(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 August 2017 (10.08.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/136851 A1

(51) International Patent Classification:
H01L 43/02 (2006.01) *G01R 33/09* (2006.01)

(21) International Application Number:
PCT/US2017/016750

(22) International Filing Date:
6 February 2017 (06.02.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15/016,507 5 February 2016 (05.02.2016) US

(63) Related by continuation (CON) or continuation-in-part (CIP) to earlier application:
US 15/016,507 (CIP)
Filed on 5 February 2016 (05.02.2016)

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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, DJ, 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, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, 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.

(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, ST, 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))*

(54) **Title**: INTEGRATED FLUXGATE DEVICE WITH THREE-DIMENSIONAL SENSING

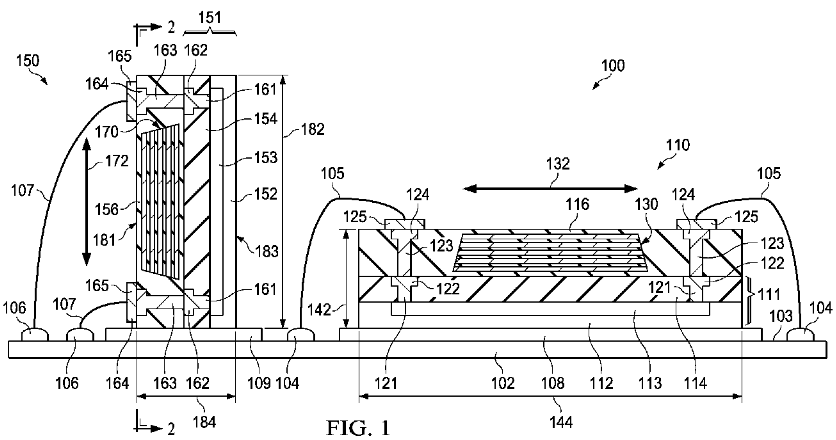

FIG. 1

(57) **Abstract**: Described examples include an electromagnetic sensing device (100) with a package substrate (102), a first die (110) mounted on the package substrate (102), and a second die (150) mounted on the package substrate (102). The first die (110) includes a first integrated circuit (113) and a first magnetic core (116) formed above the first integrated circuit (113). The first magnetic core (116) has a first sensing axis (132) parallel to a planar surface (103) of the package substrate (102). The second die (150) includes a second integrated circuit (153) and a second magnetic core (156) formed above the second integrated circuit (153). The second magnetic core (156) has a second sensing axis (172) orthogonal to the planar surface (103) of the package substrate (102).

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INTEGRATED FLUXGATE DEVICE WITH THREE-DIMENSIONAL SENSING

[0001] This relates to systems and techniques for fabrication of electromagnetic sensing devices.

BACKGROUND

[0002] A fluxgate device generally includes a magnetic core structure and coil members coiling around the magnetic core. A fluxgate device can be used for detecting a change in magnetic flux in an environment adjacent to the associated magnetic core structure. Attempts have been made to interface fluxgate devices with integrated circuits for implementing various industrial applications. For example, a fluxgate device interfaced with a control circuit can be adapted as a current measurement device for use in motor control systems, or as a position sensing device for use in robotic systems. However, these solutions are generally costly to implement and complex to operate, and they generally do not provide three-dimensional (3D) sensing in a single package platform.

SUMMARY

[0003] In described examples, an electromagnetic sensing device includes multiple integrated fluxgate dies mounted on a package substrate. One of the integrated fluxgate dies is fabricated with a shortened vertical edge such that it is mountable on the package substrate by the shorten vertical edge. The sensing direction of an integrated fluxgate die is generally orthogonal to the respective vertical edge. Advantageously, the integrated fluxgate die with the shortened vertical edge provides a sensing direction that is orthogonal to the planar surface of the package substrate.

[0004] In one example implementation, an integrated fluxgate device includes a package substrate, a first integrated fluxgate die, and a second integrated fluxgate die. Both the first and second integrated fluxgate dies are mounted on the planar surface of the package substrate. The first integrated fluxgate die includes a first semiconductor substrate and a first integrated circuit formed on the first semiconductor substrate. The first integrated fluxgate die also includes a first magnetic core formed above the first integrated circuit and oriented parallel to the planar surface of the package substrate. The second integrated fluxgate includes a second semiconductor substrate and a second integrated circuit formed on the second semiconductor substrate. The second integrated fluxgate also includes a second magnetic core formed above the second integrated circuit and oriented orthogonally to the planar surface of the package substrate.

[0005] In another example implementation, an electromagnetic sensing device includes a package substrate, a first die mounted on the package substrate, and a second die mounted on the package substrate. The first die includes a first integrated circuit and a first magnetic core formed above the first integrated circuit. The first magnetic core has a first sensing axis parallel to a planar surface of the package substrate. The second die includes a second integrated circuit and a second magnetic core formed above the second integrated circuit. The second magnetic core has a second sensing axis orthogonal to the planar surface of the package substrate.

[0006] In yet another example implementation, an integrated fluxgate circuit includes a substrate, a circuit formed on the substrate, and a fluxgate formed above the circuit. The circuit includes transistors with active regions developed on the substrate, and a metal layer formed above the active regions to provide interconnections for the transistors. The fluxgate includes a first magnetic core segment formed above the metal layer, a second magnetic core segment aligned in parallel with the first magnetic core segment, and a coil coiling around the first and second magnetic core segment to establish an aggregated magnetic core.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 shows a cross sectional side view of an electromagnetic sensing device according to one aspect.

[0008] FIG. 2 shows a partially exposed perspective view of the electromagnetic sensing device according to another aspect.

[0009] FIG. 3 shows a top view of a three-dimensional (3D) electromagnetic sensing device according to one aspect.

[0010] FIG. 4 shows a top view of another 3D electromagnetic sensing device according to another aspect.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0011] Like reference symbols in the various drawings indicate like elements. The figures are not drawn to scale.

[0012] Example embodiments include a 3D sensing fluxgate device that can be fabricated using a low-cost and high-yield process that is integratable with one or more control circuits.

[0013] According to one aspect, an integrated fluxgate device is built on a semiconductor die using the same fabrication process flow as an integrated circuit formed in the same die. As a result, the integrated fluxgate device may include one or more magnetic core structures for sensing magnetic flux in two orthogonally arranged sensing axes (e.g., X-axis and Y-axis). After the integrated fluxgate die is fabricated, it can be mounted on a package substrate. The orthogonally arranged sensing axes are usually parallel to a planar surface of the package substrate. To implement three-dimensional (3D) electromagnetic sensing, a third sensing axis (e.g., Z-axis) can be added such that it is orthogonal to a plane defined by the other two orthogonally arranged sensing axes (e.g., the X-Y plane). However, the third orthogonal sensing axis usually is added on a second package substrate because the planar surface of the first package substrate may only retain two orthogonally arranged sensing axes. As a result, the additional package substrate may render 3D sensing too space-inefficient for some compact applications. Example embodiments provide a specific solution for adding a third orthogonal sensing axis within a single package platform to facilitate space-efficient 3D sensing.

[0014] FIG. 1 shows a cross sectional side view of an electromagnetic sensing device 100 according to one aspect. The electromagnetic sensing device 100 includes a package substrate 102, a first integrated fluxgate die 110, and a second integrated fluxgate die 150. The package substrate 102 has a planar surface 103 on which a first die attach platform 108 and a second die attach platform 109 are formed. The first die attach platform 108 is configured to receive and affix the first integrated fluxgate die 110 to the package substrate 102. Likewise, the second die attach platform 109 is configured to receive and affix the second integrated fluxgate die 150 to the package substrate 102. Each of the first and second die attach platforms 108 and 109 may include an epoxy material for receiving and affixing the first and second integrated fluxgate dies 110 and 150.

[0015] The first integrated fluxgate die 110 is mounted on the planar surface 103 of the package substrate 102 via the first die attach platform 108. The first integrated fluxgate die 110 is electrically coupled to the package substrate 102 via one or more first bonding wires 105 and first solder structures 104. More specifically, the first solder structures 104 are formed on the planar surface 103 of the package substrate 102, and the first solder structures 104 are electrically coupled to the wiring structures embedded in the package substrate 102. The first bonding wires 105 electrically connect the first integrated fluxgate die 110 to the first solder structures 104, thereby allowing the first integrated fluxgate die 110 to be electrically coupled to the package substrate 102.

[0016] The first integrated fluxgate die 110 includes a first integrated fluxgate circuit, which integrates a first sensor circuit with a first fluxgate device on a single semiconductor die. The first integrated fluxgate die 110 includes a first semiconductor substrate 112, a circuit layer 114 formed on the first semiconductor substrate 112, and a fluxgate layer 116 formed on the circuit layer 114. The first semiconductor substrate 112 includes one or more transistor active regions 113, on which several transistor devices are formed. The circuit layer 114 includes one or more conductive wiring layers (e.g., polysilicon and/or metal wiring layers) for interconnecting the transistor devices formed within the transistor active regions 113. Together, the circuit layer 114 and the transistor active regions 113 form a first integrated circuit 111, which is configured to perform one or more sensing operations of the first fluxgate device formed in the fluxgate layer 116.

[0017] The first integrated fluxgate circuit embodied in the first integrated fluxgate die 110 includes inter-device connection structures for connecting the first integrated circuit 111 with the first fluxgate device formed in the fluxgate layer 116. In one implementation, the first integrated fluxgate die 110 includes lower vias 121, lower interconnect metal layers 122, upper vias 123, and upper interconnect metal layers 124. The first integrated circuit 111 can be connected to the first fluxgate device (e.g., 116) using the lower vias 121 and the lower interconnect metal layers 122. Moreover, an external circuitry (e.g., the package substrate 102 and the second integrated fluxgate die 150) may communicate with the first integrated circuit 111 via one or more first bond pads 125, which are electrically coupled to the upper interconnect metal layers 124, then to the upper vias 123, and then to the lower interconnect metal layers 122 and the lower vias 121.

[0018] Formed in the fluxgate layer 116, the first fluxgate device includes a first magnetic core 130. The first magnetic core 130 is thus positioned above the first integrated circuit 111, and the first magnetic core 130 is oriented parallel to the planar surface 103 of the package substrate 102. Accordingly, the first magnetic core 130 has a first sensing axis 132 that is parallel to the planar surface 103 of the package substrate 102. The first integrated circuit 111 includes one or more sensor circuits for calibrating and controlling the operations of the first magnetic core 130. As a result, the first integrated fluxgate circuit embodied in the first integrated fluxgate die 110 may sense a magnetic field that is parallel to the planar surface 103 of the package substrate 102.

[0019] The second integrated fluxgate die 150 is laterally (or vertically) mounted on the planar surface 103 of the package substrate 102 via the second die attach platform 109. The second integrated fluxgate die 150 is electrically coupled to the package substrate 102 via one or more second bonding wires 107 and second solder structures 106. More specifically, the second solder structures 106 are formed on the planar surface 103 of the package substrate 102, and the second solder structures 106 are electrically coupled to the wiring structures embedded in the package substrate 102. The second bonding wires 107 electrically connect the second integrated fluxgate die 150 to the second solder structures 106, thereby allowing the second integrated fluxgate die 150 to be electrically coupled to the package substrate 102. Accordingly, the second integrated fluxgate die 150 can establish a connection with the first integrated fluxgate die 110 via the package substrate 102.

[0020] The second integrated fluxgate die 150 includes a second integrated fluxgate circuit, which integrates a second sensor circuit with a second fluxgate device on a single semiconductor die. The second integrated fluxgate die 150 includes a second semiconductor substrate 152, a circuit layer 154 formed on the second semiconductor substrate 152, and a fluxgate layer 156 formed on the circuit layer 154. The second semiconductor substrate 152 includes one or more transistor active regions 153, on which several transistor devices are formed. The circuit layer 154 includes one or more conductive wiring layers (e.g., polysilicon and/or metal wiring layers) for interconnecting the transistor devices formed within the transistor active regions 153. Together, the circuit layer 154 and the transistor active regions 153 form a second integrated circuit 151, which is configured to perform one or more sensing operations of the second fluxgate device formed in the fluxgate layer 156.

[0021] The second integrated fluxgate circuit embodied in the second integrated fluxgate die 150 includes inter-device connection structures for connecting the second integrated circuit 151 with the second fluxgate device formed in the fluxgate layer 156. In one implementation, the second integrated fluxgate die 150 includes lower vias 161, lower interconnect metal layers 162, upper vias 163, and upper interconnect metal layers 164. The second integrated circuit 151 can be connected to the second fluxgate device (e.g., 156) using the lower vias 161 and the lower interconnect metal layers 162. Moreover, an external circuitry (e.g., the package substrate 102 and the first integrated fluxgate die 110) may communicate with the second integrated circuit 151 via one or more second bond pads 165, which are electrically coupled to the upper interconnect metal layers 164, then to the upper vias 163, and then to the lower interconnect metal layers 162 and the lower vias 161.

[0022] Formed in the fluxgate layer 156, the second fluxgate device includes a second magnetic core 170. The second magnetic core 170 is thus positioned above the second integrated circuit 151, and the second magnetic core 170 is oriented orthogonal to the planar surface 103 of the package substrate 102. Accordingly, the second magnetic core 170 has a second sensing axis 172 that is orthogonal to the planar surface 103 of the package substrate 102 and to the first sensing axis 132. The second integrated circuit 151 includes one or more sensor circuits for calibrating and controlling the operations of the second magnetic core 170. Alternatively, one or more sensor circuits in the first integrated circuit 111 may calibrate and control the operations of the second magnetic core 170 via the connection established by the package substrate 102. In either case, the second integrated fluxgate circuit embodied in the second integrated fluxgate die 150 may sense a magnetic field that is orthogonal to the planar surface 103 of the package substrate 102.

[0023] Together, the first and second integrated fluxgate circuits (e.g., 110 and 150) can be configured to sense a magnetic field in two orthogonally arranged axes (e.g., 132 and 172). One of these two axes is parallel to the planar surface 103, while the other one of the these two axes is orthogonal to the planar surface 103. In one implementation, each of the first and second integrated fluxgate circuits (e.g., 110 and 150) may independently control the sensing along each sensing axis. For example, the first integrated circuit 111 can be configured to generate a first excitation signal, and the second integrated circuit 151 can be configured to generate a second excitation signal independent of the first excitation signal. Then, the first magnetic core 130 is configured to sense a first magnetic field along the first sensing axis 132 in response to the first excitation signal. Separately, the second magnetic core 170 is configured to sense a second magnetic field along the second sensing axis 152 in response to the second excitation signal.

[0024] In another implementation, the first and second integrated fluxgate circuits (e.g., 110 and 150) may be commonly controlled for sensing a magnetic field in both sensing axes (e.g., 132 and 172). For example, either one of the first integrated circuit 111 or the second integrated circuit 151 can be configured to generate a first excitation signal. Then, the first magnetic core 130 is configured to sense a first magnetic field along the first sensing axis 132 in response to the first excitation signal. In a similar way, the second magnetic core 170 is configured to sense a second magnetic field along the second sensing axis 152 in response to the first excitation signal.

[0025] To enable 3D sensing, a third magnetic core (see, e.g., a third magnetic core 352 as shown in FIGS. 3 and 4) can be added to the electromagnetic sensing device 100. The third magnetic core has a third sensing axis (see, e.g., a third sensing axis 358 as shown in FIGS. 3 and 4), and it is so arranged that the third sensing axis is orthogonal to both the first and second sensing axes (e.g., 132 and 172). That way, the first and third sensing axes form a first sensing plane (e.g., an X-Y plane), the first and second sensing axes form a second sensing plane (e.g., an X-Z plane), and the third and second sensing axes form a third sensing plane (e.g., a Y-Z plane).

[0026] Because the second magnetic core 172 is arranged at a vertical position with respect to the package substrate 102, the third magnetic core can be arranged at a horizontal position with respect to the package substrate 102. Accordingly, the arrangement of the third magnetic core can be similar to the arrangement of the first magnetic core 130. Indeed, the third magnetic core can be integrated to the first integrated fluxgate die 110 according to one aspect (see, e.g., FIG. 4). However, to simplify the fabrication process of the first integrated fluxgate die 110, the third magnetic core can be implemented by a third integrated fluxgate die according to another aspect (see, e.g., FIG. 3). In either case, example embodiments provide a space-efficient and low cost solution for performing 3D electromagnetic sensing using a single package platform.

[0027] The first integrated fluxgate die 110 usually has a first attachment base width 144 and a first height 142. Meanwhile, the second integrated fluxgate die 150 has a second attachment base width 184 that is commensurate with the first height 142, and a second height 182 that is less than the first attachment base width 144. In one example implementation, the second height 182 can be less than a half of the first attachment base width 144. In another example implementation, the second height 182 can be less than one-third of the first attachment base width 144. Thus, the lateral dimension of the second integrated fluxgate die 150 can be less than the lateral dimension of the first integrated fluxgate die 110. With this dimensional relationship, the second integrated fluxgate die 150 can be mounted laterally (i.e., flipped up) without significantly increasing the vertical size of the overall package.

[0028] FIG. 2 shows a partially exposed perspective view of the electromagnetic sensing device 100 taken from a cross-section A as indicated in FIG. 1. The second integrated fluxgate die 150 has a vertical edge 202, a first horizontal edge 204, and a second horizontal edge 206. The vertical edge 202 is defined along a direction in which the second integrated fluxgate circuit is formed, and thus, the vertical edge 202 is perpendicular to a top surface 181 and a bottom surface 183 of the second integrated fluxgate die 150. Accordingly, the dimension of the vertical edge 202 corresponds to a thickness of the second integrated fluxgate die 150.

[0029] The first horizontal edge 204 and the second horizontal edge 206 are parallel to the top surface 181 and bottom surface 183 of the second integrated fluxgate die 150. The first horizontal edge 204 defines a direction that is perpendicular to the second sensing axis 172, whereas the second horizontal edge 206 defines a direction that is parallel to the second sensing axis 172. Generally, the first horizontal edge 204 is longer than the second horizontal edge 206. Unlike the first integrated fluxgate die 110, which is mounted horizontally to the package substrate 102, the second integrated fluxgate die 150 is mounted laterally to the package substrate 102. Accordingly, the vertical edge 202 and the first horizontal edge 204 define a mountable surface 208, along which the second integrated fluxgate die 150 is mounted to the package substrate 102. Moreover, unlike the first integrated fluxgate die 110, the second integrated fluxgate die 150 has the second horizontal edge 206 oriented orthogonal to the planar surface 103 of the package substrate 102.

[0030] To achieve a space-efficient package arrangement of the electromagnetic sensing device 100, the vertical edge 202, the first horizontal edge 204, and the second horizontal edge 206 may each adopt a dimensional relationship. The vertical edge 202 has a first base width 184. The first horizontal edge 204 has a second base width 186. The second horizontal edge 206 has a height 182. In one implementation, the height 182 is greater than the first base width 184 but less than three times of the first base width 184. For example, when the first base width is 0.4 mm, the height may be less than 1.2 mm. In another implementation, the height 182 may be less than 1 mm such that the second integrated fluxgate die 150 can be fitted within a 1 mm tall package.

[0031] According to one aspect, the second magnetic core 170 is configured to have a sensitivity that is commensurate with that of the first magnetic core 130. Accordingly, the hard magnetic axis of the second magnetic core 170 has an aggregated length that is commensurate with that of the hard magnetic axis of the first magnetic core 130. However, the dimensions of the second magnetic core 170 is limited by the height 182 of the second integrated fluxgate die 150 because the second sensing axis 172 is oriented orthogonal to the planar surface 103 of the package substrate 102. To that end, the second magnetic core 170 may adopt a different configuration than the first magnetic core 130.

[0032] In one example implementation, the second magnetic core 170 can be severed into multiple magnetic core segments. These magnetic core segments are aligned in parallel with each other and orthogonal to the vertical edge 202 of the second integrated fluxgate die 150. Each of these magnetic core segments has a segment length. When combined, the aggregated segment length of the magnetic core segments roughly equals or greater than a contiguous length of the first magnetic core 130. The segment length may be equally distributed among the magnetic core segments. Alternatively, one magnetic core segment may have a different segment length than another magnetic core segment.

[0033] As an example, the second magnetic core 170 may include a first magnetic core segment 210, a second magnetic core segment 230, and a third magnetic core segment 250. Each of the first, second and third magnetic core segments 210, 230 and 250 is formed above, and insulated from, the lower interconnect mater layers 122 as shown in FIG. 1. Thus, the magnetic core segments 210, 230 and 250 is free of interference from the second integrated circuit 151 positioned thereunder. As shown in FIG. 2, the first, second and third magnetic core segments 210, 230 and 250 are aligned parallel with each other. Each of the first, second and third magnetic core segments 210, 230 and 250 is aligned orthogonal to the vertical edge 202 and parallel to the first and second horizontal edges 204 and 206. When an electromagnetic coupling is established, the first, second and third magnetic core segments 210, 230 and 250 function as a single magnetic core.

[0034] In combination, the first, second and third magnetic core segments 210, 230 and 250 have an aggregated core length that is commensurate with the contiguous core length of the first magnetic core 130 to retain a similar sensitivity as the first magnetic core 130. In one implementation, the aggregated core length of the second magnetic core 170 can be substantially the same as the contiguous core length of the first magnetic core 130. Thus, where the contiguous core length of the first magnetic core 130 is 1 mm, the aggregated core length of the second magnetic core 170 can be 1 mm with a 10% deviation. In another implementation, the aggregated core length of the second magnetic core 170 can be greater than the contiguous core length of the first magnetic core 130. Thus, where the contiguous core length of the first magnetic core 130 is 1 mm, the aggregated core length of the second magnetic core 170 can be 1.2 mm with a 10% deviation.

[0035] The aggregated core length can be distributed evenly among the magnetic core segments. In one example configuration, the first magnetic core segment 210 has a first segment core length 221 that is equal to a second segment core length 241 of the second magnetic core segment 230 and a third segment core length 261 of the third magnetic core segment 250. Together, the first, second and third segment core lengths 221, 241 and 261 define the aggregated core length. Each of first, second and third segment core lengths 221, 241 and 261 can be approximately one-third of the contiguous core length of the first magnetic core 130. Thus, where the contiguous core length of the first magnetic core 130 ranges from 1 mm to 2 mm, each of the first, second and third segment core lengths 221, 241 and 261 may range from 0.3 mm to 0.7 mm.

[0036] According to one aspect, an electromagnetic coupling can be established between the first, second and third core segments 210, 230 and 250 to form an aggregated magnetic core 170. More specifically, the electromagnetic coupling can be established by a contiguous coil including multiple coil segments. In one example implementation, the second integrated fluxgate die 150 includes a contiguous coil encompassing a first coil segment 215, a second coil segment 235, and a third coil segment 255. The first, second and third coil segments 215, 235 and 255 are formed within the fluxgate layer 156 (see FIG. 1), and they are connected by conducting wires of an interconnect metal layer, such as the upper interconnect metal layers 164.

[0037] The first coil segment 215 coils around the first magnetic core segment 210. The first coil segment 215 includes first top coil members 213 and first bottom coil members 214. The first top coil members 213 can be formed in one of the upper interconnect metal layers 164, whereas the first bottom coil members 214 can be formed below the first top coil members 213. The first top coil members 213 are connected to the first bottom coil members 214 by the upper vias 163 (see FIG. 1) to form the coil rings in the first coil segment 215. The first coil segment 215 is connected to the second coil segment 235 using a wire structure formed in one of the upper interconnect metal layers 164. In one implementation, the first coil segment 215 can be connected to the second coil segment 235 using a wiring structure in the same metal layer of the first top coil members 213. In another implementation, the first coil segment 215 can be connected to the second coil segment 235 using a wiring structure in the same metal layer of the first bottom coil members 214.

[0038] The second coil segment 235 coils around the second magnetic core segment 230. The second coil segment 235 includes second top coil members 233 and second bottom coil members 234. The second top coil members 233 can be formed in one of the upper interconnect metal layers 164, whereas the second bottom coil members 234 can be formed below the second top coil members 233. The second top coil members 233 are connected to the second bottom coil members 234 by the upper vias 163 (see FIG. 1) to form the coil rings in the second coil segment 235. The second coil segment 235 is connected to the third coil segment 255 using a wire structure formed in one of the upper interconnect metal layers 164. In one implementation, the second coil segment 235 can be connected to the third coil segment 255 using a wiring structure in the same metal layer of the second top coil members 233. In another implementation, the second coil segment 235 can be connected to the third coil segment 255 using a wiring structure in the same metal layer of the second bottom coil members 234.

[0039] The third coil segment 255 coils around the third magnetic core segment 250. The third coil segment 255 includes third top coil members 253 and third bottom coil members 254. The third top coil members 253 can be formed in one of the upper interconnect metal layers 164, whereas the third bottom coil members 254 can be formed below the third top coil members 253. The third top coil members 253 are connected to the third bottom coil members 254 by the upper vias 163 (see FIG. 1) to form the coil rings in the third coil segment 255. When the coil segments 215, 235 and 255 are activated, the magnetic core segment 210, 230 and 250 are configured to sense a magnetic field in the second sensing axis 172.

[0040] Although FIG. 2 shows a single coil coiling around the first, second and third magnetic core segments 210, 230 and 250, multiple coils can be added to coil around these core segments. In one example implementation, the second integrated fluxgate die 150 may include a first coil for sensing a voltage across the first, second and third magnetic core segments 210, 230 and 250, and a second coil for conducting an excitation current flowing around the first, second and third magnetic core segments 210, 230 and 250. The first and second coils may have the same structural characteristics as described hereinabove. For example, the top coil members (e.g., 213, 233, and 253) of the first and second coils can be formed in a top interconnect metal layer (e.g., 164), which is orthogonal to the vertical edge 202 and parallel to the first and second horizontal edges 204 and 206.

[0041] As described hereinabove, example embodiments provide a space-efficient and low cost solution for performing 3D electromagnetic sensing using a single package platform. To enable 3D sensing, a third magnetic core can be added to the electromagnetic sensing device 100. The third magnetic core has a third sensing axis, and it is so arranged that the third sensing axis is orthogonal to both the first and second sensing axes (see, e.g., 132 and 172 in FIG. 1). That way, the first and third sensing axes form a first sensing plane (e.g., an X-Y plane), the first and second sensing axes form a second sensing plane (e.g., an X-Z plane), and the third and second sensing axes form a third sensing plane (e.g., a Y-Z plane).

[0042] FIG. 3 shows a top view of a 3D electromagnetic sensing (EMS) device 300 according to one aspect. The 3D EMS device 300 is modified based on the electromagnetic sensing device 100 as shown and described in FIGS. 1 and 2. The 3D EMS device 300 defines three orthogonally arranged sensing axes (i.e., 318, 338, and 358) for sensing a magnetic field in three orthogonally arranged planes (e.g., the X-Y, X-Z, and Y-Z planes). Specifically, the 3D EMS device 300 includes three separate integrated fluxgate dies for activating the three orthogonally arranged sensing axes. Like the EMS device 100, the 3D EMS device 300 includes a package substrate 301 for mounting a first die 310, a second die 330, and a third die 350 on its planar surface.

[0043] The first die 310 incorporates the structure features of the first integrated fluxgate die 110 as shown and described in FIG. 1. For example, the first die 310 includes a first magnetic core 312 coiled by a first coil 314. The first magnetic core 312 has a first contiguous core length 316 that is sufficient to sense a magnetic field along a first sensing axis 318. In one example implementation, the first contiguous core length 316 may range from 0.7 mm to 2 mm. In another implementation, the first contiguous core length 316 may be 1 mm. The first sensing axis 318 is parallel to the planar surface of the package substrate 301.

[0044] The second die 330 incorporates the structure features of the second integrated fluxgate die 150 as shown and described in FIGS. 1 and 2. For example, the second die 330 includes a second magnetic core 332 formed above the a transistor active region 336 developed within a semiconductor substrate 334. The second magnetic core 332 has two or more (e.g., three) core segments, each having a segment core length. The segment core lengths can be aggregated to an aggregated core length that is sufficient to sense a magnetic field along a second sensing axis 338. In one implementation, the aggregated core length may range from 0.7 mm to 2 mm. In another implementation, the aggregated core length may be 1 mm. The second sensing axis 338 is orthogonal to the first sensing axis 318 and the planar surface of the package substrate 301.

Together, the first and second sensing axes 318 and 338 define a first sensing plane (e.g., X-Z plane) that is orthogonal to the planar surface of the package substrate 301.

[0045] Like the first die 310, the third die 350 incorporates the structure features of the first integrated fluxgate die 110 as shown and described in FIG. 1. For example, the third die 350 includes a third magnetic core 352 coiled by a third coil 354. The third magnetic core 352 has a second contiguous core length 356 that is sufficient to sense a magnetic field along a third sensing axis 358. In one example implementation, the second contiguous core length 356 may range from 0.7 mm to 2 mm. In another implementation, the second contiguous core length 356 may be 1 mm. Like the first sensing axis 318, the third sensing axis 358 is parallel to the planar surface of the package substrate 301. The third sensing axis 358 is orthogonal to the first sensing axis 318 to define a second sensing plane (e.g., the X-Y plane) therewith. The third sensing axis 358 is also orthogonal to the second sensing axis 338 to define a third sensing plane (e.g., the Y-Z plane) therewith. While the second sensing plane is parallel to the planar surface of the package substrate 301, the third sensing plane is orthogonal to the planar surface of the package substrate 301.

[0046] Each of the first, second and third dies 310, 330 and 350 may generate its own excitation signal and perform electromagnetic sensing in response to these individually generated excitation signals. Alternatively, one of the first, second and third dies 310, 330 and 350 may generate a common excitation signal, which causes each of first, second and third dies 310, 330 and 350 to perform electromagnetic sensing. Advantageously, the 3D EMS device 300 provides a space-efficient and low cost solution to perform 3D sensing on a single package substrate.

[0047] FIG. 4 shows a top view of another 3D electromagnetic sensing device 400 according to another aspect. The 3D EMS device 400 is modified based on the electromagnetic sensing device 100 as shown and described in FIGS. 1 and 2 and the 3D EMS device 300 as shown and described in FIG. 3. The 3D EMS device 400 defines three orthogonally arranged sensing axes (i.e., 318, 338, and 358) for sensing a magnetic field in three orthogonally arranged planes (e.g., the X-Y, X-Z, and Y-Z planes). Specifically, the 3D EMS device 300 includes two separate integrated fluxgate dies for activating the three orthogonally arranged sensing axes. Like the EMS device 100, the 3D EMS device 400 includes a package substrate 401 for mounting a first die 410 and a second die 330on its planar surface.

[0048] The first die 410 can be a combination of the first die 310 and the third die 350 as shown and described in FIG. 3. Specifically, the first die 410 may incorporate both the first magnetic core 312 and the third magnetic core 352 to a single die structure. Advantageously, the first die 410 in the 3D EMS device 400 provides additional space efficiency when compared to the implementation of the 3D EMS device 300.

[0049] In this description, the term “configured to” describes structural and functional characteristics of one or more tangible non-transitory components. For example, the term “configured to” can include a particular configuration that is designed or dedicated for performing a certain function. Accordingly, a device is “configured to” perform a certain function if the device includes tangible non-transitory components that can be enabled, activated or powered to perform that certain function. Also, for example, when used for describing a device, the term “configured to” does not require the device to be configurable at any given point of time.

[0050] Regarding various functions performed by components (e.g., elements, resources) described hereinabove, the terms used to describe such components are intended to correspond, unless otherwise indicated, to any component that performs the specified function of the described component (e.g., functionally equivalent), even though not structurally equivalent to the described structure. A particular feature may have been described with respect to only one of several implementations, but such feature may be combined with one or more other features of the other implementations.

[0051] Certain features that are described in this specification in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in suitable subcombinations.

[0052] Although the drawings show operations in a particular order, such operations are not required to be performed in the particular order shown or in sequential order, and not all illustrated operations are required to be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the embodiments described hereinabove do not require such separation in all embodiments.

[0053] Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

CLAIMS

What is claimed is:

1. An integrated fluxgate device, comprising:

a package substrate having a planar surface;

a first integrated fluxgate die mounted on the planar surface of the package substrate, the first integrated fluxgate die including: a first semiconductor substrate; a first integrated circuit formed on the first semiconductor substrate; and a first magnetic core formed above the first integrated circuit and oriented parallel to the planar surface of the package substrate; and

a second integrated fluxgate die mounted on the planar surface of the package substrate, the second integrated fluxgate die including: a second semiconductor substrate; a second integrated circuit formed on the second semiconductor substrate; and a second magnetic core formed above the second integrated circuit and oriented orthogonally to the planar surface of the package substrate.

2. The integrated fluxgate device of claim 1, wherein the first integrated fluxgate die includes a third magnetic core formed above the first integrated circuit and oriented parallel to the planar surface of the package substrate and orthogonally to the first and second magnetic cores.

3. The integrated fluxgate device of claim 1, further comprising:

a third integrated fluxgate die mounted on the planar surface of the package substrate, the third integrated fluxgate die including: a third semiconductor substrate; a third integrated circuit formed on the third semiconductor substrate; and a third magnetic core formed above the third integrated circuit and oriented parallel to the planar surface of the package substrate and orthogonally to the first and second magnetic cores.

4. The integrated fluxgate device of claim 1, wherein:

the second integrated fluxgate die has a vertical edge, a first horizontal edge, and a mountable surface defined by the vertical edge and the first horizontal edge; and

the second integrated fluxgate die is mounted to the package substrate by the mountable surface.

5. The integrated fluxgate device of claim 4, wherein the second integrated fluxgate die has a second horizontal edge arranged perpendicular to the first horizontal edge, the second horizontal edge having a length less than 1 mm and position orthogonally to the planar surface of

the package substrate.

6. The integrated fluxgate device of claim 4, wherein the second integrated circuit includes a top metal layer arranged orthogonally to the vertical edge and parallel to the first horizontal edge.

7. The integrated fluxgate device of claim 4, wherein the second magnetic core includes magnetic core segments aligned in parallel with each other and orthogonally to the vertical edge of the second integrated fluxgate die.

8. The integrated fluxgate device of claim 7, wherein each of the magnetic core segments has a segment length equal to or less than 0.7 mm.

9. The integrated fluxgate device of claim 7, wherein:

the first magnetic core has a contiguous core length; and

the magnetic core segments of the second magnetic core have an aggregated core length substantially the same as the contiguous core length.

10. The integrated fluxgate device of claim 7, wherein:

the first magnetic core has a contiguous core length; and

each of the magnetic core segments of the second magnetic core has a segment core length approximately one-third of the contiguous core length.

11. An electromagnetic sensing device, comprising:

a package substrate having a planar surface;

a first die mounted on the package substrate, the first die including: a first integrated circuit; and a first magnetic core formed above the first integrated circuit, and having a first sensing axis parallel to the planar surface of the package substrate; and

a second die mounted on the package substrate, the second die including:

a second integrated circuit; and

a second magnetic core formed above the second integrated circuit, and having a second sensing axis orthogonal to the planar surface of the package substrate.

12. The electromagnetic sensing device of claim 11, wherein:

the first die includes a third magnetic core formed above the first integrated circuit; and

the third magnetic core includes a third sensing axis parallel to the planar surface of the package substrate and orthogonally to the first sensing axis and the second sensing axis.

13. The electromagnetic sensing device of claim 11, further comprising:

a third die mounted on the package substrate, the third die including: a third integrated circuit; and a third magnetic core formed above the third integrated circuit, and having a third sensing axis parallel to the planar surface and orthogonal to the first sensing axis and the second sensing axis.

14. The electromagnetic sensing device of claim 11, wherein:

the first integrated circuit is configured to generate a first excitation signal; and

the first magnetic core is configured to sense a first magnetic field along the first sensing axis in response to the first excitation signal.

15. The electromagnetic sensing device of claim 14, wherein:

the second integrated circuit is configured to generate a second excitation signal; and

the second magnetic core is configured to sense a second magnetic field along the second sensing axis in response to the second excitation signal.

16. The electromagnetic sensing device of claim 14, wherein:

the second magnetic core is configured to sense a second magnetic field along the second sensing axis in response to the first excitation signal; and

the second integrated circuit is configured to measure the sensed second magnetic field in response to the first excitation signal.

17. An integrated fluxgate circuit, comprising:

a substrate;

a circuit having transistors with active regions developed on the substrate and a metal layer formed above the active regions to provide interconnections for the transistors; and

a fluxgate having: a first magnetic core segment formed above the metal layer; a second magnetic core segment formed above the metal layer, and aligned in parallel with the first magnetic core segment; and a coil coiling around the first and second magnetic core segments to establish an aggregated magnetic core.

18. The integrated fluxgate circuit of claim 17, wherein:

the first magnetic core segment has a first segment core length;

the second magnetic core segment has a second segment core length; and

the first segment core length and the second segment core length define an aggregated core length that is about or greater than 1 mm.

19. The integrated fluxgate circuit of claim 17, wherein:

the fluxgate includes a third magnetic core segment formed above the metal layer, and aligned in parallel with the first and second magnetic core segments; and

the coil coiling around the first, second and third magnetic core segments to establish the aggregated magnetic core.

20. The integrated fluxgate circuit of claim 19, wherein:

the first magnetic core segment has a first segment core length;

the second magnetic core segment has a second segment core length;

the third magnetic core segment has a third segment core length; and

the first, second and third segment core lengths define an aggregated core length that is about or greater than 1 mm.

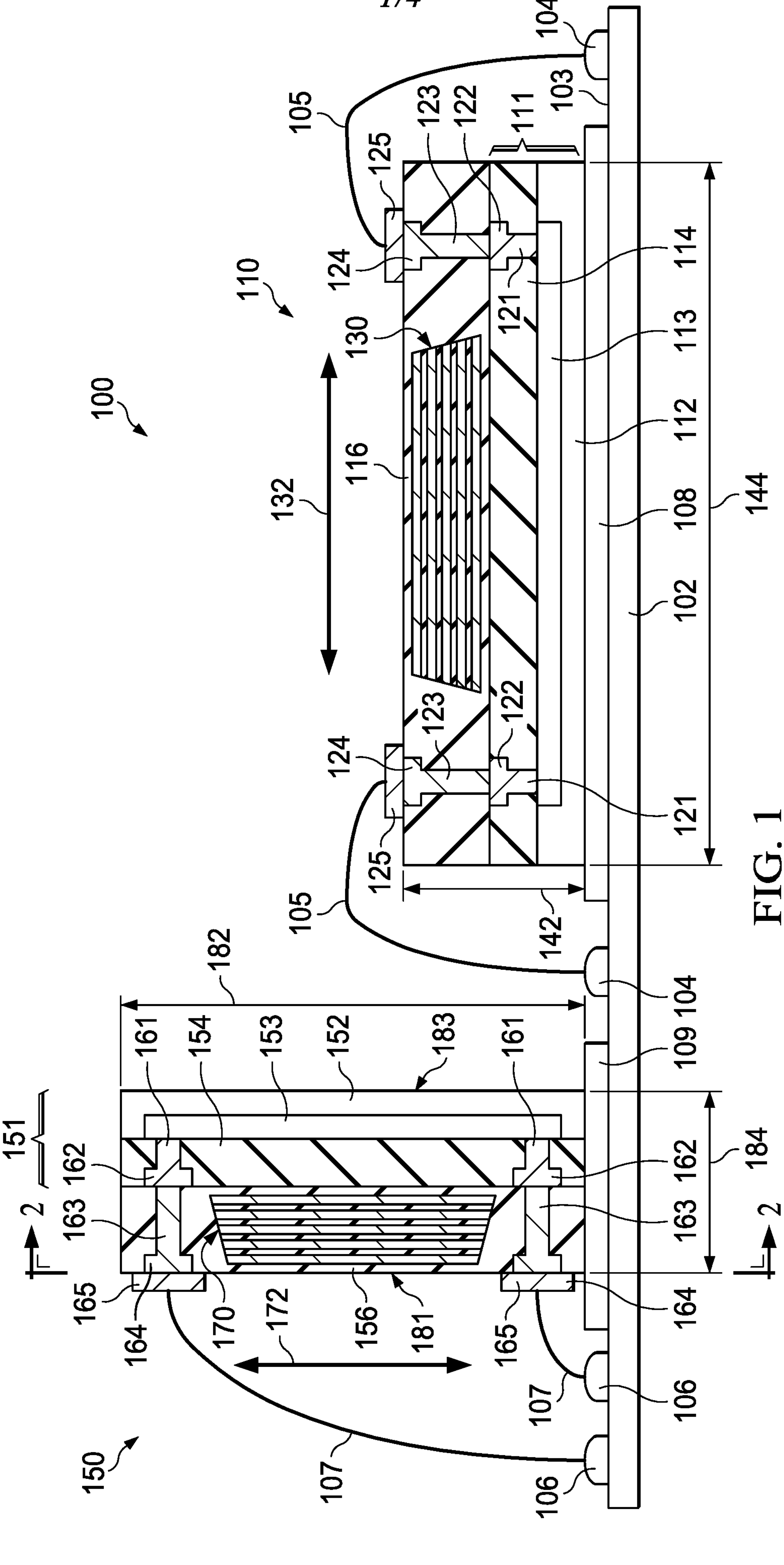
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FIG. 1

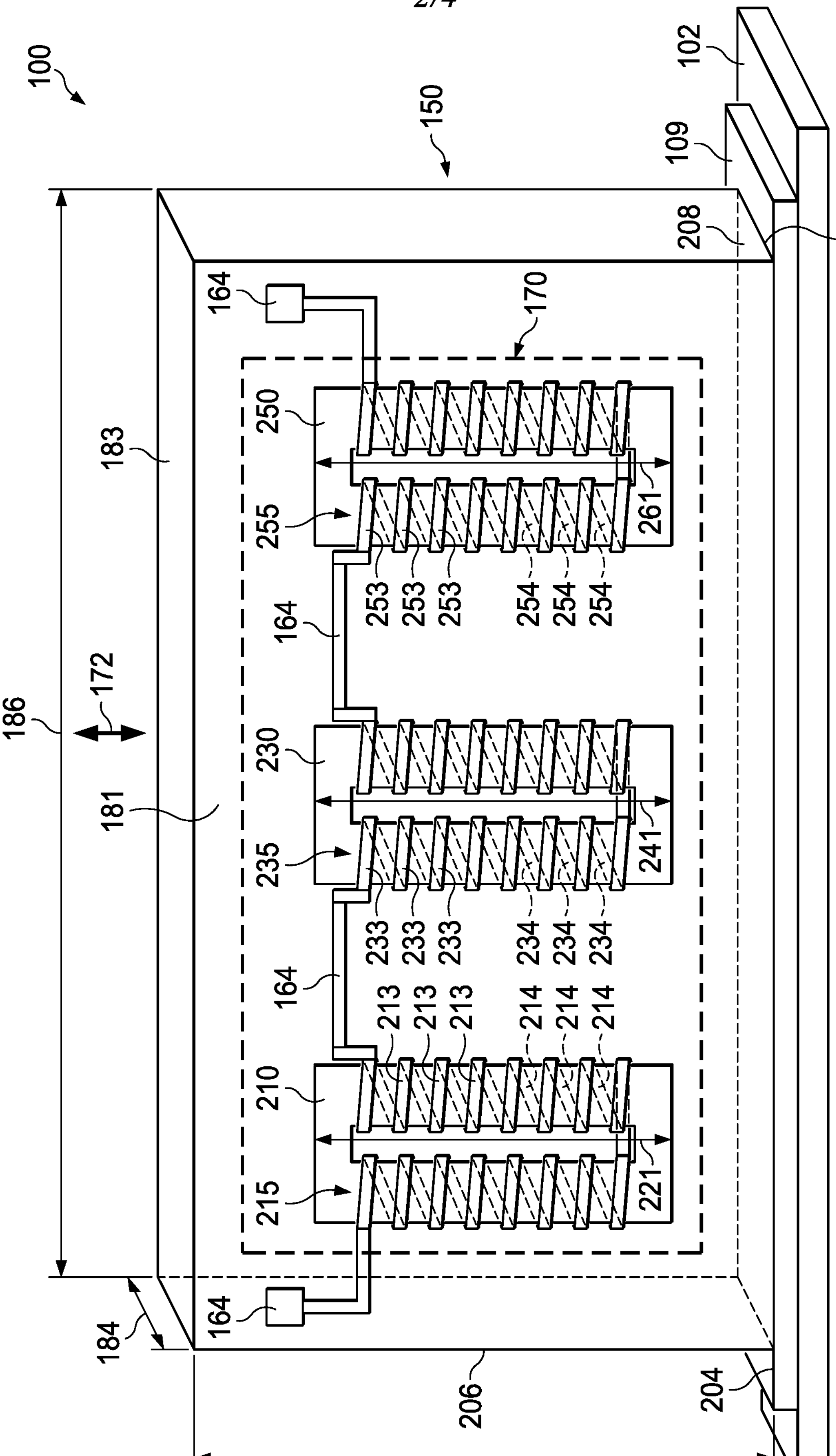
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FIG. 2

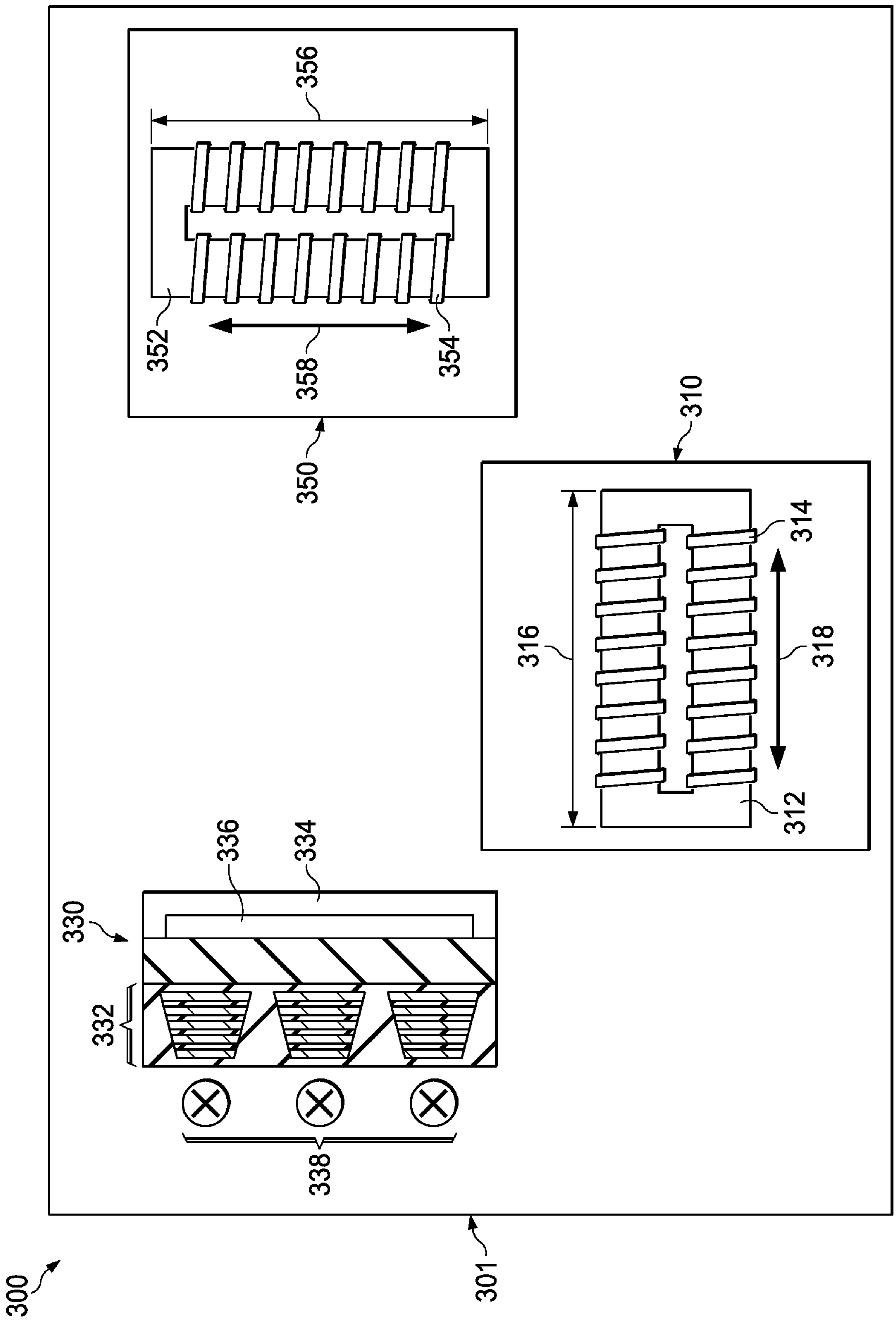
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FIG. 3

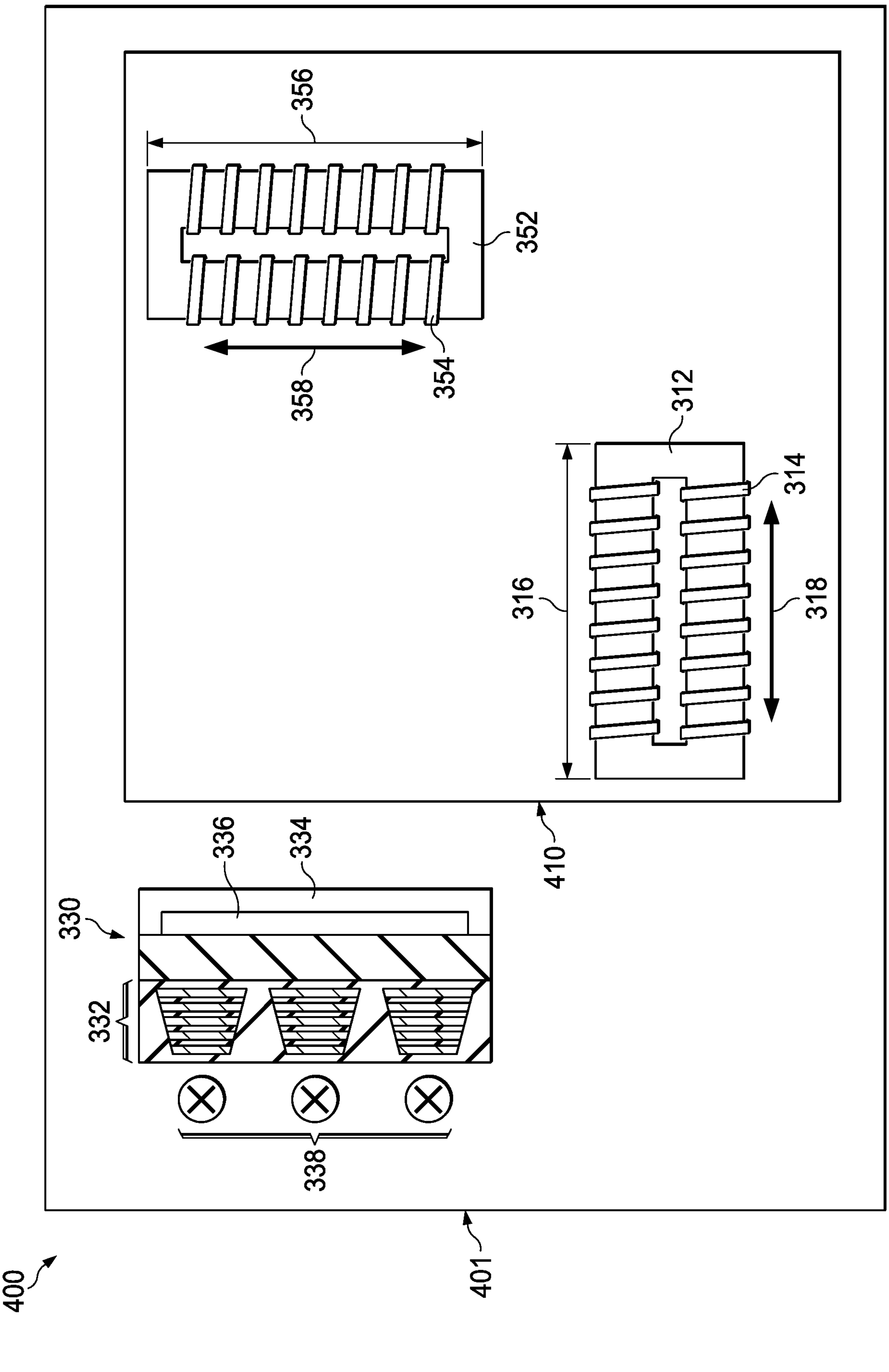

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2017/016750

A. CLASSIFICATION OF SUBJECT MATTER

H01L 43/02 *(2006.01)*
G01R 33/09 *(2006.01)*

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)

H01L 43/00, 43/02, 43/12, G01R 33/00, 33/02, 33/04, 33/06, 33/09

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)

PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE, Information Retrieval System of FIPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2015/0048820 A1 (TEXAS INSTRUMENTS INCORPORATED) 19.02.2015, [0017], fig.1, 6	17
A		1-16, 18-20
Y	WO 2009/146243 A1 (OMNIVISION TECHNOLOGIES, INC.) 03.12.2009, [0027], [0028], [0030], fig.9	17
A	US 2015/0338474 A1 (TEXAS INSTRUMENTS INCORPORATED) 26.11.2015	1-20
A	WO 2013/154440 A1 (KENNEDY, JOHN et al.) 17.10.2013	1-20
A	US 2014/0218018 A1 (TEXAS INSTRUMENTS DEUTCHLAND GMBH) 07.08.2014	1-20

[X] Further documents are listed in the continuation of Box C.

[ ] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search

10 May 2017 (10.05.2017)

Date of mailing of the international search report

18 May 2017 (18.05.2017)

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INTERNATIONAL SEARCH REPORT	International application No. PCT/US 2017/016750

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 1441234 A2 (SAMSUNG ELECTRONICS CO.LTD) 28.07.2004	1-20