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Liu et al.

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(54) **DUAL FACING BSI IMAGE SENSORS WITH WAFER LEVEL STACKING**

(71) Applicant: **Taiwan Semiconductor Manufacturing Company, Ltd.**, Hsinchu (TW)

(72) Inventors: **Ping-Yin Liu**, Yonghe (TW); **Yeur-Luen Tu**, Taichung (TW); **Chia-Shiung Tsai**, Hsin-Chu (TW); **Xiaomeng Chen**, Hsinchu (TW); **Pin-Nan Tseng**, Hsin-Chu (TW)

(73) Assignee: **TAIWAN SEMICONDUCTOR MANUFACTURING COMPANY, LTD.**, Hsin-Chu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 234 days.

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(60) Continuation of application No. 16/658,355, filed on Oct. 21, 2019, now Pat. No. 11,037,978, which is a

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(51) **Int. Cl.**
H01L 27/146 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 27/1464*** (2013.01); ***H01L 27/14618*** (2013.01); ***H01L 27/14625*** (2013.01);

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(58) **Field of Classification Search**
CPC ... H01L 27/14; H01L 27/146; H01L 27/1464; H01L 27/14618; H01L 27/14625; H01L 27/14636; H01L 27/14687

(Continued)

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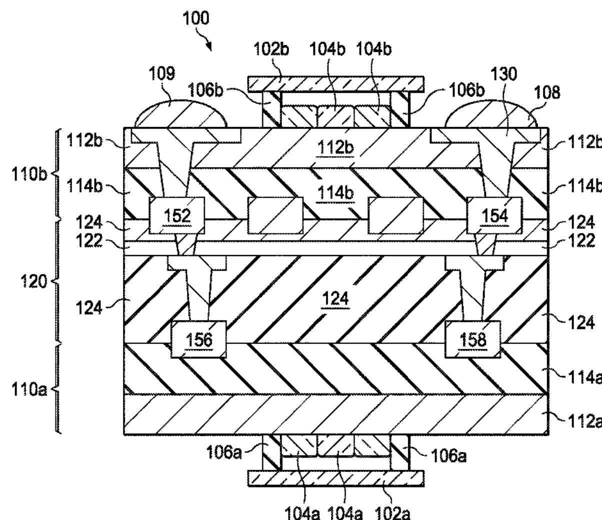
Primary Examiner — Fazli Erdem
(74) *Attorney, Agent, or Firm* — HAYNES AND BOONE, LLP

(57) **ABSTRACT**

A device includes two BSI image sensor elements and a third element. The third element is bonded in between the two BSI image sensor elements using element level stacking methods. Each of the BSI image sensor elements includes a substrate and a metal stack disposed over a first side of the substrate. The substrate of the BSI image sensor element includes a photodiode region for accumulating an image charge in response to radiation incident upon a second side of the substrate. The third element also includes a substrate and a metal stack disposed over a first side of the substrate. The metal stacks of the two BSI image sensor elements and the third element are electrically coupled.

20 Claims, 21 Drawing Sheets



Related U.S. Application Data

continuation of application No. 15/651,402, filed on Jul. 17, 2017, now Pat. No. 10,453,889, which is a division of application No. 14/039,640, filed on Sep. 27, 2013, now Pat. No. 9,711,555.

(52) **U.S. Cl.**
CPC .. ***H01L 27/14636*** (2013.01); ***H01L 27/14687*** (2013.01); *H01L 2924/0002* (2013.01)

(58) **Field of Classification Search**
USPC 257/459
See application file for complete search history.

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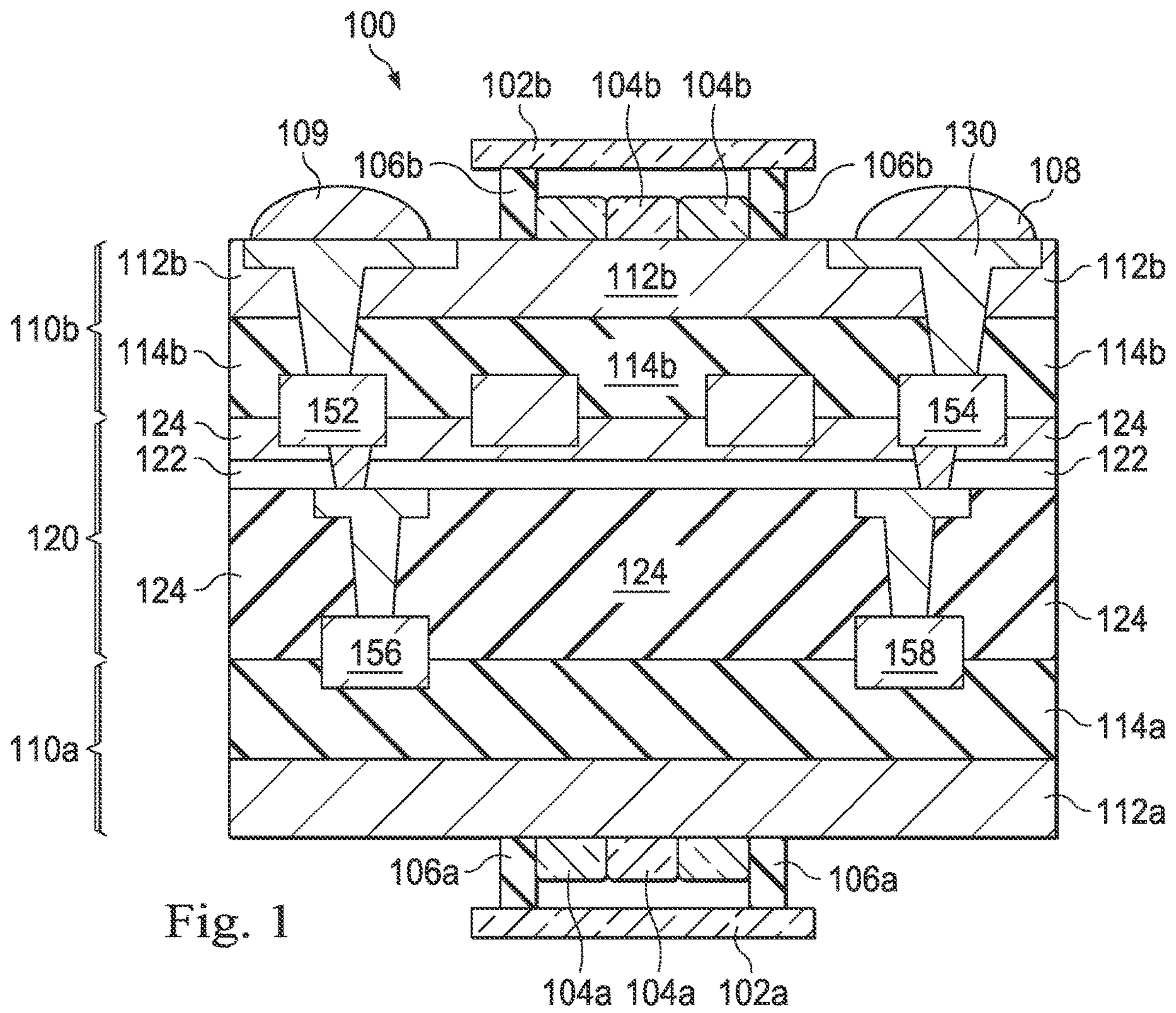

Fig. 1

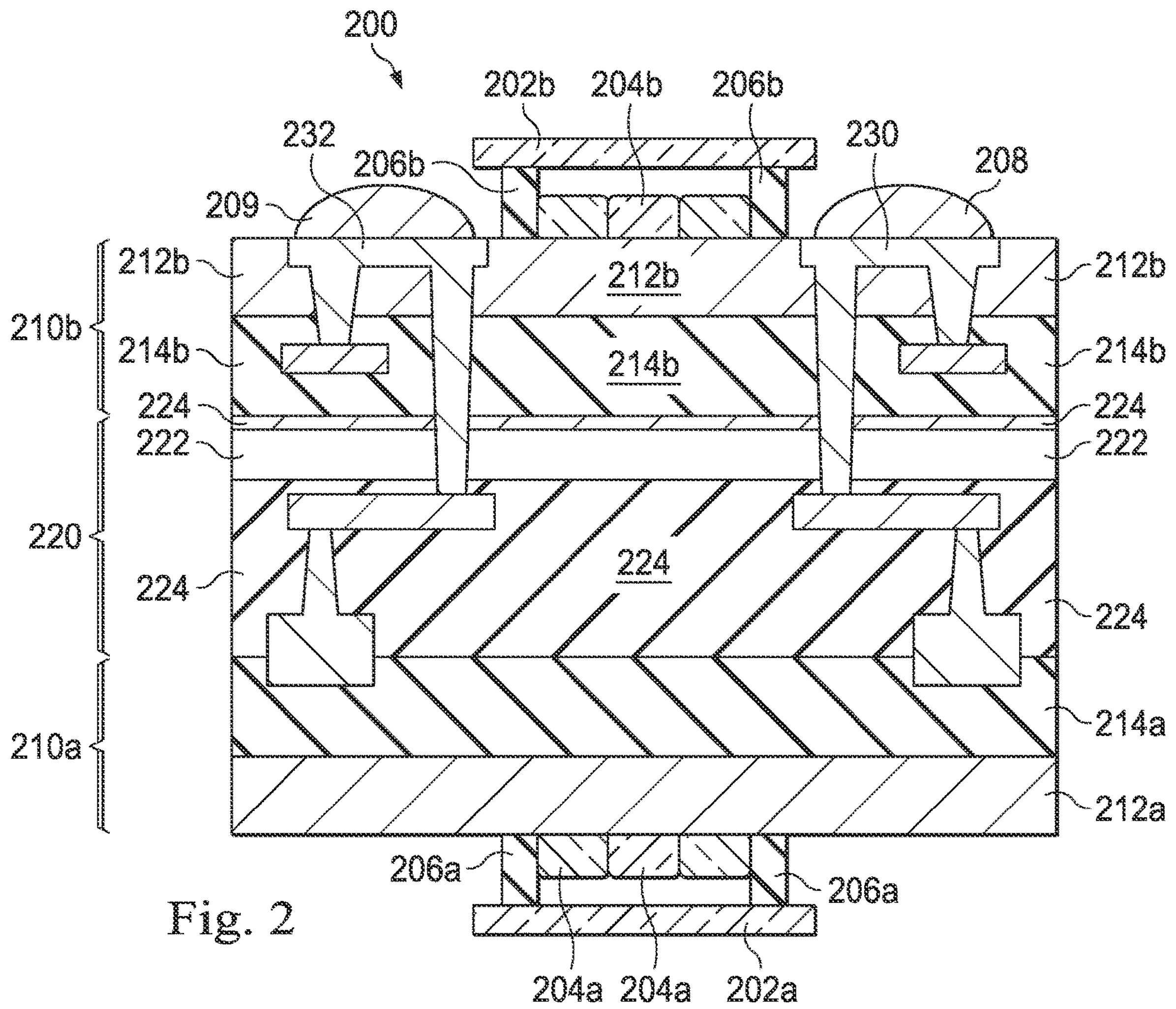

Fig. 2

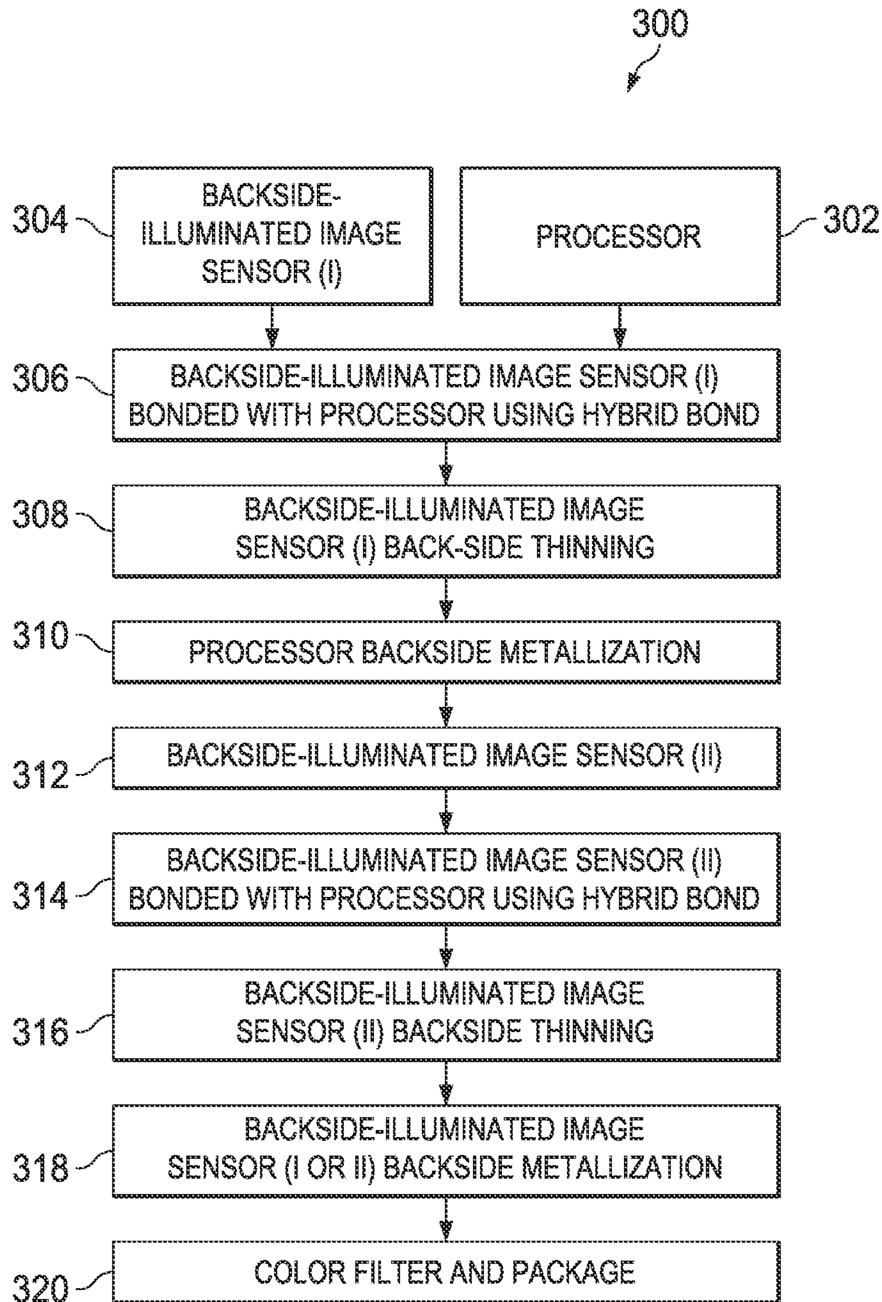

Fig. 3

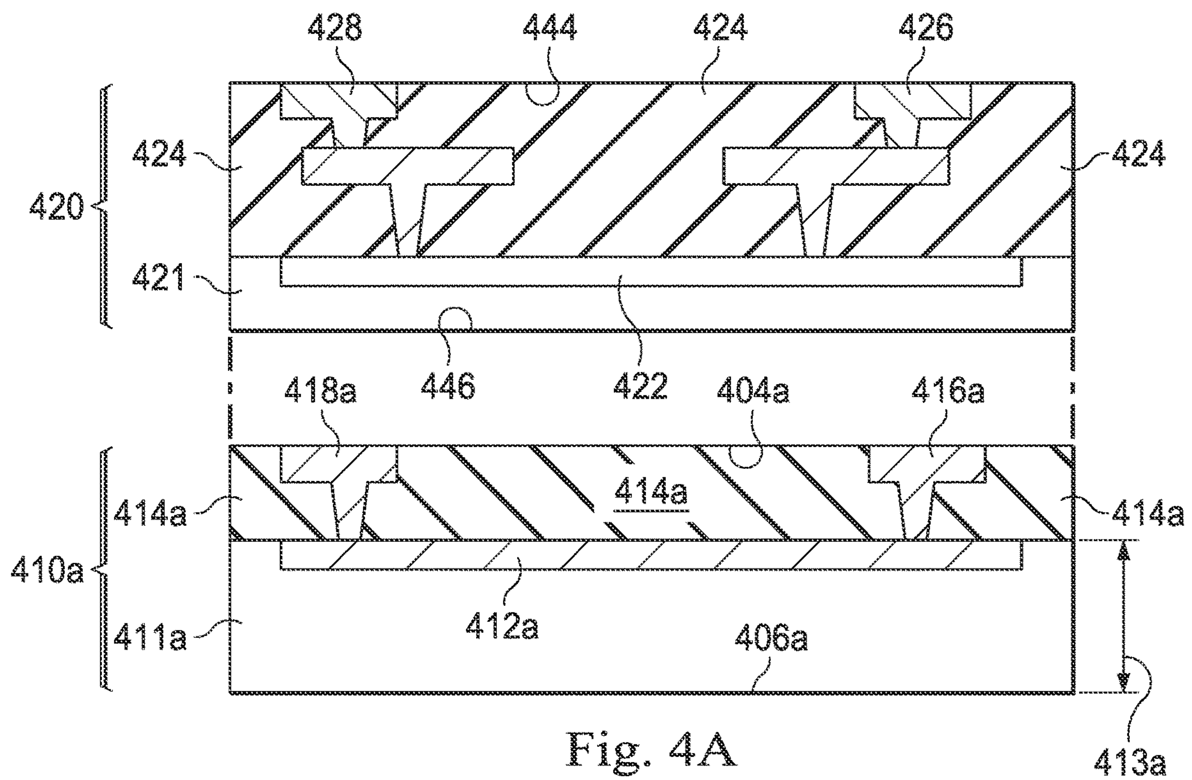

Fig. 4A

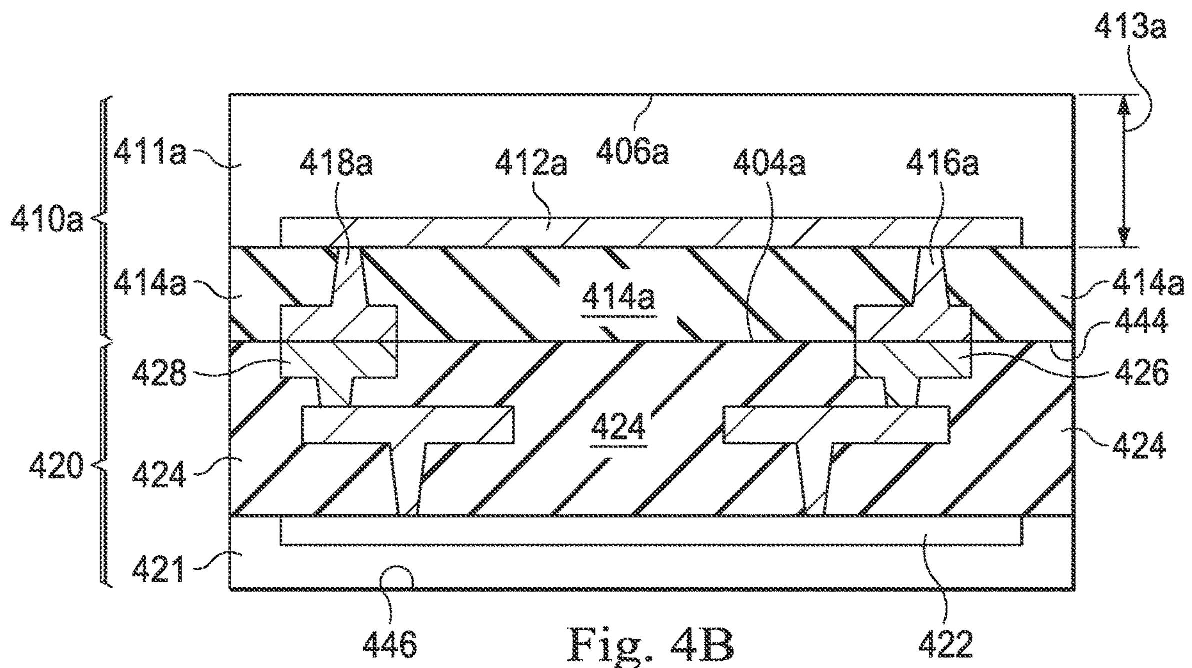

Fig. 4B

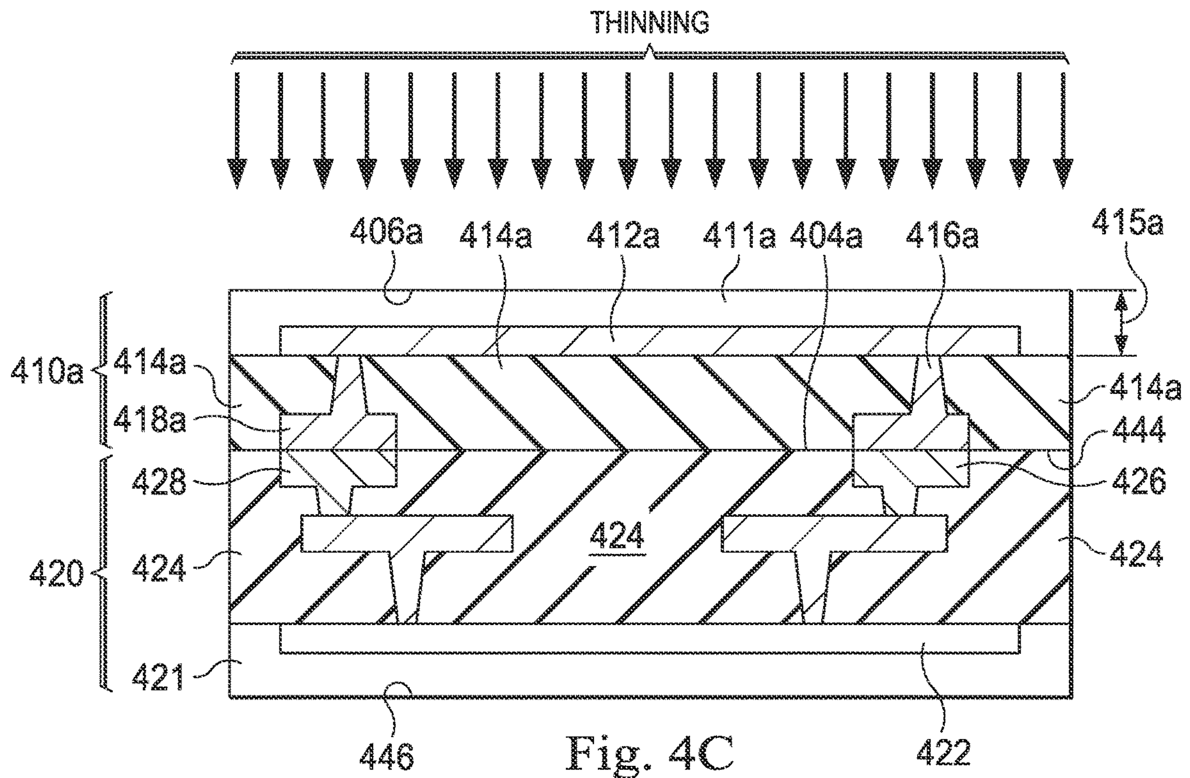

Fig. 4C

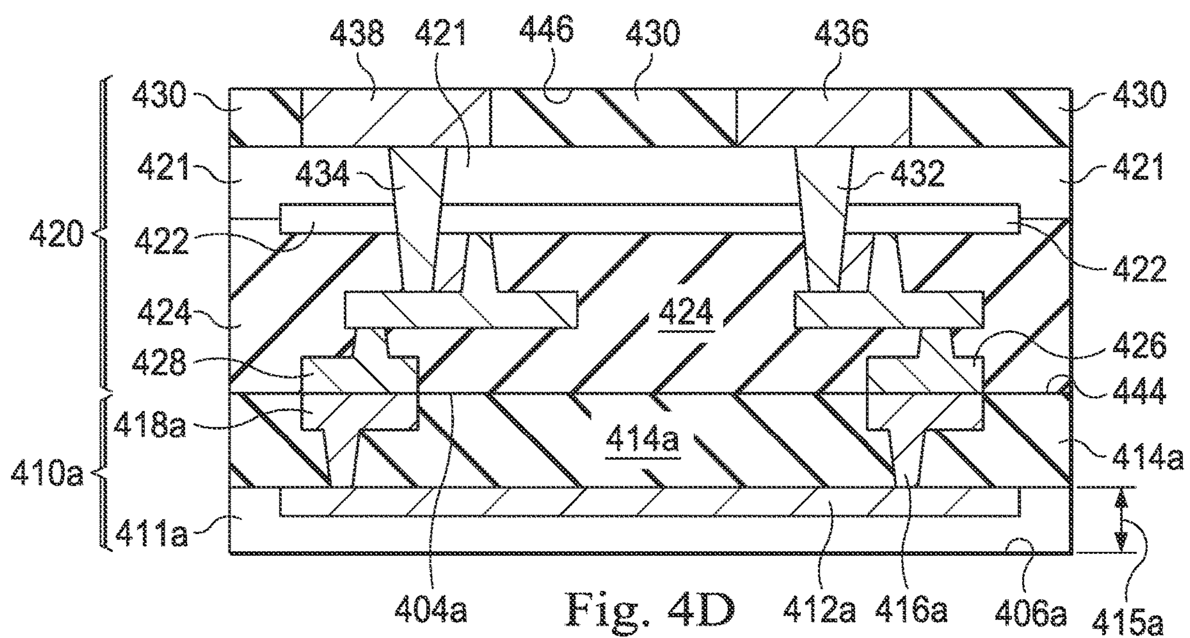

Fig. 4D

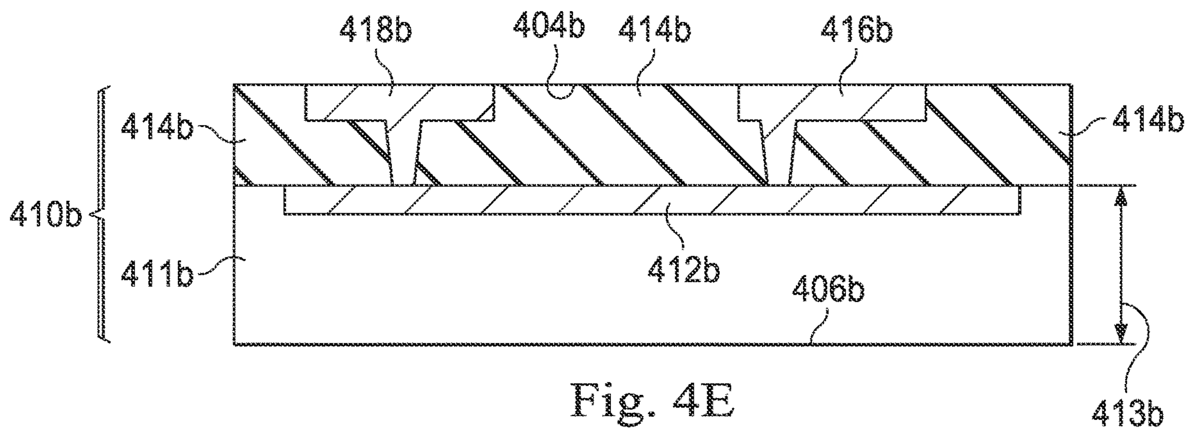

Fig. 4E

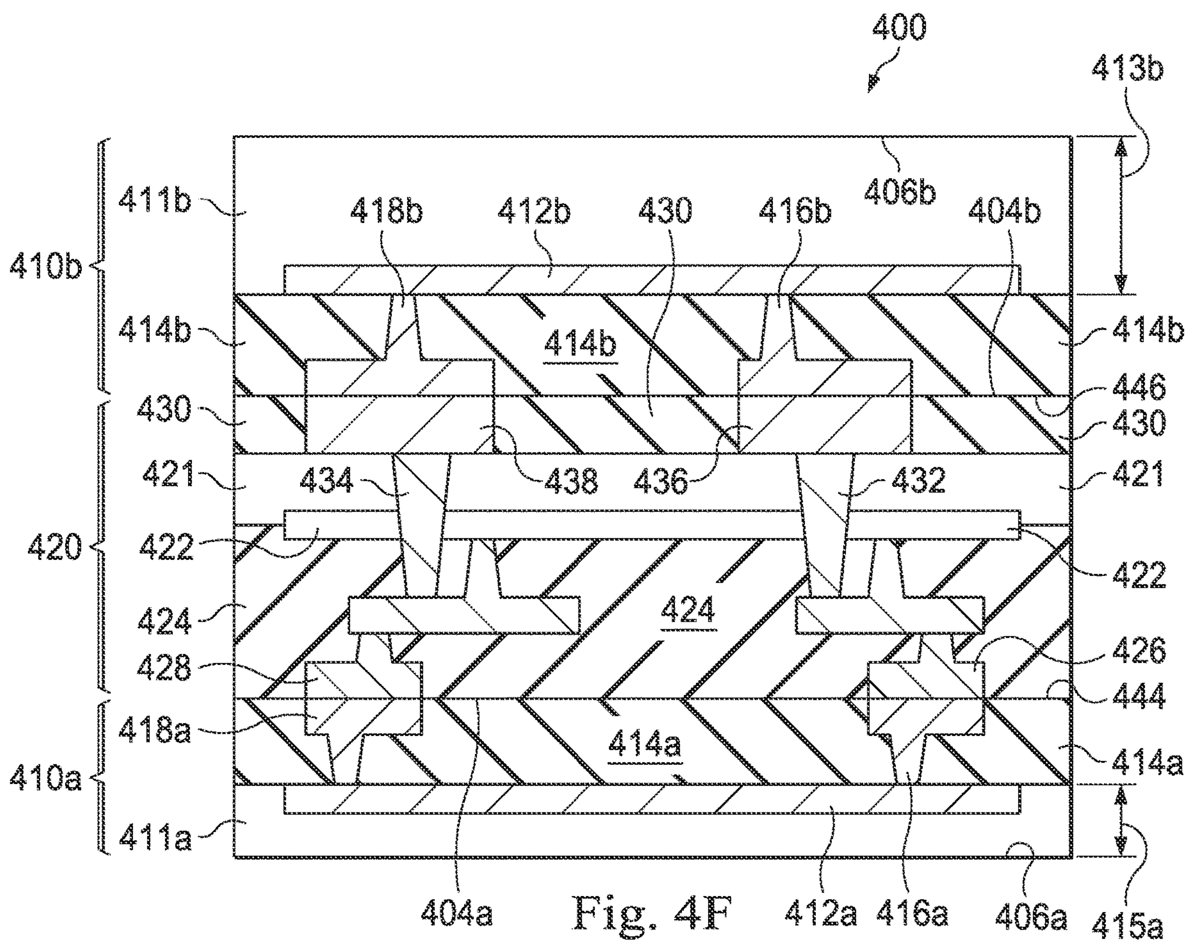

Fig. 4F

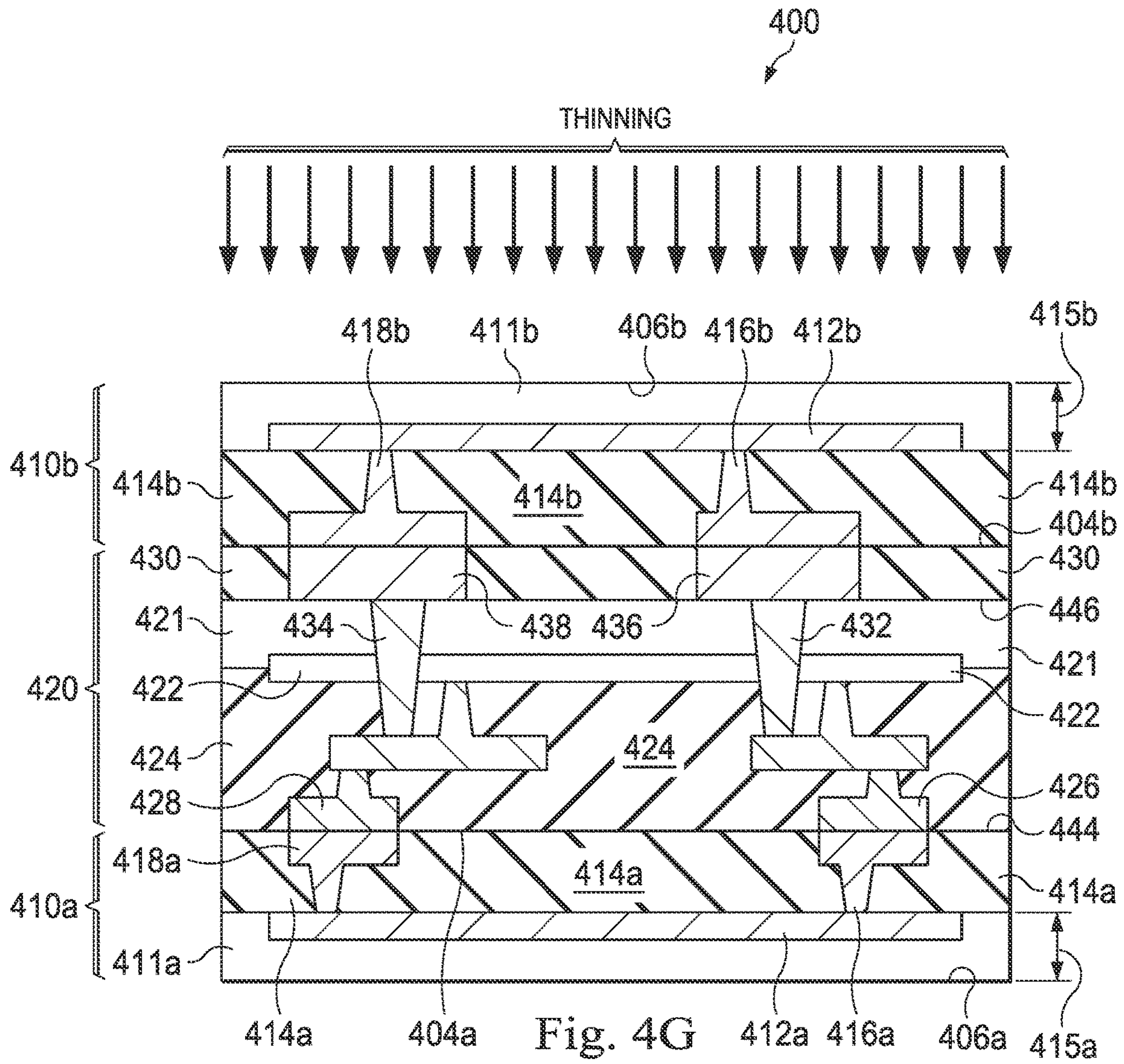

Fig. 4G

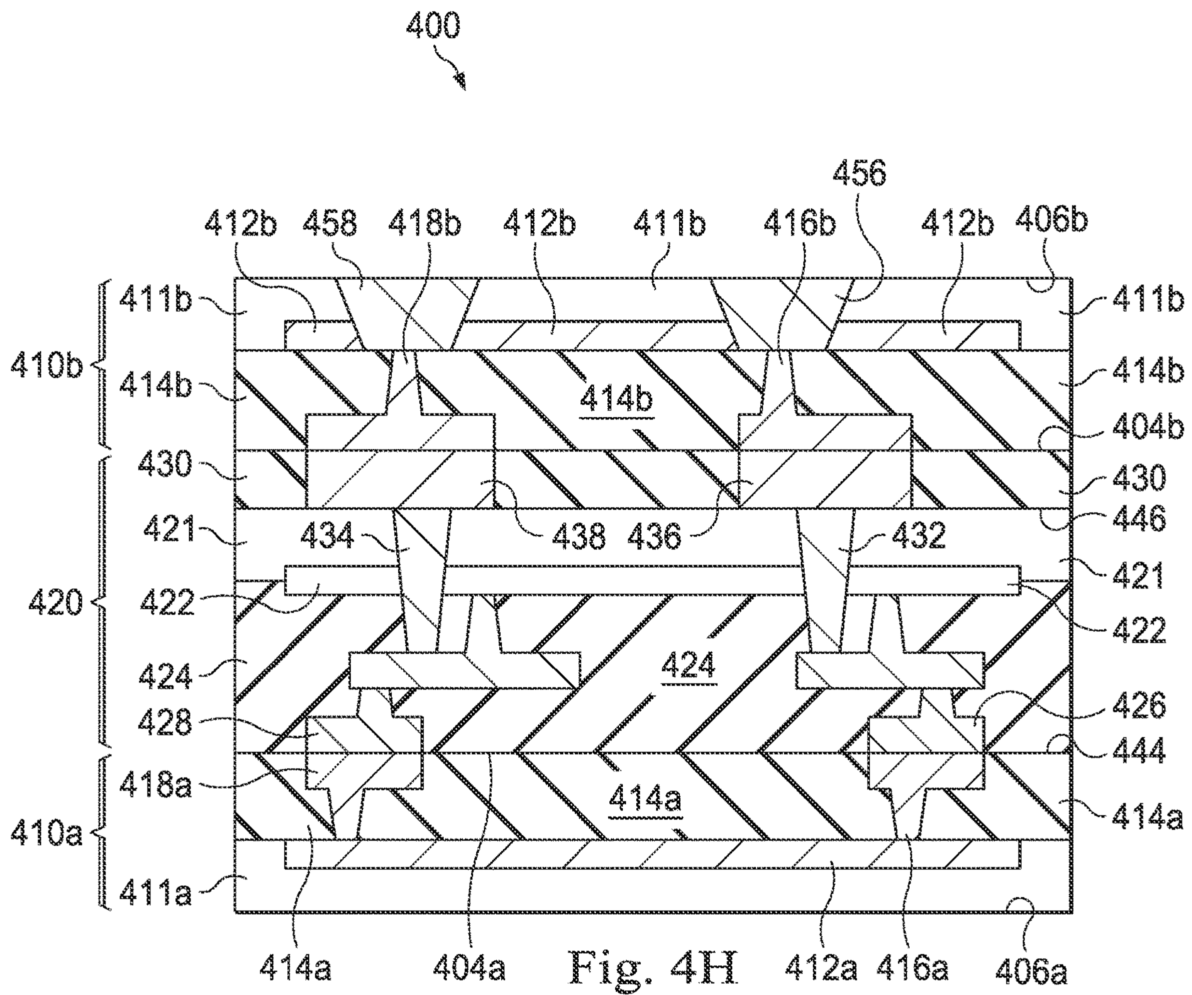

Fig. 4H

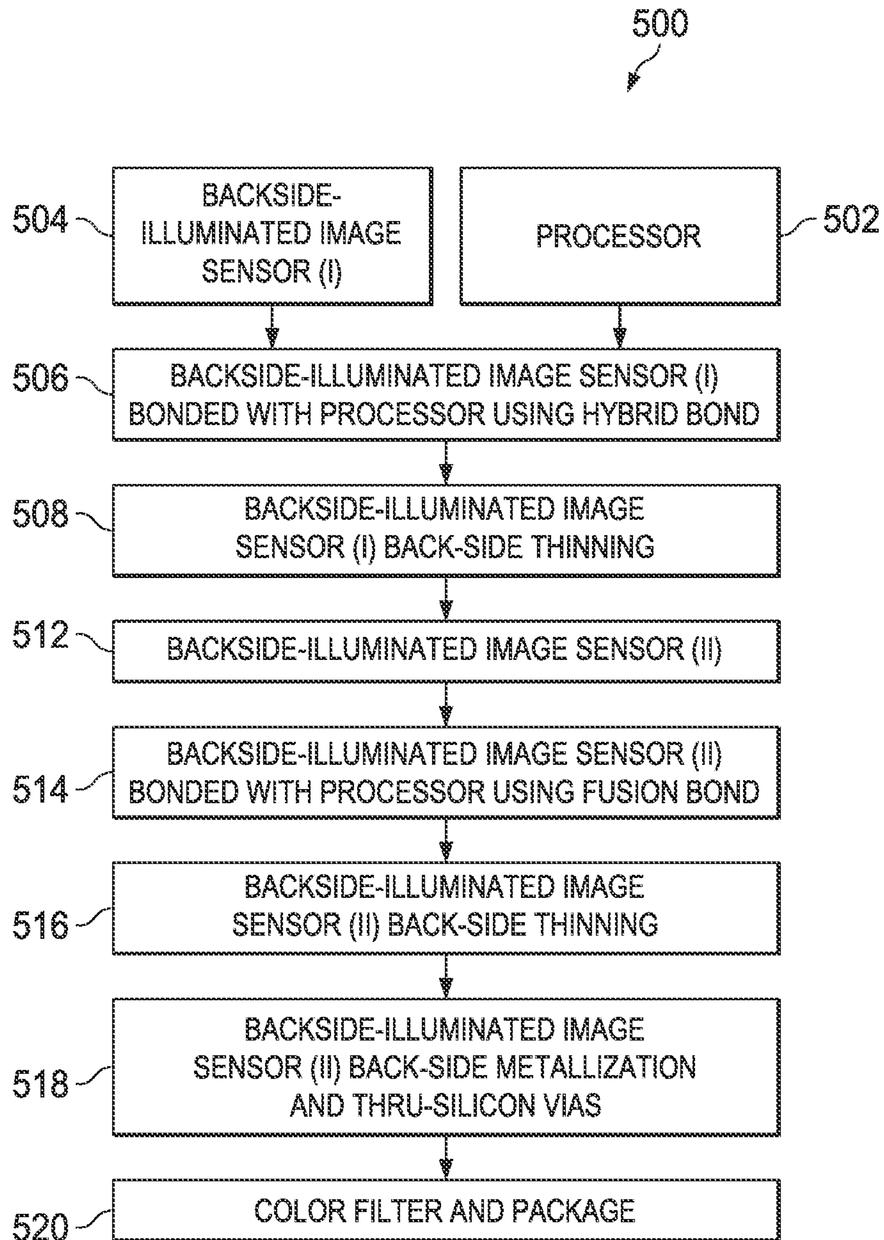

Fig. 5

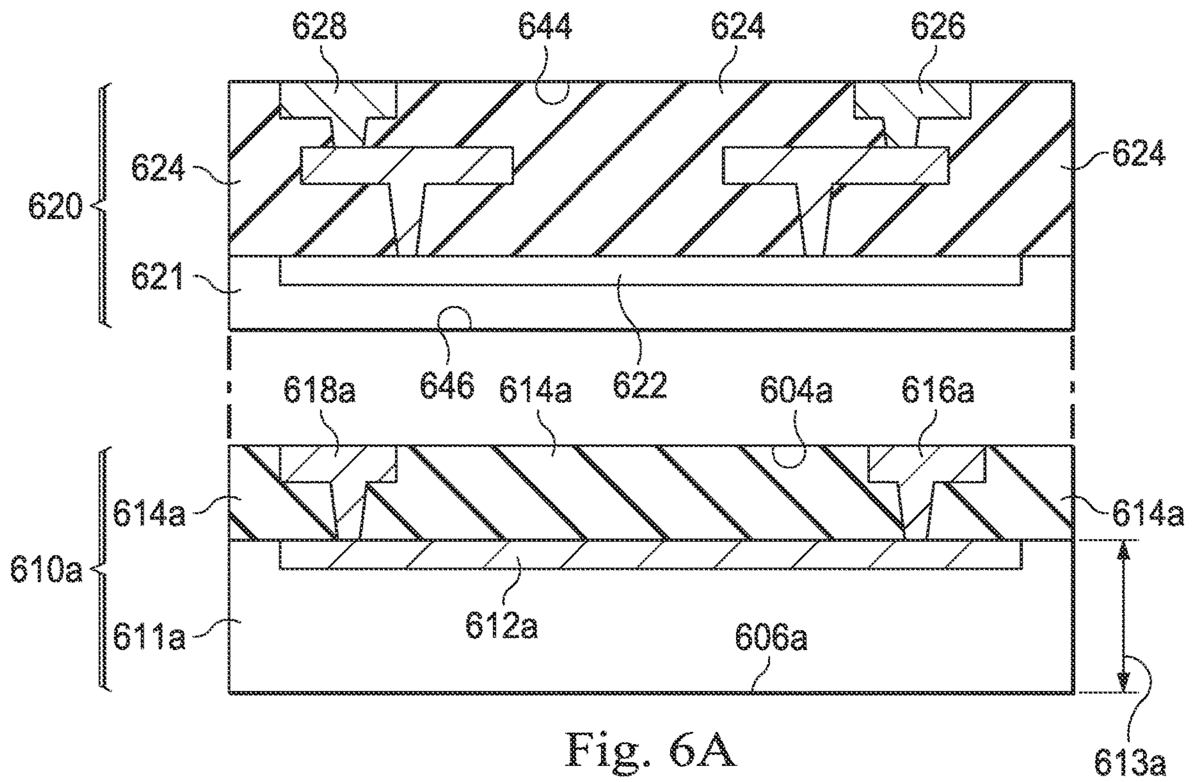

Fig. 6A

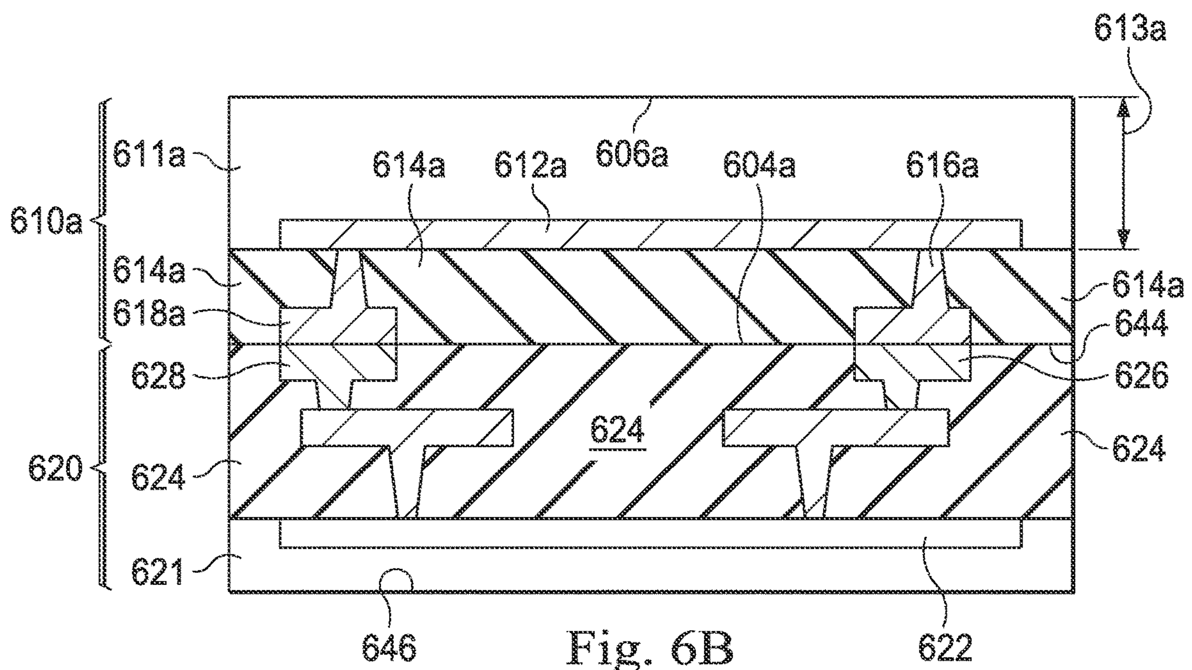

Fig. 6B

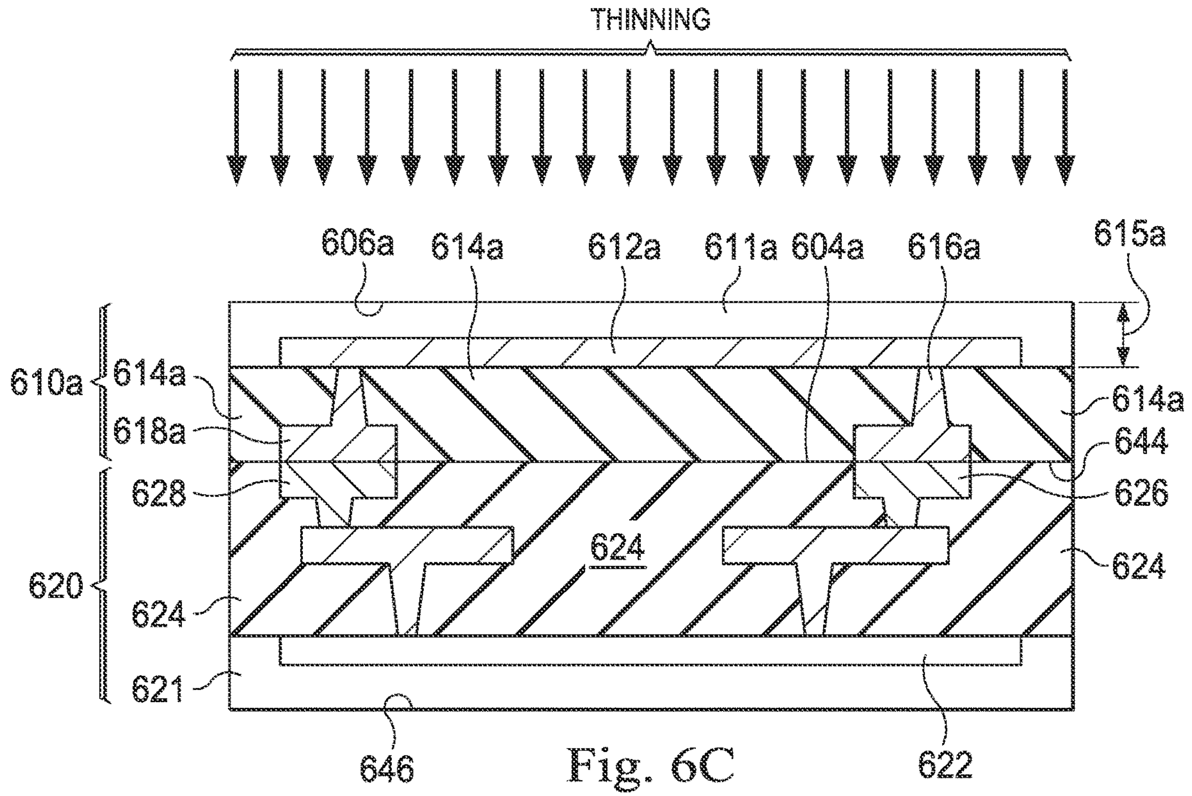

Fig. 6C

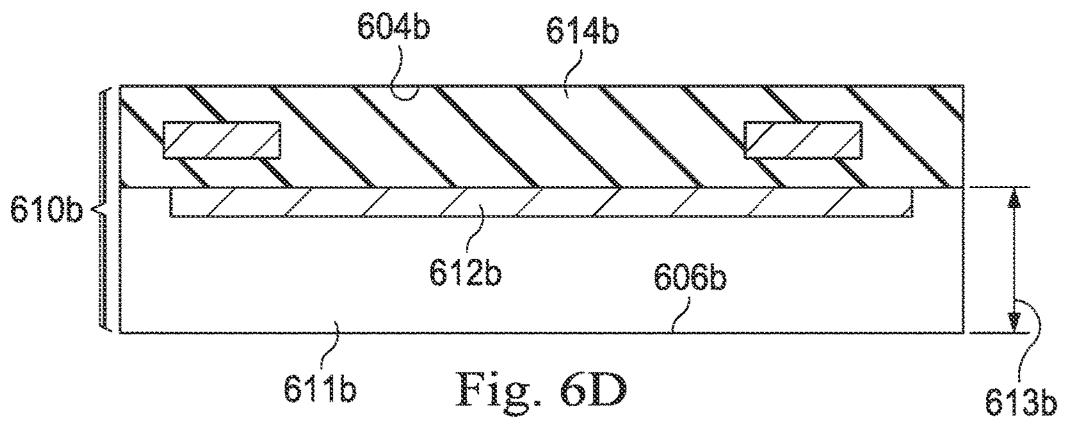

Fig. 6D

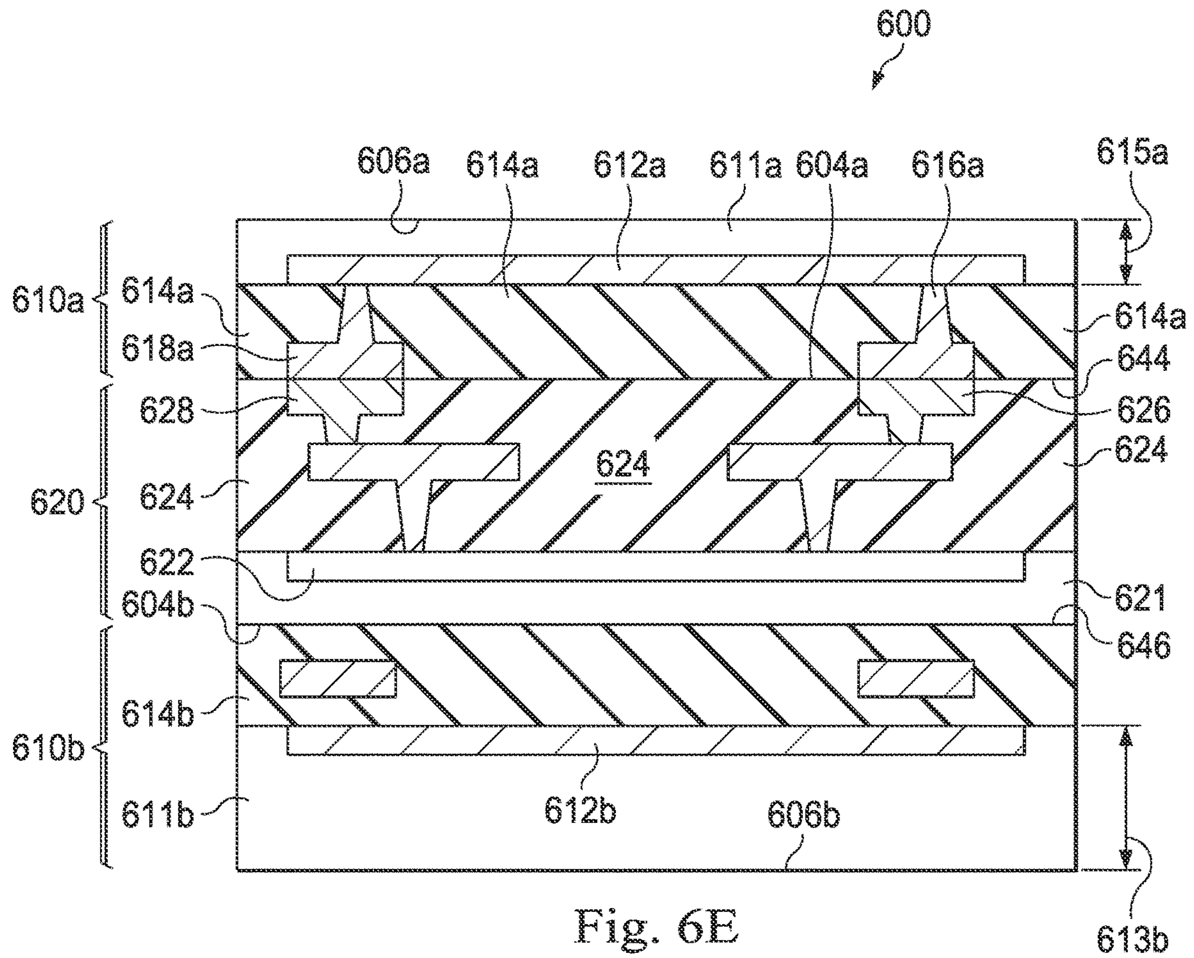

Fig. 6E

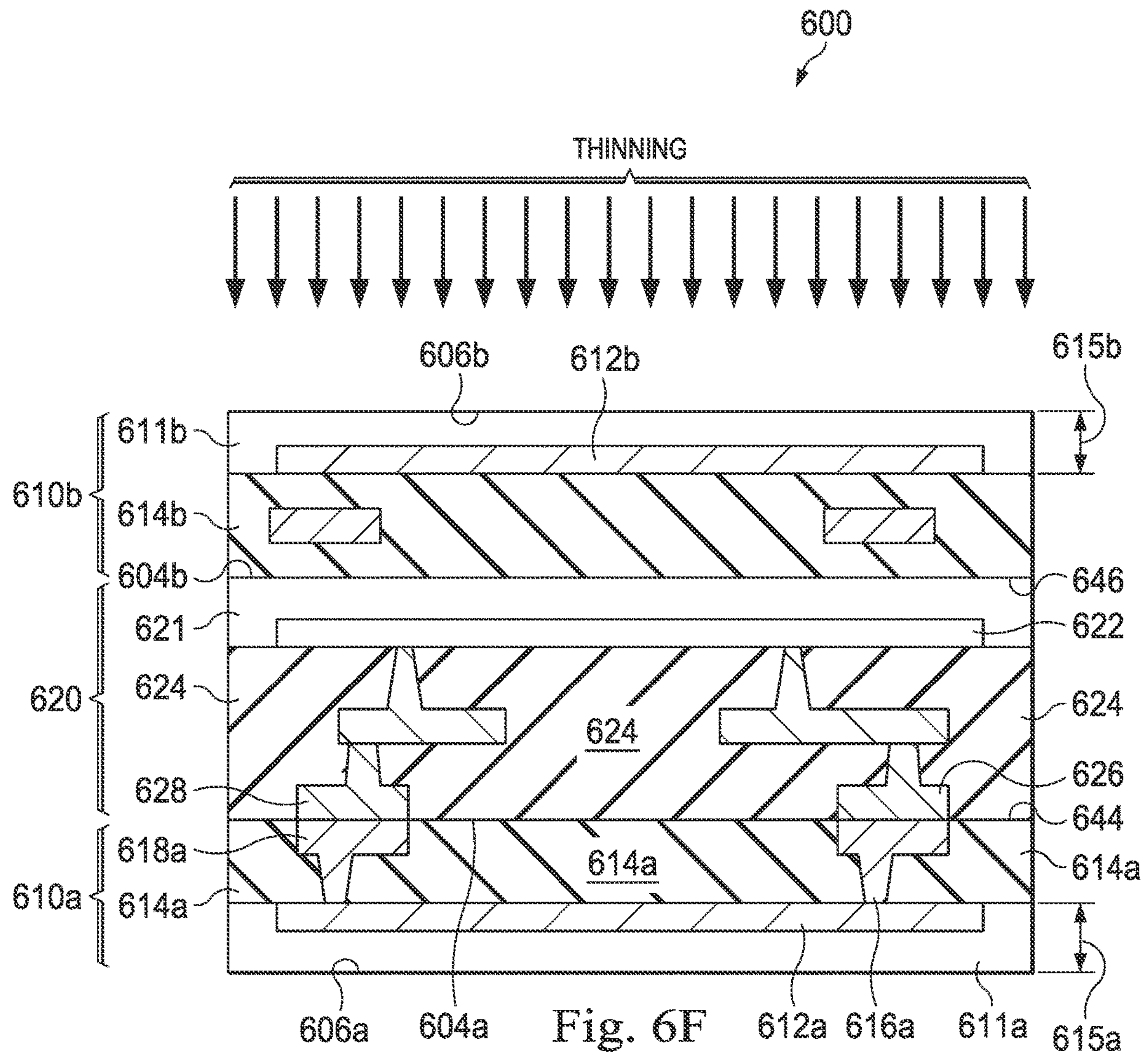

Fig. 6F

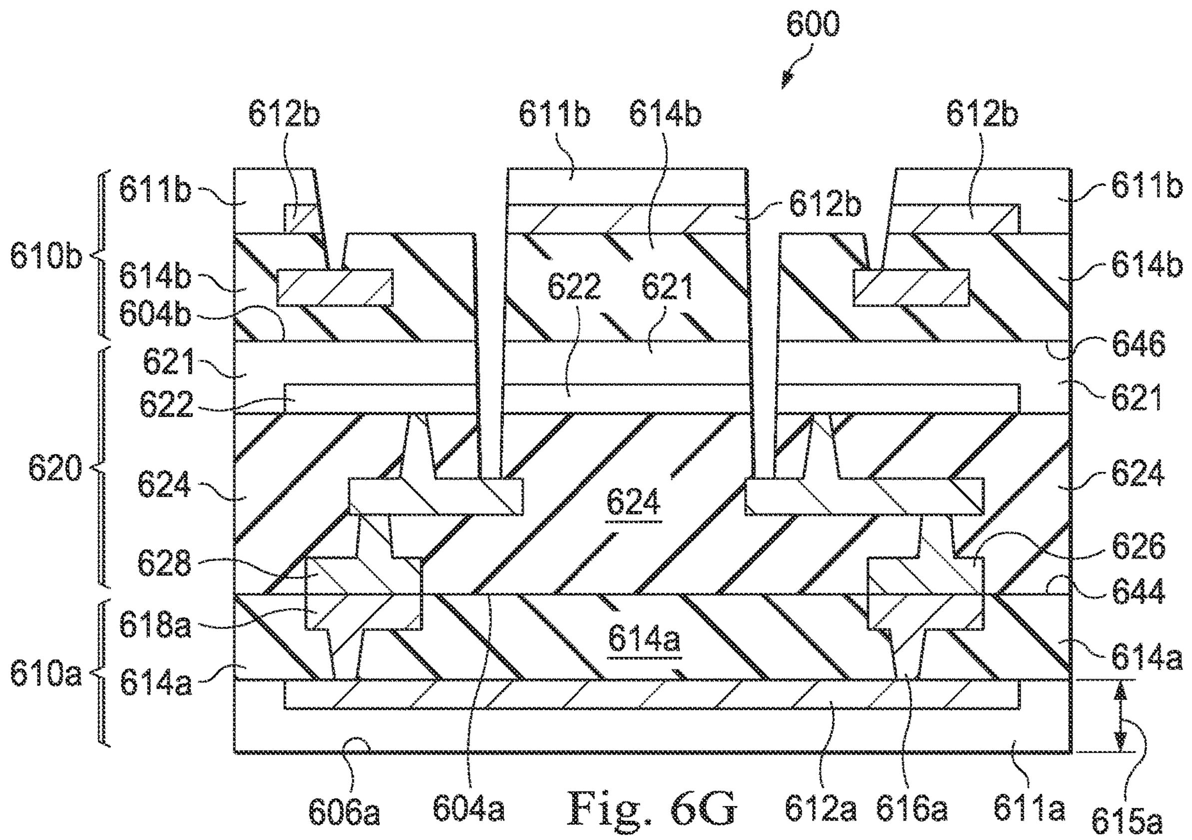

Fig. 6G

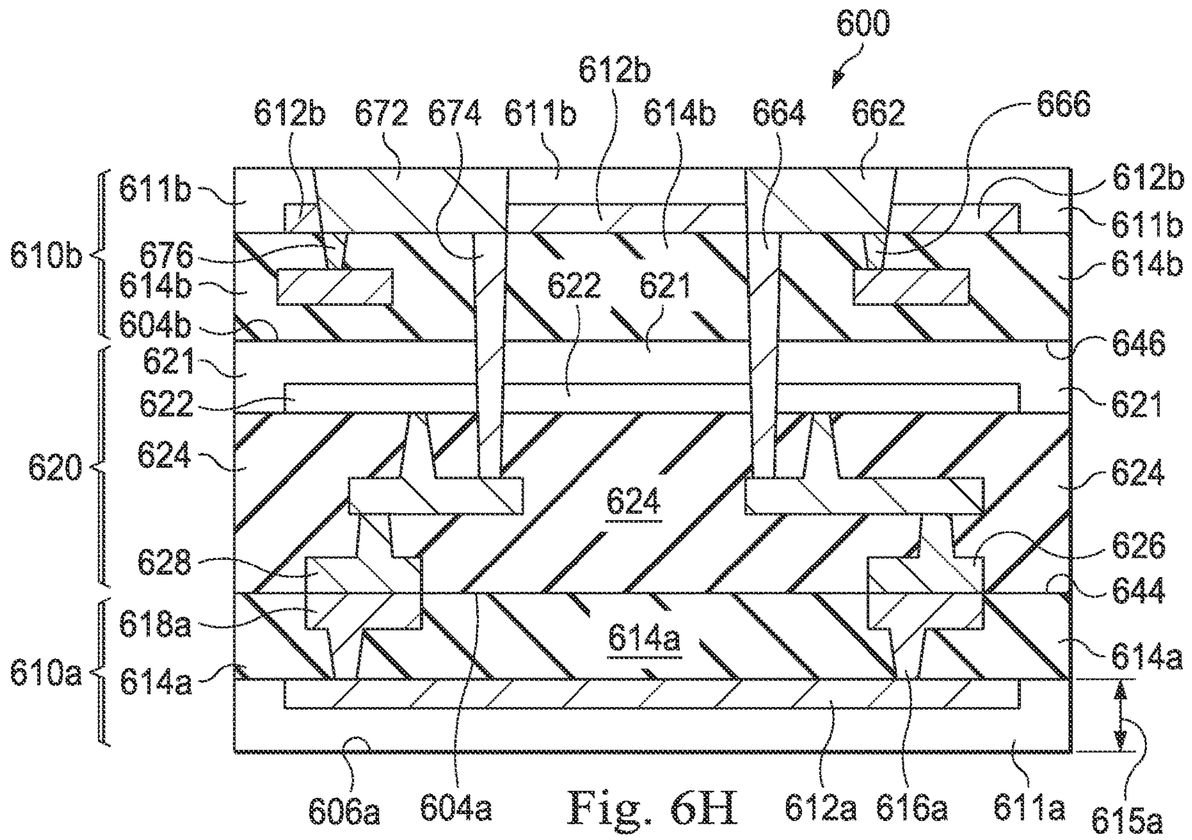

Fig. 6H

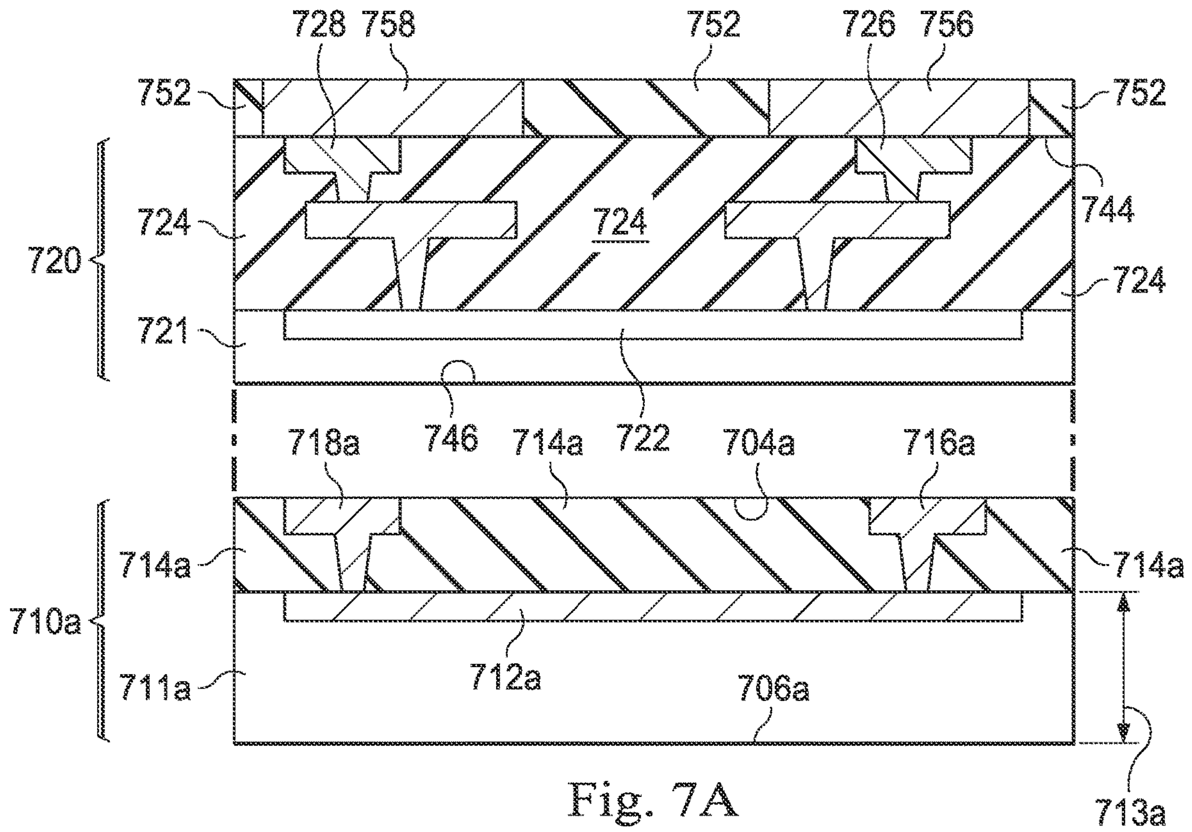

Fig. 7A

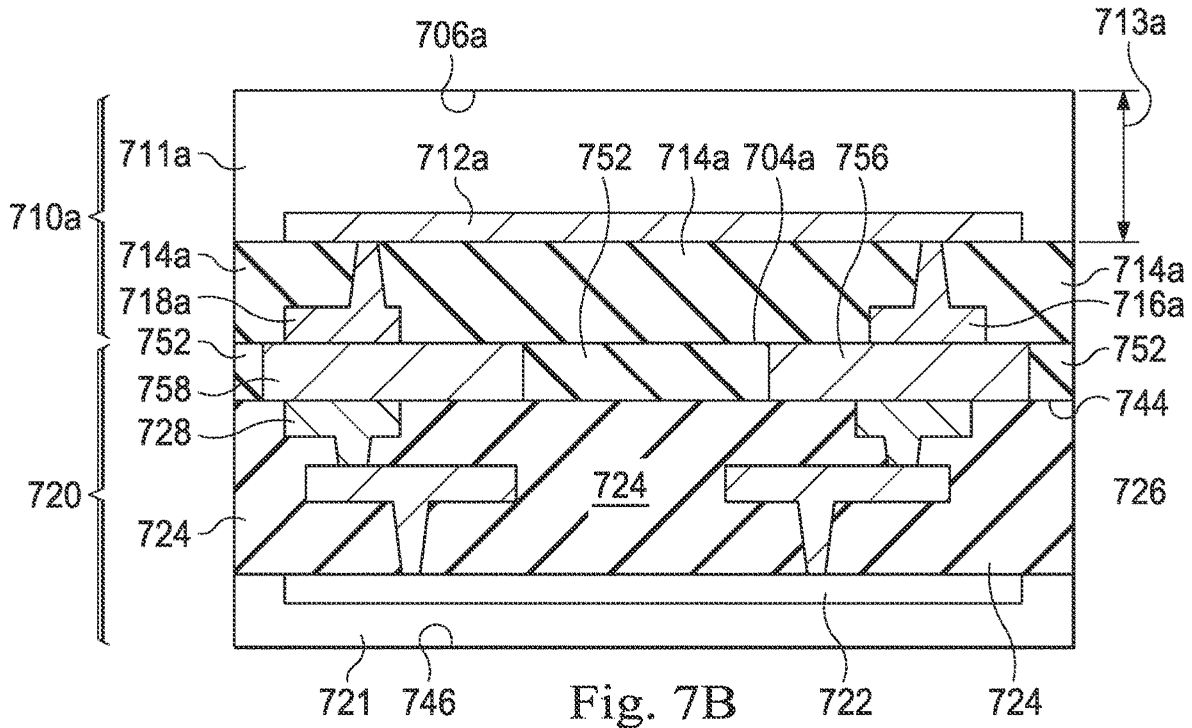

Fig. 7B

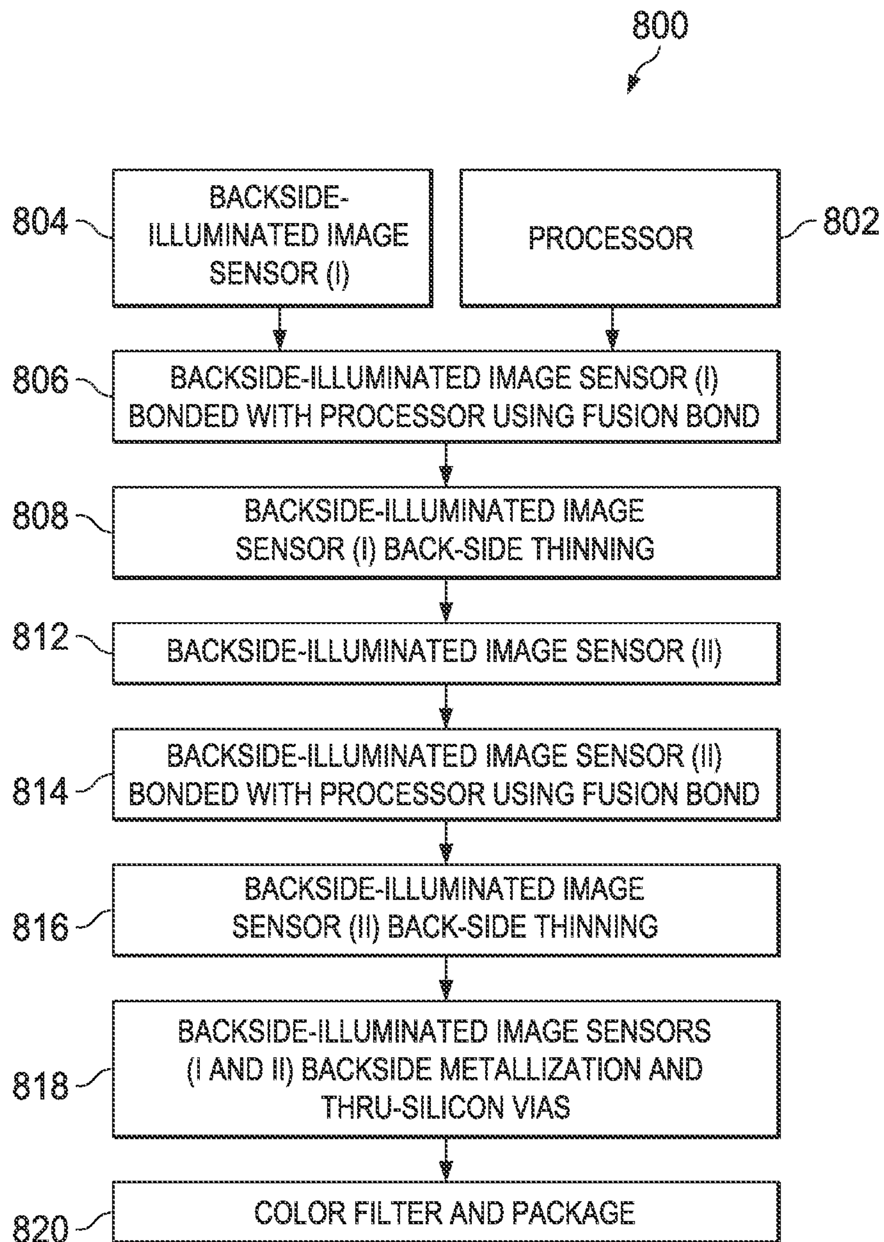

Fig. 8

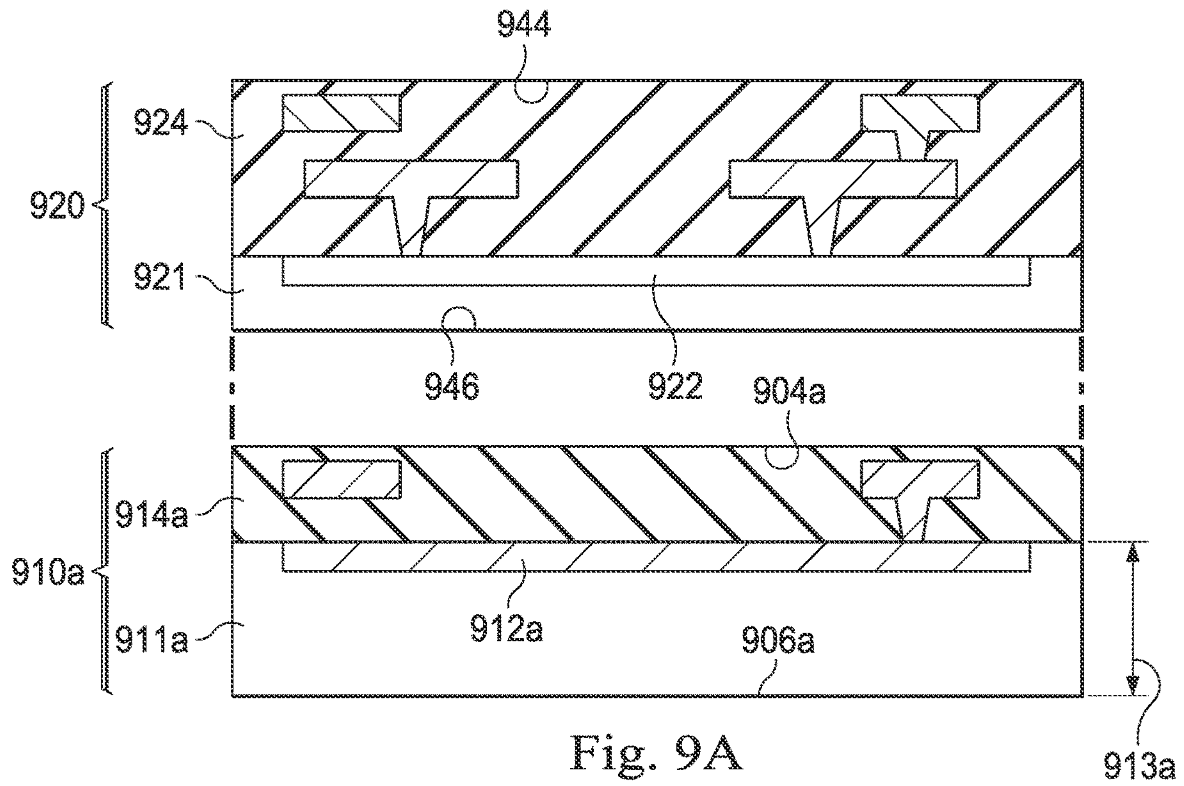

Fig. 9A

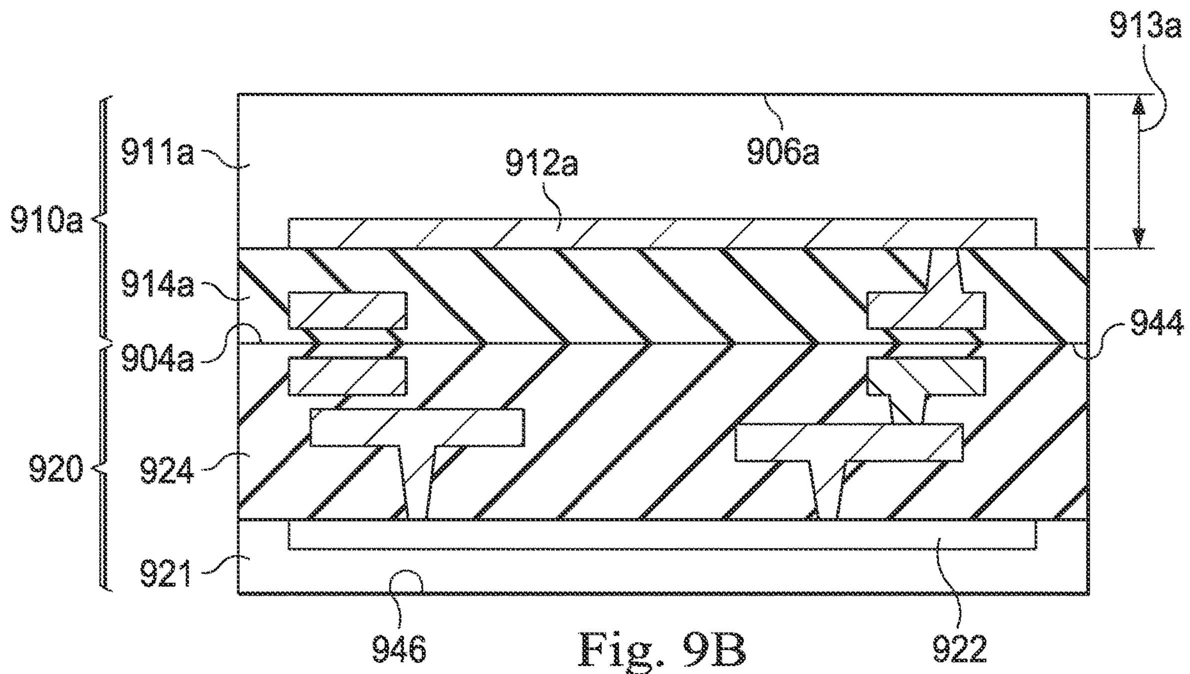

Fig. 9B

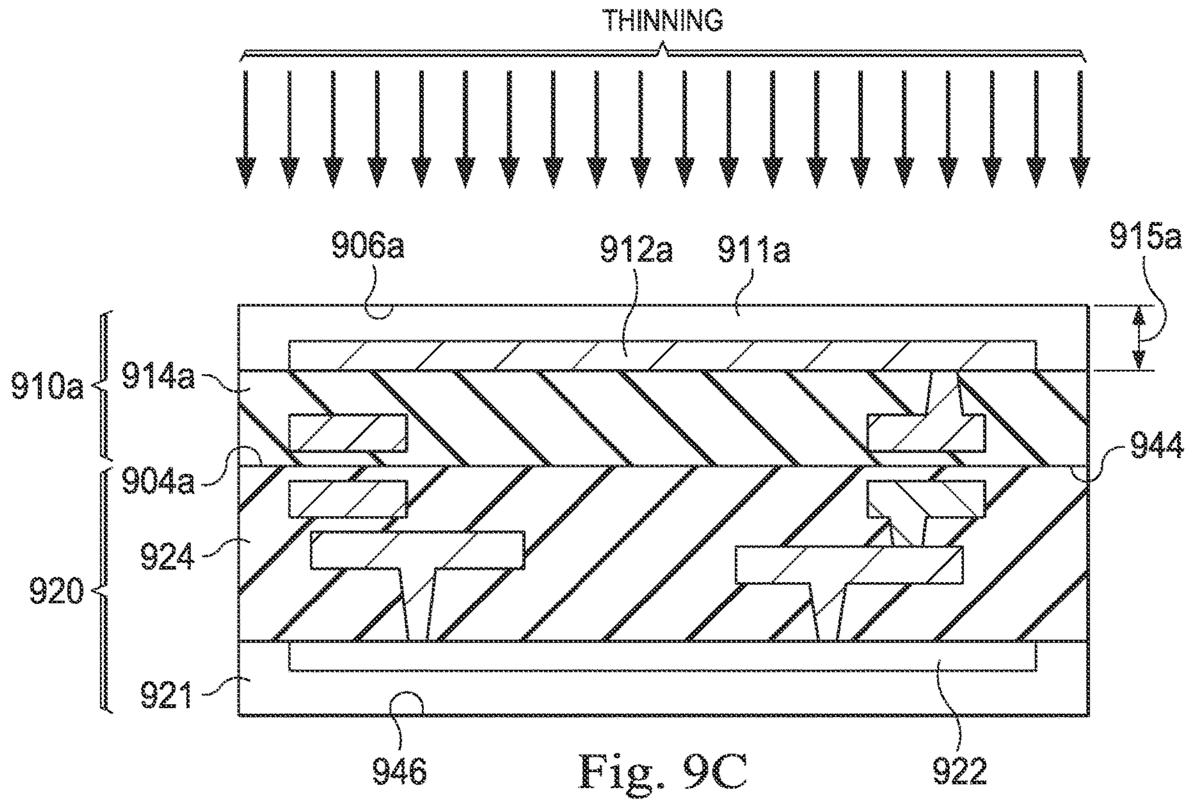

Fig. 9C

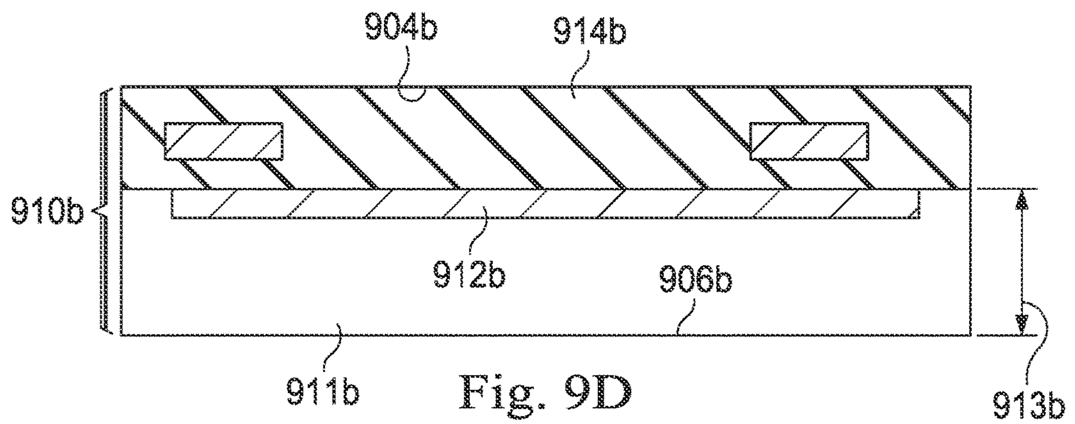

Fig. 9D

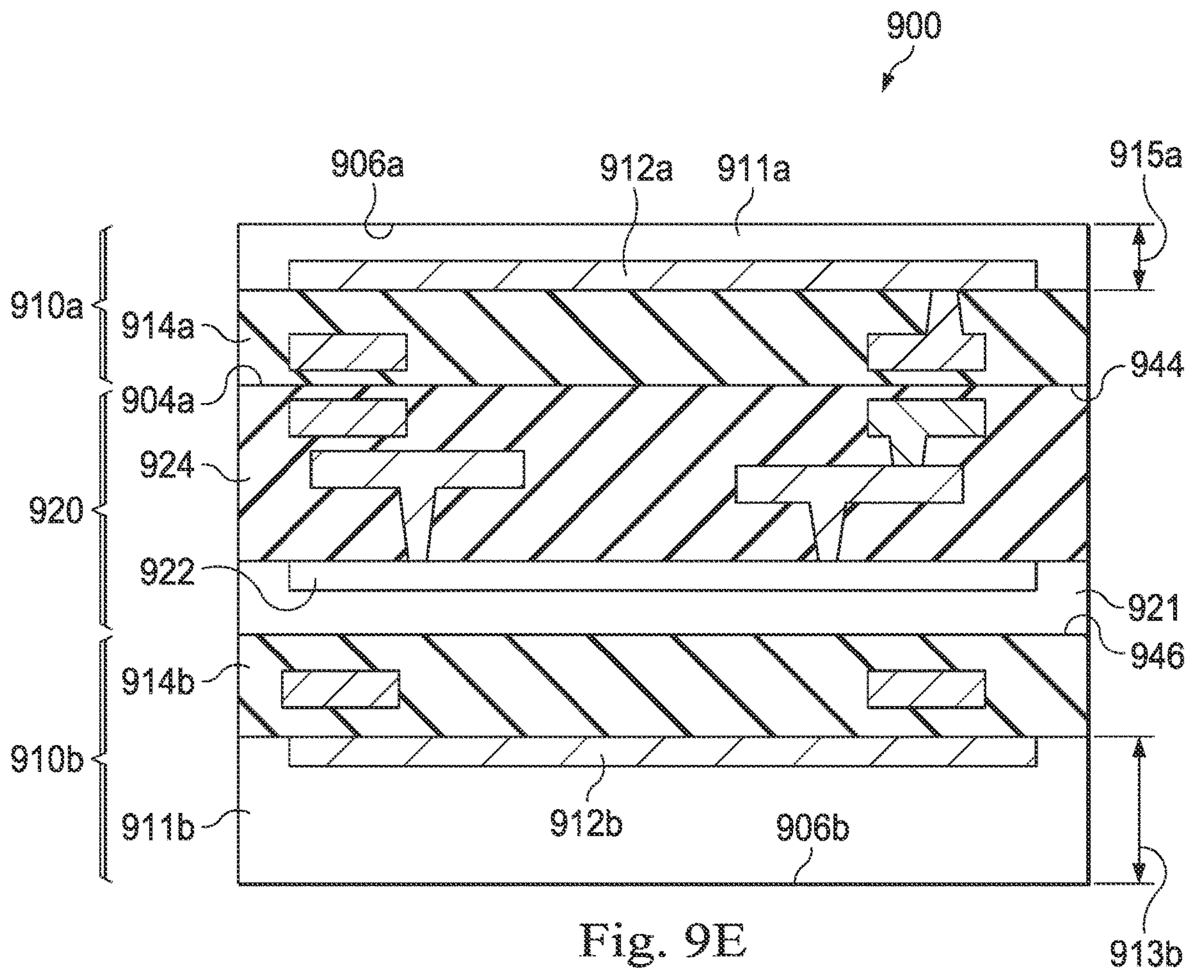

Fig. 9E

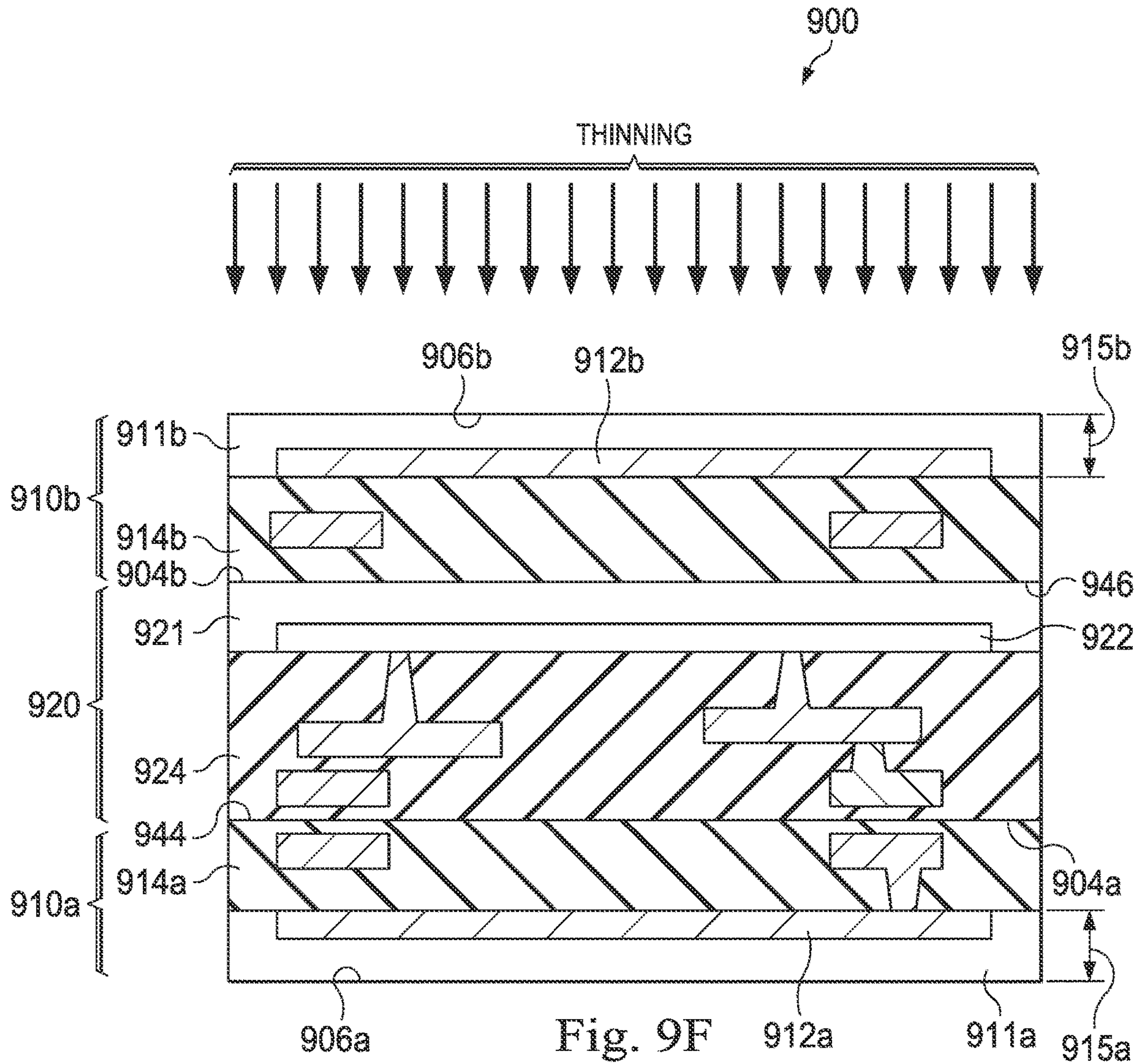

Fig. 9F

Fig. 9G

Fig. 9H

DUAL FACING BSI IMAGE SENSORS WITH WAFER LEVEL STACKING

PRIORITY DATA

The present application is a continuation application of U.S. patent application Ser. No. 16/658,355, filed Oct. 21, 2019, which is continuation application of U.S. patent application Ser. No. 15/651,402, filed Jul. 17, 2017, which is a divisional application of U.S. patent application Ser. No. 14/039,640, filed Sep. 27, 2013, each of which is hereby incorporated by reference in its entirety.

BACKGROUND

It is an ongoing trend that mobile electronic devices offer image capture capability. Some mobile electronic devices, such as a cellular phone, can capture images from both a front and a back side of the device. Many solutions exist for such dual facing camera capability. Solutions typically use two image sensors on opposing sides of the device.

Image sensors are integrated circuits (ICs) used to detect and measure radiation, such as light, received by the sensor device. A front-side illuminated (FSI) image sensor typically has pixel circuitry and metal stacks disposed on a front side of a substrate where a photosensitive or photodiode ("PD") region resides. To form an image in the PD region, the radiation passes the metal stacks. A backside-illuminated (BSI) image sensor, on the other hand, is typically formed on a thin substrate that allows the radiation to reach the PD region by passing through the substrate. A BSI image sensor offers many advantages over an FSI image sensor, such as shorter optical paths, higher quantum efficiency (QE), higher image resolution, smaller die sizes, etc.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale and are used for illustration purposes only. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

FIG. **1** illustrates an embodiment of an integrated camera module with dual-facing BSI image sensors.

FIG. **2** illustrates another embodiment of an integrated camera module with dual-facing BSI image sensors.

FIG. **3** is a flow chart for fabricating an integrated camera module with dual-facing BSI image sensors such as shown in FIG. **1**, in accordance with an embodiment.

FIGS. **4**A-**4**H are cross sectional views of forming an integrated camera module with dual-facing BSI image sensors according to the method of FIG. **3**, in accordance with an embodiment.

FIG. **5** is a flow chart for fabricating an integrated camera module with dual-facing BSI image sensors such as shown in FIG. **2**, in accordance with an embodiment.

FIGS. **6**A-**6**H are cross sectional views of forming an integrated camera module with dual-facing BSI image sensors according to the method of FIG. **5**, in accordance with an embodiment.

FIGS. **7**A and **7**B show an embodiment of an integration of a BSI image sensor wafer with a processor wafer according to various aspects of the present disclosure.

FIG. **8** is a flow chart for fabricating an integrated camera module with dual-facing BSI image sensors, in accordance with an embodiment.

FIGS. **9**A-**9**H are cross sectional views of forming an integrated camera module with dual-facing BSI image sensors according to the method of FIG. **8**, in accordance with an embodiment.

DETAILED DESCRIPTION

The following disclosure provides many different embodiments, or examples, for implementing different features of the disclosure. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed. Moreover, the performance of a first process before a second process in the description that follows may include embodiments in which the second process is performed immediately after the first process, and may also include embodiments in which additional processes may be performed between the first and second processes. Various features may be arbitrarily drawn in different scales for the sake of simplicity and clarity. Furthermore, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact.

Further, spatially relative terms, such as "beneath," "below," "lower," "above," "upper" and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as being "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the exemplary term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.

Various embodiments of the present disclosure relate generally to integration of two BSI image sensor wafers with a processor wafer to form a dual facing camera module using wafer level stacking methods. However, specific embodiments are provided as examples to teach the broader inventive concept, and one of ordinary skill in the art can easily apply the teaching of the present disclosure to other methods or device.

FIG. **1** illustrates an integrated camera module **100** according to various aspects of the present disclosure. The camera module **100** includes a processor **120** bonded in between two BSI image sensors, **110**a and **110**b. The processor **120** includes an active layer **122** which includes active circuit components such as transistors, and a metal stack **124** which includes interconnect structures for communicating within the processor **120** as well as communi-

cating between the processor **120** and the BSI image sensors **110***a* and **110***b*. The BSI image sensors **110***a*, **110***b* are similar in that they each include a PD layer **112***a*, **112***b* on its back side and a metal stack **114***a*, **114***b* on its front side. In this embodiment, the processor **120** contacts the BSI image sensors **110***a* and **110***b* through conductive features, **152**, **154**, **156** and **158**, at their bonding surfaces. The camera module **100** also includes color filter and lens modules, **104***a* and **104***b*, disposed over the back side of the respective BSI image sensors for collecting and filtering light. The camera module **100** further includes cover glass elements, **102***a* and **102***b*, and dam elements **106***a* and **106***b*, disposed over the color filter and lens modules **104***a* and **104***b*. The camera module **100** further includes bump elements **108** and **109** for providing further integration of the camera module **100** to a substrate (not shown). With such configuration as shown in FIG. **1**, the camera module **100** is able to capture radiation, such as light, incident upon both sides (dual-facing).

FIG. **2** illustrates another integrated camera module **200** according to various aspects of the present disclosure. The camera module **200** includes substantially the same elements as the camera module **100**, with a processor **220** bonded in between two BSI image sensors, **210***a* and **210***b*. In the camera module **200**, bump elements **208** and **209** are electrically coupled to the processor **220** using thru-silicon vias (TSVs), **230** and **232** (FIG. **2**), while the bump elements **108** and **109** of the camera module **100** are electrically coupled to the processor **120** through the conductive features **154** and **152** at the bonding surfaces of the processor **120** and the BSI image sensor **110***b* (FIG. **1**).

FIG. **3** illustrates a process flow **300** for fabricating an integrated camera module with dual-facing BSI image sensors, such as the camera module **100** (FIG. **1**), according to various aspects of the present disclosure. FIG. **3** is best understood in conjunction with FIGS. **4**A-**4**H.

The process flow **300** (FIG. **3**) receives a processor wafer (operation **302**) and a first BSI image sensor wafer (operation **304**). Referring to FIG. **4**A, an exemplar processor wafer **420** includes a substrate **421** and a metal stack **424** formed over the substrate **421**. The substrate **421** includes an active region **422**. The processor wafer **420** has two surfaces, **444** and **446**. The surface **444** is at a front side of the metal stack **424** and the surface **446** is at a back side of the substrate **421**. The surface **444** includes conductive pads, **426** and **428**, isolated by a dielectric material layer. The conductive pads, **426** and **428**, may contain a metal, such as copper. The dielectric material layer may include silicon oxide, silicon nitride, silicon oxynitride, a low-k material, or another suitable dielectric material. A thickness of the dielectric material layer is selected so that the dielectric material layer will effectively block migration of a metal applied to the surface **444** during a later bonding process. This will be described in more detail below. In an embodiment, the substrate **421** includes silicon. Alternatively, the substrate **421** may include another suitable semiconductor material. The active region **422** includes active and passive circuit components, such as field effect transistors (FETs), complementary metal-oxide semiconductor (CMOS) transistors, FinFETs, high voltage transistors, high frequency transistors, bipolar junction transistors, resistors, capacitors, diodes, fuses, other suitable devices, and/or combinations thereof. The metal stack **424** includes multilayer interconnect structures for electrically coupling circuit components in the active region **422**. The interconnect structures include various conductive features, such as contacts, vias, and/or conductive traces. The various conductive features include materials such as copper, aluminum, aluminum/silicon/copper alloy, titanium, titanium nitride, tungsten, polysilicon, metal silicide, and/or combinations thereof. The processor wafer **420** is provided merely as an example, and its exact composition and/or functionality do not limit the inventive principles of the present disclosure.

Referring again to FIG. **4**A, a first BSI image sensor wafer **410***a* includes a substrate **411***a* and a metal stack **414***a* formed over the substrate **411***a*. The substrate **411***a* includes a photosensitive or photodiode ("PD") region **412***a*. The BSI wafer **410***a* has two surfaces, **404***a* and **406***a*. The surface **404***a* is at a front side of the metal stack **414***a* and the surface **406***a* is at a back side of the substrate **411***a*. The surface **404***a* includes conductive pads, **416***a* and **418***a*, isolated by a dielectric material about the same as the dielectric material of the surface **444**. The conductive pads, **416***a* and **418***a*, use about the same material as that of the conductive pads **426** and **428**. The metal stack **414***a* may include one or more layers of metal separated by inter-layer dielectric (ILD) layers.

The substrate **411***a* has an initial thickness **413***a*. In some embodiments, the initial thickness **413***a* is in a range from about 100 microns (μm) to about 3000 μm, for example between about 500 μm and about 1000 μm. Radiation, such as light, is projected from the back side and enters the substrate **411***a* through the surface **406***a*.

In some embodiments, the substrate **411***a* includes an elementary semiconductor such as silicon or germanium and/or a compound semiconductor, such as silicon germanium, silicon carbide, gallium arsenic, indium arsenide, gallium nitride, and indium phosphide. Other exemplary substrate materials include alloy semiconductors, such as silicon germanium carbide, gallium arsenic phosphide, and gallium indium phosphide. The substrate **411***a* may also include non-semiconductor materials including soda-lime glass, fused silica, fused quartz, calcium fluoride (CaF_2), and/or other suitable materials. In some embodiments, the substrate **411***a* has one or more layers defined within it, such as an epitaxial layer. For example, in one such embodiment, the substrate **411***a* includes an epitaxial layer overlying a bulk semiconductor. Other layered substrates include semiconductor-on-insulator (SOI) substrates. In one such SOI substrate, the substrate **411***a* includes a buried oxide (BOX) layer formed by a process such as separation by implanted oxygen (SIMOX). In various embodiments, the substrate **411***a* may take the form of a planar substrate, a fin, a nanowire, and/or other forms.

The substrate **411***a* may include one or more doped regions. For example, the substrate **411***a* may be doped with a p-type dopant. Suitable p-type dopants include boron, gallium, indium, other suitable p-type dopants, and/or combinations thereof. Alternatively, the substrate **411***a* may include one or more regions doped with an n-type dopant such as phosphorus, arsenic, other suitable n-type dopants, and/or combinations thereof. Doping may be implemented using a process such as ion implantation or diffusion in various steps and techniques.

The PD region **412***a* includes one or more sensor element which may be standalone or an integral part of a larger pixel array, such as the array commonly found in a digital camera sensor. The sensor element detects the intensity (brightness) of radiation incident upon the back surface **406***a* of the substrate **411***a*. In some embodiments, the incident radiation is visual light. Alternatively, the incident radiation may be infrared (IR), ultraviolet (UV), x-ray, microwave, other suitable radiation, and/or combinations thereof. The sensor element may be configured to respond to particular wavelengths or ranges of wavelengths, such as red, green, and

blue wavelengths within the visible light spectrum. The sensor element(s) in the PD region **412***a* may be formed in the substrate **411***a* by a method such as diffusion and/or ion implantation.

Although not shown, the substrate **411***a* includes other structures or devices, such as a pixel circuitry for controlling and communicating with the PD region **412***a* for image acquisition, shallow trench isolations (STIs) for isolating sensor elements, and other passive or active devices.

The process flow **300** (FIG. **3**) proceeds to operation **306** where the processor wafer **420** is aligned and bonded with the BSI wafer **410***a* using a hybrid bond process. Referring to FIG. **4**B, the surface **444** is directly bonded with the surface **404***a* with the conductive pads **428** and **426** bonded with the conductive pads **418***a* and **416***a* respectively. A hybrid bond process refers to bonding of two surfaces where each surface includes at least two substantially different materials (a hybrid surface). In the present embodiment, the conductive pads, **426**, **428**, **416***a*, and **418***a*, contain a metal, such as copper, while the surfaces **444** and **404***a* contain a layer of dielectric material such as oxide, silicon oxide, silicon nitride, or silicon oxynitride. In an embodiment, the surfaces **444** and **404***a* contain a layer of silicon oxynitride having a thickness of at least 30 nanometers (nm) so as to effectively block migration of copper if the two surfaces are misaligned. In another embodiment, the surfaces **444** and **404***a* contain a layer of silicon nitride having a thickness of at least 5 nm so as to effectively block migration of copper if the two surfaces are misaligned.

In the present embodiment, the hybrid bond process includes an initial bonding process at a lower temperature followed by an annealing process at an elevated temperature. The initial bonding process may use a technique such as a direct bonding or other bonding techniques. Generally, it takes longer, e.g. a few hours, for the initial bonds to form. Therefore, a lower temperature is used during the initial bonding process to avoid undesirable changes or decomposition in the wafers **420** and **410***a*. In an embodiment, the initial bonding process may take place at room temperature or another temperature that is below 200 degrees Celsius. In an embodiment, pressure is applied to the wafers **420** and **410***a* for the initial bonds to form. The annealing process is applied after the initial bonding process to strengthen the bonds between the two hybrid surfaces **404***a* and **444**. In the present embodiment, the annealing process undergoes at least two stages of bond formation at temperatures higher than the initial bonding temperature. During a first stage, covalent bonds are formed between the dielectric materials, e.g. between two oxides, of the surfaces **420** and **410***a* at a first temperature, such as about 200 degrees Celsius. In an embodiment, the first stage takes about one and half hours. During a second stage, metal bonding are formed, e.g. by copper inter-diffusion, at a second temperature that is higher than the first temperature, such as about 350 degrees Celsius. In an embodiment, the second stage takes about half an hour. The temperatures of the annealing process are generally under about 450 degrees Celsius, as higher temperature may lead to damages in the wafers **420** and **410***a*. However, the specific temperatures and durations disclosed above are mere examples and do not limit the inventive scope of the present disclosure. Moreover, in the present embodiment, bonding of the conductive pads **426**/**416***a* and **428**/**418***a* is for illustrative purposes only and does not indicate a specific orientation of the BSI wafer **410***a* with respect to the processor wafer **420**.

The process flow **300** (FIG. **3**) proceeds to operation **308** where the first BSI wafer **410***a* is thinned down. Referring to FIG. **4**C, a thinning process is applied to thin down the BSI wafer substrate **411***a* from its back side surface **406***a*. The thinning process may include a mechanical grinding process and a chemical thinning process. A substantial amount of substrate material may be first removed from the substrate **411***a* during the mechanical grinding process. Afterwards, the chemical thinning process may apply an etching chemical to the back side of the substrate **411***a* to further thin the substrate **411***a* to a thickness **415***a*, which may be on the order of a few microns (μm). The thickness **415***a* affects a quantum efficiency of the BSI image sensors in the wafer **410***a*. In some embodiments, the thickness **415***a* is selected to improve the quantum efficiency of the BSI image sensors. In some embodiments, the thickness **415***a* is greater than about 1 μm but less than about 5 μm. The particular thicknesses disclosed in the present disclosure are mere examples and other thicknesses may be implemented depending on the type of application and design of the integrated camera module **100** (FIG. **1**).

The process flow **300** (FIG. **3**) proceeds to operation **310** where the backside of the substrate **421** undergoes a metallization process. Referring to FIG. **4**D, a passivation layer **430** is formed over the substrate **421** using a suitable process such as a process including a deposition process and a chemical mechanical polishing (CMP) process. In an embodiment, the passivation layer **430** includes a dielectric material, such as oxide or silicon oxide. Conductive features, **436**, **438**, **432** and **434**, are further formed into the passivation layer **430** and through the substrate **421** for coupling the metal stack **424** to the passivation layer **430**. The process of forming the conductive features includes etching the various layers to form thru-layer or thru-silicon vias and/or contact trenches; depositing a conductive material, such as copper, into the vias and/or trenches; and performing a CMP process to the conductive material.

The process flow **300** (FIG. **3**) proceeds to operation **312** where a second BSI wafer **410***b* is received. Referring to FIG. **4**E, the second BSI wafer **410***b* includes a substrate **411***b* and a metal stack **414***b* formed over the substrate **411***b*. The substrate **411***b* has a thickness **413***b* and includes a photosensitive or photodiode ("PD") region **412***b*. The BSI wafer **410***b* has two surfaces, **404***b* and **406***b*. The surface **404***b* is at a front side of the metal stack **414***b* and the surface **406***b* is at a back side of the substrate **411***b*. The surface **404***b* includes conductive pads, **416***b* and **418***b*, isolated by a dielectric material about the same as the dielectric material of the surface **446**. The conductive pads, **416***b* and **418***b*, use about the same material as that of the conductive pads **436** and **438**. The metal stack **414***b* may include one or more layers of metal separated by inter-layer dielectric (ILD) layers. The BSI wafer **410***b* may use a composition similar to or different from the BSI wafer **410***a*. Moreover, the BSI wafers **410***a* and **410***b* may contain the same or different number of imaging pixels.

The process flow **300** (FIG. **3**) proceeds to operation **314** where the second BSI wafer **410***b* is aligned and bonded with the processor wafer **420** using a hybrid bond process. Referring to FIG. **4**F, the surface **404***b* of the BSI wafer **410***b* is directly bonded with the surface **446** of the processor wafer **420** with the conductive pads **418***b* and **416***b* on the BSI wafer **410***b* bonded with the conductive pads **438** and **436** on the processor wafer **420** respectively. The hybrid bond process in this operation may be substantially similar to the hybrid bond process in operation **306**, with temperatures and duration suitable for the material/composition of the surfaces **446** and **404***b*. The operation **314** thus produces

an assembly **400** with the processor wafer **420** bonded in between the BSI wafers **410***a* and **410***b*.

The process flow **300** (FIG. **3**) proceeds to operation **316** where the second BSI wafer **410***b* is thinned down. Referring to FIG. **4**G, a thinning process is applied to thin down the BSI wafer substrate **411***b* from its back side surface **406***b*. The thinning process in this operation may be substantially similar to the thinning process in operation **308**. The substrate **411***b* is thinned to a thickness **415***b*, which may be on the order of a few microns (μm). In some embodiments, the thickness **415***b* is greater than about 1 μm but less than about 5 μm. The thickness **415***b* may be similar to or different from the thickness **415***a* depending on the type of application and design of the integrated camera module **100** (FIG. **1**).

The process flow **300** (FIG. **3**) proceeds to operation **318** where conductive features are formed on the back side of the BSI wafer **410***b* (or **410***a*) so that the assembly **400** may be further integrated with other components of the integrated camera module **100** (FIG. **1**). Referring to FIG. **4**H, conductive features **458** and **456** are formed into the substrate **411***b* and are coupled to the metal stack **414***b* and/or the metal stack **424**. The process of forming the conductive features **458** and **456** includes etching the substrate **411***b* to form thru-layer or thru-silicon vias and/or contact trenches; depositing a conductive material, such as copper, into the vias and/or trenches; and performing a polishing process to the conductive material. Either the back side of the BSI wafer **410***b* or the back side of the BSI wafer **410***a* may be used for operation **318**.

The process flow **300** (FIG. **3**) proceeds to operation **320** to complete the integrated camera module **100** (FIG. **1**). Operation **320** may include forming color filters and lens over both sides of the assembly **400**, installing glass covers over the color filters and lens, installing package balls over the conductive pads **448** and **446** for further integration, and so on.

FIG. **5** illustrates a process flow **500** for fabricating an integrated camera module with dual-facing BSI image sensors, such as the camera module **200** (FIG. **2**), according to various aspects of the present disclosure. FIG. **5** is best understood in conjunction with FIGS. **6**A-**6**H. For simplicity purposes, where an operation in the process flow **500** is similar to an operation in the process flow **300**, a reference to the process flow **300** is made and differences are highlighted.

The process flow **500** (FIG. **5**) receives a processor wafer (operation **502**) and a first BSI image sensor wafer (operation **504**). Referring to FIG. **6**A, an exemplar processor wafer **620** includes a substrate **621** and a metal stack **624** formed over the substrate **621**. The substrate **621** includes an active region **622**. The processor wafer **620** has two surfaces, **644** and **646**. The surface **644** is at a front side of the metal stack **624** and the surface **646** is at a back side of the substrate **621**. The surface **644** includes conductive pads, **626** and **628**, isolated by a dielectric material. The structure and composition of the processor wafer **620** is similar to the processor wafer **420** (FIG. **4**A). Also shown in FIG. **6**A is an exemplar BSI image sensor wafer **610***a*. The BSI wafer **610***a* includes a substrate **611***a* and a metal stack **614***a* formed over the substrate **611***a*. The substrate **611***a* includes a photosensitive or photodiode ("PD") region **612***a*. The BSI wafer **610***a* has two surfaces, **604***a* and **606***a*. The surface **604***a* is at a front side of the metal stack **614***a* and the surface **606***a* is at a back side of the substrate **611***a*. The surface **604***a* includes conductive pads, **616***a* and **618***a*, isolated by a dielectric material about the same as the dielectric material of the surface **644**. The substrate **611***a* has an initial thickness **613***a*. The structure and composition of the BSI wafer **610***a* is similar to the BSI wafer **410***a* (FIG. **4**A).

The process flow **500** (FIG. **5**) proceeds to operation **506** where the processor wafer **620** is aligned and bonded with the BSI wafer **610***a* using a hybrid bond process. Referring to FIG. **6**B, the surface **644** is directly bonded with the surface **604***a* with the conductive pads **628** and **626** bonded with the conductive pads **618***a* and **616***a* respectively. The hybrid bond process in this operation is similar to the hybrid bond process in operation **306** (FIG. **3**).

The process flow **500** (FIG. **5**) proceeds to operation **508** where the first BSI wafer **610***a* is thinned down. Referring to FIG. **6**C, a thinning process similar to the thinning process in operation **308** (FIG. **3**) is applied to thin down the BSI wafer substrate **611***a* from its back side surface **606***a* to a thickness **615***a*, which may be on the order of a few microns (μm). In some embodiments, the thickness **615***a* is greater than about 1 μm but less than about 5 μm. The particular thicknesses disclosed in the present disclosure are mere examples and other thicknesses may be implemented depending on the type of application and design of the integrated camera module **200** (FIG. **2**).

The process flow **500** (FIG. **5**) proceeds to operation **512** where a second BSI wafer **610***b* is received. Referring to FIG. **6**D, the second BSI wafer **610***b* includes a substrate **611***b* and a metal stack **614***b* formed over the substrate **611***b*. The substrate **611***b* has a thickness **613***b* and includes a PD region **612***b*. The BSI wafer **610***b* has two surfaces, **604***b* and **606***b*. The surface **604***b* is at a front side of the metal stack **614***b* and the surface **606***b* is at a back side of the substrate **611***b*. A difference between the BSI wafer **610***b* and the second BSI wafer **410***b* (FIG. **4**E) received in the process flow **300** (FIG. **3**) is that the surface **604***b* does not include conductive features and only includes a material which is about the same as the material of the surface **646** on the back side of the processor wafer substrate **621**. The BSI wafers **610***a* and **610***b* may contain the same or a different number of imaging pixels.

The process flow **500** (FIG. **5**) proceeds to operation **514** where the second BSI wafer **610***b* is aligned and bonded with the processor wafer **620** using a fusion bond process. Referring to FIG. **6**E, the surface **646** is directly bonded with the surface **604***b*. A fusion bond process refers to bonding of two surfaces where the two surfaces have about same material. In an embodiment, the two surfaces, **646** and **604***b*, include silicon or silicon oxide. In another embodiment, the two surfaces, **646** and **604***b*, include silicon oxynitride or silicon nitride. Other materials or combinations suitable for direct bonding may be used for the two surfaces **646** and **604***b*. The fusion bond process includes an initial bonding process followed by an annealing process. The initial bonding process may use a direct bonding technique or other bonding techniques and is performed at a suitable temperature, such as below 200 degrees Celsius. The annealing process is used to strengthen the bonds between the two surfaces **646** and **604***b*. In an embodiment, the annealing process is used to convert hydrogen bonds formed in the initial bonding process to covalent bonds at a suitable temperature, such as about 200 degrees Celsius. The operation **514** thus produces an assembly **600** with the processor wafer **620** bonded in between the BSI wafers **610***a* and **610***b*.

The process flow **500** (FIG. **5**) proceeds to operation **516** where the second BSI wafer **610***b* is thinned down. Referring to FIG. **6**F, a thinning process is applied to thin down the BSI wafer substrate **611***b* from its back side surface **606***b*. The thinning process in this operation is similar to the

thinning process in operation **316** (FIG. **3**). The substrate **611***b* is thinned to a thickness **615***b*, which may be on the order of a few microns (μm). In some embodiments, the thickness **615***b* is greater than about 1 μm but less than about 5 μm. The thickness **615***b* may be similar to or different from the thickness **615***a* depending on the type of application and design requirements of the integrated camera module **200** (FIG. **2**).

The process flow **500** (FIG. **5**) proceeds to operation **518** where conductive pads are formed over the surface **606***b* and thru-layer and/or thru-silicon vias are formed to electrically couple the conductive pads to both the second BSI wafer **610***b* and the processor wafer **620**. Referring to FIG. **6**G, in the present embodiment, operation **518** etches the back side of the substrate **611***b* for defining openings for conductive pads, etches through the substrate **611***b* for defining openings for vias contacting the metal stack **614***b*, and etches through both the second BSI wafer **610***b* and the substrate **621** for defining openings for vias contacting the metal stack **624**. Referring to FIG. **6**H, operation **518** proceeds to forming an isolation layer in the openings by a process, such as deposition; etching the isolation layer; depositing a conductive material into the etched isolation layer; and performing a polishing process, such as a CMP process, to the conductive material to form the conductive pads, **662** and **672**, and the thru-silicon vias, **664**, **666**, **674** and **676**. Other embodiments of forming the conductive pads **662** and **672** and electrically coupling them to the metal stacks **614***b* and **624** are possible.

The process flow **500** (FIG. **5**) proceeds to operation **520** to complete the integrated camera module **200** (FIG. **2**). Operation **520** may include forming color filters and lens over both sides of the assembly **600**; installing glass covers over the color filters and lens; installing package balls over the conductive pads, **662** and **672** for further integration; and so on.

In both the process flows, **300** and **500**, a hybrid bond process is used to bond a BSI wafer to a processor wafer, such as illustrated in FIGS. **4**B, **4**F and **6**B. FIGS. **7**A and **7**B illustrate a method of using a redistribution layer during such a hybrid bond process.

Referring to FIG. **7**A, a redistribution layer **752** is formed over a metal stack **724** of a processor wafer **720**. The redistribution layer **752** includes conductive pads **756** and **758** that are electrically coupled to the conductive pads **726** and **728** and substantially extend surface areas of the conductive pads **726** and **728** respectively. The conductive pads **756** and **758** are isolated by a dielectric material, such as oxide. The process of forming the redistribution layer **752** includes depositing the dielectric material over the metal stack **724**, etching the dielectric material for defining openings for the conductive pads **756** and **758**, filling the openings with a conductive material such as copper, and performing a polishing process, such as a CMP process, to the conductive material. FIG. **7**A also shows a BSI wafer **710***a* with a bonding surface **704***a* and two conductive pads **716***a* and **718***a* on the bonding surface **704***a*.

Referring to FIG. **7**B, the BSI wafer **710***a* is aligned and bonded to the processor wafer **720** with the redistribution layer **752** providing another bonding surface. Since the conductive pad **756** (or **758**) has a substantially larger surface area than the conductive pad **716***a* (or **718***a*), using the redistribution layer **752** generally provides benefits for increasing design tolerance of the conductive pad **716***a* (or **718***a*) and increasing design tolerance of the alignment operation during the hybrid bond process. A redistribution layer, such as the layer **752**, may be part of the processor wafer **720** when the processor wafer **720** is received, such as in the operation **302** (FIG. **3**) and the operation **502** (FIG. **5**). Alternatively, the processor wafer **720** may be processed to include the redistribution layer **752** after it is received and before it is bonded with the BSI wafer. Alternatively, a redistribution layer may be formed over a metal stack of a BSI wafer before it is bonded to a metal stack of a processor wafer.

FIG. **8** illustrates a process flow **800** for fabricating an integrated camera module with dual-facing BSI image sensors according to various aspects of the present disclosure. The process flow **800** is similar to the process flow **500** (FIG. **5**), with differences discussed below. One difference is that both BSI sensors are bonded with a processor wafer using fusion bond processes in the process flow **800**. FIG. **8** can be better understood when discussed with an example device, as shown in FIGS. **9**A-**9**H. For simplicity purposes, where an operation in the process flow **800** is similar to an operation in the process flow **500**, a reference to the process flow **500** is made and differences are highlighted.

The process flow **800** receives a processor wafer (operation **802**) and a first BSI image sensor wafer (operation **804**). Referring to FIG. **9**A, an exemplar processor wafer **920** includes a substrate **921** and a metal stack **924** formed over the substrate **921**. The substrate **921** includes an active region **922**. The processor wafer **920** has two surfaces, **944** and **946**. The surface **944** is at a front side of the metal stack **924** and the surface **946** is at a back side of the substrate **921**. The surface **944** includes a dielectric material. The structure and composition of the processor wafer **920** is similar to the processor wafer **620** (FIG. **6**A). A difference is that the surface **944** does not include conductive pads. Also shown in FIG. **9**A is an exemplar BSI image sensor wafer **910***a*. The BSI wafer **910***a* includes a substrate **911***a* and a metal stack **914***a* formed over the substrate **911***a*. The substrate **911***a* includes a photosensitive or photodiode ("PD") region **912***a*. The BSI wafer **910***a* has two surfaces, **904***a* and **906***a*. The surface **904***a* is at a front side of the metal stack **914***a* and the surface **906***a* is at a back side of the substrate **911***a*. The surface **904***a* includes a dielectric material about the same as the dielectric material of the surface **944**. The substrate **911***a* has an initial thickness **913***a*. The structure and composition of the BSI wafer **910***a* is similar to the BSI wafer **610***a* (FIG. **6**A). A difference is that the surface **904***a* does not include conductive pads.

The process flow **800** (FIG. **8**) proceeds to operation **806** where the processor wafer **920** is aligned and bonded with the BSI wafer **910***a* using a fusion bond process. Referring to FIG. **9**B, the surface **944** is directly bonded with the surface **904***a*. The fusion bond process in this operation is similar to the fusion bond process in operation **514** (FIG. **5**).

The process flow **800** (FIG. **8**) proceeds to operation **808** where the first BSI wafer **910***a* is thinned down. Referring to FIG. **9**C, a thinning process similar to the thinning process in operation **508** (FIG. **5**) is applied to thin down the BSI wafer substrate **911***a* from its back side surface **906***a* to a thickness **915***a*, which may be on the order of a few microns (μm). In some embodiments, the thickness **915***a* is greater than about 1 μm but less than about 5 μm. The particular thicknesses disclosed in the present disclosure are mere examples and other thicknesses may be implemented depending on the type of application and design of the integrated camera module to be fabricated.

The process flow **800** (FIG. **8**) proceeds to operation **812** where a second BSI wafer **910***b* is received. Referring to FIG. **9**D, the second BSI wafer **610***b* includes a substrate **911***b* and a metal stack **914***b* formed over the substrate **911***b*.

The substrate **911***b* has a thickness **913***b* and includes a PD region **912***b*. The BSI wafer **910***b* has two surfaces, **904***b* and **906***b*. The surface **904***b* is at a front side of the metal stack **914***b* and the surface **906***b* is at a back side of the substrate **911***b*. The surface **904***b* includes a material which is about the same as the material of the surface **946**. The BSI wafers **910***a* and **910***b* may contain the same or a different number of imaging pixels.

The process flow **800** (FIG. **8**) proceeds to operation **814** where the second BSI wafer **910***b* is aligned and bonded with the processor wafer **920** using a fusion bond process. Referring to FIG. **9**E, the surface **946** is directly bonded with the surface **904***b*. The fusion bond process in this operation is similar to the fusion bond process in operation **514** (FIG. **5**).

The process flow **800** (FIG. **8**) proceeds to operation **816** where the second BSI wafer **910***b* is thinned down. Referring to FIG. **9**F, a thinning process is applied to thin down the BSI wafer substrate **911***b* from its back side surface **906***b*. The thinning process in this operation is similar to the thinning process in operation **516** (FIG. **5**). The substrate **911***b* is thinned to a thickness **915***b*, which may be on the order of a few microns (μm). In some embodiments, the thickness **915***b* is greater than about 1 μm but less than about 5 μm. The thickness **915***b* may be similar to or different from the thickness **915***a* depending on the type of application and design requirements of the integrated camera module to be fabricated.

The process flow **800** (FIG. **8**) proceeds to operation **818** where conductive pads and thru-layer and/or thru-silicon vias are formed to electrically couple both the BSI wafers **910***a* and **910***b* to the processor wafer **920**. FIG. **9**G illustrates that the wafers **910***a*, **910***b* and **920** are etched. FIG. **9**H illustrates that conductive features **962**, **964**, **966**, **972**, **974** and **976** are formed to couple the metal stacks in the three wafers. The processes of etching the wafers and forming the conductive features are similar to those in operation **518** (FIG. **5**).

The process flow **800** (FIG. **8**) proceeds to operation **820** to complete the integrated camera module. Operation **820** may include forming color filters and lens over both sides of the assembly **900**; installing glass covers over the color filters and lens; and so on.

The foregoing outlines features of several embodiments so that those of ordinary skill in the art may better understand the aspects of the present disclosure. Those of ordinary skill in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those of ordinary skill in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

In one exemplary aspect, the present disclosure is directed to a device including a first BSI image sensor, a second BSI image sensor, and a third element. The first BSI image sensor includes a first substrate and a first metal stack disposed over a first side of the first substrate. The first substrate includes a photodiode region for accumulating an image charge in response to radiation incident upon a second side of the first substrate. The first metal stack is operatively coupled to the first substrate for receiving image data from the first substrate. The first metal stack includes a first material layer at a first side of the first metal stack. The second BSI image sensor includes a second substrate and a second metal stack disposed over a first side of the second substrate. The second substrate includes a photodiode region for accumulating an image charge in response to radiation incident upon a second side of the second substrate. The second metal stack is operatively coupled to the second substrate for receiving image data from the second substrate. The second metal stack includes a second material layer at a first side of the second metal stack. The third element includes a third substrate and a third metal stack disposed over a first side of the third substrate. The third substrate includes an active region. The third metal stack includes a third material layer at a first side of the third metal stack. The first side of the first metal stack is bonded to the first side of the third metal stack and the first metal stack is electrically coupled to the third metal stack. The first side of the second metal stack is bonded to a second side of the third substrate and the second metal stack is electrically coupled to the third metal stack.

In another exemplary aspect, the present disclosure is directed to a method for fabricating a dual facing BSI image sensor assembly. The method includes receiving a first BSI image sensor element, a second BSI image sensor element, and a third element. The first BSI image sensor element includes a first substrate and a first metal stack formed over a first side of the first substrate. The first substrate includes a photodiode region for sensing radiation incident upon a second side of the first substrate. A first side of the first metal stack includes a first plurality of conductive features. The second BSI image sensor element includes a second substrate and a second metal stack formed over a first side of the second substrate. The second substrate includes a photodiode region for sensing radiation incident upon a second side of the second substrate. A first side of the second metal stack includes a second plurality of conductive features. The third element includes a third substrate and a third metal stack formed over a first side of the third substrate. A first side of the third metal stack includes a third plurality of conductive features. The method further includes bonding the first side of the first metal stack to the first side of the third metal stack using a first hybrid bond process and thinning the first substrate from the second side of the first substrate to a first thickness. The method further includes forming a passivation layer over a second side of the third substrate, wherein a first side of the passivation layer includes a fourth plurality of conductive features that is electrically coupled to the third metal stack. The method further includes bonding the first side of the second metal stack to the first side of the passivation layer using a second hybrid bond process and thinning the second substrate from the second side of the second substrate to a second thickness.

In another exemplary aspect, the present disclosure is directed to a method for fabricating an integrated camera module having dual facing BSI image sensors. The method includes receiving a first BSI image sensor element, a second BSI image sensor element, and a third element. The first BSI image sensor element includes a first substrate and a first metal stack formed over a first side of the first substrate. The first substrate includes a photodiode region for sensing radiation incident upon a second side of the first substrate. The second BSI image sensor element includes a second substrate and a second metal stack formed over a first side of the second substrate. The second substrate includes a photodiode region for sensing radiation incident upon a second side of the second substrate. The third element includes a third substrate and a third metal stack formed over a first side of the third substrate. The method further includes

bonding a first side of the first metal stack to a first side of the third metal stack and thinning the first substrate from the second side of the first substrate to a first thickness. The method further includes bonding a first side of the second metal stack to a second side of the third substrate layer using a first fusion bond process; thinning the second substrate from the second side of the second substrate to a second thickness; and forming conductive features over the second side of the second substrate, wherein the conductive features electrically couple the second metal stack to the third metal stack.

What is claimed is:

1. A device comprising:

a first image sensor element having a first surface that includes a first conductive portion and a first dielectric portion;

a second image sensor element having a photosensitive region and a second surface that includes a second dielectric portion;

a processing element disposed between the first and second image sensors, the processing element having a third surface that includes a second conductive portion and a third dielectric portion and a fourth surface that include a fourth dielectric portion, wherein the second conductive portion directly interfaces with the first conductive portion, the third dielectric portion directly interfaces with first dielectric portion and the fourth dielectric portion directly interfaces with the second dielectric portion; and

a first conductive feature extending from the photosensitive region to the processing element.

2. The device of claim **1**, wherein the first conductive feature includes a conductive pad and a via.

3. The device of claim **1**, wherein a first portion of the photosensitive region is disposed on a first side of the first conductive feature and a second portion of the photosensitive region is disposed on a second side of the first conductive features, wherein the first side is opposite the second side.

4. The device of claim **1**, wherein the third surface that includes the second conductive portion and the third dielectric portion are part of an interconnect structure and the fourth surface that include the fourth dielectric portion is part of a substrate, and

wherein the first conductive feature extends through the substrate and into the interconnect structure.

5. The device of claim **4**, wherein an active region is disposed on the substrate and the first conductive feature extends through the active region.

6. The device of claim **1**, wherein the third surface that includes the second conductive portion and the third dielectric portion are part of a redistribution layer.

7. The device of claim **1**, further comprising a second conductive feature extending from the photosensitive region to the processing element.

8. A device comprising:

a first image sensor element having a first photosensitive region and a first surface that includes a first dielectric portion;

a second image sensor element having a second photosensitive region and a second surface that includes a second dielectric portion;

an interconnect structure disposed on a substrate between the first and second image sensor elements, the interconnect structure including a third surface that includes a third dielectric portion and the substrate having a fourth surface that includes a fourth dielectric portion, the third dielectric portion directly interfacing with the first dielectric portion and the fourth dielectric portion directly interfacing with the second dielectric portion; and

a first conductive feature extending from one of the first and second photodiode regions to the interconnect structure.

9. The device of claim **8**, wherein the first and third dielectric portions are formed of the same material.

10. The device of claim **8**, wherein the first photosensitive region includes a first number of pixels and the second photosensitive region includes a second number of pixels, the second number of pixels being different than the first number of pixels.

11. The device of claim **8**, further comprising a second conductive feature extending from the second photodiode region to the interconnect structure, and

wherein the first conductive feature extends from the first photodiode region to the interconnect structure.

12. The device of claim **11**, wherein the interconnect structure includes a third conductive feature having a first side facing the first image sensor element and a second side facing the second image sensor image, and

wherein the first conductive feature directly interfaces with the first side of the third conductive feature and the second conductive feature directly interfaces with the second side of the third conductive feature.

13. The device of claim **8**, wherein at least one of the first image sensor element and the second image sensor element is a back side illuminated image sensor element.

14. The device of claim **8**, wherein the substrate further includes an active region, and

wherein the first conductive feature extends through the active region.

15. A device comprising:

a first image sensor, wherein the first image sensor includes a first conductive portion and a first dielectric portion;

a second image sensor, wherein the second image sensor includes a second conductive portion and a second dielectric portion; and

a third element disposed between the first image sensor and the second image sensor, the third element having a first surface and a second surface, the first surface including a third conductive portion and a third dielectric portion and the second surface including a fourth conductive portion and a fourth dielectric portion, wherein the third conductive portion directly interfaces with the first conductive portion and the fourth conductive portion directly interfaces with the second conductive portion, wherein the third dielectric portion directly interfaces with first dielectric portion and the fourth dielectric portion directly interfaces with the second dielectric portion.

16. The device of claim **15**, wherein the fourth dielectric portion is part of passivation layer, and

wherein the fourth conductive portion is at least partially embedded within the passivation layer.

17. The device of claim **15**, wherein the first image sensor includes a first photosensitive region that is electrically coupled to the third conductive portion via the first conductive portion.

18. The device of claim **15**, wherein the first conductive portion and the first dielectric portion are part of a first interconnect structure, and

wherein the second conductive portion and the second dielectric portion are part of a second interconnect structure.

19. The device of claim **15**, wherein the first and third conductive portions are formed of the same material and the first and third dielectric portions are formed of the same material.

20. The device of claim **15**, wherein the third element further includes:

a semiconductor substrate; and

an interconnect structure disposed on a first side of the semiconductor substrate, wherein the first surface including the third conductive portion and the third dielectric portion are part of the interconnect structure, and

wherein the fourth conductive portion and the fourth dielectric portion are disposed on a second side of the semiconductor substrate, the second side being different than the first side, and

wherein a conductive via extends from the fourth conductive portion and through the semiconductor substrate to the interconnect structure to electrically couple the fourth conductive portion to the interconnect structure.

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