block diagram depicts a particular illustrative embodiment of a mobile device that includes a substrate 602 and a spiral inductor 604, the mobile device generally designated 600. The mobile device 600, or components thereof, may include, implement, or be included within a device such as: a communications device, a mobile phone, a cellular phone, a computer, a portable computer, a tablet, an access point, a set top box, an entertainment unit, a navigation device, a personal digital assistant (PDA), a fixed location data unit, a mobile location data unit, a desktop computer, a monitor, a computer monitor, a television, a tuner, a radio, a satellite radio, a music player, a digital music player, a portable music player, a video player, a digital video player, a digital video disc (DVD) player, or a portable digital video player.

[0040] The mobile device 600 may include a processor 612, such as a digital signal processor (DSP). The processor 612 may be coupled to a memory 632 (e.g., a non-transitory computer-readable medium).

[0041] FIG. 6 also shows a display controller 626 that is coupled to the processor 612 and to a display 628. A coder/decoder (CODEC) 634 can also be coupled to the processor 612. A speaker 636 and a microphone 638 can be coupled to the CODEC 634. A wireless controller 640 can be coupled to the processor 612 and can be further coupled to a radio frequency (RF) stage 606 that includes the substrate 602 and the spiral inductor 604. The RF stage 606 may be coupled to an antenna 642. In other embodiments, the substrate 602 and the spiral inductor 604 may be included in, or configured to provide inductance to, other components of the mobile device 600. The substrate 602 and the spiral inductor 604 may be included in a LC voltage controlled oscillator (LC-VCO), an LC-based filter, a matching circuit, or another component of the RF stage 606.

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[0042] In a particular embodiment, the spiral inductor 604 is coupled to (e.g., deposited above) the substrate 602. The spiral inductor 604 may include a first conductive spiral and a second conductive spiral overlaying the first conductive spiral. A first portion of an innermost turn of the spiral inductor 604 may have a first thickness in a direction perpendicular to the substrate 602. The first portion of the innermost turn may include a first portion of the first conductive spiral (and not include the second conductive spiral). A second portion of the innermost turn may include a first portion of the second conductive spiral. A portion of an outermost turn of the spiral inductor 604 may have a second thickness in the direction perpendicular to the substrate that is greater than the first thickness. A portion of the outermost turn may include a second portion of the first conductive spiral and a second portion of the second conductive spiral. For example, the substrate 602 may correspond to the substrate 102 of FIG. 1, and the spiral inductor 604 may correspond to the spiral inductor 104 of FIG. 1 or the varying thickness spiral inductor 304 of FIG. 3.

[0043] In another particular embodiment, the spiral inductor 604 is coupled to (e.g., deposited above) the substrate 602. A first portion of an innermost turn of the spiral inductor 604 may have a first thickness in a direction perpendicular to the substrate 602. A second portion of the innermost turn of the spiral inductor 604 may have a second thickness, in the direction perpendicular to the substrate, that is greater than the first thickness. A thickness of the spiral inductor 604 in the direction perpendicular to the substrate 602 may increase according to a gradient from the first thickness to the second thickness. For example, the substrate 602 may correspond to the substrate 202 of FIG. 2, and the spiral inductor 604 may correspond to the spiral inductor 204 of FIG. 2.

[0044] In a particular embodiment, the processor 612, the display controller 626, the memory 632, the CODEC 634, and the wireless controller 640 are included in a system-in-package or system-on-chip device 622. An input device 630 and a power supply 644 may be coupled to the system-on-chip device 622. Moreover, in a particular embodiment, and as illustrated in FIG. 6, the RF stage 606, the display 628, the input device 630, the speaker 636, the microphone 638, the antenna 642, and the power supply 644 are external to the system-on-chip device 622. However, each of the RF stage 606, the display 628, the input device 630, the speaker 636, the microphone 638, the antenna 642, and the power supply 644 can be coupled to a component of the system-on-chip

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device 622, such as an interface or a controller. The RF stage 606 may be included in the system-on-chip device 622 or may be a separate component, as shown in FIG. 6.

[0045] In a particular embodiment, an apparatus (such as the mobile device 600) includes means for storing energy in a magnetic field (e.g., the spiral inductor 104 of FIG. 1, the varying thickness spiral inductor 304 of FIG. 3, or the spiral inductor 604 of FIG. 6) coupled to means for supporting layers (e.g., the substrate 102 of FIG. 1 or the substrate 602 of FIG. 6) and having a spiral shape. The means for storing energy may include a first conductive spiral and a second conductive spiral overlaying the first conductive spiral. A portion of an innermost turn of the means for storing energy may have a first thickness in a direction perpendicular to the means for supporting layers. The first portion of the innermost turn may include a first portion of the first conductive spiral and may not include the second conductive spiral. A second portion of the innermost turn may include a first portion of the second conductive spiral. A portion of an outermost turn of the means for storing energy may have a second thickness in the direction perpendicular to the substrate that is greater than the first thickness. A portion of the outermost turn may include a second portion of the first conductive spiral and a second portion of the second conductive spiral. For example, the means for supporting layers may include or correspond to the substrate 102 of FIG. 1 or the substrate 602 of FIG. 6, and the means for storing energy may include or correspond to the spiral inductor 104 of FIG. 1, the varying thickness spiral inductor 304 of FIG. 3, or the spiral inductor 604 of FIG. 6. The first conductive spiral may include or correspond to the second conductive spiral 110 or the conductive layer 108 of FIG. 1. The second conductive spiral may include or correspond to the conductive layer 108 or the first conductive spiral 106 of FIG. 1. The first portion of the innermost turn may include or correspond to the first portion 120 or the second portion 122 of FIG. 1. The second portion of the innermost turn may correspond to the second portion 122 or the third portion 126 of FIG. 1. The portion of the outermost turn may include or correspond to the fourth portion 124 of FIG. 1.

[0046] In another particular embodiment, an apparatus (such as the mobile device 600) includes means for storing energy in a magnetic field (e.g., the spiral inductor 204 of FIG. 2 or the spiral inductor 604 of FIG. 6) coupled to means for supporting layers (e.g., the substrate 202 of FIG. 2 or the substrate 602 of FIG. 6) and having a spiral shape. A

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portion of an innermost turn of the means for storing energy may have a first thickness in a direction perpendicular to the means for supporting layers, and a portion of an outermost turn of the means for storing energy may have a second thickness that is greater than the first thickness in the direction perpendicular to the means for supporting layers. For example, the means for supporting layers may include or correspond to the substrate 202 of FIG. 2 or the substrate 602 of FIG. 6, and the means for storing energy may include or correspond to the spiral inductor 204 of FIG. 2 or the spiral inductor 604 of FIG. 6. The first portion of the innermost turn may include or correspond to the first point 214 of FIG. 2, and the second portion of the innermost turn may include or correspond to the second point 212 of FIG. 2.

[0047] The foregoing disclosed devices and functionalities may be designed and configured into computer files (e.g. RTL, GDSII, GERBER, etc.) stored on computer-readable media. Some or all such files may be provided to fabrication handlers to fabricate devices based on such files. Resulting products include wafers that are then cut into dies and packaged into chips. The chips are then employed in devices described above. FIG. 7 depicts a particular illustrative embodiment of an electronic device manufacturing process 700.

[0048] Physical device information 702 is received at the manufacturing process 700, such as at a research computer 706. The physical device information 702 may include design information representing at least one physical property of an electronic device, such as a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2). For example, the physical device information 702 may include physical parameters, material characteristics, and structure information that is entered via a user interface 704 coupled to the research computer 706. The research computer 706 includes a processor 708, such as one or more processing cores, coupled to a computer-readable medium such as a memory 710. The memory 710 may store computer-readable instructions that are executable to cause the processor 708 to transform the physical device information 702 to comply with a file format and to generate a library file 712.

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[0049] In a particular embodiment, the library file 712 includes at least one data file including the transformed design information. For example, the library file 712 may include a library of electronic devices (e.g., semiconductor devices), including a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2), provided for use with an electronic design automation (EDA) tool 720.

[0050] The library file 712 may be used in conjunction with the EDA tool 720 at a design computer 714 including a processor 716, such as one or more processing cores, coupled to a memory 718. The EDA tool 720 may be stored as processor executable instructions at the memory 718 to enable a user of the design computer 714 to design a circuit including a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2), using the library file 712. For example, a user of the design computer 714 may enter circuit design information 722 via a user interface 724 coupled to the design computer 714. The circuit design information 722 may include design information representing at least one physical property of an electronic device, such as a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2). To illustrate, the circuit design property may include identification of particular circuits and relationships to other elements in a circuit design, positioning information, feature size information, interconnection information, or other information representing a physical property of an electronic device.

[0051] The design computer 714 may be configured to transform the design information, including the circuit design information 722, to comply with a file format. To illustrate, the file formation may include a database binary file format representing planar geometric shapes, text labels, and other information about a circuit layout in a hierarchical format, such as a Graphic Data System (GDSII) file format. The design computer 714 may be configured to generate a data file including the transformed design information, such as a GDSII file 726 that includes information describing a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor

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204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2), in addition to other circuits or information. To illustrate, the data file may include information corresponding to a system-on-chip (SOC) or a chip interposer component that includes a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2), and that also includes additional electronic circuits and components within the SOC.

[0052] The GDSII file 726 may be received at a fabrication process 728 to manufacture a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2) according to transformed information in the GDSII file 726. For example, a device manufacture process may include providing the GDSII file 726 to a mask manufacturer 730 to create one or more masks, such as masks to be used with photolithography processing, illustrated in FIG. 7 as a representative mask 732. The mask 732 may be used during the fabrication process to generate one or more wafers 733, which may be tested and separated into dies, such as a representative die 736. The die 736 includes a circuit including a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2).

[0053] In a particular embodiment, the fabrication process 728 may be initiated by or controlled by a processor 734. The processor 734 may access a memory 735 that includes executable instructions such as computer-readable instructions or processor-readable instructions. The executable instructions may include one or more instructions that are executable by a computer, such as the processor 734.

[0054] The fabrication process 728 may be implemented by a fabrication system that is fully automated or partially automated. For example, the fabrication process 728 may be automated and may perform processing steps according to a schedule. The fabrication system may include fabrication equipment (e.g., processing tools) to perform one or more operations to form an electronic device. For example, the fabrication equipment may be configured to form one or more conductive spirals, to form one or more conductive layers, to form one or more passivation layers, to form one or more

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conductive vias, to perform one or more etches, to form one or more metal structures, or to form other integrated circuit elements using integrated circuit manufacturing processes (e.g., wet etching, dry etching, deposition, planarization, lithography, or a combination thereof).

[0055] The fabrication system may have a distributed architecture (e.g., a hierarchy). For example, the fabrication system may include one or more processors, such as the processor 734, one or more memories, such as the memory 735, and/or controllers that are distributed according to the distributed architecture. The distributed architecture may include a high-level processor that controls or initiates operations of one or more low-level systems. For example, a high-level portion of the fabrication process 728 may include one or more processors, such as the processor 734, and the low-level systems may each include or may be controlled by one or more corresponding controllers. A particular controller of a particular low-level system may receive one or more instructions (e.g., commands) from a high-level system, may issue sub-commands to subordinate modules or process tools, and may communicate status data back to the high-level system. Each of the one or more low-level systems may be associated with one or more corresponding pieces of fabrication equipment (e.g., processing tools). In a particular embodiment, the fabrication system may include multiple processors that are distributed in the fabrication system. For example, a controller of a low-level system component of the fabrication system may include a processor, such as the processor 734.

[0056] Alternatively, the processor 734 may be a part of a high-level system, subsystem, or component of the fabrication system. In another embodiment, the processor 734 includes distributed processing at various levels and components of a fabrication system.

[0057] Thus, the memory 735 may include processor-executable instructions that, when executed by the processor 734, cause the processor 734 to initiate or control formation of a first conductive spiral of a spiral inductor coupled to a substrate. For example, a first conductive layer including the first conductive spiral may be formed by one or more deposition tools, such as a flowable chemical vapor deposition (FCVD) tool or a spin-on deposition tool. The first conductive spiral may be etched from the first conductive layer by one or more etching machines or etchers, such as a wet etcher, a dry etcher, or a plasma etcher. Execution of the processor-executable instructions may further cause the

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processor 734 to initiate or control formation of a second conductive spiral of the spiral inductor. For example, a second conductive layer including the second conductive spiral may be formed by one or more deposition tools, such as a flowable chemical vapor deposition (FCVD) tool or a spin-on deposition tool. The second conductive spiral may be etched from the second conductive layer by one or more etching machines or etchers, such as a wet etcher, a dry etcher, or a plasma etcher. The second conductive spiral may overlay the first conductive spiral. A first portion of an innermost turn of the spiral inductor may have a first thickness in a direction perpendicular to the substrate. The first portion of the innermost turn may include a first portion of the first conductive spiral and may not include the second conductive spiral. A second portion of the innermost turn may include a first portion of the second conductive spiral. A portion of an outermost turn of the spiral inductor may have a second thickness in the direction perpendicular to the substrate. The second thickness may be greater than the first thickness. The portion of the outermost turn may include a second portion of the first conductive spiral and a second portion of the second conductive spiral.

[0058] Further, the memory 735 may include processor-executable instructions that, when executed by the processor 734, cause the processor 734 to initiate or control formation of a conductive spiral of a spiral inductor coupled to a substrate. For example, a first conductive layer including the conductive spiral may be formed by one or more deposition tools, such as a flowable chemical vapor deposition (FCVD) tool or a spin-on deposition tool. The conductive spiral may be etched from the first conductive layer by one or more etching machines or etchers, such as a wet etcher, a dry etcher, or a plasma etcher. Execution of the processor-executable instructions may further cause the processor 734 to initiate or control formation of a conductive layer of the spiral inductor above the conductive spiral. For example, a second conductive layer including the conductive layer may be formed by one or more deposition tools, such as a flowable chemical vapor deposition (FCVD) tool or a spin-on deposition tool. The conductive layer may be etched from the second conductive layer by one or more etching machines or etchers, such as a wet etcher, a dry etcher, or a plasma etcher. A first portion of an innermost turn of the spiral inductor may have a first thickness in a direction perpendicular to the substrate. A second portion of the innermost turn may have a second thickness in the direction perpendicular to the substrate. The second thickness

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may be greater than the first thickness. A thickness of the spiral inductor may increase according to a gradient from the first thickness to the second thickness.

[0059] As an illustrative example, the processor 734 may control a step for forming a first conductive spiral of a spiral inductor coupled to a substrate. For example, the processor 734 may be embedded in or coupled to one or more controllers that control one or more pieces of fabrication equipment to perform the step for forming the first conductive spiral of the spiral inductor coupled to the substrate. The processor 734 may control the step for forming the first conductive spiral by controlling formation of the first conductive spiral, by controlling one or more other processes configured to form the first conductive spiral, or any combination thereof. The processor 734 may also control a step for forming a second conductive spiral of the spiral inductor. The processor 734 may control the step for forming the second conductive spiral by controlling formation of the second conductive spiral, by controlling one or more other processes configured to form the second conductive spiral, or any combination thereof. The second spiral may overlay the first conductive spiral. A first portion of an innermost turn of the spiral inductor may have a first thickness in a direction perpendicular to the substrate. The first portion of the innermost turn may include a first portion of the first conductive spiral and may not include the second conductive spiral. A second portion of the innermost turn may include a first portion of the second conductive spiral. A portion of an outermost turn of the spiral inductor may have a second thickness in the direction perpendicular to the substrate. The second thickness may be greater than the first thickness. The portion of the outermost turn may include a second portion of the first conductive spiral and a second portion of the second conductive spiral. Integrated circuit manufacturing processes may be used to fabricate the first conductive spiral and the second conductive spiral (e.g., wet etching, dry etching, deposition, planarization, lithography, or a combination thereof).

[0060] As another illustrative example, the processor 734 may control a step for forming a conductive spiral of a spiral inductor coupled to a substrate. For example, the processor 734 may be embedded in or coupled to one or more controllers that control one or more pieces of fabrication equipment to perform the step for forming the conductive spiral of the spiral inductor coupled to the substrate. The processor 734 may control the step for forming the conductive spiral by controlling formation of the conductive spiral,

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by controlling one or more other processes configured to form the conductive spiral, or any combination thereof. The processor 734 may also control a step for forming a conductive layer of the spiral inductor above the conductive spiral. The processor 734 may control the step for forming the conductive layer by controlling formation of the conductive layer, by controlling one or more other processes configured to form the conductive layer, or any combination thereof. A first portion of an innermost turn of the spiral inductor may have a first thickness in a direction perpendicular to the substrate. A second portion of the innermost turn may have a second thickness in the direction perpendicular to the substrate. The second thickness may be greater than the first thickness. A thickness of the spiral inductor may increase according to a gradient from the first thickness to the second thickness. Integrated circuit manufacturing processes may be used to fabricate the conductive spiral and the conductive layer (e.g., wet etching, dry etching, deposition, planarization, lithography, or a combination thereof).

[0061] The die 736 may be provided to a packaging process 738 where the die 736 is incorporated into a representative package 740. For example, the package 740 may include the single die 736 or multiple dies, such as a system-in-package (SiP) arrangement. The package 740 may be configured to conform to one or more standards or specifications, such as Joint Electron Device Engineering Council (JEDEC) standards.

[0062] Information regarding the package 740 may be distributed to various product designers, such as via a component library stored at a computer 746. The computer 746 may include a processor 748, such as one or more processing cores, coupled to a memory 750. A printed circuit board (PCB) tool may be stored as processor executable instructions at the memory 750 to process PCB design information 742 received from a user of the computer 746 via a user interface 744. The PCB design information 742 may include physical positioning information of a packaged electronic device on a circuit board, the packaged electronic device corresponding to the package 740 including a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2).

[0063] The computer 746 may be configured to transform the PCB design information 742 to generate a data file, such as a GERBER file 752 with data that includes physical

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positioning information of a packaged electronic device on a circuit board, as well as layout of electrical connections such as traces and vias, where the packaged electronic device corresponds to the package 740 including a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2). In other embodiments, the data file generated by the transformed PCB design information may have a format other than a GERBER format.

[0064] The GERBER file 752 may be received at a board assembly process 754 and used to create PCBs, such as a representative PCB 756, manufactured in accordance with the design information stored within the GERBER file 752. For example, the GERBER file 752 may be uploaded to one or more machines to perform various steps of a PCB production process. The PCB 756 may be populated with electronic components including the package 740 to form a representative printed circuit assembly (PCA) 758.

[0065] The PCA 758 may be received at a product manufacturer 760 and integrated into one or more electronic devices, such as a first representative electronic device 762 and a second representative electronic device 764. As an illustrative, non-limiting example, the first representative electronic device 762, the second representative electronic device 764, or both, may be selected from a set top box, a music player, a video player, an entertainment unit, a navigation device, a communications device, a personal digital assistant (PDA), a fixed location data unit, and a computer, into which a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2), is integrated. As another illustrative, non-limiting example, one or more of the electronic devices 762 and 764 may be remote units such as mobile phones, hand-held personal communication systems (PCS) units, portable data units such as personal data assistants, global positioning system (GPS) enabled devices, navigation devices, fixed location data units such as meter reading equipment, or any other device that stores or retrieves data or computer instructions, or any combination thereof. Although FIG. 7 illustrates remote units according to teachings of the disclosure, the disclosure is not limited to these illustrated units. Embodiments of the disclosure may be suitably employed in any device which includes active integrated circuitry including memory and on-chip circuitry.

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[0066] A device that includes a spiral inductor (e.g., corresponding to the spiral inductor 104 of FIG. 1 or the spiral inductor 204 of FIG. 2) coupled to a substrate (e.g., corresponding to the substrate 102 of FIG. 1 or the substrate 202 of FIG. 2), may be fabricated, processed, and incorporated into an electronic device, as described in the illustrative manufacturing process 700. One or more aspects of the embodiments disclosed with respect to FIGS. 1-6 may be included at various processing stages, such as within the library file 712, the GDSII file 726, and the GERBER file 752, as well as stored at the memory 710 of the research computer 706, the memory 718 of the design computer 714, the memory 750 of the computer 746, the memory of one or more other computers or processors (not shown) used at the various stages, such as at the board assembly process 754, and also incorporated into one or more other physical embodiments such as the mask 732, the die 736, the package 740, the PCA 758, other products such as prototype circuits or devices (not shown), or any combination thereof. Although various representative stages are depicted with reference to FIGS. 1-6, in other embodiments fewer stages may be used or additional stages may be included. Similarly, the process 700 of FIG. 7 may be performed by a single entity or by one or more entities performing various stages of the manufacturing process 700.

[0067] In conjunction with the described embodiments, a non-transitory computer-readable medium stores instructions that, when executed by a processor, cause the processor to initiate formation of a first conductive spiral of a spiral inductor coupled to a substrate. The non-transitory computer readable medium may further store instructions that, when executed by the processor, cause the processor to initiate formation of a second conductive spiral of the spiral inductor. The second conductive spiral may overlay the first conductive spiral. A first portion of an innermost turn of the spiral inductor may have a first thickness in a direction perpendicular to the substrate. The first portion of the innermost turn may include a first portion of the first conductive spiral and may not include the second conductive spiral. A second portion of the innermost turn may include a first portion of the second conductive spiral. A portion of an outermost turn of the spiral inductor may have a second thickness in the direction perpendicular to the substrate. The second thickness may be greater than the first thickness. The portion of the outermost turn may include a second portion of the first conductive spiral and a second portion of the second conductive spiral. The non-transitory computer-readable

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medium may correspond to the memory 632 of FIG. 6 or to the memory 710, the memory 718, or the memory 750 of FIG. 7. The processor may correspond to the processor 612 of FIG. 6 or to the processor 708, the processor 716, or the processor 748 of FIG. 7. The substrate may correspond to the substrate 102 of FIG. 1, the substrate 202 of FIG. 2, or the substrate 602 of FIG. 6. The spiral inductor may correspond to the spiral inductor 104 of FIG. 1, the spiral inductor 204 of FIG. 2, the varying thickness spiral inductor 304 of FIG. 3, or the spiral inductor 604 of FIG. 6. The first conductive spiral may correspond to the conductive layer 108 or the second conductive spiral 110 of FIG. 1 or to the conductive layer 208 or the second conductive spiral 210 of FIG. 2. The second conductive spiral may correspond to the first conductive spiral 106 or the conductive layer 108 of FIG. 1 or to the first conductive spiral 206 or the conductive layer 208 of FIG. 2.

[0068] In conjunction with the described embodiments, a non-transitory computer-readable medium stores instructions that, when executed by a processor, cause the processor to initiate formation of a conductive spiral of a spiral inductor coupled to a substrate. The non-transitory computer readable medium may further store instructions that, when executed by the processor, cause the processor to form a conductive layer of the spiral inductor above the conductive spiral. A first portion of an innermost turn of the spiral inductor may have a first thickness in a direction perpendicular to the substrate. A second portion of the innermost turn may have a second thickness in the direction perpendicular to the substrate. The second thickness may be greater than the first thickness. A thickness of the spiral inductor may increase according to a gradient from the first thickness to the second thickness. The non-transitory computer-readable medium may correspond to the memory 710, the memory 718, or the memory 750 of FIG. 7. The processor may correspond to the processor 708, the processor 716, the processor 734, or the processor 748 of FIG. 7. The substrate may correspond to the substrate 202 of FIG. 2 or the substrate 602 of FIG. 6. The spiral inductor may correspond to the spiral inductor 204 of FIG. 2, or the spiral inductor 604 of FIG. 6. The conductive spiral may correspond to the conductive layer 208 or the second conductive spiral 210 of FIG. 2. The conductive layer may correspond to the first conductive spiral 206 or the conductive layer 208 of FIG. 2.

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[0069] Those of skill would further appreciate that the various illustrative logical blocks, configurations, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software executed by a processor, or combinations of both. Various illustrative components, blocks, configurations, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or processor executable instructions depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

[0070] The steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in memory, such as random access memory (RAM), flash memory, read-only memory (ROM), programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), registers, hard disk, a removable disk, a compact disc read-only memory (CD-ROM). The memory may include any form of non-transient storage medium known in the art. An exemplary storage medium (e.g., memory) is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an application-specific integrated circuit (ASIC). The ASIC may reside in a computing device or a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a computing device or user terminal.

[0071] The previous description of the disclosed embodiments is provided to enable a person skilled in the art to make or use the disclosed embodiments. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the principles defined herein may be applied to other embodiments without departing from the scope of the disclosure. Thus, the present disclosure is not intended to be

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limited to the embodiments shown herein but is to be accorded the widest scope possible consistent with the principles and novel features as defined by the following claims.

CLAIMS:

1. An apparatus comprising:
a substrate; and
a spiral inductor coupled to the substrate, the spiral inductor comprising a first
conductive spiral and a second conductive spiral overlaying the first
conductive spiral,
wherein a first portion of an innermost turn of the spiral inductor has a first
thickness in a direction perpendicular to the substrate, wherein the first
portion of the innermost turn includes a first portion of the first
conductive spiral and does not include the second conductive spiral,
wherein a second portion of the innermost turn includes a first portion of the
second conductive spiral, and
wherein a portion of an outermost turn of the spiral inductor has a second
thickness in the direction perpendicular to the substrate, wherein the
second thickness is greater than the first thickness, and wherein the
portion of the outermost turn includes a second portion of the first
conductive spiral and a second portion of the second conductive spiral.
2. The apparatus of claim 1, wherein a first length of the first conductive spiral is
greater than a second length of the second conductive spiral.
3. The apparatus of claim 1, wherein the spiral inductor further comprises a
conductive layer between the first conductive spiral and the second conductive spiral,
wherein a third portion of the innermost turn of the spiral inductor has a third thickness
in the direction perpendicular to the substrate, wherein the third thickness is less than the
second thickness and greater than the first thickness, wherein the third portion of the
innermost turn includes a third portion of the first conductive spiral and a first portion of
the conductive layer and does not include the second conductive spiral.
4. The apparatus of claim 3, wherein the first portion of the innermost turn does
not include the conductive layer.

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5. The apparatus of claim 3, wherein the portion of the outermost turn of the spiral inductor includes a second portion of the conductive layer.

6. The apparatus of claim 3, wherein the conductive layer comprises a discontinuous spiral.

7. The apparatus of claim 3, wherein the conductive layer comprises an input lead, an output lead, or a combination thereof.

8. The apparatus of claim 1, further comprising a passivation layer formed between the first conductive spiral and the second conductive spiral.

9. The apparatus of claim 8, wherein the first conductive spiral is electrically connected to the second conductive spiral by a via that extends through a portion of the passivation layer.

10. The apparatus of claim 1, wherein a thickness of the innermost turn in the direction perpendicular to the substrate monotonically increases from the first portion of the innermost turn to the second portion of the innermost turn.

11. The apparatus of claim 1, wherein the substrate is a dielectric substrate formed of a glass material, an alkaline earth boro-aluminosilicate glass, Silicon (Si), Gallium Arsenide (GaAs), Indium Phosphate (InP), Silicon Carbide (SiC), a glass-based laminate, sapphire (Al_2O_3), quartz, a ceramic, Silicon on Insulator (SOI), Silicon on Sapphire (SOS), high resistivity Silicon (HRS), Aluminum Nitride (AlN), a plastic, or a combination thereof.

12. The apparatus of claim 1, wherein the spiral inductor is formed of aluminum, copper, silver, gold, tungsten, molybdenum, an alloy of aluminum, silver, gold, tungsten, or molybdenum, or a combination thereof.

13. The apparatus of claim 1, wherein the spiral inductor is a stepped layer stack inductor.

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14. The apparatus of claim 1, wherein a trace width associated with the spiral inductor is a minimum trace width that can be manufactured using a particular process technology used to fabricate the spiral inductor.

15. The apparatus of claim 1, integrated in at least one die.

16. The apparatus of claim 1, further comprising a device selected from a mobile phone, a tablet, a set top box, a music player, a video player, an entertainment unit, a navigation device, a communications device, a personal digital assistant (PDA), a fixed location data unit, and a computer, into which the substrate and the spiral inductor are integrated.

17. A method comprising:

forming a first conductive spiral of a spiral inductor coupled to a substrate; and forming a second conductive spiral of the spiral inductor, wherein the second conductive spiral overlays the first conductive spiral,

wherein a first portion of an innermost turn of the spiral inductor has a first thickness in a direction perpendicular to the substrate, wherein the first portion of the innermost turn includes a first portion of the first conductive spiral and does not include the second conductive spiral, wherein a second portion of the innermost turn includes a first portion of the second conductive spiral,

wherein a portion of an outermost turn of the spiral inductor has a second thickness in the direction perpendicular to the substrate, wherein the second thickness is greater than the first thickness, and wherein the portion of the outermost turn includes a second portion of the first conductive spiral and a second portion of the second conductive spiral.

18. The method of claim 17, wherein forming the first conductive spiral and forming the second conductive spiral are initiated by a processor integrated into an electronic device.

19. An apparatus comprising:

a substrate; and

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a spiral inductor coupled to the substrate,
wherein a first portion of an innermost turn of the spiral inductor has a first thickness in a direction perpendicular to the substrate,
wherein a second portion of the innermost turn has a second thickness in the direction perpendicular to the substrate, wherein the second thickness is greater than the first thickness, and
wherein a thickness of the spiral inductor in the direction perpendicular to the substrate increases according to a gradient from the first thickness to the second thickness.

20. The apparatus of claim 19, wherein a portion of an outermost turn of the spiral inductor has a third thickness in the direction perpendicular to the substrate, wherein the third thickness is greater than the first thickness.

21. The apparatus of claim 20, wherein the second thickness is equal to the third thickness.

22. The apparatus of claim 20, wherein the third thickness is greater than the second thickness.

23. The apparatus of claim 20, wherein the thickness of the spiral inductor monotonically increases from the first thickness to the third thickness.

24. The apparatus of claim 19, wherein the spiral inductor is a gradient layer stack inductor.

25. The apparatus of claim 19, integrated in at least one die.

26. The apparatus of claim 19, further comprising a device selected from a mobile phone, a tablet, a set top box, a music player, a video player, an entertainment unit, a navigation device, a communications device, a personal digital assistant (PDA), a fixed location data unit, and a computer, into which the substrate and the spiral inductor are integrated.

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27. A method comprising:

forming a conductive spiral of a spiral inductor coupled to a substrate; and
forming a conductive layer of the spiral inductor above the conductive spiral,
wherein a first portion of an innermost turn of the spiral inductor has a first

thickness in a direction perpendicular to the substrate,

wherein a second portion of the innermost turn has a second thickness in the
direction perpendicular to the substrate, wherein the second thickness is
greater than the first thickness, and

wherein a thickness of the spiral inductor increases according to a gradient from
the first thickness to the second thickness.

28. The method of claim 27, wherein the conductive layer comprises a second
conductive spiral.

29. The method of claim 27, wherein the conductive layer comprises a
discontinuous spiral.

30. The method of claim 27, wherein forming the conductive spiral and forming
the conductive layer are initiated by a processor integrated into an electronic device.

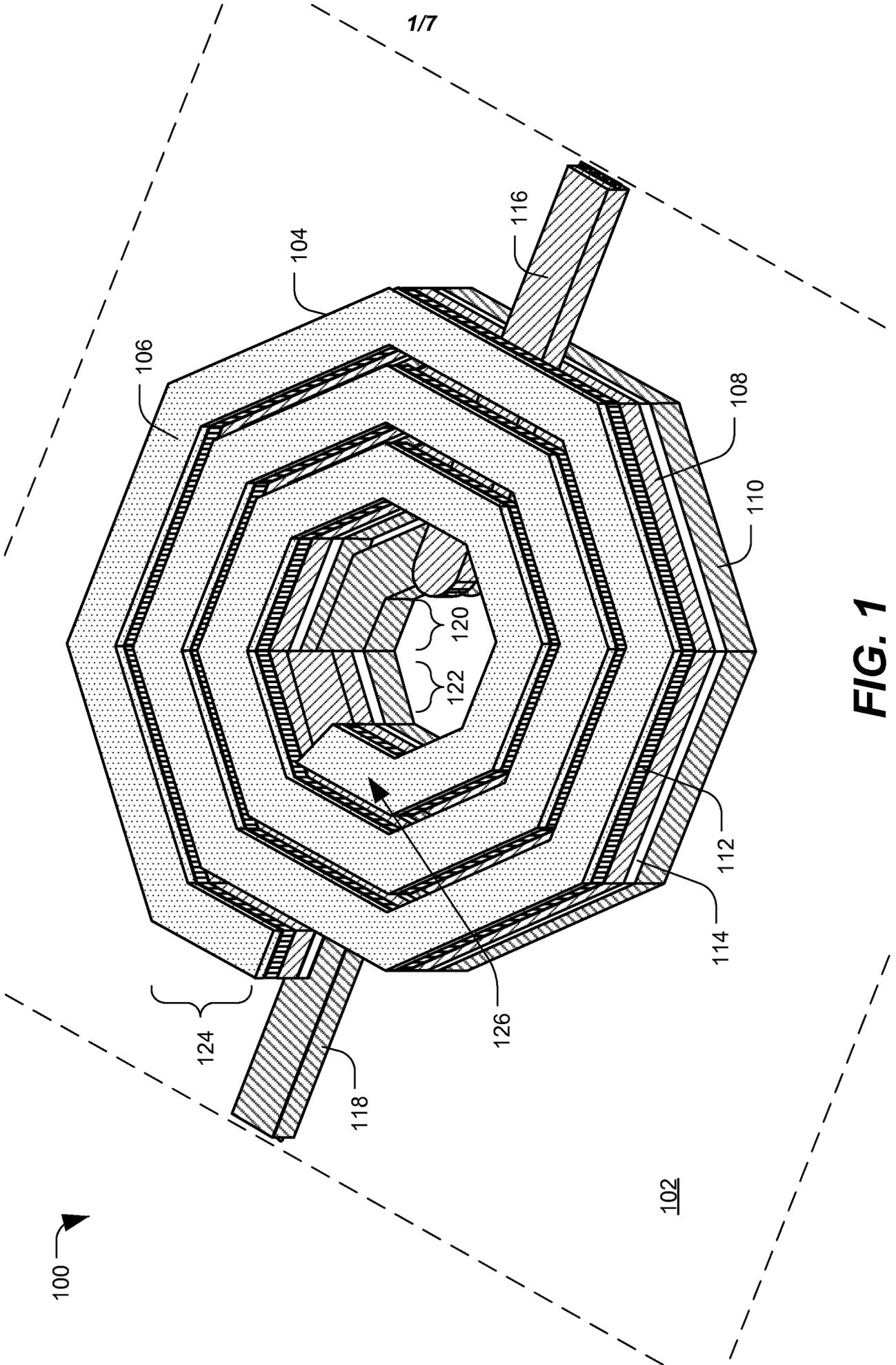


FIG. 1

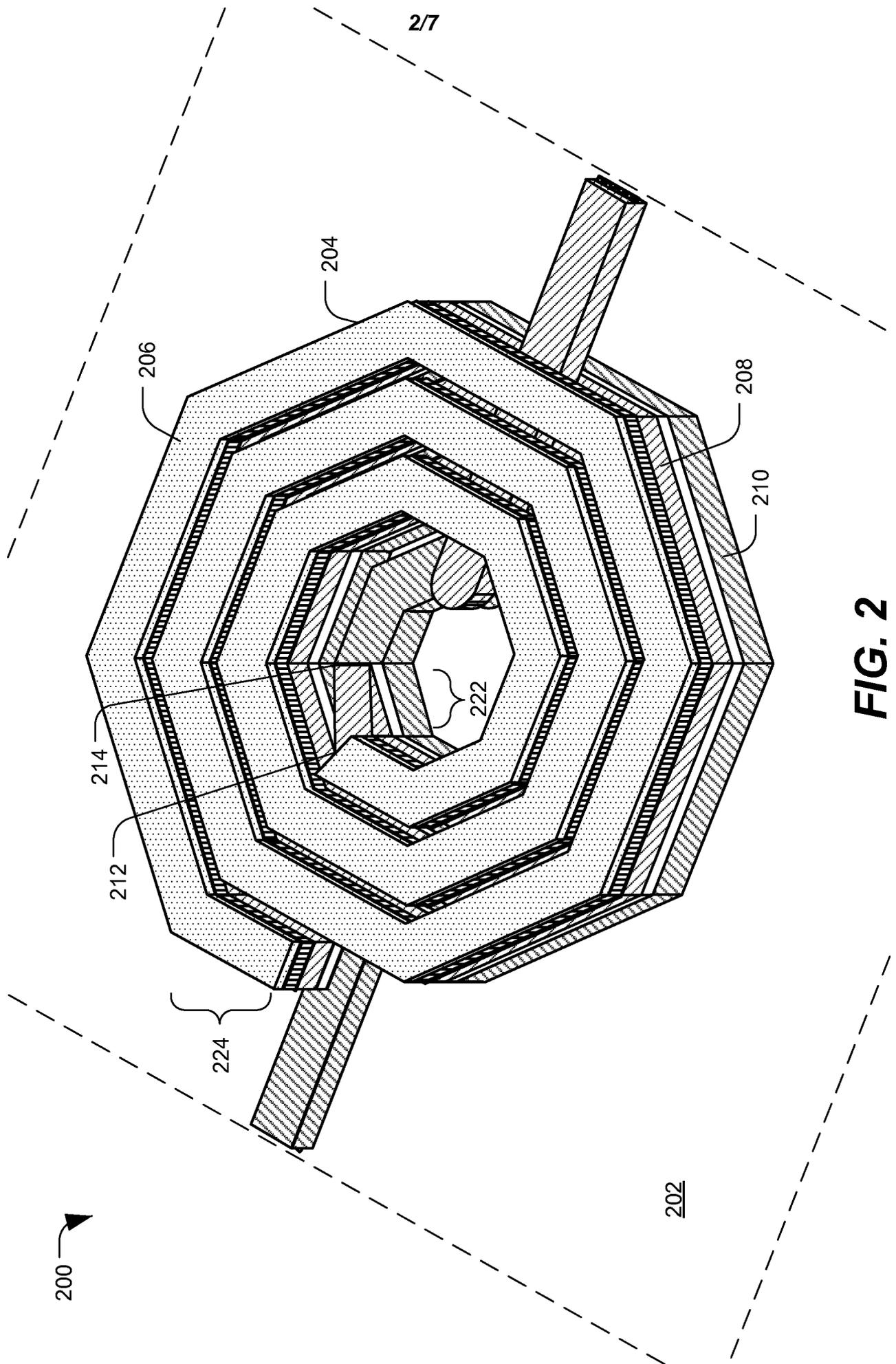
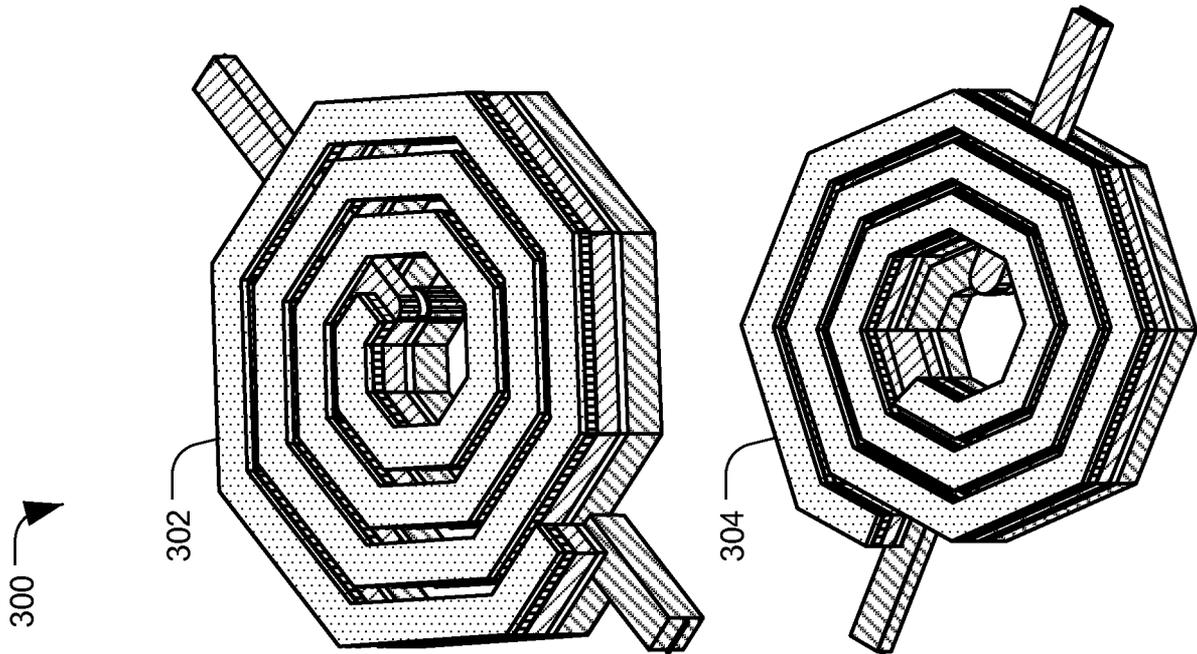
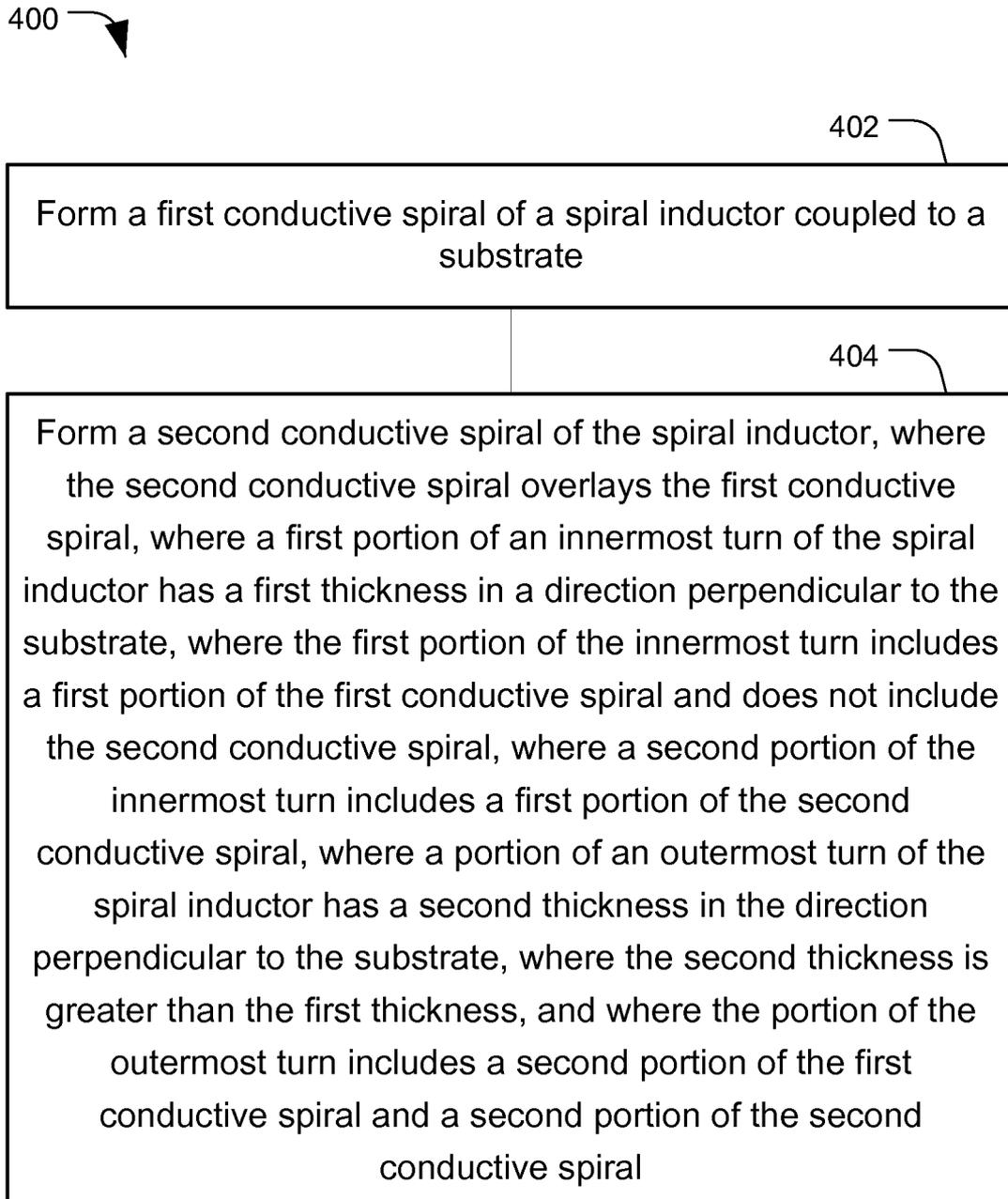


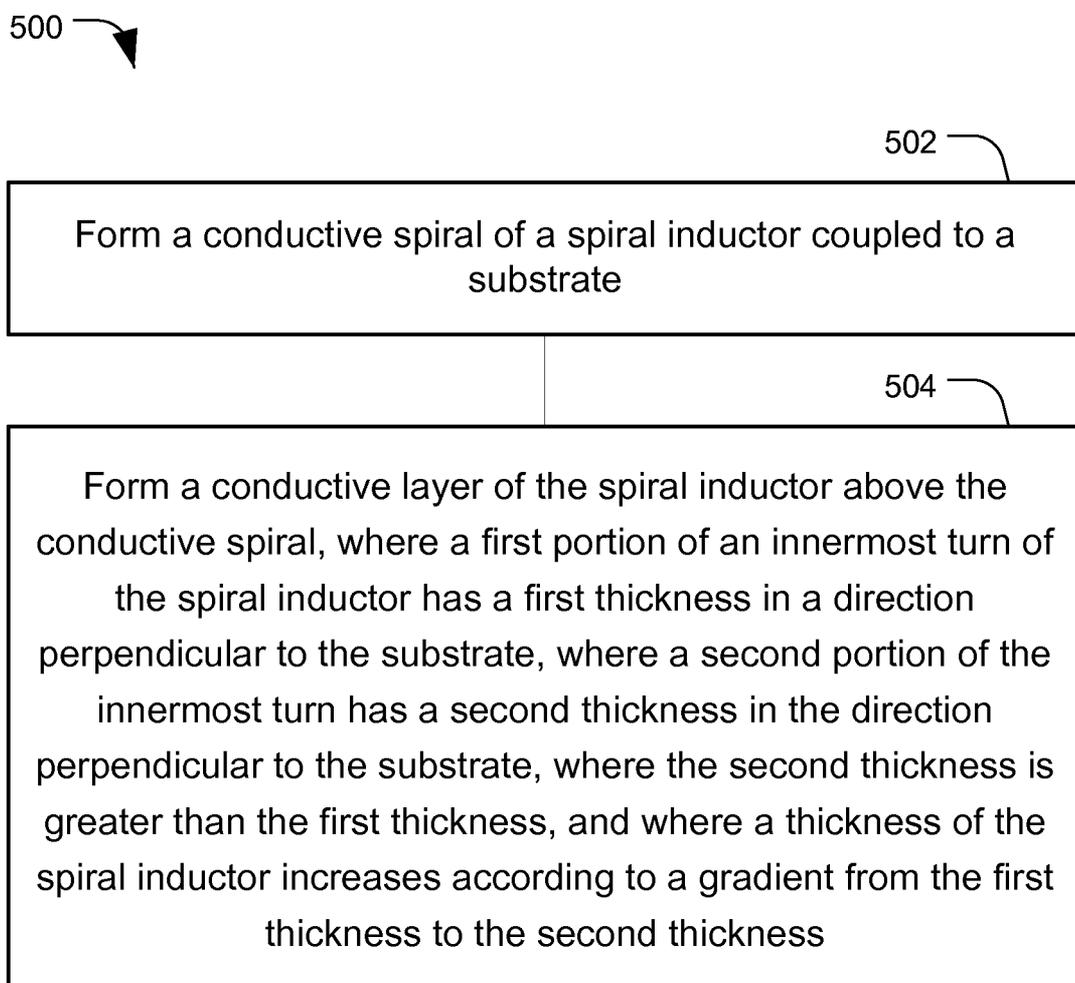
FIG. 2



	L (nH)	Q	Area (mm ²)	Q/Area
Nonvarying	4.9851	32.974	0.575	57.4
Varying	4.9851	33.775	0.571	59.2
Change	0.00%	2.43%	-0.72%	3.17%

FIG. 3

**FIG. 4**

**FIG. 5**

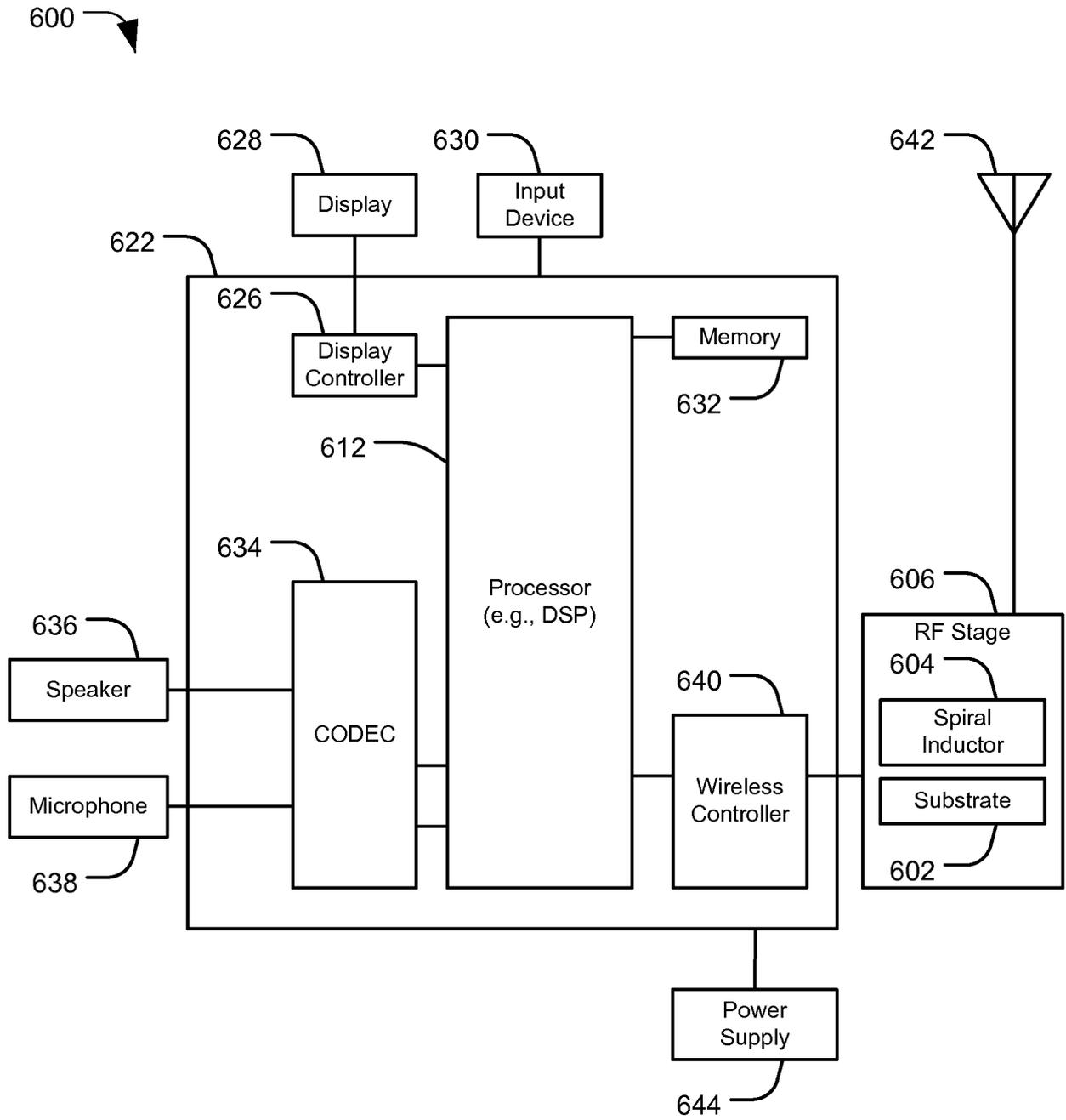


FIG. 6

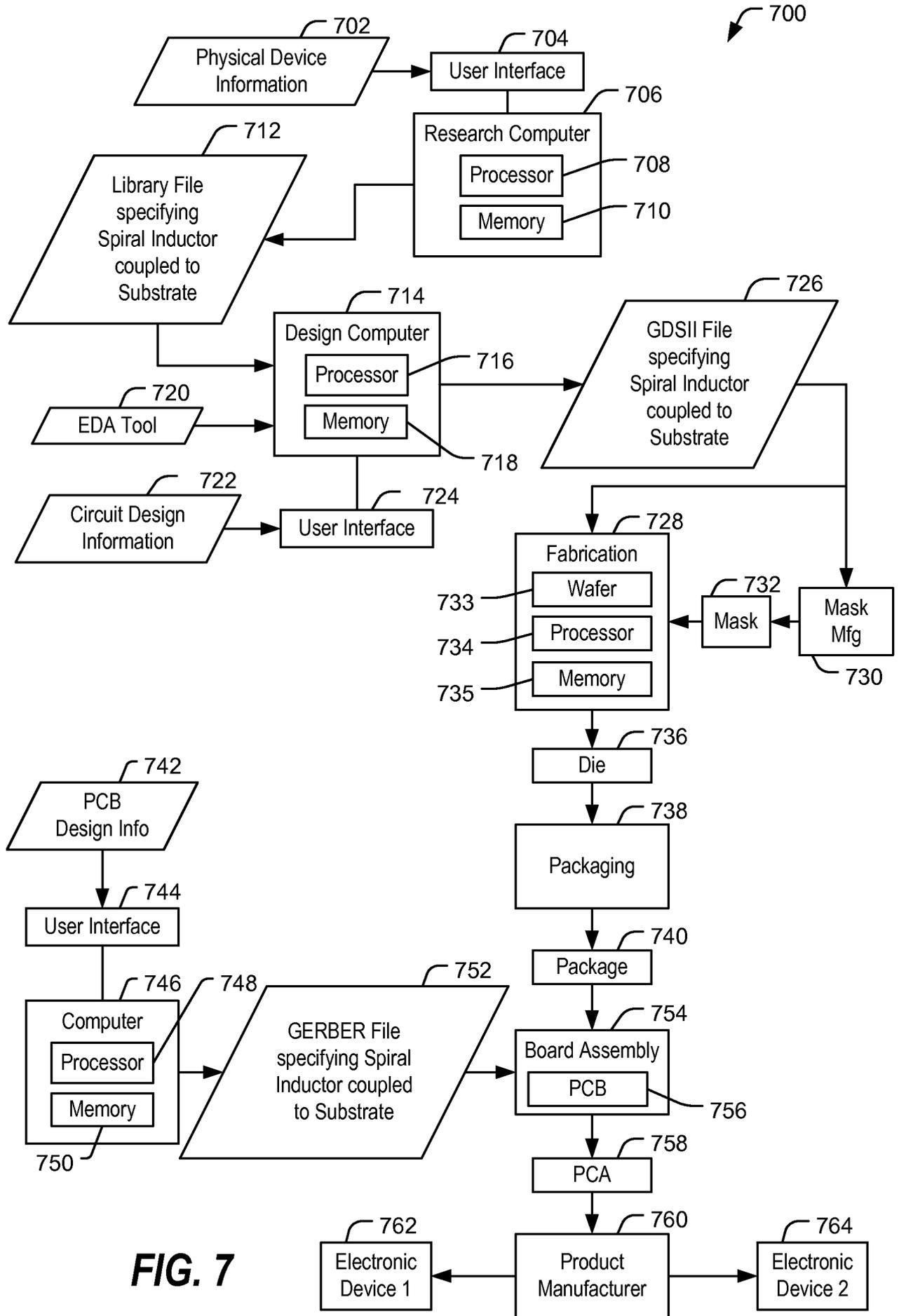


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/048723

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01F17/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 2005/104158 A1 (BHATTACHARJEE JISHNU [US] ET AL) 19 May 2005 (2005-05-19) abstract; figure 3a -----	1-30
A	US 2008/169895 A1 (LEE SHENG-YUAN [TW]) 17 July 2008 (2008-07-17) figure 3a -----	1-30
A	US 2009/146770 A1 (LEE MING-WEI [TW] ET AL) 11 June 2009 (2009-06-11) abstract; figure 5a -----	1-30
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Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search 10 October 2014	Date of mailing of the international search report 20/10/2014
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Rouzier, Brice
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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/048723

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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