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<i>Additional inventors are being named on the _____ separately numbered sheets attached hereto.</i>		
TITLE OF THE INVENTION (500 characters max):		
Photosensing Imager and Methods of Making the Same		
<i>Direct all correspondence to:</i> CORRESPONDENCE ADDRESS		
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ENCLOSED APPLICATION PARTS (check all that apply)		
☐ Application Data Sheet. See 37 CFR 1.76 ☐ CD(s), Number of CDs _____		
☒ Drawing(s) <i>Number of Sheets</i> <u>11</u> ☐ Other (specify) _____		
☒ Specification (e.g. description of the invention) <i>Number of Pages</i> <u>10</u>		
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Page 2 of 2

PTO/SB/16 (12-08)

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SIGNATURE /Todd B. Alder/ Date March 5, 2010

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TELEPHONE (801) 566-6633 Docket Number: 3035-011.PROV

PHOTOSENSING IMAGER AND METHODS OF MAKING THE SAME

TECHNICAL FIELD

The present disclosure relates to broadband photosensing imagers and methods of making the same. More specifically, the present invention relates to photosensing pixel devices having textured interfaces for increasing the effective absorption length and methods of making the same.

BACKGROUND

The interaction of light with semiconductor devices is at the core of some of the most important innovations of our time. Silicon imaging devices are used in various technologies today, such as, for example, digital cameras, optical mouse, video cameras, and cell phones. Charge-coupled devices (CCDs) dominated the digital imaging word until complementary metal-oxide-semiconductor (CMOS) imagers improved in performance. CMOS sensors are typically manufactured from silicon, and can covert visible incident light into photocurrent and ultimately into a digital image. To date, there is no good silicon based technology for detecting infrared incident electromagnetic radiation, in part because silicon is an indirect band gap semiconductor and has a band gap of 1.1 eV. The absorption of electromagnetic radiation having a wavelength of about 1100 nm is very low in silicon and even lower at longer wavelengths in the infrared spectrum. There are other applications that could benefit from a silicon imager that is capable of detecting infrared electromagnetic radiation, such as military and security applications.

In addition, if the semiconductor layer forming the photo detecting diodes is thin, the absorption of red, orange, and yellow light may be low. Visible imagers could thus benefit from techniques to increase light absorption and quantum efficiency.

SUMMARY

The following invention provides devices and methods of manufacturing photo sensing pixels and imagers that are able to detect visible as well as infrared electromagnetic radiation. Imagers are typically comprised of multiple light photosensing pixels. The pixels disclosed in the present invention can include a semiconductor bulk substrate, at least one transistor disposed near the substrate, and at least one light diffusing region formed in or

near the semiconductor substrate. The light diffusing region can include light diffusing features configured to increase the effective absorption length of the photosensing pixel. The light diffusing features can be cones, pyramids, pillars, protrusions, and features that have been inverted. It should be noted that any feature that creates a textured surface can be used. For example, depositing an additional material on the device can create a textured surface (e.g. quantum dots). Manipulating the feature sizes, dimensions, and locations can allow the diffusing region to be tunable for a specific wavelength. Varying the material near the light diffusing region can also tune the device for a specific wavelength.

The light diffusing region can be formed by several methods known to those skilled in the art. Known methods or processes for creating a light diffusing region are wet or dry etches, such as isotropic or anisotropic etches, nanoimprinting, and material deposition.

Further, the photosensing pixels of the present invention can include at least one trench isolation for reducing optical or electrical crosstalk with a neighboring pixel in an imaging array. The trench isolation can include a dielectric material, a reflective material, or even a conductive material. The trench isolation can enable the device to reflect and trap light in the semiconductor substrate until the light can be absorbed.

In another embodiment of the present invention, a method for manufacturing a photosensing pixel is provided. Such a method can include steps of, providing a semiconductor substrate, forming a light diffusing region in or near the semiconductor substrate, attaching a first support substrate to one side of photosensing pixel, and forming a wavelength confining trench within at least a portion of the semiconductor substrate. The method can further include a step of disposing at least one transistor about the semiconductor substrate. In another embodiment removing a portion of the semiconductor substrate is taught. The removal or thinning of a semiconductor substrate can be effective for improving the responsivity or speed of the device. A passivation layer can also be disposed on the photosensing pixel to help protect and /or reduce the dark current of the device. A second support substrate can be attached to the device for supporting the device. Typically, the second support substrate is located on the opposite side of the pixel from the first support substrate. The first support substrate can subsequently be removed to allow for further processing.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and advantage of the present invention, reference is being made to the following detailed description of preferred embodiments and in connection with the accompanying drawings, in which:

Fig. 1 is a prior art illustration depicting the absorption depth of a standard silicon wafer for a given wavelength.

Figs. 2 – 6 show the progressive steps for forming a photosensing pixel in accordance with at least one embodiment of the present invention.

Fig. 7A is a cross-sectional view of a photosensing pixel having deep trench isolation in accordance with at least one embodiment of the present invention.

Fig. 7B is a cross-sectional view of a photosensing pixel having deep trench isolation in accordance with another embodiment of the present invention.

Fig. 8 is a top view of two photosensing imagers configured in a simple array according to another embodiment of the present invention.

Fig. 9 is a cross-sectional view of a backside illuminated imager sensor in accordance with an embodiment of the present invention.

Fig. 10 is a cross-sectional view of a frontside illuminated image sensor in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION

The following disclosure provides broadband photosensing pixels and imagers and methods of making the same. Typical silicon photodetecting imagers have limited light absorption/detection properties. Infrared light is mostly transparent to silicon based detectors. As a result, other materials (e.g. InGaAs) have been used to detect infrared wavelengths greater than 1000nm. Silicon, however, is cheap to manufacture and can detect wavelengths in the visible spectrum. Conventional silicon requires substantial absorption depth for photons having wavelengths longer than approximately 500nm. Fig. 1 depicts the absorption properties of conventional silicon as different wavelengths of light 110 (e.g. visible light, 400nm – 700nm). As shown, visible light can be absorbed in the shallow depths, however, absorption of longer wavelengths with standard silicon wafer depth 120 (approximately 850 μm) is poor if at all. The present invention effectively reduces the absorption depth of silicon to less than 850 μm , thus allowing more effective absorption of

longer wavelengths as compared to standard silicon. In other words, the devices of the present invention are able to absorb longer wavelengths (e.g. >1000 nm) with a thin silicon substrate. This can be accomplished by increasing the effective absorption length or depth of the semiconductor substrate. In addition to increasing the effective absorption length, the response rate or response speed can also be increased by the thinner substrate.

Photosensing imagers are typically comprised of photodiodes or pixels that are capable of absorbing electromagnetic radiation in a specific wavelength range. Imagers can be passive pixel sensors (PPS), active pixel sensors (APS), or a digital pixel sensor imagers (DPS). The main difference is the image sensor read out architecture. For example, the semiconductor photosensing imager can be a three or four transistor active pixel sensor (3T APS or 4T APS). Imagers can be front side illumination (FSI) or back side illumination (BSI). There are advantages and disadvantages to both architectures. In a typical FSI imager, incident light enters the semiconductor device by first passing by a transistor and metal circuitry. The light, however, scatters off of the transistors and circuitry prior to entering the light sensing portion of the imager, thus causing optical loss and noise. A lens can be disposed on the topside of a FSI pixel to direct and focus the incident light to the light sensing active region of the device, thus partially evading the circuitry. BSI imagers are configured to have the light sensing portion opposite the transistor and circuitry. Incident light enters the device via the light sensing portion and being mostly absorbed in the light sensing portion before reaching the circuitry. BSI allows for smaller pixel architecture and a high fill factor for the imager. As mentioned, the present invention can be adapted for either configuration. It should also be understood that the present invention can be used in a CMOS imager architecture or even in a CCD imager architecture.

Turning now to the figures; FIG. 2 – 6 illustrate steps for manufacturing a photosensing pixel according to at least one embodiment of the present invention. FIG. 2 shows a cross-section of a FSI photosensing pixel device 200. The photosensing pixel device may include a semiconductor substrate 202. The semiconductor substrate is also referred to bulk semiconductor material by those skilled in the art. The bulk semiconductor substrate can be selected from various semiconductor materials such as silicon, amorphous silicon (a-Si), microcrystalline silicon, multi-crystalline silicon, and mono-crystal silicon, as well as other semiconductor materials. The semiconductor material can have a thickness less than 750 μm , 650 μm , 100 μm , 50 μm , 10 μm , or even 2 μm . A portion of semiconductor

substrate can include at least one doped region 204. The doped region is typically doped with an electron donating or hole donating species cause the region to become more positive or negative in polarity as compared to the semiconductor substrate. In the present example, doped region 204 can be p⁺ doped. The region can be doped by a number of known processes to those skilled in the art. In one embodiment the region can be a layer formed by epitaxial methods. Highly doped region 206 can be formed on or near another doped region 204 to create a pinned diode. In the present example, the semiconductor substrate can be negative in polarity, while doped regions 204 and 206 can be doped with p⁺ and n⁻ dopants respectively. In some embodiments, variations of n(--), n(-), n(+), n(++), p(--), p(-), p(+), or p(++) type semiconductor layer may be used. It should be noted that in one embodiment doped region 206 can be the light diffusing region as discussed below. In other words, light diffusing elements may be formed on or in the highly doped region.

The device of FIG. 2 can further include metal regions 208, 210, 212; at least one via 214, passivation layer 216, trench isolation 218 and transfer gate 220. Most of the elements needed are found in standard CMOS imagers. Trench isolation elements can become essential element to maintain pixel to pixel uniformity by reducing optical and electrical crosstalk. The trench isolation can be shallow or deep trench isolation as shown in FIG. 7A. The trench isolation may include a dielectric material, reflective material, conductive material and light diffusing features. The isolation layer can be configured to reflect the incident light until it is absorbed, thereby increase the effective absorption length of the device.

FIG. 3 illustrates another progressive step in a method of manufacturing a photosensing pixel device 300 according to one embodiment of the present invention. In figure 3, a bonding layer or adhesive layer 222 is disposed onto the passivation layer. Subsequently, a carrier substrate or carrier wafer 224 can be disposed on the bonding layer. The carrier substrate can be made of a semiconductor material that is the same or similar to the bulk semiconductor material.

FIG. 4 illustrates a light diffusing region 226 formed near semiconductor substrate. The light diffusing region can include light dispersing features such as cones, pillars pyramids, microlens, quantum dots and features that are inverted. The light diffusing region can be tunable to a desired wavelength by varying the dimensions of the features. Tuning the device can allow specific wavelengths or colors of light to be absorbed. It is also contemplated to modify the distance and location of a feature(s) to a neighboring feature to

achieve a specific tunable property. In addition to these methods, varying the material near the light diffusing region can create a wavelength specific photosensing pixel device. It should be noted that the wavelength specific photosensing pixel devices can be differ from one pixel to the next and can be incorporated into an imaging array. For example a 4 x 4 array can include a blue, green, red and infrared light absorbing pixel.

The light diffusing region can be formed by several methods. For example the micrometer or nanometer size light diffusing features can be formed by a lasing, anisotropic etch, isotropic etch, nanoimprint methods and depositing additional material. For example, pillar features can be incorporated into pixels by thinning or removing material from a FSI wafer from the back side of the semiconductor substrate to a thickness of 20 μm by using deep trench isolation and etching techniques. An anisotropic etch can be used to produce a sloping backside pyramid structure, or spherical, parabolic, and lens structures with reflectors. These larger features on the backside of the pillars will also serve to diffuse and reflect the light.

The light diffusing regions described herein may allow the device to obtain multiple passes of the incident light, mainly the longer wavelength light (e.g. infrared). The absorption coefficient of silicon is low in the near infrared and red portion of the visible spectrum. The amount of absorption can be proportional to the distance ($\alpha\ell$) the light travels in the silicon before being absorbed and contributing to photocurrent. The net result is the photosensing pixel can absorb light having a wavelength in the range of about 400nm to about 1200nm. This is accomplished by internal reflection and increasing the effective absorption length to be greater than the thickness of the semiconductor substrate.

Standard CMOS active pixel sensor imagers either FSI or BSI can be modified by adding a light diffusing region for scattering and reflecting light to provide enhance absorption in the near infrared. Increased quantum efficiency can also be achieved in some of the embodiments of the present invention. Any increase in quantum efficiency can make a large difference in the signal to noise ratio of the device. Improving pixel uniformity from one photosensing pixel to a neighboring pixel and quantum efficiency is also achievable by the teachings herein.

Figure 5 shows the photosensing pixel structure 200 with a second or an additional carrier support substrate 230 attached on an opposing side from the first carrier support substrate. A reflective layer or bonding layer or a combination thereof can be disposed

between the light diffusing region 226, a reflective bonding layer and the second carrier support substrate 230. The reflective layer 228 can be comprised of a silver material, aluminum material or any known material that can reflect light. A reflective layer may be desirable in order to maintain light within the semiconductor substrate region thereby preventing any optical loss or back scattering. This reflective layer may assist in increasing the quantum efficiency of the device. The second carrier support substrate is utilized to facilitate the removal of the first carrier substrate as shown in FIG. 6 while maintaining support of the device.

Trench isolation can be deep trench isolation as shown in FIG. 7A. The trench isolation can include a dielectric material, a reflective material, a conductive material, or a combination thereof, and light diffusing features. The isolation layer can be configured to reflect the incident light until it is absorbed, thereby increasing the effective absorption length of the device. Pillar features can be incorporated into pixels by thinning or removing material from a FSI wafer from the back side of the semiconductor substrate to a thickness of 20 μm by using deep trench isolation and etching techniques. The light diffusing and reflecting region 226 can be formed by several methods. For example the micrometer or nanometer size light diffusing features can be formed by a lasing, anisotropic etch, isotropic etch, nanoimprint methods and depositing additional material. The light diffusing and reflecting region in conjunction with the isolation areas serves to form an optical cavity.

An alternative embodiment is shown in Fig. 7B where an anisotropic etch can be used to produce a sloping backside pyramid structure 226, or spherical, parabolic, and lens structures with reflectors. These larger features on the backside of the pillars will also serve to diffuse and reflect the light and form an optical cavity.

Other pixel and imager architectures are contemplated herein. It should be understood that a non-bulk material can be formed near a doped region in the device. The addition of a non-bulk material can allow for the light diffusing features to be formed on or in the non-bulk material. A metal layer defining an aperture can also be included in one embodiment of the current invention. The metal layer can be formed near the doped regions and can have a light entering region that defines an aperture. This light entering region can also include an antireflecting material.

Fig. 8 is a top view of photosensing imaging array 800. The array is shown in a simplistic view. It should be understood that many variations can be made to the array and

should not be considered limiting. In the present example the array comprises two photosensing pixels as disclosed herein. Each photosensing pixel can include a boundary region 808 which can include metal circuitry; a light active region 806 where the light diffusing region may be located and at least one transistor element 804. Other read out and circuitry elements 802 can be used and shared by both photosensing pixels.

Fig. 9 shows a backside illuminated, BSI, imager according to one embodiment of the invention. A lens, 240, and antireflecting coating, 236, can be disposed on the backside of the pixel 200 after thinning and isolation. Color filter 238 can be disposed near the lens to selectively allow specific wavelengths to pass through and be absorbed by the photosensing pixel. A light scattering and reflecting layer, 234, is disposed on the front of the pixel to give diffusive scattering and reflection of the incident light, 232, that reaches the front of the pixel. This can result in the incident light being confined in a cavity by reflections on all sides and a maximum possible absorption of particularly the longer wavelengths not strongly absorbed by the silicon. The photo generated carriers are collected by the p-n junction diode, 204.

Fig. 10 shows a front side illuminated, FSI, imager according to another embodiment of the invention. A lens 240, and antireflecting passivation layer, 216, are placed on the front side of the pixel 200 after semiconductor fabrication is completed. A light scattering layer 236, and reflecting layer 238, are placed on the back of the pixel to give diffusive scattering and reflection of the incident light 232, that reaches the back of the pixel. This results in the incident light being confined in a cavity by reflections on all sides and a maximum possible absorption of particularly the longer wavelengths not strongly absorbed by the silicon. Fig. 10 also shows the use of an aperture 246 formed by metal or other reflective material 244, to increase the effectiveness of the optical cavity. Lens 240, serves to focus the light through the aperture 246. The photo generated carriers are collected by the p-n junction diode, 204.

In still another embodiment, the present invention contemplates a method for manufacturing a photosensing pixel. Such a method may include the steps of providing a semiconductor substrate; forming a light diffusing region in or near the semiconductor substrate; attaching a first support substrate to one side of the photosensing pixel; and forming a wavelength confining trench within at least a portion of the semiconductor substrate. The method may also include the step of disposing at least one transistor about

the semiconductor substrate and removing a portion of the semiconductor substrate. The step of removing can be accomplished by many methods known by those skilled in the art; etching, chemical mechanical polishing, and ion implanting (i.e. smart cut) to name a few. The step of removing the semiconductor material can also be accomplished while forming the light diffusing region. A further step of annealing the device to remove any defects is also contemplated. Rapid thermal anneal or laser annealing may be used to localize the anneal, this may also minimize any damage that could happen to the circuitry during processing. The anneal step can also be performed prior to depositing any circuitry or read out elements.

The present invention should not be considered limited to the particular embodiments described above, but rather should be understood to cover all aspects of the invention as fairly set out in the attached claims. Various modifications, equivalent processes, as well as numerous structures to which the present invention may be applicable, will be readily apparent to those skilled in the art to which the present invention is directed upon review of the present disclosure.

ABSTRACT

The present disclosure is directed towards semiconductor photodetecting imagers and methods for manufacturing and further processing such imagers. In particular, the present invention discloses photodetecting imagers that have been processed with a laser or other methods to create a textured surface for extended wavelength absorption or improved quantum efficiency in the infrared and visible wavelengths. The imagers disclosed herein can be used for military applications, security applications, or commercial visible imagers.

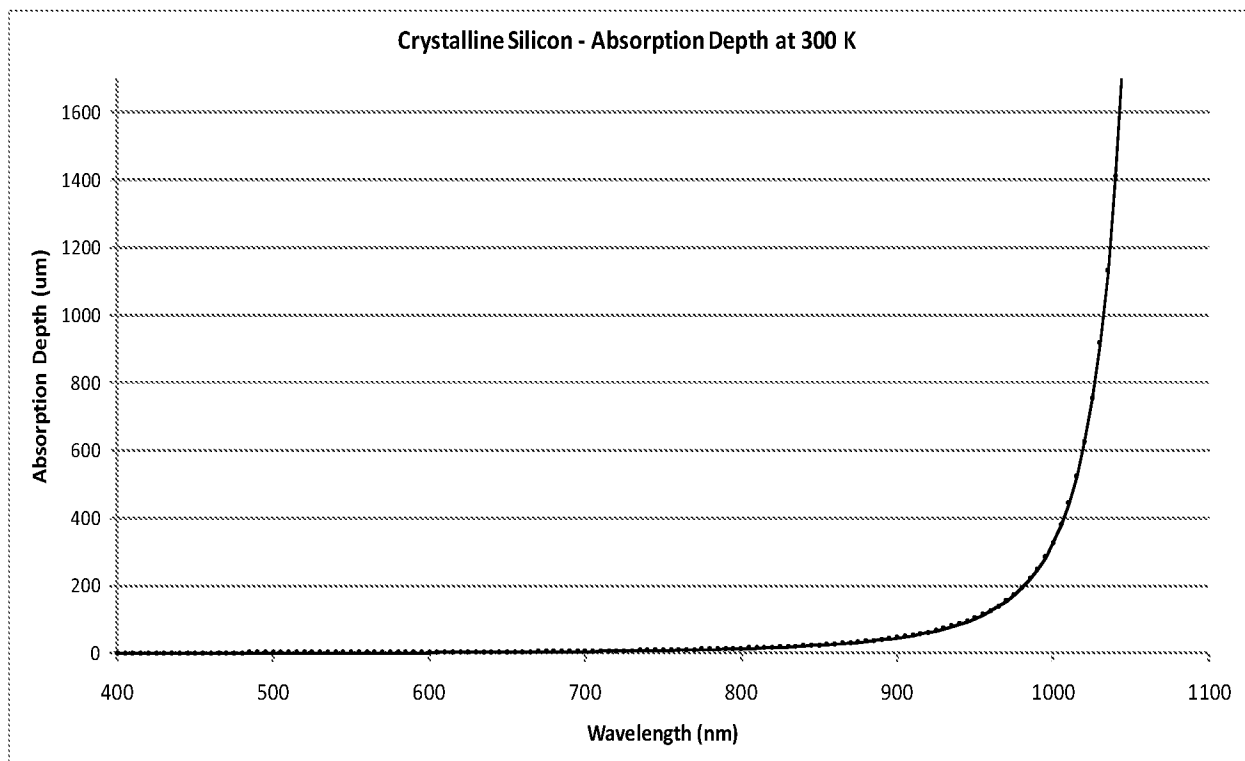
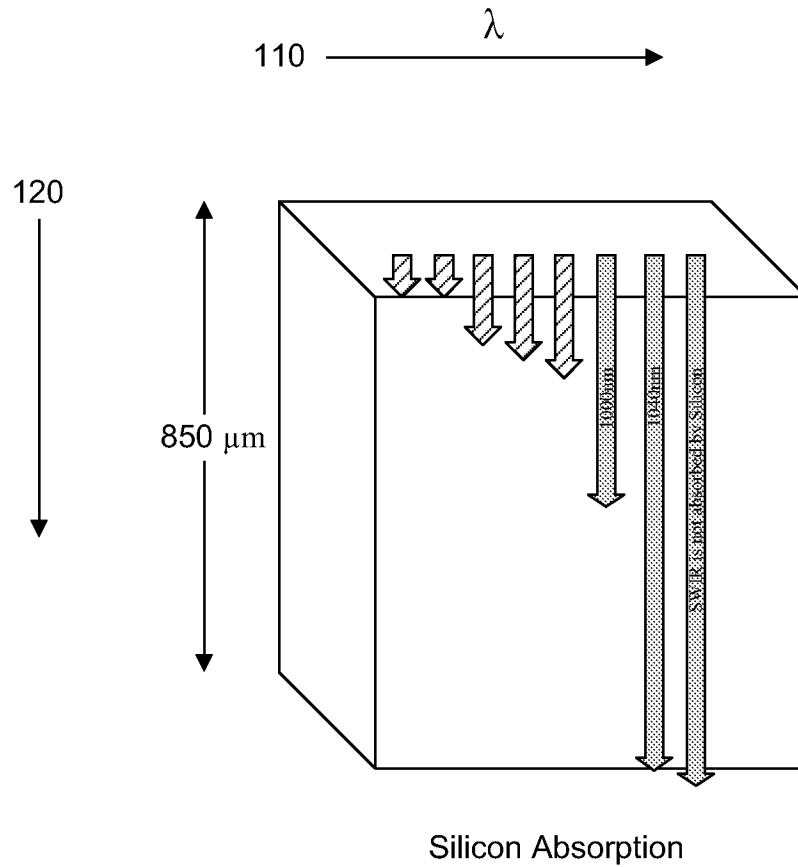


FIG. 1

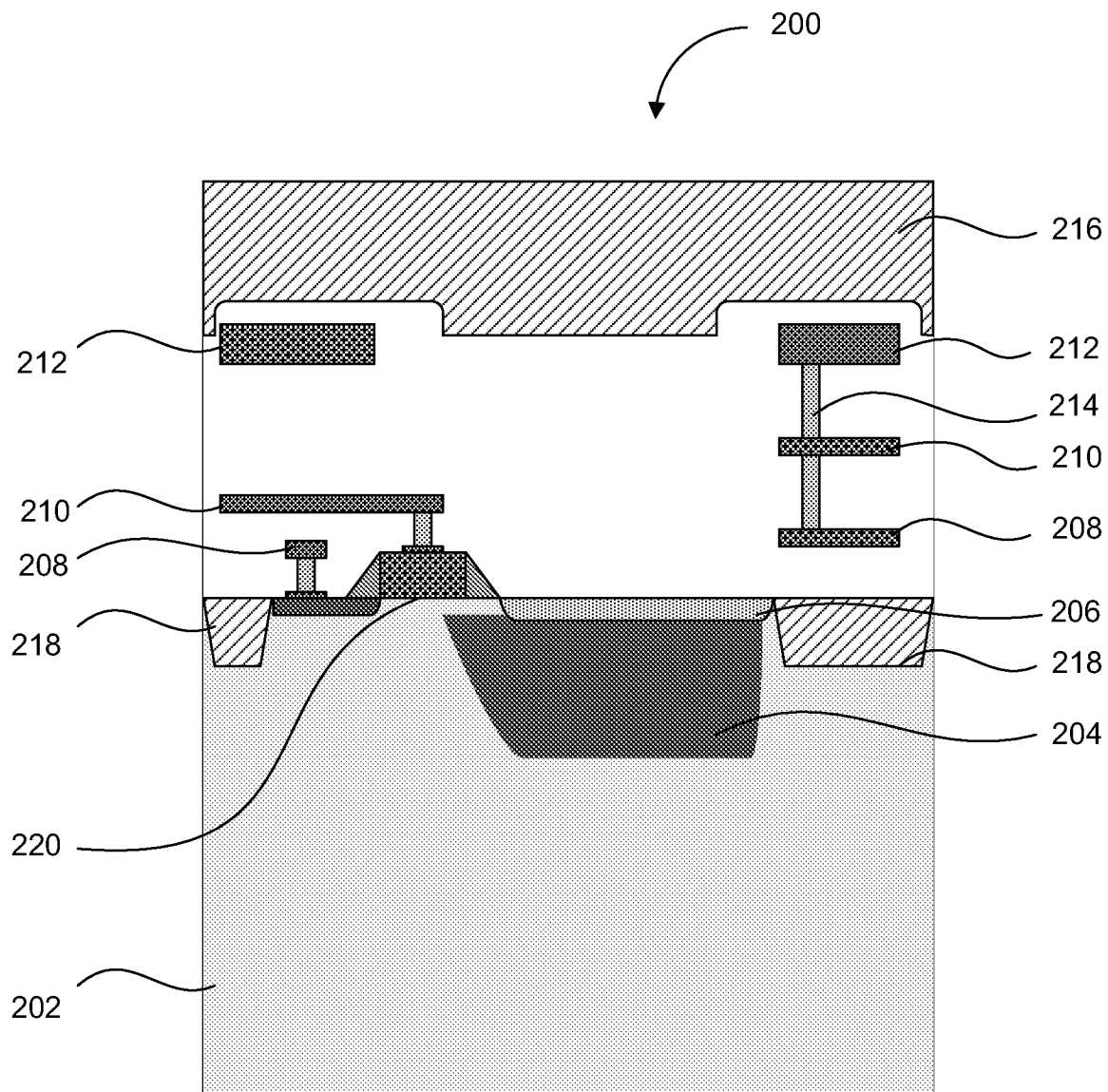


FIG. 2

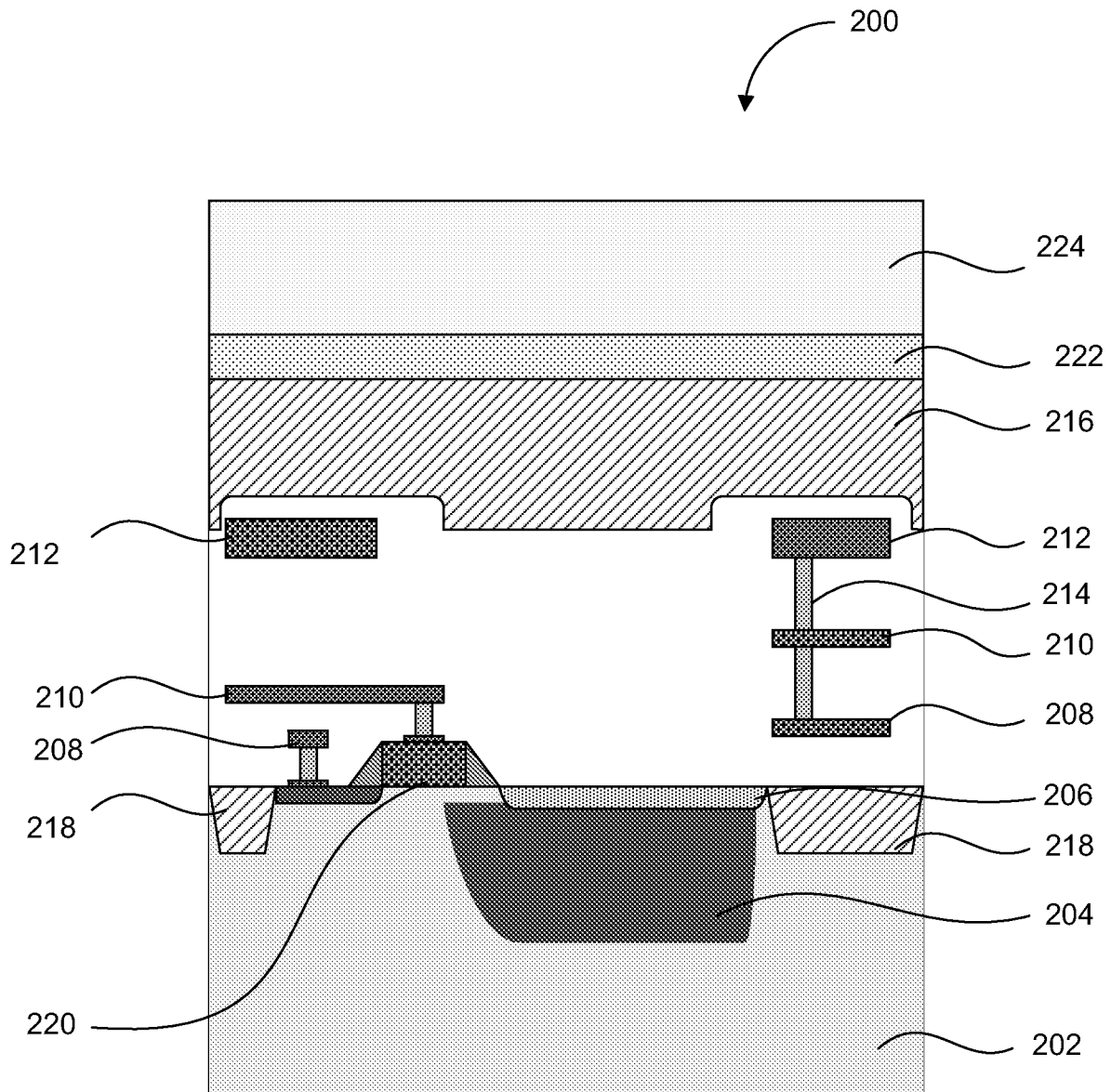


FIG. 3

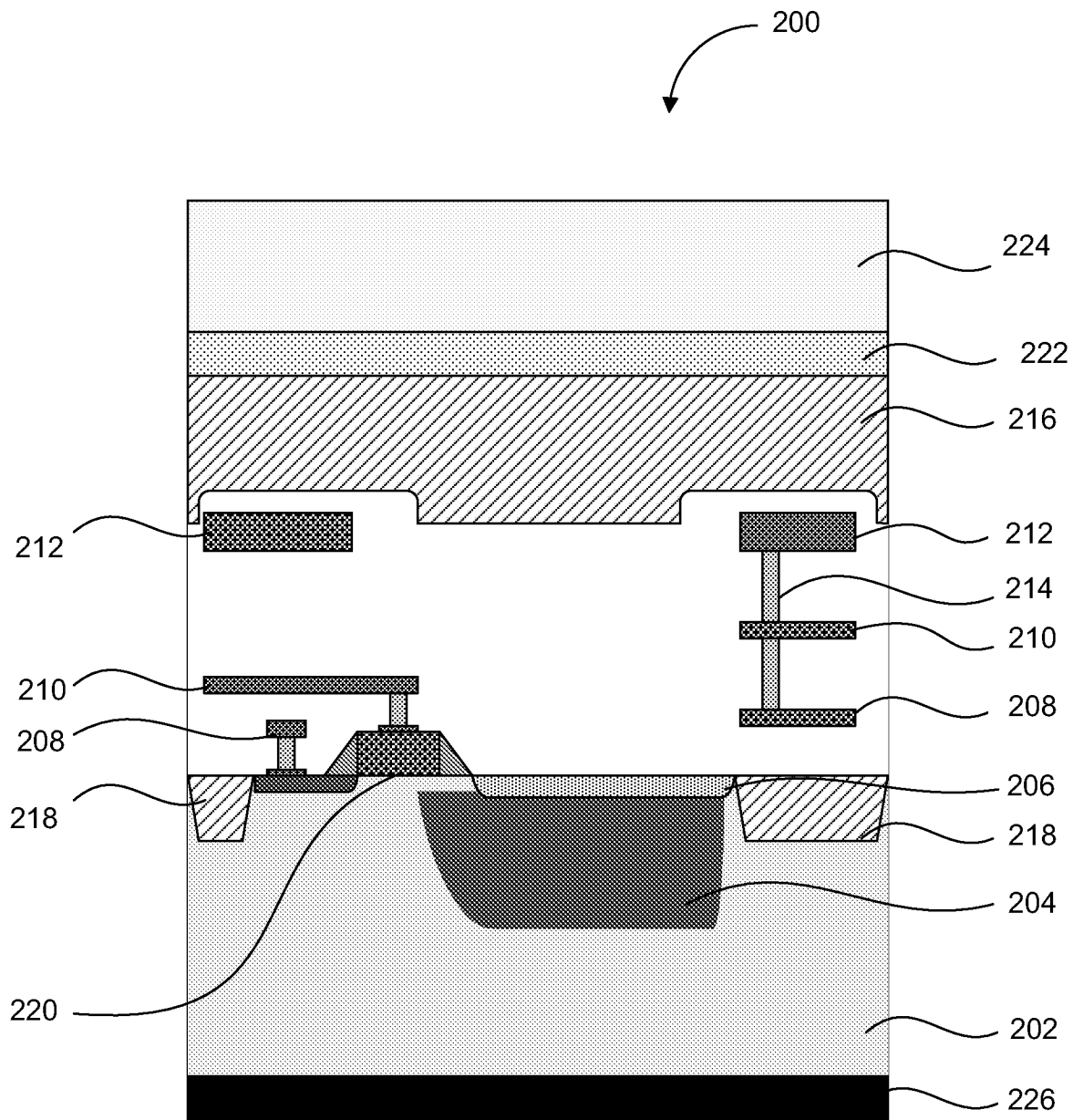


FIG. 4

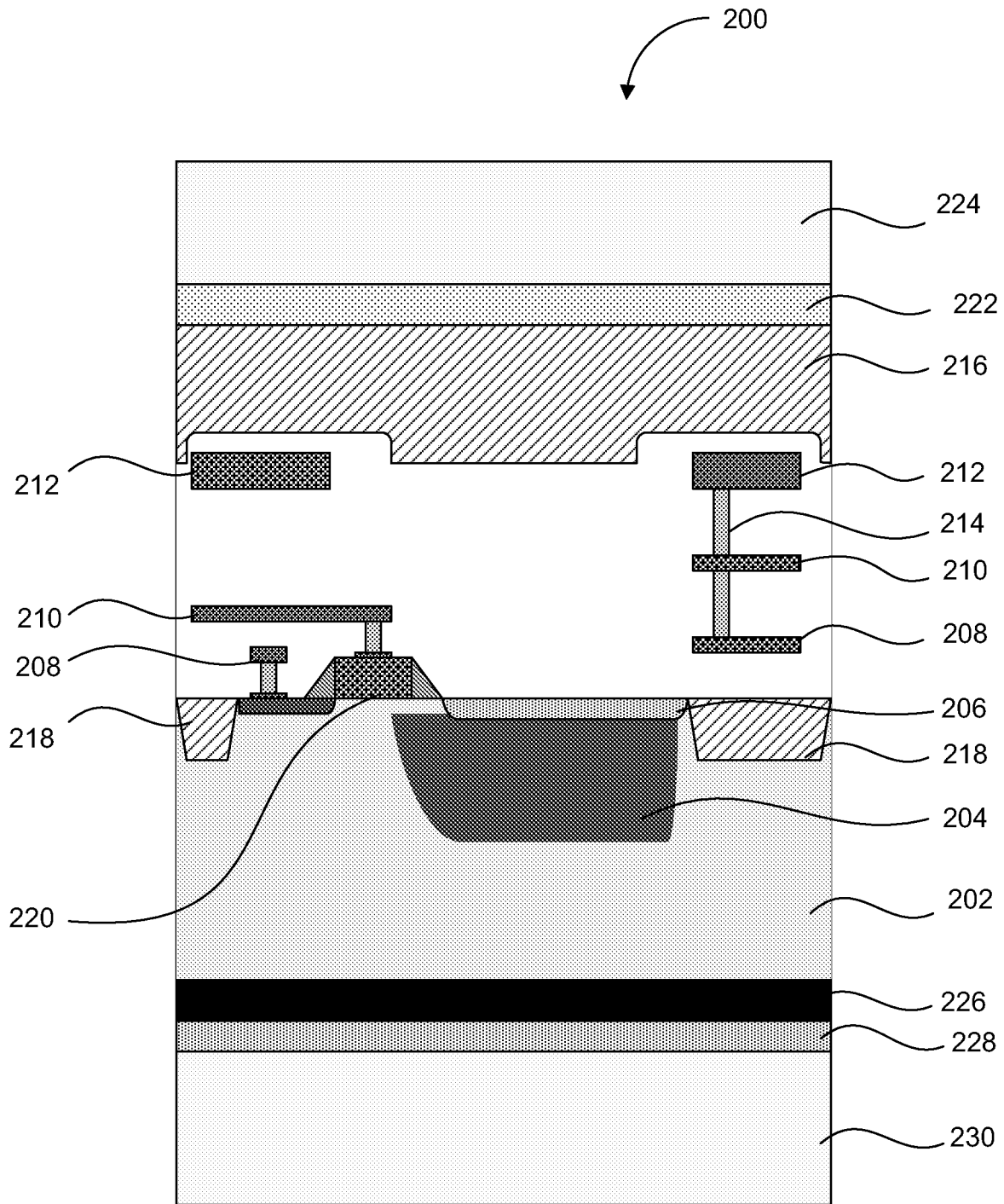


FIG. 5

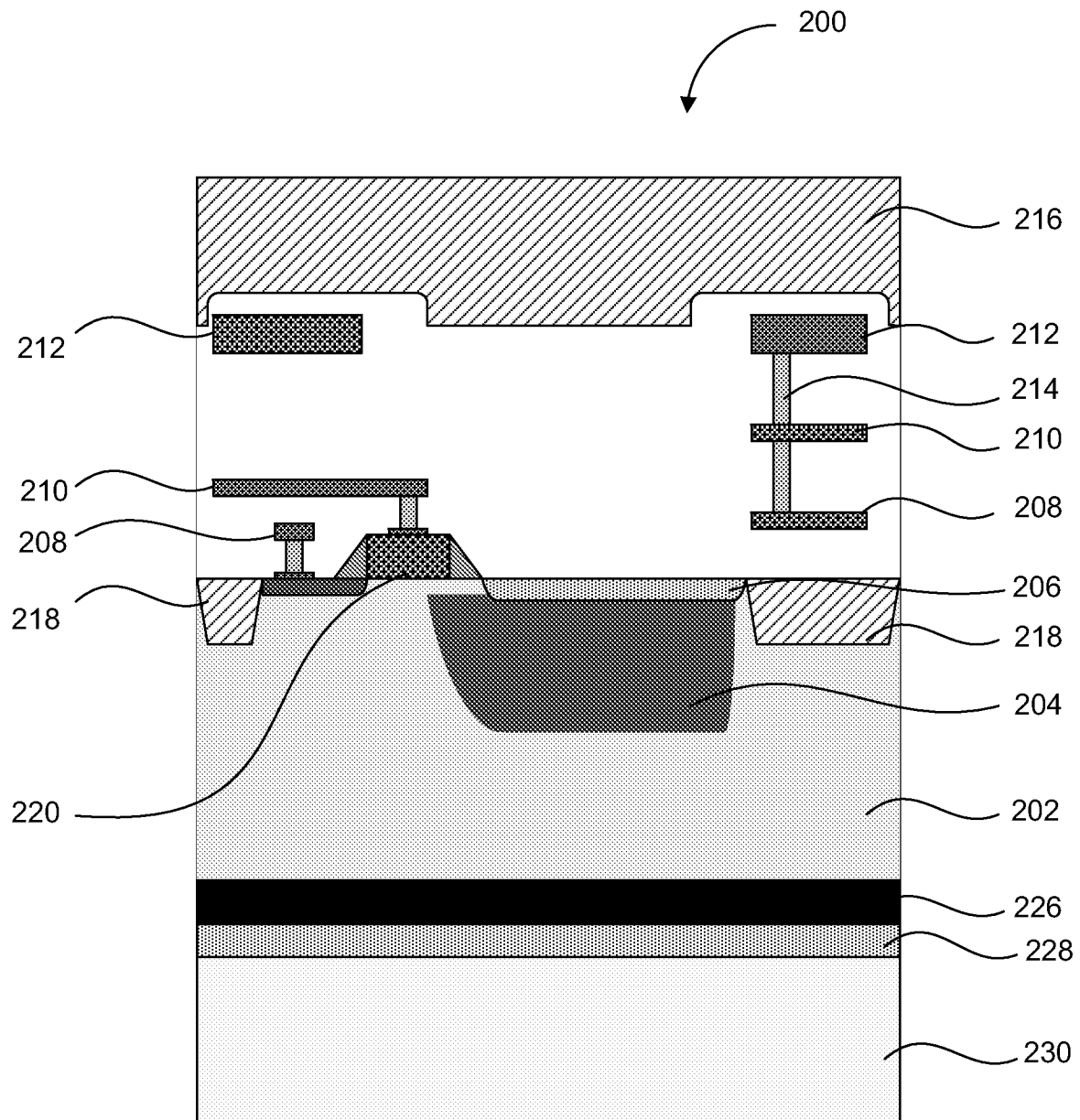


FIG. 6

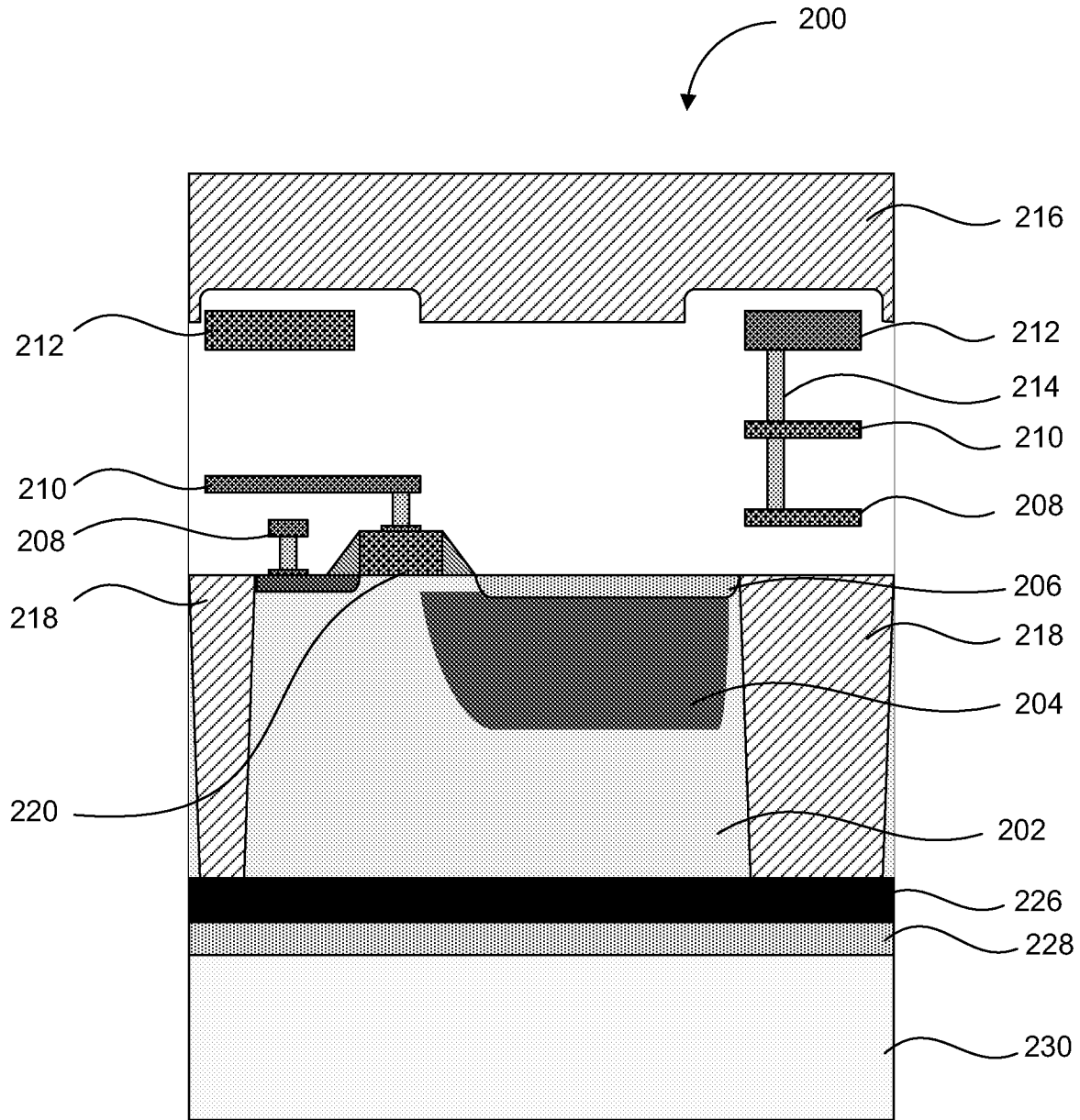


FIG. 7a

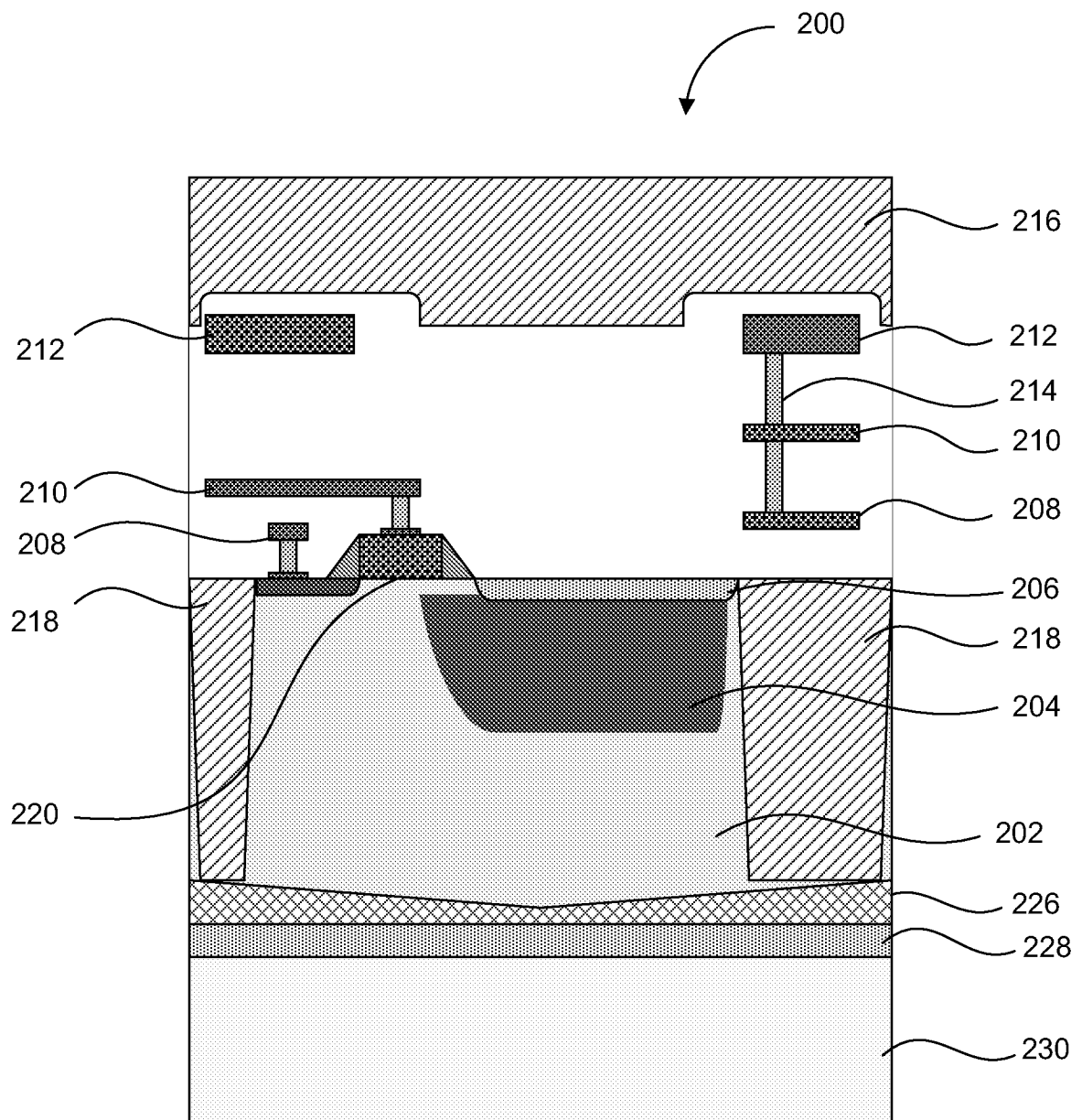


FIG. 7b

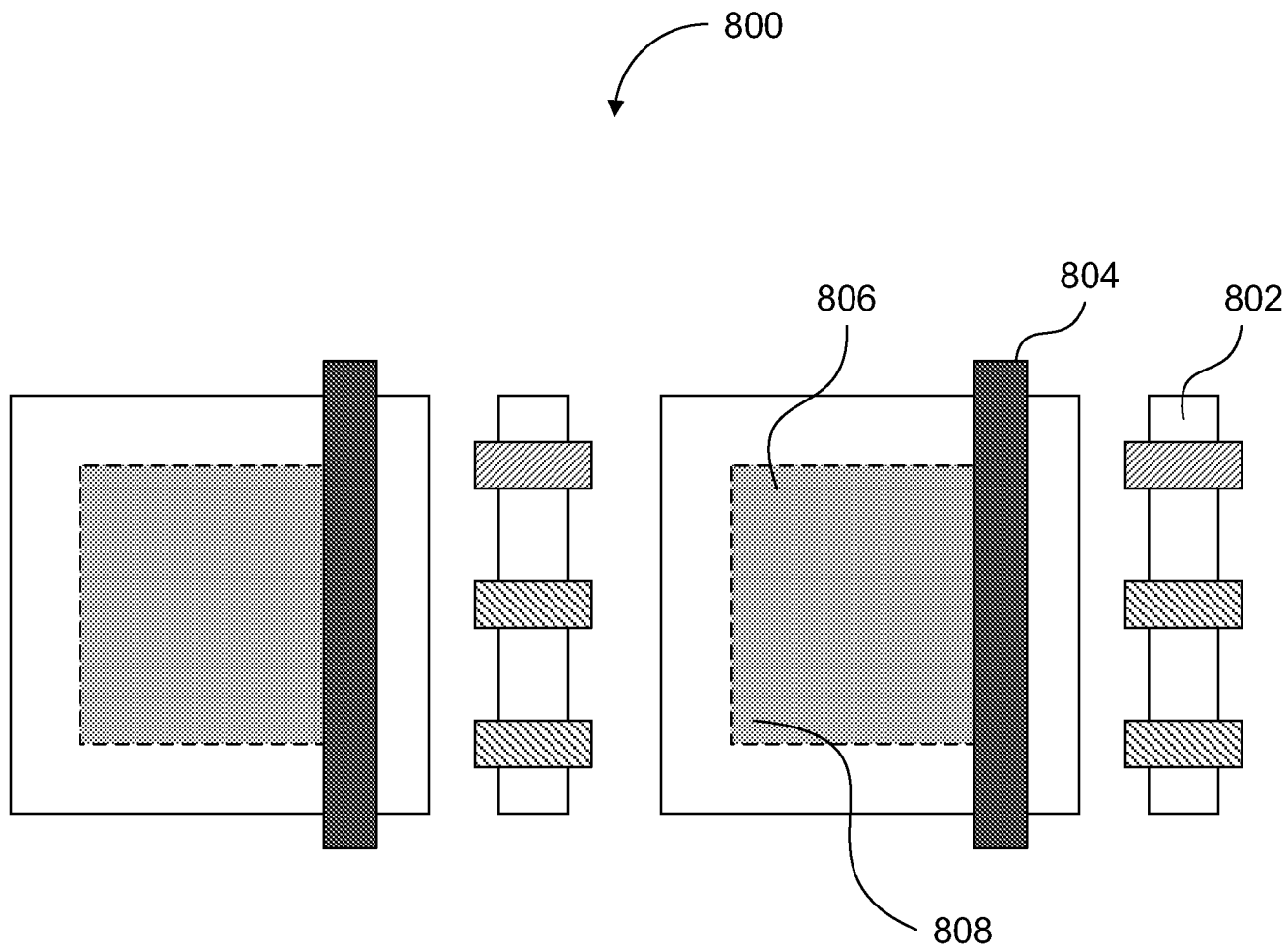


FIG. 8

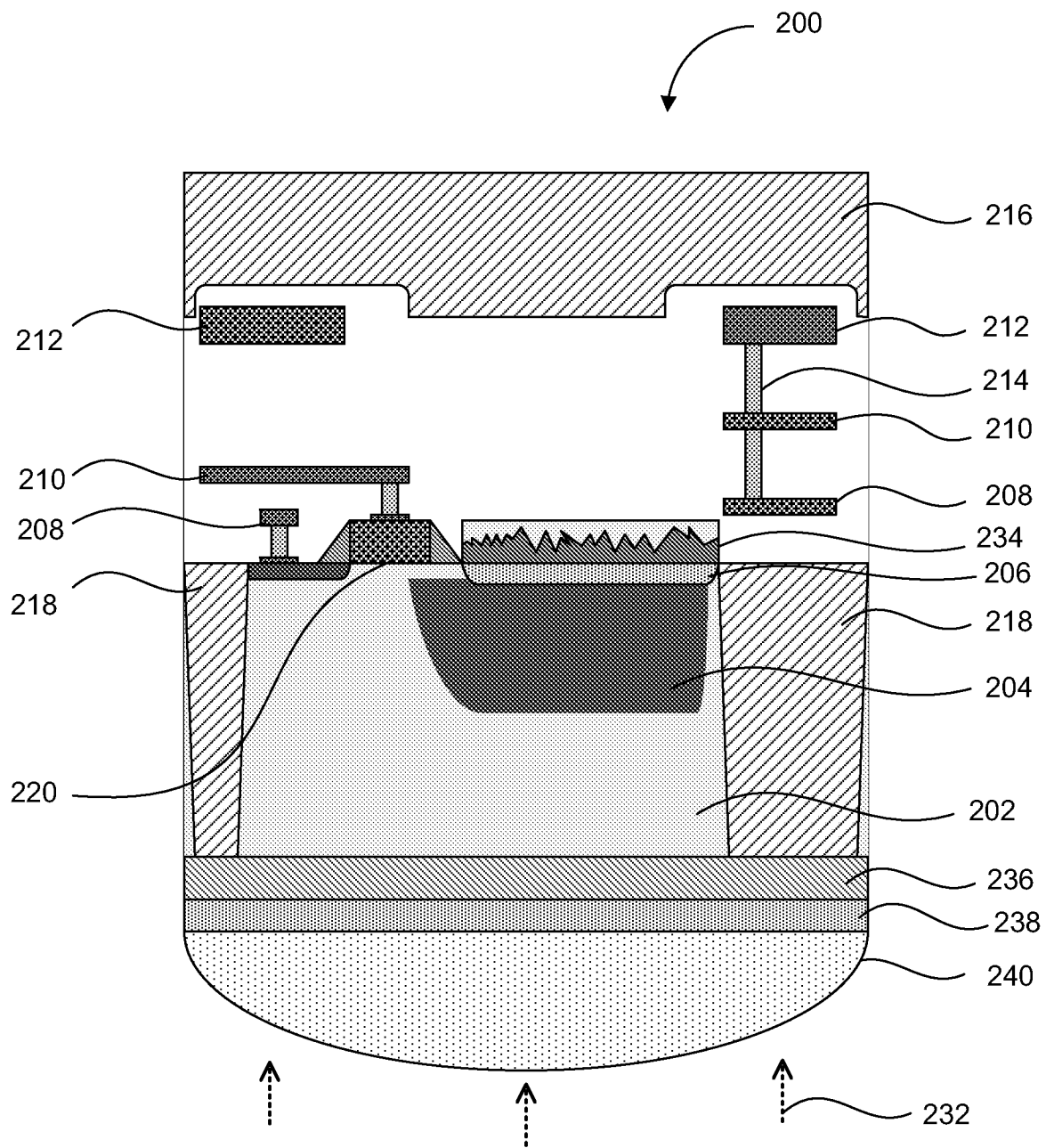


FIG. 9

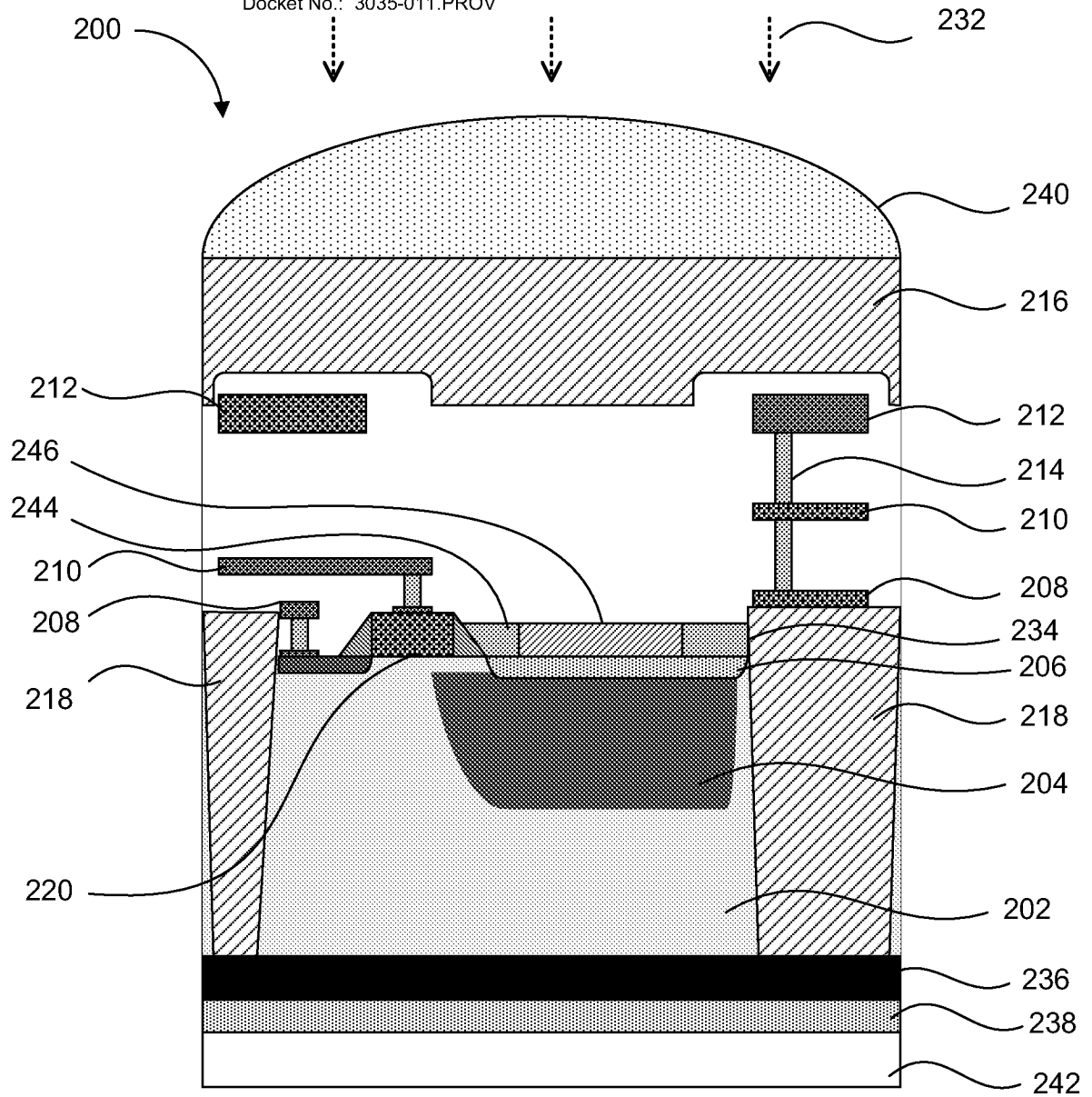


FIG. 10

Electronic Patent Application Fee Transmittal

Application Number:				
Filing Date:				
Title of Invention:	Photosensing Imager and Methods of Making the Same			
First Named Inventor/Applicant Name:	Homayoon Haddad			
Filer:	Todd Brent Alder/Nicole Solomon			
Attorney Docket Number:	3035-011.PROV			
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International Application Number:	
Confirmation Number:	5067
Title of Invention:	Photosensing Imager and Methods of Making the Same
First Named Inventor/Applicant Name:	Homayoon Haddad
Customer Number:	20551
Filer:	Todd Brent Alder/Nicole Solomon
Filer Authorized By:	Todd Brent Alder
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Application Type:	Provisional

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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY. DOCKET NO	TOT CLAIMS	IND CLAIMS
61/311,004	03/05/2010		110	3035-011.PROV		

CONFIRMATION NO. 5067

20551
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FILING RECEIPT



Date Mailed: 03/30/2010

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If Required, Foreign Filing License Granted: 03/26/2010

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 61/311,004**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No

**** SMALL ENTITY ****

Title

Photosensing Imager and Methods of Making the Same

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