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O'Brien et al.

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(54) **STACKED 2D CMOS WITH INTER METAL LAYERS**

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(58) **Field of Classification Search**

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See application file for complete search history.

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(57) **ABSTRACT**

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Embodiments disclosed herein include semiconductor devices and methods of forming such devices. In an embodiment, a semiconductor device comprises a first transistor on a first level, and a second transistor on a second level above the first level. In an embodiment, an insulating layer is between the first level and the second level, and a via passes through the insulating layer, and electrically couples the first transistor to the second transistor. In an embodiment, the first transistor and the second transistor comprise a first channel, and a second channel over the first channel. In an embodiment, the first second transistor further comprise a gate structure between the first channel and the second channel, a source contact on a first end of the first channel and the second channel, and a drain contact on a second end of the first channel and the second channel.

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(51) **Int. Cl.**

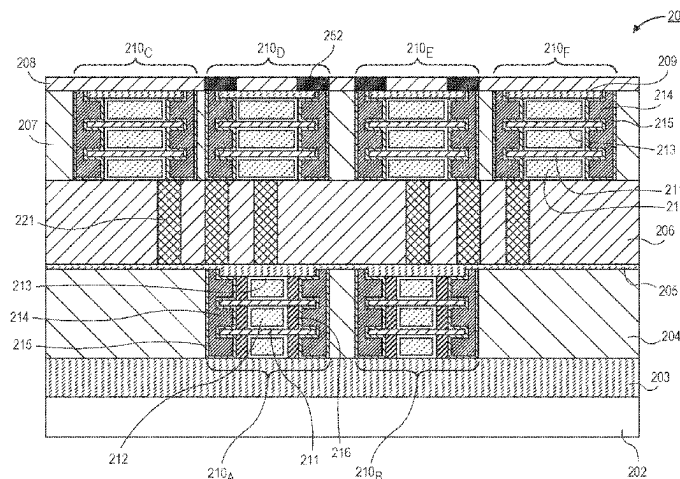
H10B 12/00 (2023.01)
H01L 23/48 (2006.01)
H10B 10/00 (2023.01)
H10D 30/67 (2025.01)
H10D 62/10 (2025.01)
H10D 64/23 (2025.01)

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

CPC **H10D 84/85** (2025.01); **H01L 23/481** (2013.01); **H10B 10/125** (2023.02); **H10D 30/6713** (2025.01); **H10D 30/6729** (2025.01);

19 Claims, 18 Drawing Sheets



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H10D 84/85 (2025.01)
H10D 88/00 (2025.01)

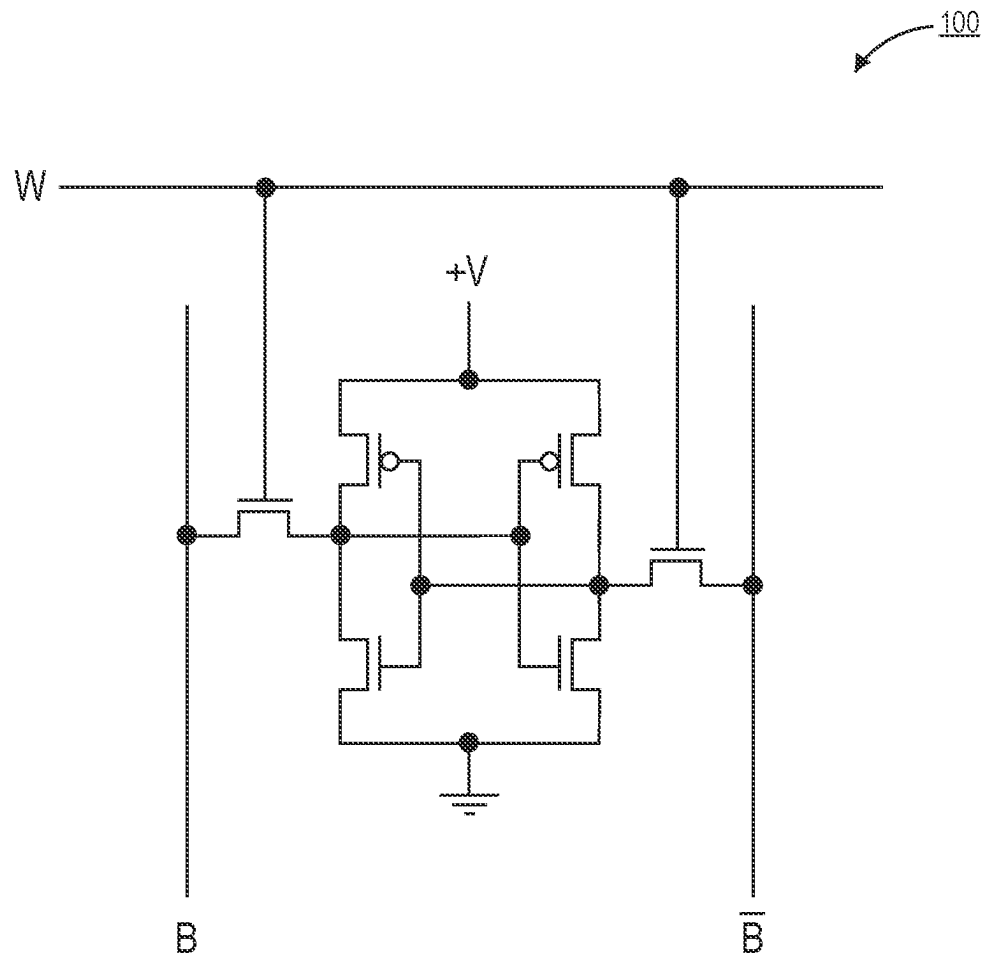
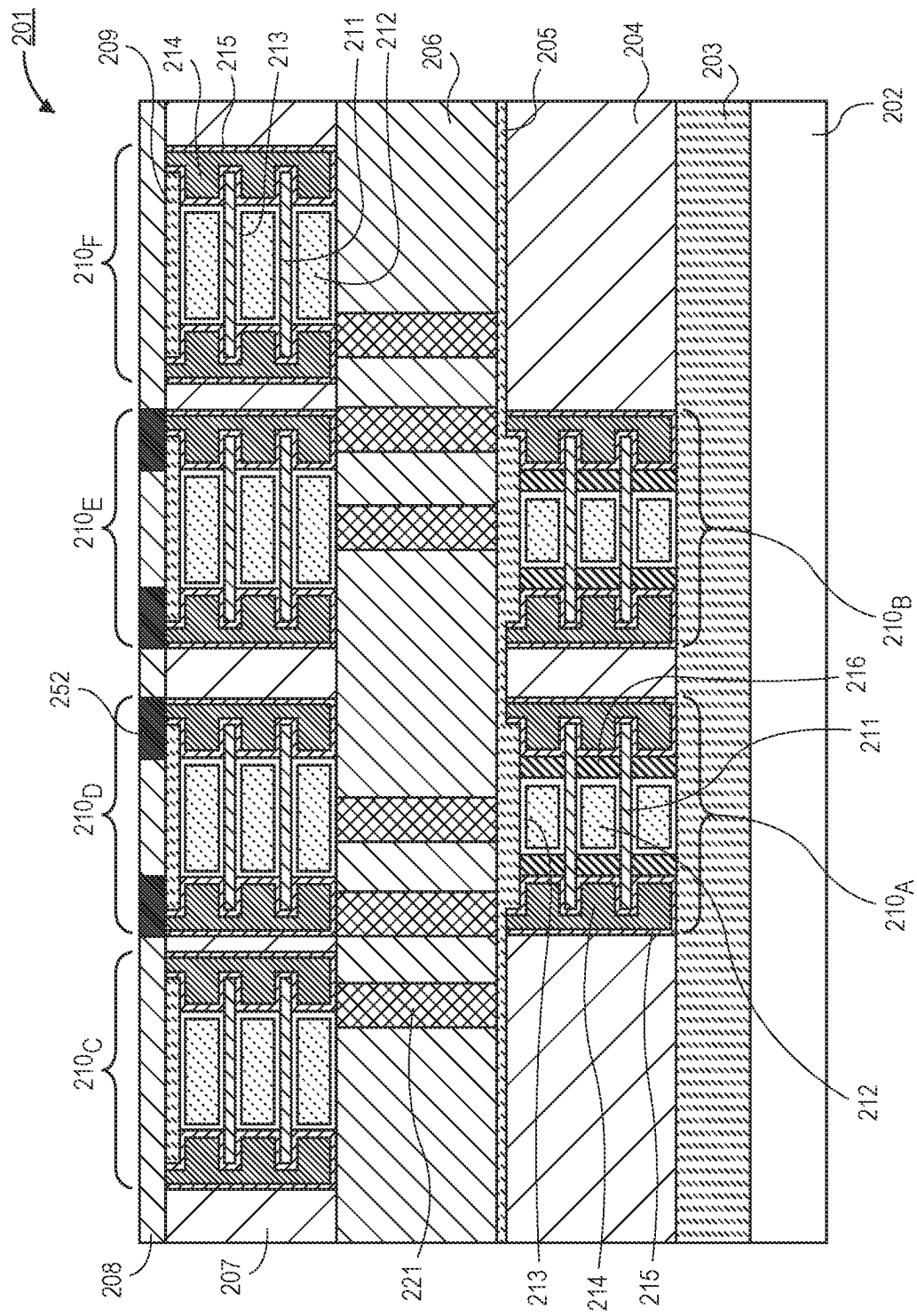


FIG. 1

2. **Ge**

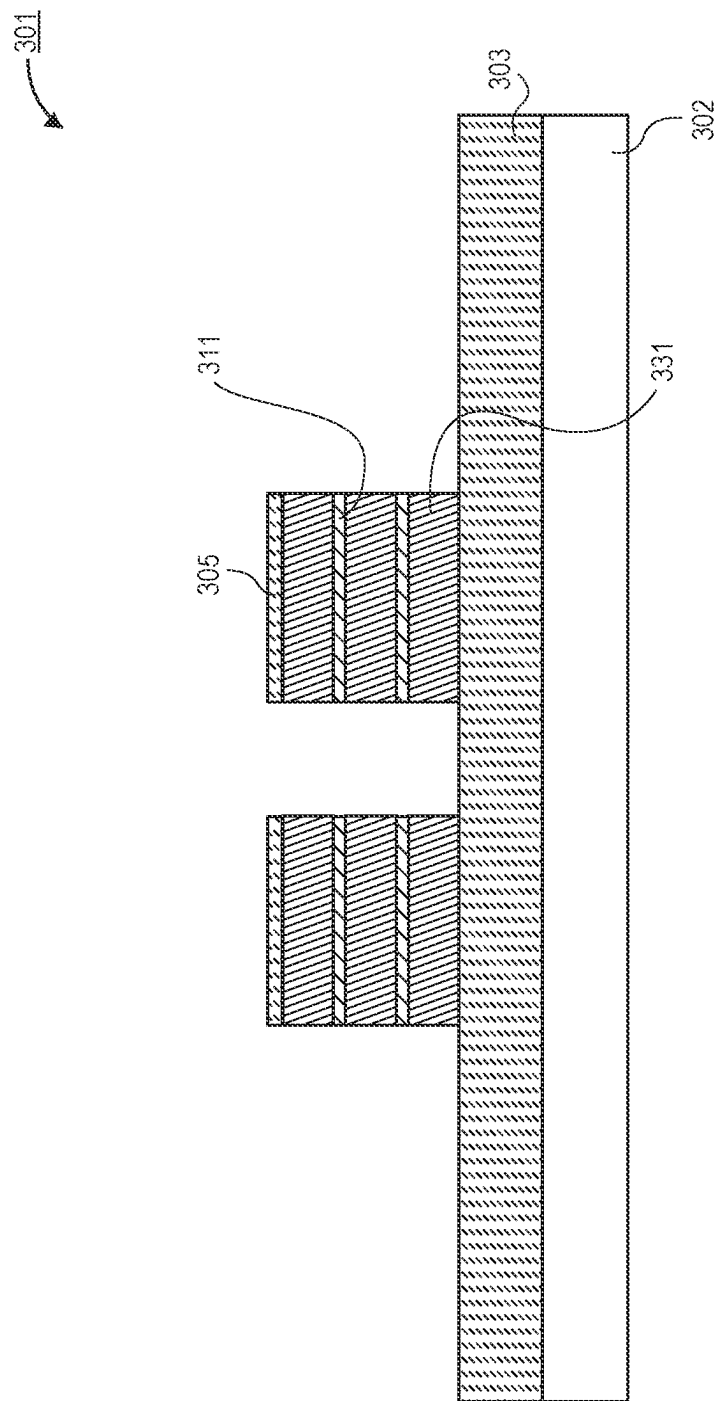


FIG. 3A

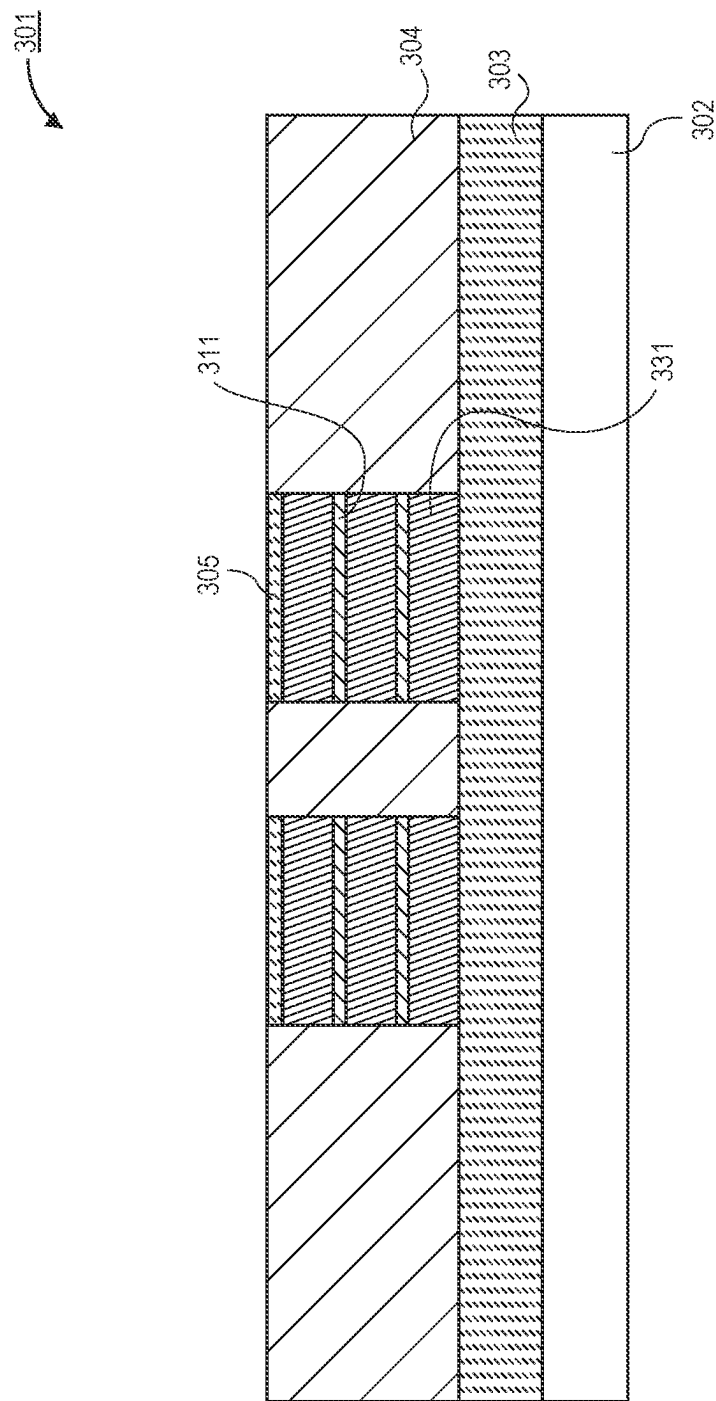


FIG. 3B

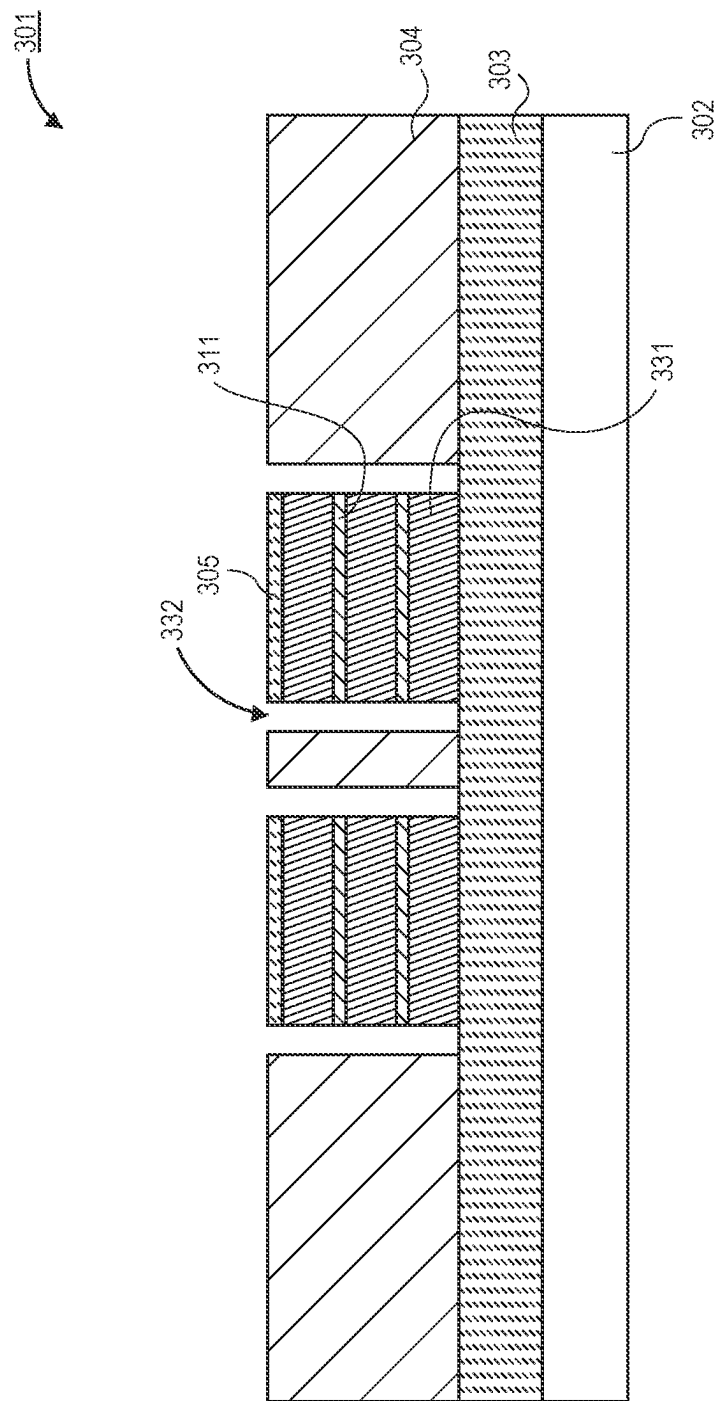


FIG. 3C

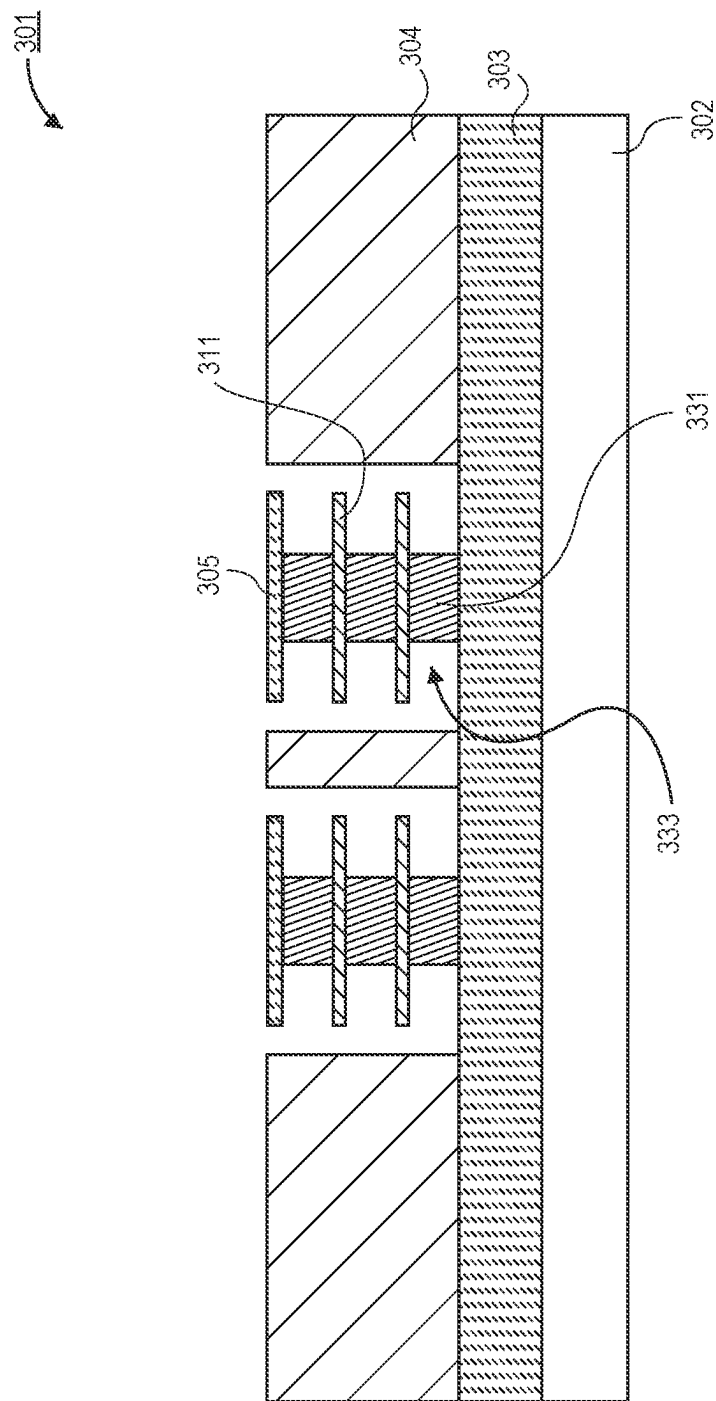
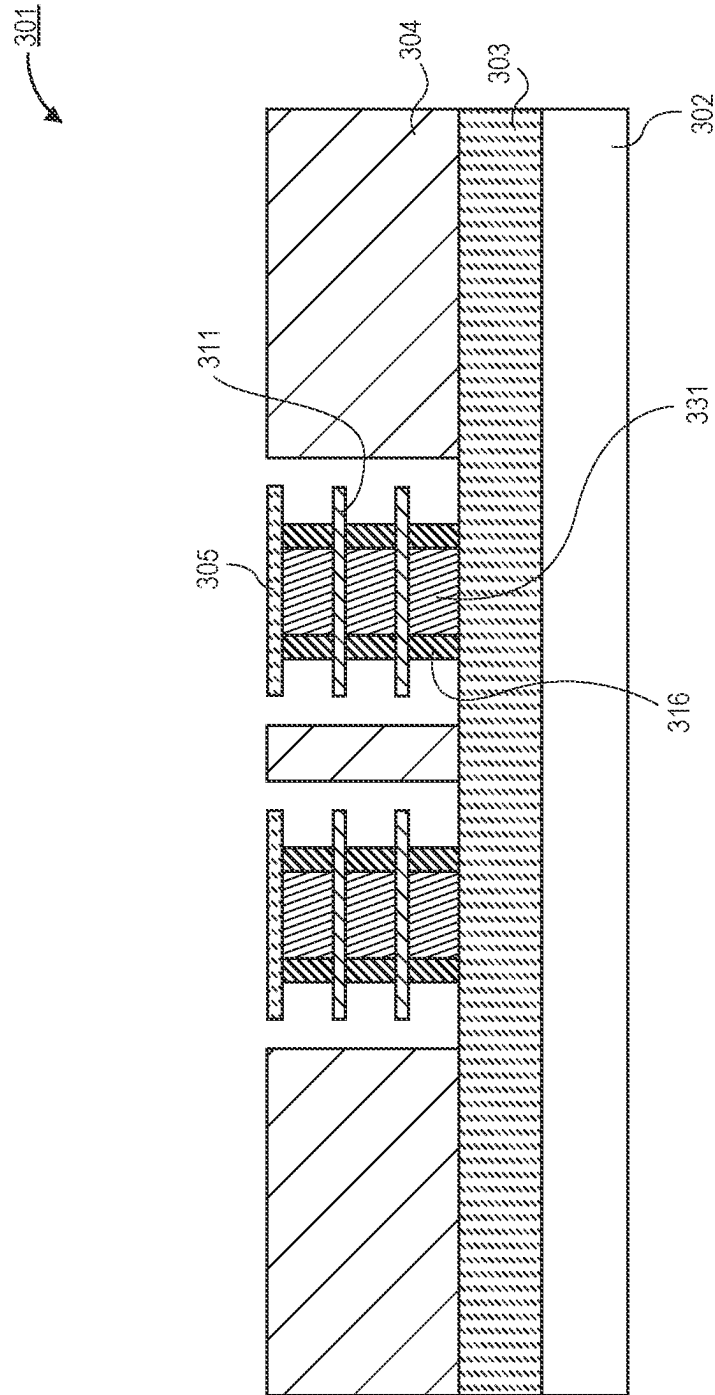


FIG. 3D



W
3
G^s
—
L

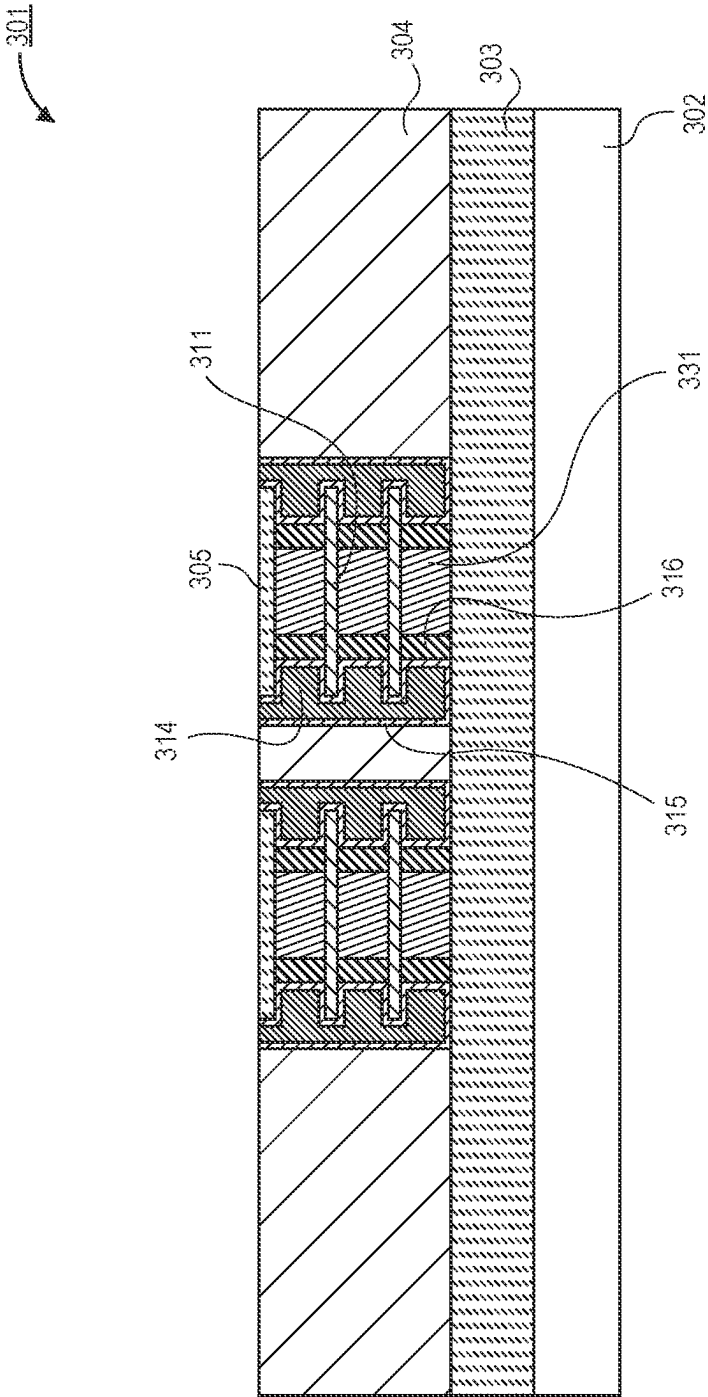


FIG. 3F

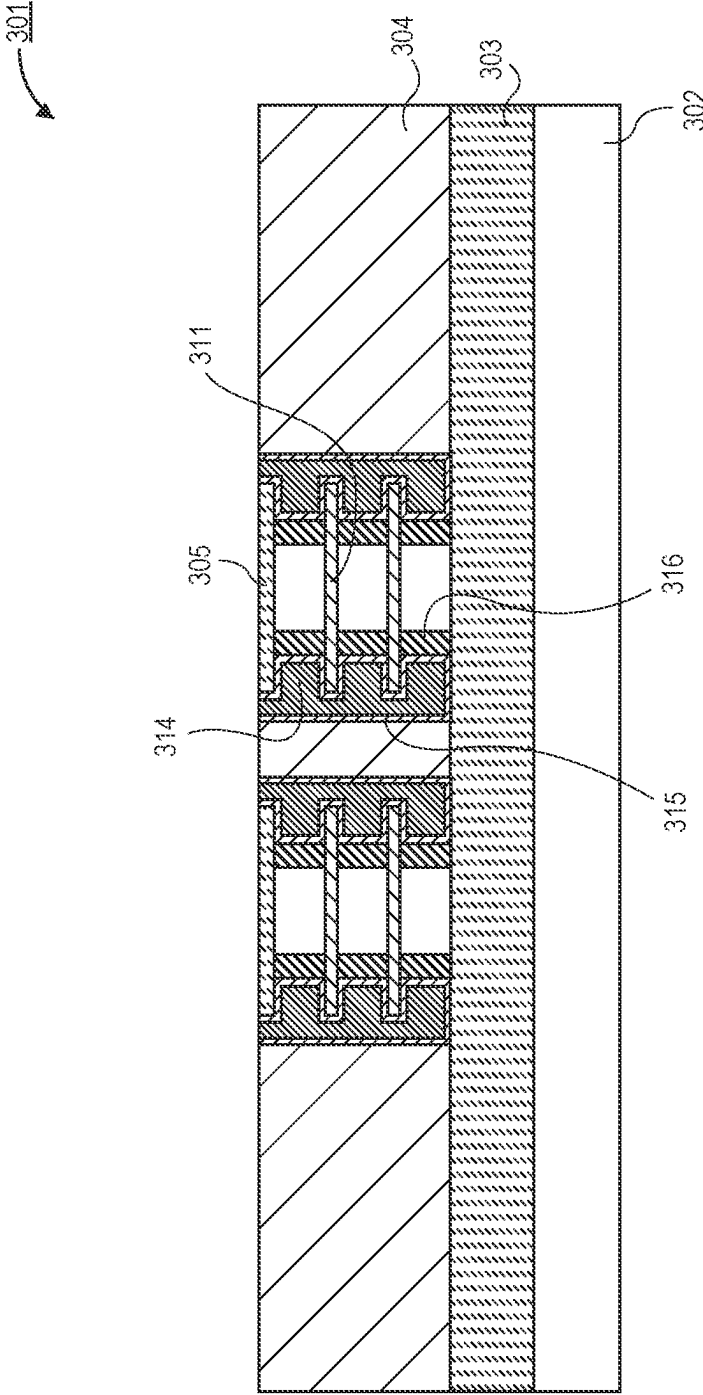


FIG. 3G

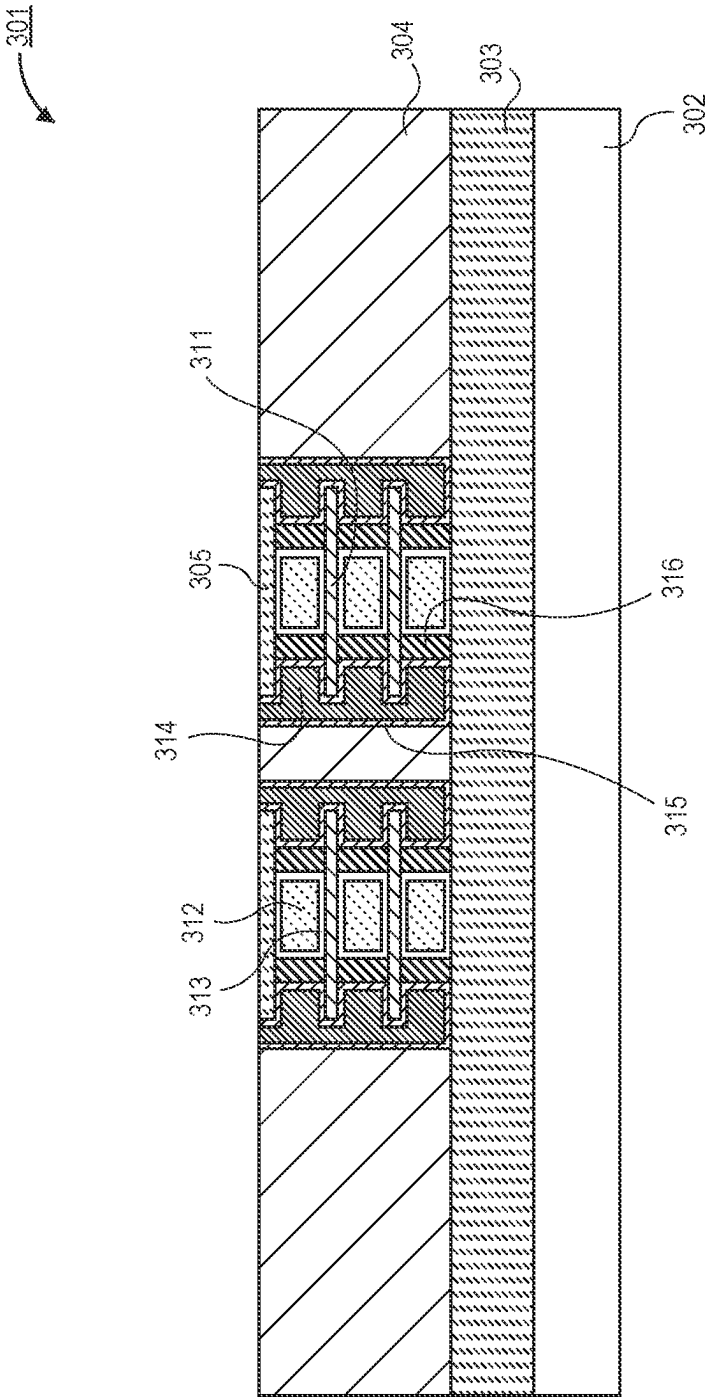


FIG. 3H

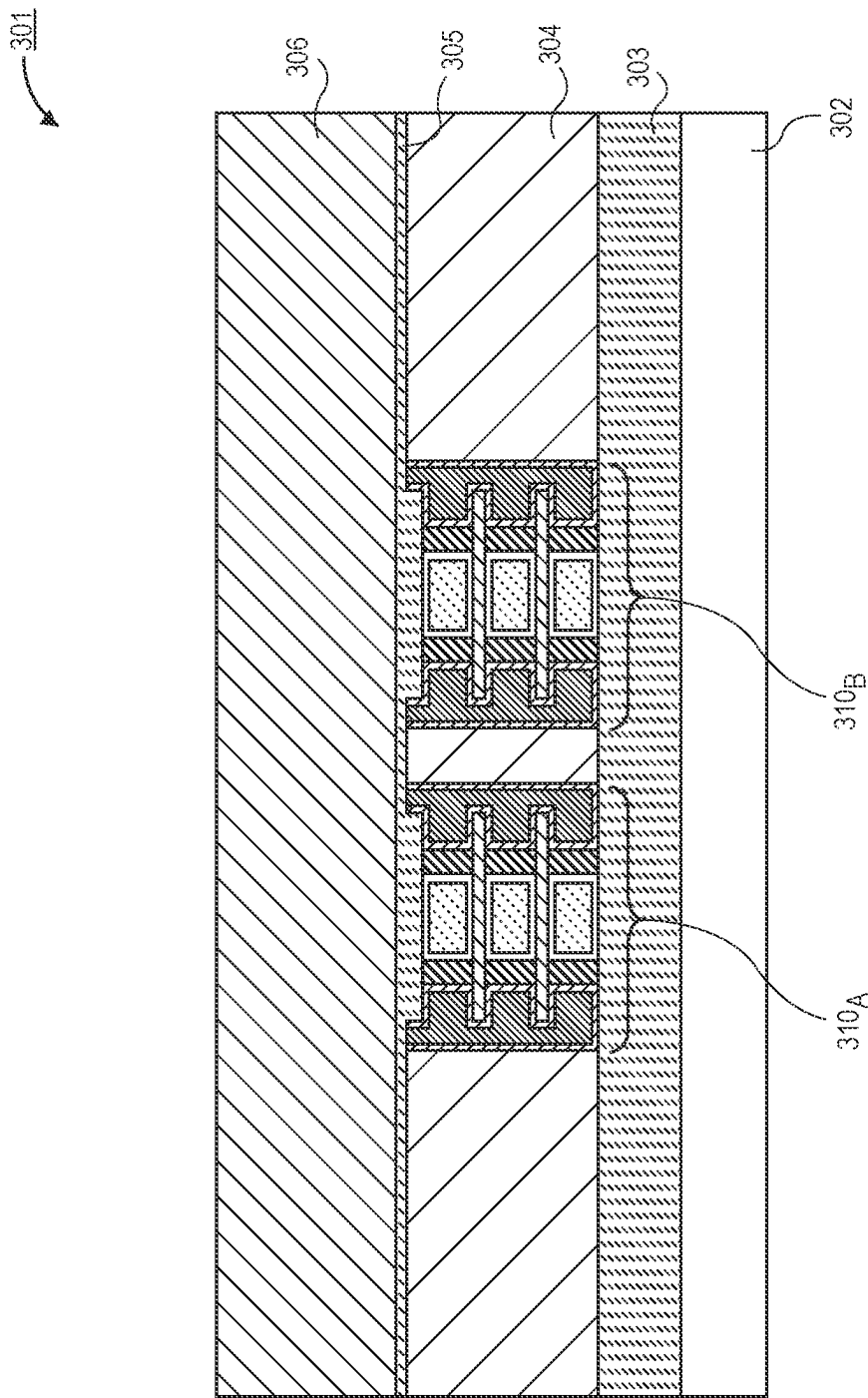


FIG. 31

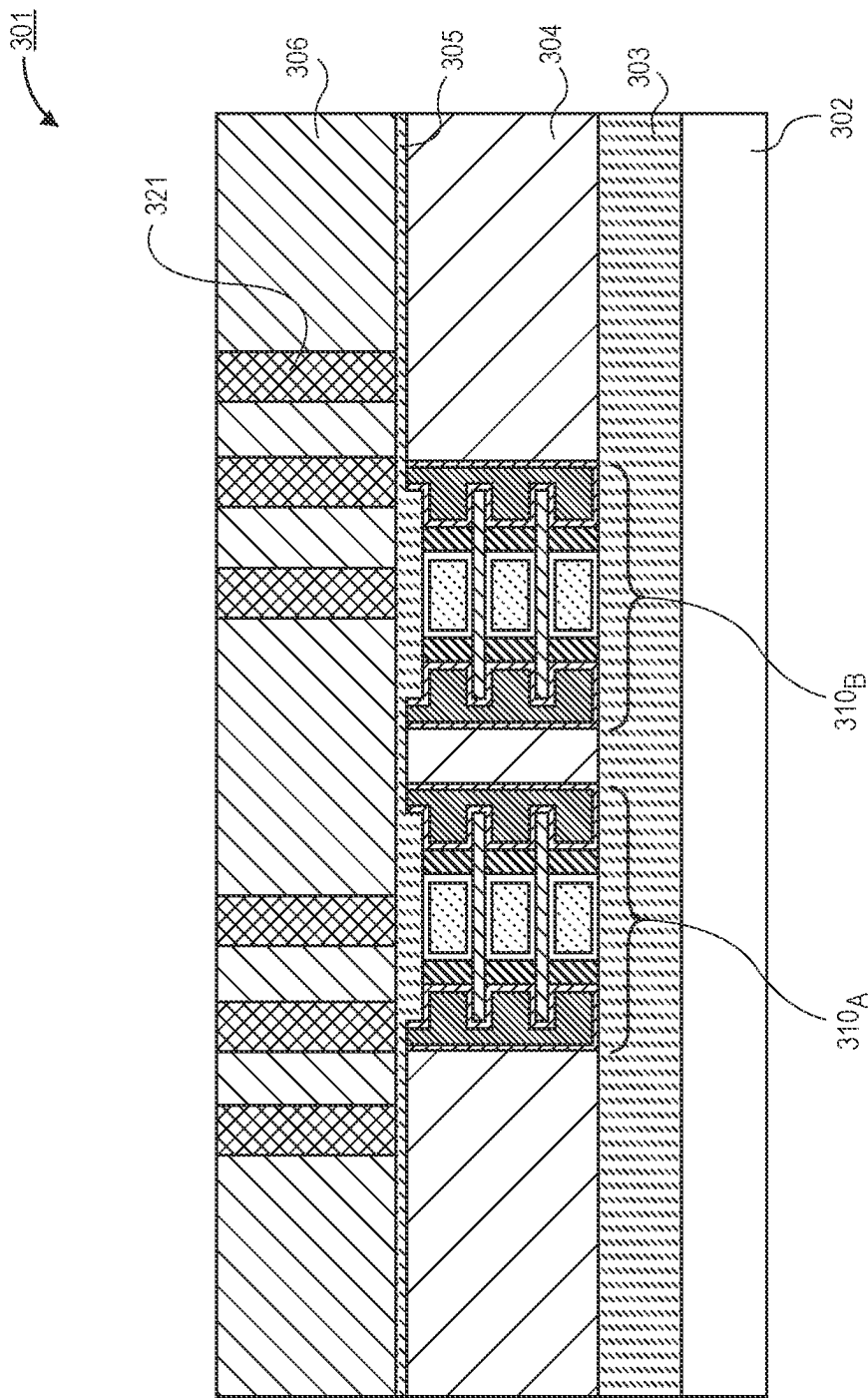


FIG. 3J

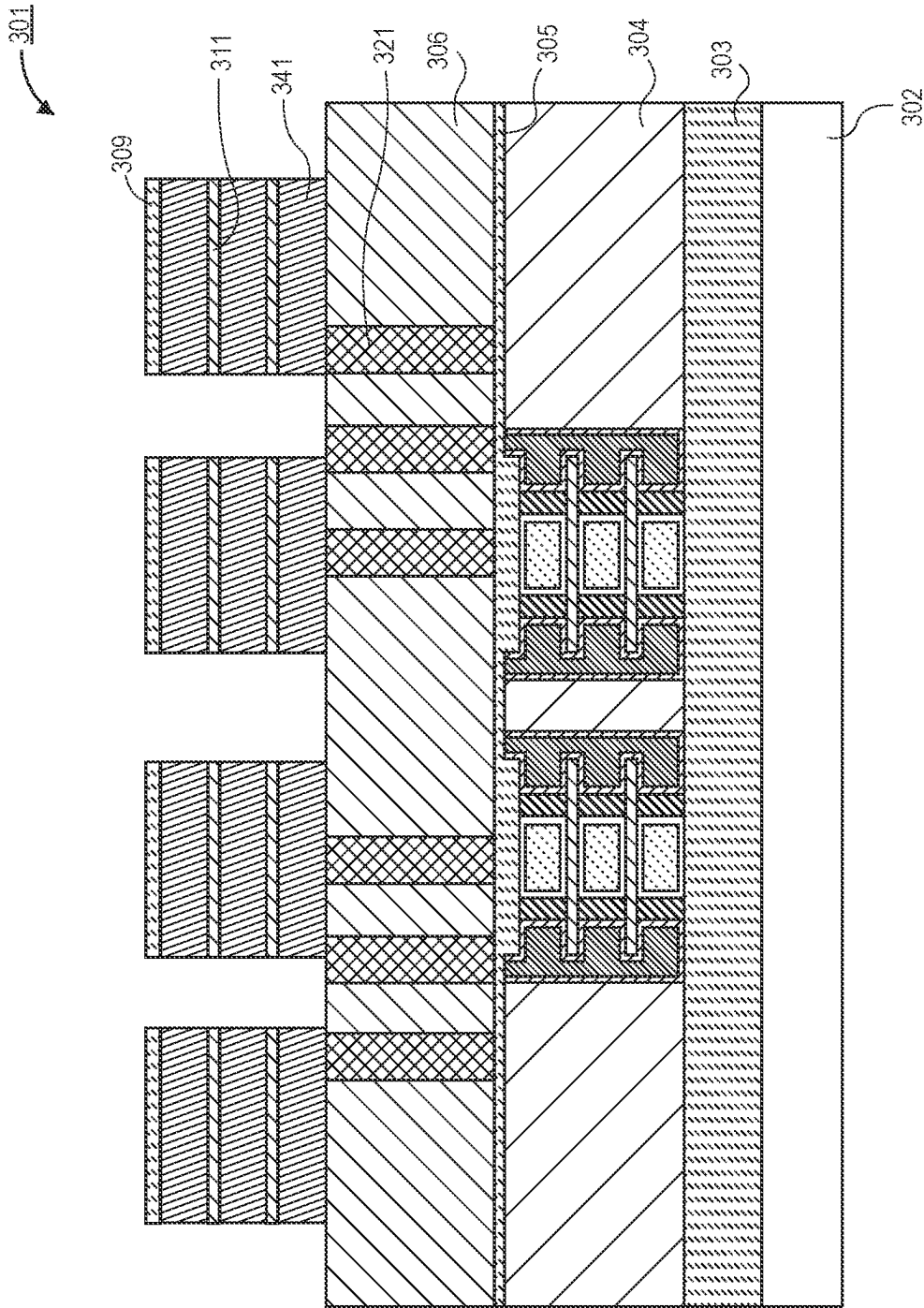


FIG. 3K

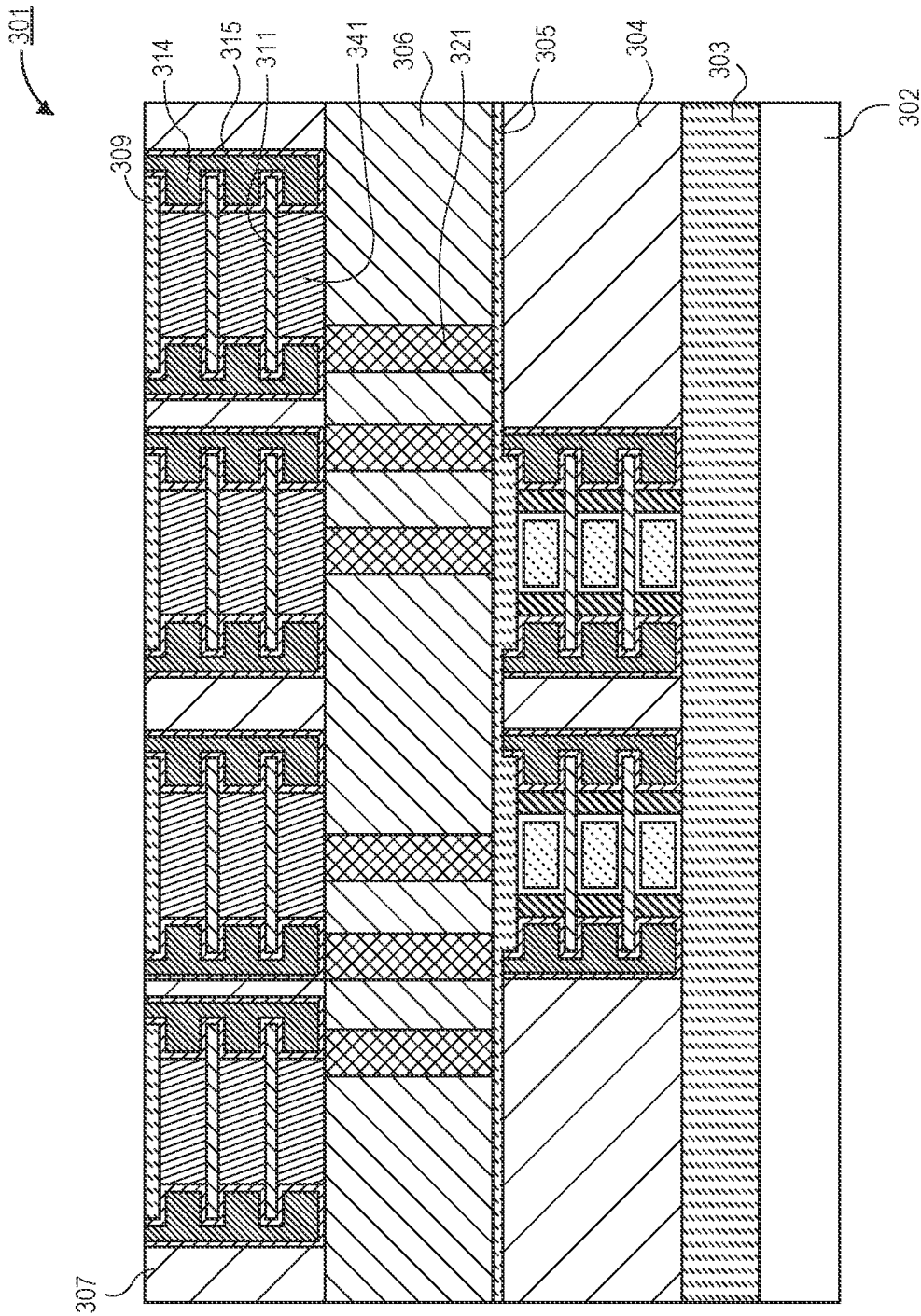


FIG. 3L

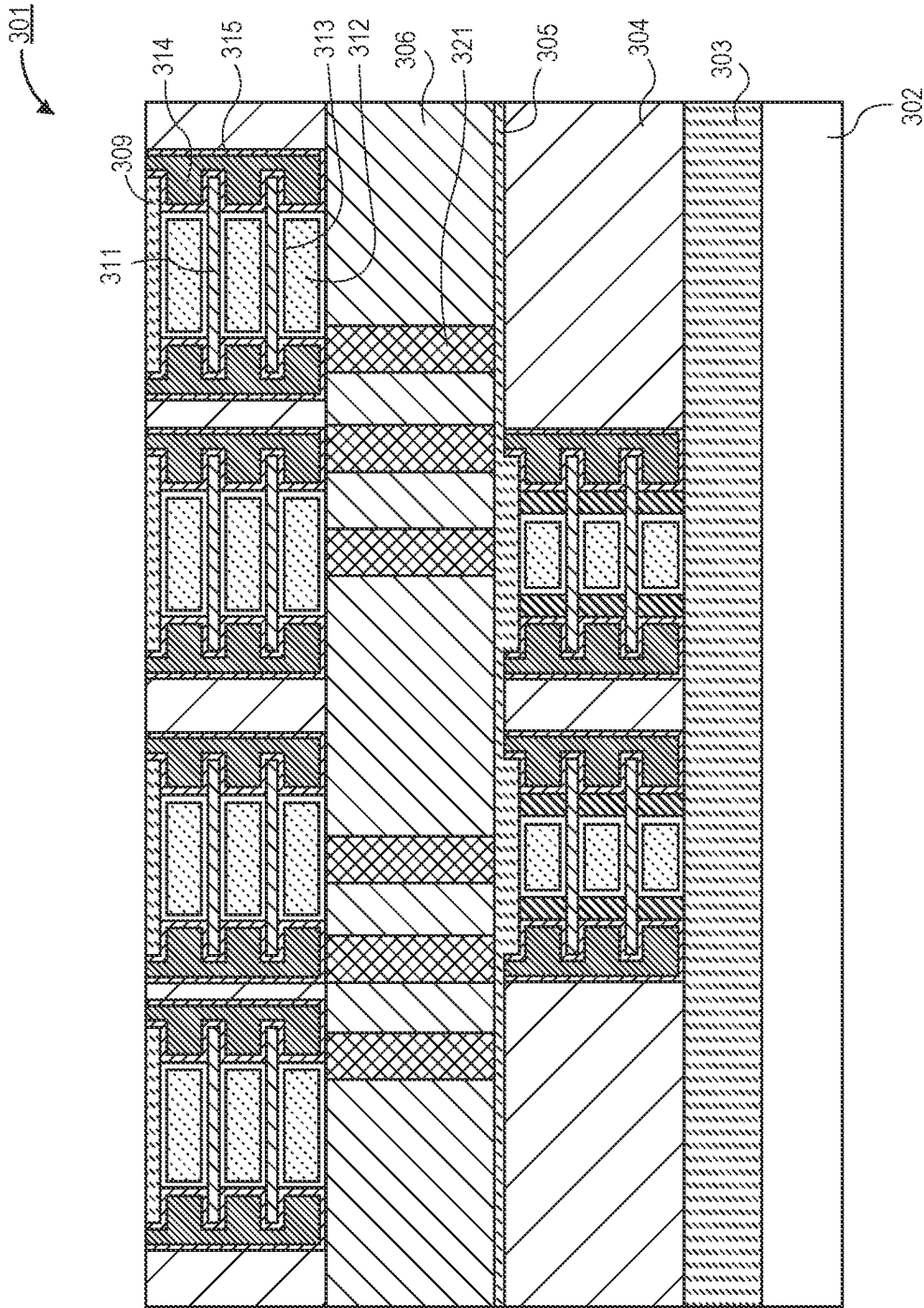


FIG. 3M

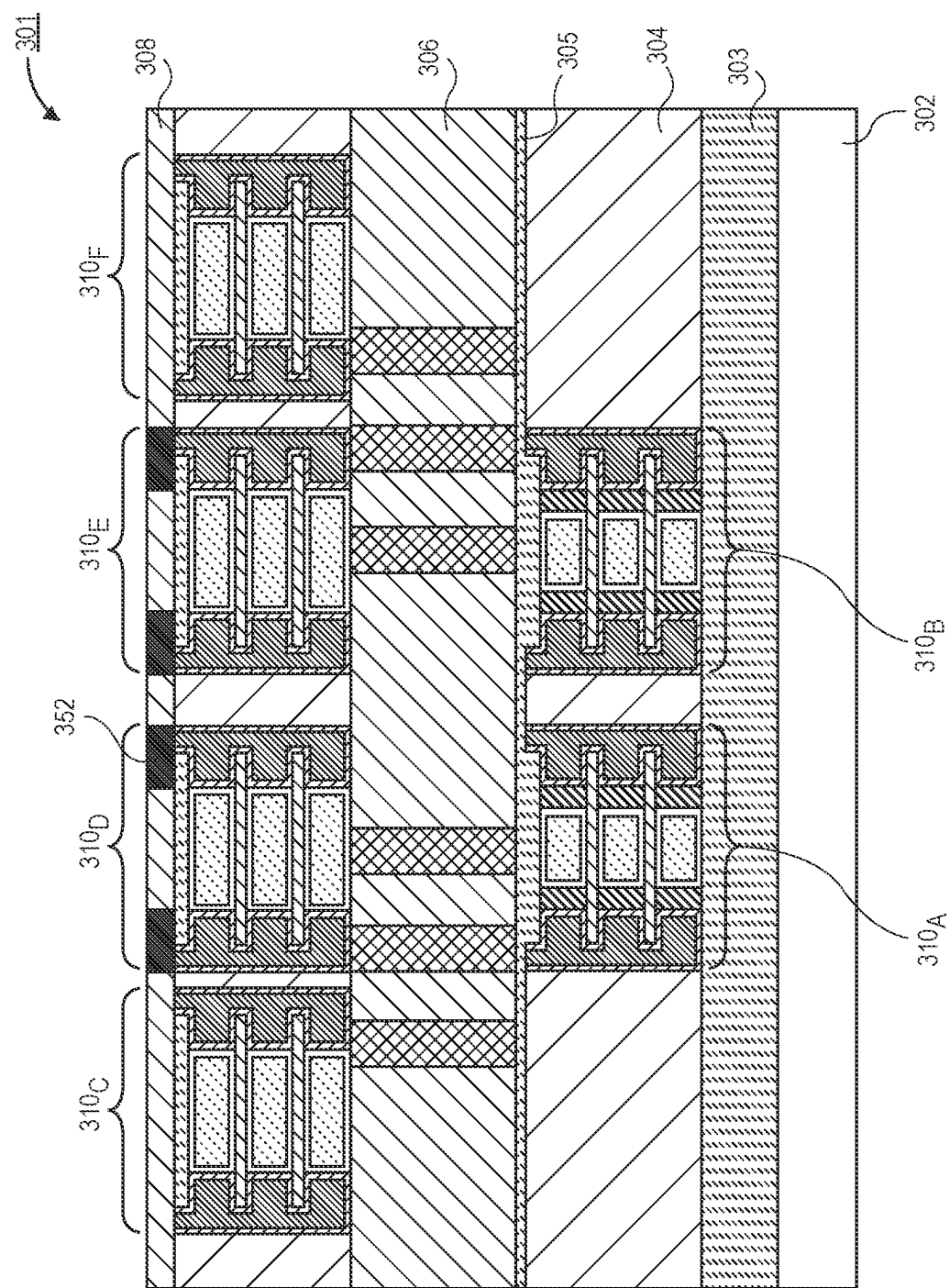
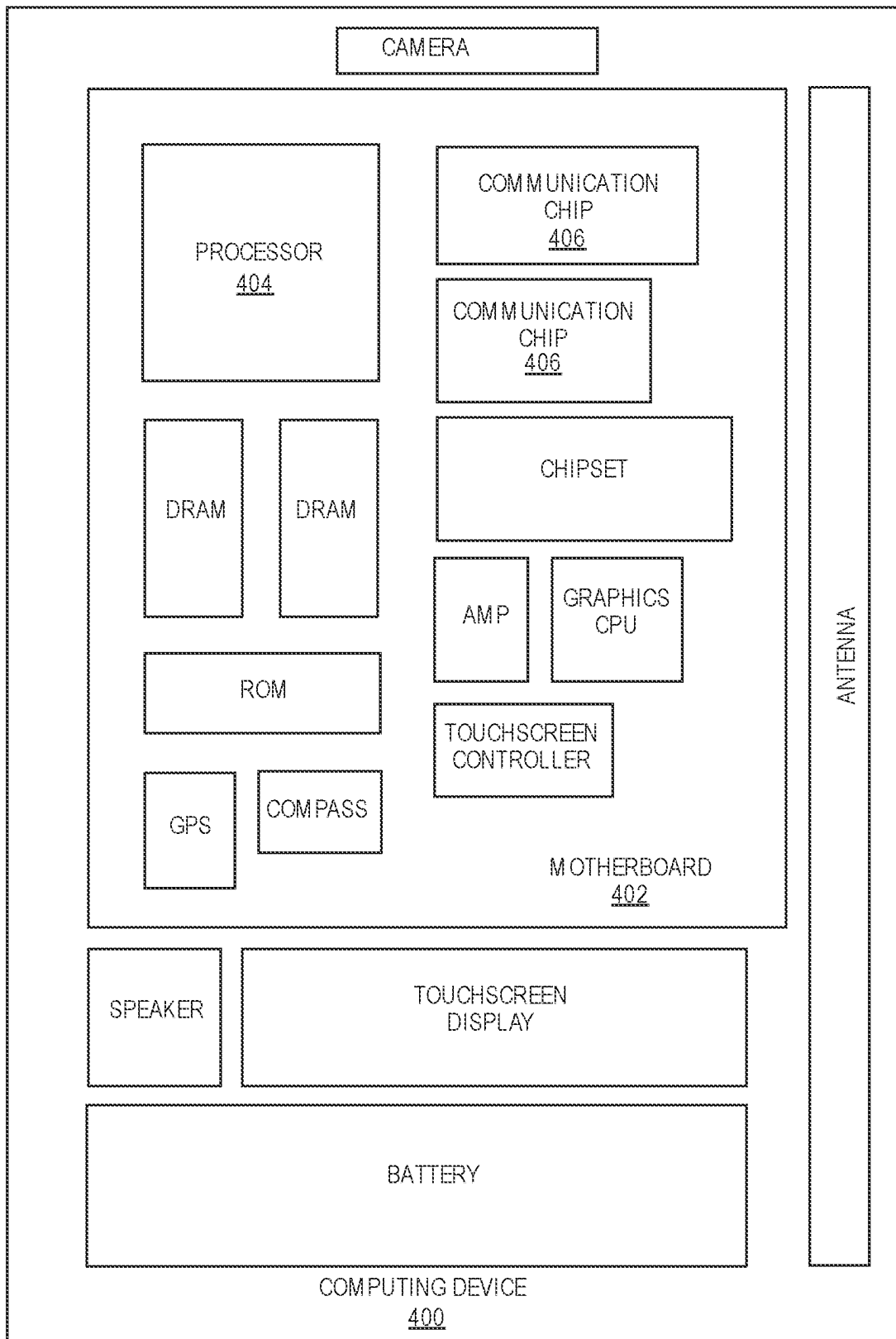


FIG. 3N

**FIG. 4**

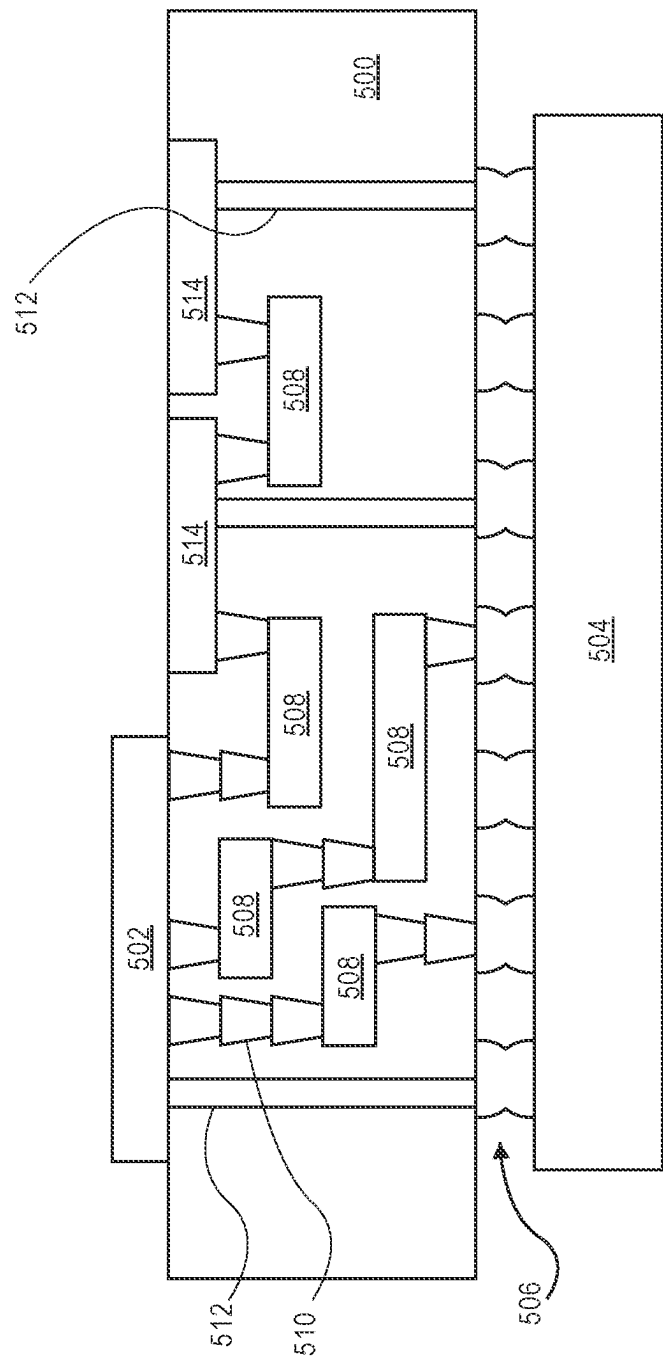


FIG. 5

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STACKED 2D CMOS WITH INTER METAL LAYERS

TECHNICAL FIELD

Embodiments of the disclosure are in the field of semiconductor structures and processing and, in particular, to stacked 2D CMOS devices with inter metal layers.

BACKGROUND

For the past several decades, the scaling of features in integrated circuits has been a driving force behind an ever-growing semiconductor industry. Scaling to smaller and smaller features enables increased densities of functional units on the limited real estate of semiconductor chips. For example, shrinking transistor size allows for the incorporation of an increased number of memory or logic devices on a chip, lending to the fabrication of products with increased capacity. The drive for ever-more capacity, however, is not without issue. The necessity to optimize the performance of each device becomes increasingly significant.

Variability in conventional and currently known fabrication processes may limit the possibility to further extend them into the 10 nanometer node or sub-10 nanometer node range. Consequently, fabrication of the functional components needed for future technology nodes may require the introduction of new methodologies or the integration of new technologies in current fabrication processes or in place of current fabrication processes.

In the manufacture of integrated circuit devices, multi-gate transistors, such as tri-gate transistors and gate-all-around (GAA) transistors, have become more prevalent as device dimensions continue to scale down. Tri-gate transistors and GAA transistors are generally fabricated on either bulk silicon substrates or silicon-on-insulator substrates. In some instances, bulk silicon substrates are preferred due to their lower cost and compatibility with the existing high-yielding bulk silicon substrate infrastructure.

Scaling multi-gate transistors has not been without consequence, however. As the dimensions of these fundamental building blocks of microelectronic circuitry are reduced and as the sheer number of fundamental building blocks fabricated in a given region is increased, the constraints on the semiconductor processes used to fabricate these building blocks have become overwhelming.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of a six transistor (6T) SRAM cell, in accordance with an embodiment.

FIG. 2 is a cross-sectional illustration of a semiconductor device with stacked transistors, in accordance with an embodiment.

FIG. 3A is a cross-sectional illustration of device stacks with channels and sacrificial layers over a substrate, in accordance with an embodiment.

FIG. 3B is a cross-sectional illustration of the structure after an insulating layer is disposed around the device stacks, in accordance with an embodiment.

FIG. 3C is a cross-sectional illustration of the structure after openings are formed at the ends of the device stacks, in accordance with an embodiment.

FIG. 3D is a cross-sectional illustration of the structure after the sacrificial layers are recessed, in accordance with an embodiment.

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FIG. 3E is a cross-sectional illustration of the structure after spacers are provided at the ends of the sacrificial layers, in accordance with an embodiment.

FIG. 3F is a cross-sectional illustration of the structure after source contacts and drain contacts are formed, in accordance with an embodiment.

FIG. 3G is a cross-sectional illustration of the structure after the sacrificial layers are fully removed, in accordance with an embodiment.

FIG. 3H is a cross-sectional illustration of the structure after a gate structure is formed around the channels, in accordance with an embodiment.

FIG. 3I is a cross-sectional illustration of the structure after an insulating layer is disposed over the bottom transistors, in accordance with an embodiment.

FIG. 3J is a cross-sectional illustration of the structure after vias are formed through the insulating layer, in accordance with an embodiment.

FIG. 3K is a cross-sectional illustration of the structure after device stacks with channels and sacrificial layers are formed over the insulating layer, in accordance with an embodiment.

FIG. 3L is a cross-sectional illustration of the structure after source contacts and drain contacts are formed over the channels, in accordance with an embodiment.

FIG. 3M is a cross-sectional illustration of the structure after gate structures are formed around the channels, in accordance with an embodiment.

FIG. 3N is a cross-sectional illustration of the structure after contacts are made to the top transistors, in accordance with an embodiment.

FIG. 4 illustrates a computing device in accordance with one implementation of an embodiment of the disclosure.

FIG. 5 is an interposer implementing one or more embodiments of the disclosure.

DESCRIPTION OF THE EMBODIMENTS

Embodiments described herein comprise stacked 2D CMOS devices with inter metal layers. In the following description, numerous specific details are set forth, such as specific integration and material regimes, in order to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to one skilled in the art that embodiments of the present disclosure may be practiced without these specific details. In other instances, well-known features, such as integrated circuit design layouts, are not described in detail in order to not unnecessarily obscure embodiments of the present disclosure. Furthermore, it is to be appreciated that the various embodiments shown in the Figures are illustrative representations and are not necessarily drawn to scale.

Certain terminology may also be used in the following description for the purpose of reference only, and thus are not intended to be limiting. For example, terms such as “upper”, “lower”, “above”, “below”, “bottom,” and “top” refer to directions in the drawings to which reference is made. Terms such as “front”, “back”, “rear”, and “side” describe the orientation and/or location of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import.

The continued scaling of transistor devices has led to a decrease in the footprint of memory cells. For example, six

transistor (6T) SRAM cells experience improved density by decreasing the footprint of individual transistors. An example of an 6T SRAM cell **100** is shown in FIG. 1. One difficulty to further scaling is the need to have both P-type and N-type transistor devices that are coupled together. In existing stacked architectures there are no metal layers between stacked N-MOS and P-MOS devices.

Accordingly, embodiments disclosed herein include stacked CMOS devices with metal interlayers which enables cell size reduction. In a particular embodiment, such an architecture may be used to reduce the footprint of 6T SRAM cells. However, it is to be appreciated that embodiments may include any cell architecture that requires N-MOS transistors coupled to P-MOS transistors in a stacked configuration.

Referring now to FIG. 2, a cross-sectional illustration of a semiconductor device **201** is shown, in accordance with an embodiment. In an embodiment, the semiconductor device **201** may comprise a plurality of transistors **210**. For example, six transistors **210A–210F** are shown in FIG. 2. In an embodiment, the transistors **210A** and **210E** may be provided in a first layer **204**, and the transistors **210C–210F** may be provided in a second layer **207**. In an embodiment, transistors **210A** and **210E** may be a first conductivity type and the transistors **210C–210F** may be a second conductivity type. For example, transistors **210A** and **210E** may be P-type transistors, and transistors **210C–210F** may be N-type transistors.

As shown, the first layer **204** is separated from the second layer **207** by an insulating layer **206**. In an embodiment, vias **221** may be provided through the insulating layer **206**. The vias **221** may electrically couple transistors **210** in the second layer **207** to transistors **210** in the first layer **204**. As such, compact cell architectures are enabled. In the illustrated embodiment, the vias **221** land on insulating layers **205**. However, it is to be appreciated that electrical connections to the source/drains and/or gates can be made through the insulating layers **205** out of the plane of FIG. 2.

In an embodiment, the semiconductor device **201** may be formed over a semiconductor substrate **202**. In an embodiment, the underlying semiconductor substrate **202** represents a general workpiece object used to manufacture integrated circuits. The semiconductor substrate **202** often includes a wafer or other piece of silicon or another semiconductor material. Suitable semiconductor substrates **202** include, but are not limited to, single crystal silicon, polycrystalline silicon and silicon on insulator (SOI), as well as similar substrates formed of other semiconductor materials, such as substrates including germanium, carbon, or group III-V materials. In an embodiment, an insulating layer **203** is provided over the semiconductor substrate **202**. The insulating layer **203** may include a silicon oxide (e.g., SiO_2) or a silicon nitride (e.g., SiN_x).

In an embodiment, transistors **210A** and **210E** are provided in the first layer **204** over the insulating layer **203**. In an embodiment, the transistors **210A** and **210E** may each comprise one or more semiconductor channels **211**. In an embodiment, the semiconductor channels **211** may include nanoribbon, nanosheet, or nanowire form factors. Generally, the semiconductor channels **211** may be suitable form factors for gate-all-around (GAA) transistor architectures. In an embodiment, the semiconductor channels **211** may include any suitable semiconductor material. For example, the semiconductor channels **211** may comprise silicon.

In an embodiment, the semiconductor channels **211** may be surrounded by a gate structure. The gate structure may include a gate dielectric **213** and a gate metal **212**. The gate

dielectric **213** may be a high-k dielectric material. As used herein, high-k may refer to a dielectric constant equal to or greater than the dielectric constant of silicon dioxide (SiO_2). Examples of high-k gate dielectric materials include, for instance, hafnium oxide, hafnium silicon oxide, lanthanum oxide, lanthanum aluminum oxide, zirconium oxide, zirconium silicon oxide, tantalum oxide, titanium oxide, barium strontium titanium oxide, barium titanium oxide, strontium titanium oxide, yttrium oxide, aluminum oxide, lead scandium tantalum oxide, and lead zinc niobate. In some embodiments, an annealing process may be carried out on the gate dielectric layer to improve its quality when a high-k material is used.

In an embodiment, the gate metal **212** may comprise a workfunction metal and a fill metal. When the gate metal **212** will serve as an N-type workfunction metal, the gate metal **212** preferably has a workfunction that is between about 3.9 eV and about 4.2 eV. N-type materials that may be used to form the gate metal **212** include, but are not limited to, hafnium, zirconium, titanium, tantalum, aluminum, and metal carbides that include these elements, i.e., titanium carbide, zirconium carbide, tantalum carbide, hafnium carbide and aluminum carbide. When the gate metal **212** will serve as a P-type workfunction metal, the gate metal **212** preferably has a workfunction that is between about 4.9 eV and about 5.2 eV. P-type materials that may be used to form the gate metal **212** include, but are not limited to, ruthenium, palladium, platinum, cobalt, nickel, and conductive metal oxides, e.g., ruthenium oxide.

In an embodiment, source contacts and drain contacts (sometimes referred to collectively as source/drain contacts) may be provided around the ends of the semiconductor channels **211**. In an embodiment, the source/drain contacts may comprise a conformal liner **215** and a fill metal **214**. For example, the conformal liner **215** may include antimony, and the fill metal **214** may comprise gold. In an embodiment, the source/drain contacts **214/215** may be physically separated from the gate structure **213/214** by spacers **216**.

In an embodiment, transistors **210C–210F** are provided in the second layer **207** over the insulating layer **206**. In an embodiment, the transistors **210C–210F** may each comprise one or more semiconductor channels **211**. In an embodiment, the semiconductor channels **211** may include nanoribbon, nanosheet, or nanowire form factors. Generally, the semiconductor channels **211** may be suitable form factors for GAA transistor architectures. In an embodiment, the semiconductor channels **211** may include any suitable semiconductor material. For example, the semiconductor channels **211** may comprise silicon.

In an embodiment, the semiconductor channels **211** may be surrounded by a gate structure. The gate structure may include a gate dielectric **213** and a gate metal **212**. The gate dielectric **213** may be a high-k dielectric material, such as one of the high-k dielectric materials listed above. In an embodiment, the gate metal **212** may comprise a workfunction metal and a fill metal. The workfunction metal may be one of the workfunction metals listed above.

In an embodiment, the ends of the semiconductor channels **211** may be surrounded by source/drain contacts. For example, the source/drain contacts may comprise a conformal liner **215** and a fill metal **214**. For example, the conformal liner **215** may include antimony, and the fill metal **214** may comprise gold. In contrast to the transistors **210A** and **210B**, the source/drain contacts **215/214** may be separated from the gate metal **212** by the gate dielectric **213**.

In an embodiment, an insulating layer **209** may be provided above the gate structure **212/213** of each of the

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transistors **210c-210F**. An additional insulating layer **208** may also be provided above the transistors **210c-210F**. In an embodiment, contacts **252** may pass through the insulating layer **208** to provide electrical connections to the source/drain contacts **214/215**.

Referring now to FIGS. **3A-3N**, a series of cross-sectional illustrations depicting a process for forming a semiconductor device with a plurality of transistors is shown, in accordance with an embodiment. In an embodiment, the semiconductor device in FIGS. **3A-3N** may be substantially similar to the semiconductor device **201** described with respect to FIG. **2**.

Referring now to FIG. **3A**, a cross-sectional illustration of a semiconductor device **301** at a stage of manufacture is shown, in accordance with an embodiment. In an embodiment, the semiconductor device **301** may include a substrate **302** and an insulator **303** over the substrate **302**. The substrate **302** may be a semiconductor substrate, such as a silicon substrate. In an embodiment, device stacks are provided over the insulator **303**. The device stacks may include semiconductor channels **311** alternating with sacrificial layers **331**. In the illustrated embodiment, a pair of semiconductor channels **311** are shown, but it is to be appreciated that any number of semiconductor channels **311** may be used. In an embodiment an insulator **305** may be provided over the top most sacrificial layer **331**.

In an embodiment, sacrificial layers **331** may be any material that can be selectively etched with respect to semiconductor channels **311**. Channels **311** and sacrificial layers **331** may each be a material such as, but not limited to, silicon, germanium, SiGe, GaAs, InSb, GaP, GaSb, InAlAs, InGaAs, GaSbP, GaAsSb, and InP. In a specific embodiment, channels **311** are silicon and sacrificial layers **331** are SiGe. In another specific embodiment, channels **311** are germanium, and the sacrificial layers **331** are SiGe.

Referring now to FIG. **3B**, a cross-sectional illustration of the semiconductor device **301** after an insulating layer **304** is deposited is shown, in accordance with an embodiment. In an embodiment, the insulating layer **304** may be deposited over the device stacks and recessed back. In an embodiment, the insulating layer **304** may have a top surface that is substantially coplanar with a top surface of the insulator **305**.

Referring now to FIG. **3C**, a cross-sectional illustration of the semiconductor device **301** after openings **332** are formed along the edges of device stacks is shown, in accordance with an embodiment. As shown, the openings **332** may pass entirely through a thickness of the insulating layer **304**. The openings **332** expose the ends of the sacrificial layers **331**.

Referring now to FIG. **3D**, a cross-sectional illustration of the semiconductor device **301** after the sacrificial layers **331** are recessed is shown, in accordance with an embodiment. In an embodiment, the sacrificial layers **331** are etched to form recesses **333**. The recesses **333** expose the ends of the channels **311**. In an embodiment, sacrificial layers **331** may be recessed using any known etchant that is selective to channels **311**. In an embodiment, sacrificial layers **331** are recessed by a timed wet etch process. The selectivity of the etchant may be greater than 50:1 for sacrificial material over channel material. In an embodiment, the selectivity is greater than 100:1. In an embodiment where channels **311** are silicon and sacrificial layers **331** are silicon germanium, sacrificial layers **331** may be selectively removed using a wet etchant such as, but not limited to, aqueous carboxylic acid/nitric acid/HF solution and aqueous citric acid/nitric acid/HF solution. In an embodiment where channels **311** are germanium and sacrificial layers **331** are silicon germanium, sacrificial layers **331** are recessed using a wet etchant such as, but not limited to, ammonium hydroxide (NH₄OH),

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tetramethylammonium hydroxide (TMAH), ethylenediamine pyrocatechol (EDP), or potassium hydroxide (KOH) solution.

Referring now to FIG. **3E**, a cross-sectional illustration of the semiconductor device **301** after spacers **316** are formed over the sacrificial layers **331** is shown, in accordance with an embodiment. In an embodiment, the spacers **316** may be an insulating material. For example, the spacers **316** may include a silicon oxide or a silicon nitride. In an embodiment, the spacers **316** may be a material that is etch selective to the insulating layer **304**.

Referring now to FIG. **3F**, a cross-sectional illustration of the semiconductor device **301** after source/drain contacts are formed around the ends of the channels **311** is shown, in accordance with an embodiment. In an embodiment, the source/drain contacts comprise a conformal liner **315** and a fill metal **314**. For example, the conformal liner **315** may include antimony, and the fill metal **314** may include gold.

Referring now to FIG. **3G**, a cross-sectional illustration of the semiconductor device **301** after the sacrificial layers **331** are removed is shown, in accordance with an embodiment. In an embodiment, the sacrificial layers **331** may be removed with any suitable etching process. The etchant may have access to the sacrificial layers **331** through openings out of the plane of FIG. **3G**.

Referring now to FIG. **3H**, a cross-sectional illustration of the semiconductor device **301** after a gate structure is formed between the channels **311** is shown, in accordance with an embodiment. In an embodiment, the gate structure comprises a gate dielectric **313** and a gate metal **312**. The gate dielectric **313** may be a high-k dielectric material, such as one of those listed in greater detail above. In an embodiment, the gate metal **312** may comprise a workfunction metal, such as one of those listed in greater detail above.

Referring now to FIG. **3I**, a cross-sectional illustration of the semiconductor device **301** after insulating layer **305** and insulating layer **306** are disposed over the transistors **310A** and **310E** is shown, in accordance with an embodiment.

Referring now to FIG. **3J**, a cross-sectional illustration of the semiconductor device **301** after vias **321** are formed through the insulating layer **306** is shown, in accordance with an embodiment. In an embodiment, the vias **321** may be formed with an etching and deposition process. In an embodiment, the vias **321** may comprise any conductive material, such as, but not limited to tungsten.

Referring now to FIG. **3K**, a cross-sectional illustration of the semiconductor device **301** after device stacks are provided above the insulating layer **306** is shown, in accordance with an embodiment. In an embodiment, the device stacks include semiconductor channels **311** and sacrificial layers **341**. In an embodiment, two channels **311** are shown. However, it is to be appreciated that any number of channels **311** may be used. In an embodiment, the channels **311** and the sacrificial layers **341** may be materials that are etch selective to each other. In an embodiment, an insulating layer **309** may be provided over the device stacks.

Referring now to FIG. **3L**, a cross-sectional illustration of the semiconductor device **301** after source/drain contacts are formed around the ends of the channels **311** is shown, in accordance with an embodiment. In an embodiment, the insulating layer **307** may be formed around the device stacks. The sacrificial layers **341** are recessed to expose the ends of the channels **311**. A conformal liner **315** and a fill metal **314** are then deposited in order to form the source/drain contacts.

Referring now to FIG. **3M**, a cross-sectional illustration of the semiconductor device **301** after a gate structure is

formed around the channels **311** is shown, in accordance with an embodiment. In an embodiment, the sacrificial layers **341** are removed to form a cavity between the channels **311**. Thereafter, a gate dielectric **313** is conformally deposited. The gate dielectric **313** may be a high-k dielectric material, such as one listed above. A gate metal **312** is then provided over the gate dielectric **313**. The gate metal **312** may be a workfunction metal, such as one listed above.

Referring now to FIG. **3N**, a cross-sectional illustration of the semiconductor device **301** after an insulating layer **308** is provided over the transistors **310c-310f** is shown, in accordance with an embodiment. In an embodiment, contacts **352** may be formed through the insulating layer **308**.

FIG. **4** illustrates a computing device **400** in accordance with one implementation of an embodiment of the disclosure. The computing device **400** houses a board **402**. The board **402** may include a number of components, including but not limited to a processor **404** and at least one communication chip **406**. The processor **404** is physically and electrically coupled to the board **402**. In some implementations the at least one communication chip **406** is also physically and electrically coupled to the board **402**. In further implementations, the communication chip **406** is part of the processor **404**.

Depending on its applications, computing device **400** may include other components that may or may not be physically and electrically coupled to the board **402**. These other components include, but are not limited to, volatile memory (e.g., DRAM), non-volatile memory (e.g., ROM), flash memory, a graphics processor, a digital signal processor, a crypto processor, a chipset, an antenna, a display, a touchscreen display, a touchscreen controller, a battery, an audio codec, a video codec, a power amplifier, a global positioning system (GPS) device, a compass, an accelerometer, a gyroscope, a speaker, a camera, and a mass storage device (such as hard disk drive, compact disk (CD), digital versatile disk (DVD), and so forth).

The communication chip **406** enables wireless communications for the transfer of data to and from the computing device **400**. The term “wireless” and its derivatives may be used to describe circuits, devices, systems, methods, techniques, communications channels, etc., that may communicate data through the use of modulated electromagnetic radiation through a non-solid medium. The term does not imply that the associated devices do not contain any wires, although in some embodiments they might not. The communication chip **406** may implement any of a number of wireless standards or protocols, including but not limited to Wi-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, long term evolution (LTE), Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, Bluetooth, derivatives thereof, as well as any other wireless protocols that are designated as 3G, 4G, 5G, and beyond. The computing device **400** may include a plurality of communication chips **406**. For instance, a first communication chip **406** may be dedicated to shorter range wireless communications such as Wi-Fi and Bluetooth and a second communication chip **406** may be dedicated to longer range wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

The processor **404** of the computing device **400** includes an integrated circuit die packaged within the processor **404**. In an embodiment, the integrated circuit die of the processor may comprise a memory cell with stacked transistors with a conductive via between the stacked transistors, as described herein. The term “processor” may refer to any device or

portion of a device that processes electronic data from registers and/or memory to transform that electronic data into other electronic data that may be stored in registers and/or memory.

The communication chip **406** also includes an integrated circuit die packaged within the communication chip **406**. In an embodiment, the integrated circuit die of the communication chip may comprise a memory cell with stacked transistors with a conductive via between the stacked transistors, as described herein.

In further implementations, another component housed within the computing device **400** may comprise a memory cell with stacked transistors with a conductive via between the stacked transistors, as described herein.

In various implementations, the computing device **400** may be a laptop, a netbook, a notebook, an ultrabook, a smartphone, a tablet, a personal digital assistant (PDA), an ultra mobile PC, a mobile phone, a desktop computer, a server, a printer, a scanner, a monitor, a set-top box, an entertainment control unit, a digital camera, a portable music player, or a digital video recorder. In further implementations, the computing device **400** may be any other electronic device that processes data.

FIG. **5** illustrates an interposer **500** that includes one or more embodiments of the disclosure. The interposer **500** is an intervening substrate used to bridge a first substrate **502** to a second substrate **504**. The first substrate **502** may be, for instance, an integrated circuit die. The second substrate **504** may be, for instance, a memory module, a computer motherboard, or another integrated circuit die. In an embodiment, one of both of the first substrate **502** and the second substrate **504** may comprise a memory cell with stacked transistors with a conductive via between the stacked transistors, in accordance with embodiments described herein. Generally, the purpose of an interposer **500** is to spread a connection to a wider pitch or to reroute a connection to a different connection. For example, an interposer **500** may couple an integrated circuit die to a ball grid array (BGA) **506** that can subsequently be coupled to the second substrate **504**. In some embodiments, the first and second substrates **502/504** are attached to opposing sides of the interposer **500**. In other embodiments, the first and second substrates **502/504** are attached to the same side of the interposer **500**. And in further embodiments, three or more substrates are interconnected by way of the interposer **500**.

The interposer **500** may be formed of an epoxy resin, a fiberglass-reinforced epoxy resin, a ceramic material, or a polymer material such as polyimide. In further implementations, the interposer **500** may be formed of alternate rigid or flexible materials that may include the same materials described above for use in a semiconductor substrate, such as silicon, germanium, and other group III-V and group IV materials.

The interposer **500** may include metal interconnects **508** and vias **510**, including but not limited to through-silicon vias (TSVs) **512**. The interposer **500** may further include embedded devices **514**, including both passive and active devices. Such devices include, but are not limited to, capacitors, decoupling capacitors, resistors, inductors, fuses, diodes, transformers, sensors, and electrostatic discharge (ESD) devices. More complex devices such as radio-frequency (RF) devices, power amplifiers, power management devices, antennas, arrays, sensors, and MEMS devices may also be formed on the interposer **500**. In accordance with embodiments of the disclosure, apparatuses or processes disclosed herein may be used in the fabrication of interposer **500**.

Thus, embodiments of the present disclosure may comprise a memory cell with stacked transistors with a conductive via between the stacked transistors.

The above description of illustrated implementations of embodiments of the disclosure, including what is described in the Abstract, is not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. While specific implementations of, and examples for, the disclosure are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the disclosure, as those skilled in the relevant art will recognize.

These modifications may be made to the disclosure in light of the above detailed description. The terms used in the following claims should not be construed to limit the disclosure to the specific implementations disclosed in the specification and the claims. Rather, the scope of the disclosure is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

Example 1: a semiconductor device, comprising: a first transistor on a first level; a second transistor on a second level above the first level; an insulating layer between the first level and the second level; and a via through the insulating layer, wherein the via electrically couples the first transistor to the second transistor, wherein the first transistor and the second transistor comprise: a first channel; a second channel over the first channel; a gate structure between the first channel and the second channel; a source contact on a first end of the first channel and the second channel; and a drain contact on a second end of the first channel and the second channel.

Example 2: the semiconductor device of Example 1, wherein the first transistor further comprises: a first spacer between the source contact and the gate structure; and a second spacer between the drain contact and the gate structure.

Example 3: the semiconductor device of Example 1 or Example 2, wherein the source contact and the drain contact wrap around ends of the first channel and ends of the second channel.

Example 4: the semiconductor device of Examples 1-3, wherein the source contact and the drain contact comprise a conformal layer and a fill layer.

Example 5: the semiconductor device of Example 4, wherein the conformal layer comprises antimony and the fill layer comprises gold.

Example 6: the semiconductor device of Examples 1-5, wherein the via electrically couples the source contact of the first transistor to the source contact of the second transistor.

Example 7: the semiconductor device of Examples 1-6, wherein the first transistor is a P-type transistor, and wherein the second transistor is an N-type transistor.

Example 8: the semiconductor device of Examples 1-7, wherein the first transistor and the second transistor are components of an SRAM cell.

Example 9: the semiconductor device of Example 8, wherein the first transistor and the second transistor are components of a six transistor (6T) SRAM cell.

Example 10: the semiconductor device of Examples 1-9, wherein the first transistor and the second transistor are gate-all-around (GAA) transistors.

Example 11: an SRAM cell comprising: a first transistor in a first layer; a second transistor in the first layer; a third transistor in a second layer; a fourth transistor in the second layer; a fifth transistor in the second layer;

a sixth transistor in the second layer; an insulating layer between the first layer and the second layer; and vias through the insulating layer, wherein the vias electrically couple the first transistor and the second transistor to the fourth transistor and the fifth transistor.

Example 12: the SRAM cell of Example 11, wherein the first transistor and the second transistor are P-type transistors, and wherein the third transistor, the fourth transistor, the fifth transistor, and the sixth transistor are N-type transistors.

Example 13: the SRAM cell of Example 11 or Example 12, wherein the transistors comprise: a first channel; a second channel over the first channel; a gate structure between the first channel and the second channel; a source contact on a first end of the first channel and the second channel; and a drain contact on a second end of the first channel and the second channel.

Example 14: the SRAM cell of Example 13, wherein the first transistor and the second transistor further comprise: a first spacer between the source contact and the gate structure; and a second spacer between the drain contact and the gate structure.

Example 15: the SRAM cell of Example 13 or Example 14, wherein the source contact and the drain contact wrap around ends of the first channel and ends of the second channel.

Example 16: the SRAM cell of Example 15, wherein the source contact and the drain contact comprise a conformal layer and a fill layer

Example 17: the SRAM cell of Example 16, wherein the conformal layer comprises antimony and the fill layer comprises gold.

Example 18: an electronic system, comprising: a board; a package substrate coupled to the board; and a die coupled to the package substrate, wherein the die comprises: a first transistor on a first level; a second transistor on a second level above the first level; an insulating layer between the first level and the second level; and a via through the insulating layer, wherein the via electrically couples the first transistor to the second transistor, wherein the first transistor and the second transistor comprise: a first channel; a second channel over the first channel; a gate structure between the first channel and the second channel; a source contact on a first end of the first channel and the second channel; and a drain contact on a second end of the first channel and the second channel.

Example 19: the electronic system of Example 18, wherein the first transistor and the second transistor are part of a six transistor SRAM cell.

Example 20: the electronic system of Example 18 or Example 19, wherein the first transistor further comprises: a first spacer between the source contact and the gate structure; and a second spacer between the drain contact and the gate structure.

What is claimed is:

1. A semiconductor device, comprising:

- a first transistor on a first level;
- a second transistor on a second level above the first level;
- an insulating layer between the first level and the second level; and
- a via through the insulating layer, wherein the via electrically couples the first transistor to the second transistor, wherein each of the first transistor and the second transistor comprises:
 - a first channel;
 - a second channel over the first channel;

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- a gate structure between the first channel and the second channel;
 a source contact on a first end of the first channel and the second channel; and
 a drain contact on a second end of the first channel and the second channel.
2. The semiconductor device of claim 1, wherein the first transistor further comprises:
 a first spacer between the source contact and the gate structure; and
 a second spacer between the drain contact and the gate structure.
3. The semiconductor device of claim 1, wherein the source contact and the drain contact wrap around ends of the first channel and ends of the second channel.
4. The semiconductor device of claim 1, wherein the source contact and the drain contact comprise a conformal layer and a fill layer.
5. The semiconductor device of claim 4, wherein the conformal layer comprises antimony and the fill layer comprises gold.
6. The semiconductor device of claim 1, wherein the via electrically couples the source contact of the first transistor to the source contact of the second transistor.
7. The semiconductor device of claim 1, wherein the first transistor is a P-type transistor, and wherein the second transistor is an N-type transistor.
8. The semiconductor device of claim 1, wherein the first transistor and the second transistor are components of an SRAM cell.
9. The semiconductor device of claim 8, wherein the first transistor and the second transistor are components of a six transistor (6T) SRAM cell.
10. The semiconductor device of claim 1, wherein the first transistor and the second transistor are gate-all-around (GAA) transistors.
11. An SRAM cell comprising:
 a first transistor in a first layer;
 a second transistor in the first layer;
 a third transistor in a second layer;
 a fourth transistor in the second layer;
 a fifth transistor in the second layer;
 a sixth transistor in the second layer;
 an insulating layer between the first layer and the second layer; and
 vias through the insulating layer, wherein the vias electrically couple the first transistor and the second transistor to the fourth transistor and the fifth transistor, wherein each of the first, second, third, fourth, fifth and sixth transistors comprises:
 a first channel;
 a second channel over the first channel;
 a gate structure between the first channel and the second channel;

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- a source contact on a first end of the first channel and the second channel; and
 a drain contact on a second end of the first channel and the second channel.
12. The SRAM cell of claim 11, wherein the first transistor and the second transistor are P-type transistors, and wherein the third transistor, the fourth transistor, the fifth transistor, and the sixth transistor are N-type transistors.
13. The SRAM cell of claim 11, wherein each of the first transistor and the second transistor further comprises:
 a first spacer between the source contact and the gate structure; and
 a second spacer between the drain contact and the gate structure.
14. The SRAM cell of claim 11, wherein the source contact and the drain contact wrap around ends of the first channel and ends of the second channel.
15. The SRAM cell of claim 14, wherein the source contact and the drain contact comprise a conformal layer and a fill layer.
16. The SRAM cell of claim 15, wherein the conformal layer comprises antimony and the fill layer comprises gold.
17. An electronic system, comprising:
 a board;
 a package substrate coupled to the board; and
 a die coupled to the package substrate, wherein the die comprises:
 a first transistor on a first level;
 a second transistor on a second level above the first level;
 an insulating layer between the first level and the second level; and
 a via through the insulating layer, wherein the via electrically couples the first transistor to the second transistor, wherein each of the first transistor and the second transistor comprises:
 a first channel;
 a second channel over the first channel;
 a gate structure between the first channel and the second channel;
 a source contact on a first end of the first channel and the second channel; and
 a drain contact on a second end of the first channel and the second channel.
18. The electronic system of claim 17, wherein the first transistor and the second transistor are part of a six transistor SRAM cell.
19. The electronic system of claim 17, wherein each of the first transistor further comprises:
 a first spacer between the source contact and the gate structure; and
 a second spacer between the drain contact and the gate structure.

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