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### SEMICONDUCTOR IMAGE-SENSING STRUCTURE

#### Abstract

A semiconductor image-sensing structure includes a semiconductor substrate having a front side and a back side, a photo-sensing element disposed in the semiconductor substrate, a transistor disposed over the front side of the semiconductor substrate, and a metal reflector disposed over the front side of the semiconductor substrate. The metal reflector surrounds a gate structure of the transistor from a plan view on the front side of the semiconductor substrate.

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## Background/Summary

PRIORITY CLAIM AND CROSS-REFERENCE [0001] This application is a continuation application of U.S. patent application Ser. No. 17/813,947 filed on Jul. 21, 2022, entitled of “SEMICONDUCTOR IMAGE-SENSING STRUCTURE”, the disclosure of which is hereby incorporated by reference in its entirety.

### BACKGROUND

[0002] Semiconductor image sensors are used to sense radiation, such as light. Complementary metal-oxide-semiconductor (CMOS) image sensors (CIS) are widely used in various applications, such as digital cameras and mobile phone cameras. Such cameras utilize an array of pixels located in a semiconductor substrate, including photodiodes and transistors that can absorb radiation projected toward the semiconductor substrate and convert the sensed radiation into electrical signals.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0004] FIG. 1 shows a CMOS image sensor (CIS) architecture in accordance with some embodiments of the present disclosure.

[0005] FIG. 2 is a schematic view of a semiconductor image-sensing structure in accordance with some embodiments of the present disclosure.

[0006] FIG. 3 shows a plan view of a semiconductor image-sensing structure in accordance with some embodiments of the present disclosure.

[0007] FIG. 4 shows a plan view of a semiconductor image-sensing structure in accordance with some embodiments of the present disclosure.

[0008] FIG. 5 is a cross-sectional view of a semiconductor image-sensing structure in accordance with some embodiments of the present disclosure.

[0009] FIG. 6 is a cross-sectional view of a semiconductor image-sensing structure in accordance with some embodiments of the present disclosure.

[0010] FIG. 7 is a schematic view of a semiconductor image-sensing structure in accordance with some embodiments of the present disclosure.

### DETAILED DESCRIPTION OF THE DISCLOSURE

[0011] The following disclosure provides many different embodiments, or examples, for implementing different features of the provided subject matter. 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. For example, 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. 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.

[0012] 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. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.

[0013] Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the disclosure are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. Any numerical value, however, inherently contains certain errors necessarily resulting from the standard deviation found in the respective testing measurements. Also, as used herein, the terms “substantially,” “approximately” or “about” generally mean within a value or range that can be contemplated by people having ordinary skill in the art. Alternatively, the terms “substantially,” “approximately” or “about” mean within an acceptable standard error of the mean when considered by one of ordinary skill in the art. People having ordinary skill in the art can understand that the acceptable standard error may vary according to different technologies. Other than in the operating/working examples, or unless otherwise expressly specified, all of the numerical ranges, amounts, values and percentages such as those for quantities of materials, durations of times, temperatures, operating conditions, ratios of amounts, and the likes thereof disclosed herein should be understood as modified in all instances by the terms “substantially,” “approximately” or “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the present disclosure and attached claims are approximations that can vary as desired. At the very least, each numerical parameter should be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. Ranges can be expressed herein as being from one endpoint to another endpoint or between two endpoints. All ranges disclosed herein are inclusive of the endpoints, unless specified otherwise.

[0014] Backside illumination (BSI) image sensors are replacing front-side illumination sensors for their greater efficiency in capturing photons. During formation of the BSI image sensors, the BSI image sensors and logic circuits are formed in a semiconductor substrate of a wafer (or silicon chip), followed by formation of a back-end-of-line (BEOL) interconnect structure over a front side of the semiconductor substrate, and an optical stack including color filters and micro-lenses corresponding to the image sensors disposed over a back side of the semiconductor substrate.

[0015] It is found that light having large wavelengths, e.g., wavelengths greater than 610 nanometers, may pass through the BSI image sensors, the semiconductor substrate, and even the BEOL interconnect structure. The large-wavelength light may be absorbed by dielectric layers of the BEOL interconnect structure, where the BEOL metallization layers are located. The large-wavelength light may be transmitted to a carrier wafer or an application specific integrated circuit (ASIC) wafer. Light not absorbed by the image sensors is lost.

[0016] The present disclosure therefore provides a semiconductor image-sensing structure having a reflective structure formed by front-end-of-line (FEOL) manufacturing operations. The reflective structure helps reflect light back into image sensors and reduces light entering a BEOL interconnect structure. Accordingly, light quantum efficiency (QE) of large-wavelength light is improved.

[0017] Referring to FIG. 1, an image sensor device **100** is provided. The image sensor device **100** may include an array of semiconductor image-sensing structures **110** (e.g., pixels). In some embodiments, the image sensor device **100** may be a CIS or active pixel sensor. In some embodiments, the image sensor device **100** may be a charge coupled device (CCD) or passive pixel sensor. In some embodiments, the image sensor device **100** is a back-side illuminated (BSI) sensor device. The image sensor device **100** includes a plurality of the semiconductor image-sensing structures **110** arranged in the array for measuring an intensity or a brightness of radiation. In some

embodiments, each of the semiconductor image-sensing structures **110** may include at least one photo-sensing element, such as a photodiode. In other embodiments, the semiconductor image-sensing structures **110** may include pinned photodiodes. In some embodiments, photogate detectors, phototransistors, and/or other detectors known in the art may be used as the semiconductor image-sensing structures **110**. It should be understood that the image sensor device **100** may include many hundreds or thousands of semiconductor image-sensing structures **110** in a sensor array area. In some embodiments, readout circuits **120** and pixel control circuits (i.e., logic drive circuits) **122** may be disposed at sides of the array of the semiconductor image-sensing structures **110**, as shown in FIG. 1, but the disclosure is not limited thereto. For simplicity, a single semiconductor image-sensing structure **110** is described in the present disclosure; however, typically an array of such semiconductor image-sensing structures **110** may form the image sensor device **100**, as illustrated in FIG. 1.

[0018] Referring to FIG. 2, in some embodiments, the semiconductor image-sensing structure **110** may include a reset transistor (RST), a source follower transistor (SF), a row selector transistor (SEL or RSL) and a transfer transistor (Tx). In such embodiments, the semiconductor image-sensing structure **110** is referred to as a four-transistor structure, or a 4T structure. However, various other configurations are possible, including, for example, a 3T structure or a 5T structure. Additional circuitry and input/outputs such as the readout circuits **120** and the pixel control circuits **122** are typically provided adjacent to the array of semiconductor image-sensing structures **110** for providing an operation environment for the semiconductor image-sensing structures **110** and for supporting external communications with the semiconductor image-sensing structures **110**.

[0019] Still referring to FIG. 2, the semiconductor image-sensing structure **110** further includes a photo-sensing element (i.e., photodiode) PD. The photo-sensing element PD is electrically connected in series to the transfer transistor Tx. The transfer transistor Tx is electrically connected in series to the reset transistor RST. A gate structure of the source follower transistor SF is electrically connected to a source region of the reset transistor RST, and a drain region of the source follower transistor SF is electrically connected to a power supply. The row selector transistor RSL is electrically connected in series to the source follower transistor SF. The reset transistor RST may function to reset the semiconductor image-sensing structure **110**, e.g., by resetting a floating diffusion region (or a floating node FD), described below. The source follower transistor SF may allow a voltage of the semiconductor image-sensing structure **110** to be observed without removing an accumulated charge. The row selector transistor RSL may be a row-select transistor and may allow a single row of the image-sensing elements in an array, such as the array of FIG. 1, to be read when the row selector transistor RSL is turned on. The drain of the transfer transistor Tx includes a floating diffusion region FD, described below. The transfer transistor Tx can move signal charges accumulated in the photo-sensing element PD to the floating diffusion region FD. For example, a transfer gate structure (or a gate structure of the transfer transistor Tx) controls a transfer of electrons between the photo-sensing element PD and the floating diffusion region FD. Because the floating diffusion region FD is coupled to the gate structure of the source follower transistor SF, if the row selector transistor RSL is turned on (i.e., if the row is selected), then data is output from the semiconductor image-sensing structure **110**.

[0020] Please refer to FIGS. 3 and 4, wherein each of FIGS. 3 and 4 is a plan view of a semiconductor image-sensing structure **110** in accordance with various embodiments of the present disclosure. It should be noted that same elements in FIGS. 3 and 4 are depicted by same numerals and may have similar materials; therefore, repeated description is omitted. Each of the semiconductor image-sensing structures **110** includes a semiconductor substrate **102** (shown in FIGS. 5 and 6). Further, each of the semiconductor image-sensing structures **110** includes a sensing region **104** defined in the semiconductor substrate **102**. Referring to FIGS. 3 and 4, in some embodiments, each of the semiconductor image-sensing structures **110** includes a gate structure **130** disposed over the sensing region **104**. In some embodiments, the gate structure **130** covers

portions of the sensing region **104**. In some embodiments, the gate structure **130** may be a gate structure of the transfer transistor Tx, but the disclosure is not limited thereto. In some embodiments, the semiconductor image-sensing structure **110** may include other gate structures such as gate structures **132** of the reset transistors RST, gate structures **134** of the source follower transistors SF, and gate structures **136** of the row selector transistors RSL. In such embodiments, the gate structures **132**, **134** and **136** are all disposed in a position offset from the sensing region **104**, as shown in FIGS. **3** and **4**. It should be understood that each of the transistors has other elements such as a source region, a drain region, etc.; however, such elements are omitted from FIGS. **3** and **4** for brevity.

[0021] Additionally, arrangements of the abovementioned transistors can be modified according to various product designs.

[0022] Still referring to FIGS. **3** and **4**, in some embodiments, each of the semiconductor image-sensing structures **110** further includes a reflective structure **140**. The reflective structure **140** is disposed over the sensing region **104**. Further, the reflective structure **140** is separated from the gate structures **130** of the transfer transistors Tx. A ratio of an area of the reflective structure **140** to an area of the sensing region **104** is between approximately 65% and approximately 80%, but the disclosure is not limited thereto. In some embodiments, a ratio of an area of the gate structure **130** to the area of the sensing region **104** is between approximately 20% and approximately 35%, but the disclosure is not limited thereto.

[0023] In some embodiments, the reflective structure **140** may have a continuous configuration, as shown in FIG. **4**. In other embodiments, the reflective structure **140** may have a configuration of islands that are separated from each other, as shown in FIG. **3**. It should be noted that shapes, configurations, and locations of the reflective structure **140** are very flexible, and can be modified according to different product designs.

[0024] Referring to FIG. **4**, in some embodiments, the semiconductor image-sensing structure **110** may further include another reflective structure **142**. The reflective structure **142** includes a material same as a material of the reflective structure **140**. The reflective structure **142** may be formed by operations same as those for forming the reflective structure **140**. The reflective structure **142** is disposed beyond the sensing region **104**. Further, the reflective structure **142** is separated from all of the gate structures **130**, **132**, **134** and **136**. In some embodiments, the reflective structure **142** is separated from the reflective structure **140**, as shown in FIG. **4**, but the disclosure is not limited thereto. In some embodiments, the reflective structures **140** and **142** are coupled. It should be noted that a shape, a configuration and an arrangement of the reflective structure **142** can be modified depending on various product designs for improved light reflection.

[0025] In some embodiments, the reflective structures **140** and **142**, and the gate structures **130**, **132**, **134** and **136** may include a same material formed by same operations. For example, all of the gate structures **130**, **132**, **134** and **136** and the reflective structures **140** and **142** include a same semiconductor material, such as polysilicon, but the disclosure is not limited thereto. In other embodiments, all of the gate structures **130**, **132**, **134** and **136**, and the reflective structures **140** and **142** include same metal materials. In still other embodiments, the reflective structures **140** and **142** include materials different from those of the gate structures **130**, **132**, **134** and **136**. For example but not limited thereto, all the gate structure **130**, **132**, **134** and **136** include metal materials, while the reflective structures **140** and **142** include a semiconductor material such as polysilicon.

Alternatively, all the gate structure **130**, **132**, **134** and **136** include a same semiconductor material, while the reflective structures **140** and **142** include metal materials.

[0026] Please referring to FIGS. **5** and **6**, which are cross-sectional views of a semiconductor image-sensing structure **100** in accordance with various embodiments of the disclosure. It should be noted that a plan view of the semiconductor image-sensing structures shown in FIGS. **5** and **6** may be similar to those shown in FIGS. **3** and **4**, but the disclosure is not limited thereto. Further, same elements shown in FIGS. **3** to **6** may designated by same numerals, and details, such as

materials, of same elements shown in FIGS. 3 to 6 are omitted for brevity.

[0027] As shown in FIGS. 5 and 6, the semiconductor image-sensing structure **110** includes a semiconductor substrate **102**. The semiconductor substrate **102** has a front side **102F** and a back side **102B** opposite to the front side **102F**. In some embodiments, the semiconductor substrate **102** may be formed of a semiconductor material such as silicon, germanium, diamond or like materials. Compound materials used for semiconductor substrates such as silicon germanium, silicon carbide, gallium arsenide, indium arsenide, indium phosphide, or combinations of these may be used. In alternative embodiments, the semiconductor substrate **102** may include a silicon on insulator (SOI) semiconductor substrate.

[0028] The semiconductor image-sensing structure **110** may include a photo-sensing element **112** such as a photodiode **112** configured to convert light signals (photons) to electrical signals. The photo-sensing element **112** is disposed to receive light with a predetermined wavelength. In some embodiments, the photo-sensing element **112** is operated to sense visible light of incident light. In other embodiments, the photo-sensing element **112** is operated to sense infrared (IR) and/or near-infrared (NIR) of the incident light.

[0029] The semiconductor image-sensing structure **110** may include an isolation structure, such as a deep-trench isolation (DTI) structure **150**, surrounding and between the photo-sensing elements **112** as shown in FIGS. 5 and 6. In some embodiments, the isolation structure **150** may extend from the back side **102B** into the semiconductor substrate **102**. Further, the isolation structures **150** separate the photo-sensing elements **112** from each other. In some embodiments, a depth of the isolation structure **150** may be equal to a thickness of the semiconductor substrate **102**, but the disclosure is not limited thereto. For example, the depth of the isolation structure **150** may be less than the thickness of the semiconductor substrate **102**, as shown in FIGS. 5 and 6, but the disclosure is not limited thereto. The isolation structure **150** provides optical isolation between neighboring photo-sensing elements **112**, thereby serving as a semiconductor substrate isolation grid and reducing cross-talk.

[0030] In some embodiments, logic devices, such as a transistor **160**, can be disposed over the front side **102F** of the semiconductor substrate **102**. The transistor **160** may be configured to enable readout of the photo-sensing element **112**. In some embodiments, the transistor **160** is the transfer transistor. The transfer transistor includes a gate structure **162** and a source/drain region (not shown). The source/drain regions may refer to a source or a drain, individually or collectively, depending on context. The transistor **160** may further include other elements such as spacers, and/or stressors of the source/drain regions, and the gate structure **162** may further include elements such as a gate dielectric layer and a gate conductive layer. Descriptions of such details are omitted for brevity.

[0031] The semiconductor image-sensing structure **110** further includes a back-end-of-line (BEOL) interconnect structure **170** disposed over the front side **102F** of the semiconductor substrate **102**. The BEOL interconnect structure **170** (i.e., BEOL metallization layers **174**) is electrically connected to the semiconductor image-sensing structure **110**. For example, the BEOL interconnect structure **170** electrically connects the transistor **160** to other circuits, as shown in FIGS. 5 and 6. Further, the BEOL interconnect structure **170** electrically connects the semiconductor image-sensing structure **110** to other structures, devices or circuits. In some embodiments, the BEOL interconnect structure **170** includes a plurality of dielectric layers **172**, and a plurality of metallization layers **174** and via conductors **176** disposed in the dielectric layers **172**.

[0032] In some embodiments, the semiconductor image-sensing structure **110** includes a reflective structure **140** disposed over the front side **102F** of the semiconductor substrate **102**. In some embodiments, the reflective structure **140** may further include a gate dielectric layer and a gate conductive layer, though not shown. In some embodiments, the reflective structure **140** further includes a spacer **144** over sidewalls of itself, as shown in FIGS. 5 and 6. As mentioned above, the transistor **160** (i.e., the gate structure **162**) is electrically connected to the BEOL interconnect

structure **170**, but transistor **160** (i.e., the gate structure **162**, the spacer **164** and the source/drain regions) is separated from the reflective structure **140**. Further, the reflective structure **140** is separated from the BEOL metallization layers **174** of the BEOL interconnect structure **170**. In some embodiments, the reflective structure **140** is separated from other elements. In such embodiments, the reflective structure **140** is electrically isolated or electrically floating over the front side **102F** of the semiconductor substrate **102** and embedded in the dielectric layer **172**.

[0033] Referring to FIG. 5, in some embodiments, the gate structure **162** of the transistor **160** and the reflective structure **140** are formed by same operations; therefore, the gate structure **162** and the reflective structure **140** include one or more same materials. For example, the gate structure **162** and the reflective structure **140** may both include a semiconductor material layer, such as a polysilicon layer. Further, the gate structure **162** and the reflective structure **140** may both further include a gate dielectric layer between the semiconductor substrate **102** and the semiconductor material layer. When the gate structure **162** and the reflective structure **140** are formed by the same operation, a dielectric layer (not shown) is formed over the front side **102F** of the semiconductor substrate **102**, and a semiconductor material layer (i.e., a doped or undoped polysilicon layer) is sequentially formed over the dielectric layer. A patterning operation using a patterned photoresist and a patterned hard mask is then performed on the semiconductor material layer and the dielectric layer, thereby simultaneously forming the gate structure **162** and the reflective structure **140** over the front side **102F** of the semiconductor substrate **102**.

[0034] It should be noted that a top surface of the gate structure **162** and a top surface of the reflective structure **140** are aligned with each other. In such embodiments, a top surface of the semiconductor layer of the gate structure **162** and a top surface of the semiconductor layer of the reflective structure **140** are aligned with each other. In some embodiments, a bottom surface of the gate structure **162** and a bottom surface of the reflective structure **140** are aligned with each other. In such embodiments, a bottom surface of the gate dielectric layer of the gate structure **162** and a bottom surface of the gate dielectric layer of the reflective structure **140** are aligned with each other. In some embodiments, a height of the gate structure **162** and a height of the reflective structure **140** are the same. However, a dimension of the reflective structure **140** is greater than a dimension of the gate structure **162** of the transistor **160**. Further, at least a portion of the reflective structure **140** overlaps the photo-sensing element **112**.

[0035] In some embodiments, spacers **164** and **144** are subsequently formed on sidewalls of the gate structure **162** and the reflective structure **140**. In some embodiments, the spacers **164** and **144** are made of silicon nitride (SiN), silicon carbide (SiC), SiO, silicon oxynitride (SiON), silicon carbon or another suitable material, but the disclosure is not limited thereto. In some embodiments, the spacers **164** and **144** are formed by deposition and etching back operations.

[0036] In some embodiments, source/drain regions (not shown) are formed at opposite sides of the gate structure **162**. In such embodiments, the source/drain regions may be formed by forming recesses in the semiconductor substrate **102** and growing a strained material in the recesses by an epitaxial (epi) process. In addition, a lattice constant of the strained material may be different from a lattice constant of the semiconductor substrate **102**. Accordingly, the source/drain regions may have stressors that improve carrier mobility. In some embodiments, Ge, SiGe, InAs, InGaAs, InSb, GaSb, InAlP, InP, SiP, or a combination thereof, can be used to form the source/drain regions, depending on whether the FET device is a p-type FET device or an n-type FET device. For example, SiGe may be used to form the source/drain regions of the PFET device, while SiP is used to form the source/drain regions of the NFET device.

[0037] Still referring to FIG. 5, in some embodiments, the gate structure **162** and the reflective structure **140** include a same metal material. In such embodiments, the gate structure **162** and the reflective structure **140** may undergo a replacement polysilicon gate (RPG) operation. Accordingly, a dielectric layer and a semiconductor material layer may be sequentially formed over the front side **102F** of the semiconductor substrate **102**, followed by the abovementioned patterning operation.

Thus, a sacrificial gate structure and a temporary reflective structure are formed over the front side **102F** of the semiconductor substrate **102**. Other elements, such as spacers, source/drain regions, an etch stop layer such as contact etch stop layer (CESL), and an inter-layer dielectric (ILD) layer are formed over the front side **102F** of the semiconductor substrate **102**. Thereafter, the sacrificial gate structure and the temporary reflective structure are replaced with metal materials. Accordingly, the gate structure **162** and the reflective structure **140** may include a high-k gate dielectric layer, at least a work function metal layer (e.g., a titanium aluminum (TiAl) layer or a tantalum aluminum (TaAl) layer), a gap-filling metal layer (e.g., an aluminum (Al) layer), and other layers such as a barrier layer and/or an etch stop layer are formed.

[0038] In some embodiments, the formation of the gate structure **162** and the reflective structure **140** may be integrated with RPG approaches. Thus, process integration is improved.

[0039] In some embodiments, the gate structure **162** of the transistor **160** and the reflective structure **140** may include different materials. For example, the gate structure **162** includes a semiconductor material, and the reflective structure **140** includes metal materials. In such embodiments, RPG operations may be performed to replace the temporary reflective structure (including semiconductor material) with metal material, while the gate structure **162** of the transistor **160** is protected from the RPG operations.

[0040] In some embodiments, the RPG operations are performed to replace the sacrificial gate structure with metal materials, while the reflective structure **140** is protected from the RPG operations. In such embodiments, the gate structure **162** of the transistor **160** includes metal material, and the reflective structure **140** includes semiconductor material.

[0041] The semiconductor image-sensing structure **110** further includes an anti-reflective coating (ARC) **152** and a dielectric layer **154** disposed over the back side **102B** of the semiconductor substrate **102**, as shown in FIGS. 5 and 6. In some embodiments, the ARC **152** may extend into the semiconductor substrate **102** and covers sidewalls and bottoms of the isolation structure **150**. In some embodiments, the dielectric layer **154** is coupled to the isolation structure **150**. In some embodiments, the dielectric layer **154** can include, for example, an oxide such as silicon dioxide, but the disclosure is not limited thereto. In some embodiments, the dielectric layer **154** provide a flat and even surface over the back side **102B** of the semiconductor substrate **102**.

[0042] The semiconductor image-sensing structure **110** further includes a color filter **180** disposed over the semiconductor substrate **102** on the back side **102B**. Further, the color filter **180** is aligned with the photo-sensing element **112**, as shown in FIGS. 5 and 6. In some embodiments, a low-n grid **182** may be disposed between the color filter **180** and the back side **102B** of the semiconductor substrate **102**. The color filter **180** may have a refractive index that is less than a refractive index of the low-n grid **182**. It will be appreciated that due to the different refractive indices of the color filter **180** and the low-n grid **182**, when light, such as photons, encounter an interface between the color filter **180** and the low-n grid **182**, the light is reflected away from the low-n grid **182** and back into the color filter **180** or into the semiconductor substrate **102**, such that the light is not directed toward an incorrect neighboring photodiode.

[0043] The color filter **180** allows different specific colors or wavelengths of light to through. For example, the color filter **180** may allow red light, or wavelengths corresponding to red light, to pass through, while allowing substantially no other colors of light to therethrough. The color filter **180** may allow blue light, or wavelengths corresponding to blue light, to pass through, while allowing substantially no other colors of light to pass through. Alternatively, the color filter **180** may allow green light, or wavelengths corresponding to green light, to pass through, while allowing substantially no other colors of light to pass through. In some embodiments, other colors of light may be allowed to exclusively pass through the color filter **180**, but the disclosure is not limited thereto.

[0044] The semiconductor image-sensing structure **110** further includes a micro-lens **184** disposed over the color filter **180**. The micro-lens **184** is configured to focus light toward the photo-sensing



element **112**.

[0045] According to the semiconductor image-sensing structure **110** provided by the present disclosure, the reflective structure **140** is formed by FEOL operations. The reflective structure **140** helps to reflect light before it enters the BEOL interconnect structure **170**; therefore, light quantum efficiency (QE) of the semiconductor image-sensing structure **110** is improved. In some embodiments, QE for the light of greater wavelengths is further improved by the reflective structure **140**.

[0046] In some comparative approaches that provide a reflective structure in the BEOL interconnect structure **170**, such approaches suffer from complicated designs for BEOL wire routing. In contrast with the comparative approaches, the reflective structure **140** of the present disclosure is separated from the BEOL metallization layers **174** by the dielectric layer **172** of the BEOL interconnect **170**; thus, design of wire routing of the BEOL metallization layers **174** is simplified, which is beneficial for all aspects of design and fabrication.

[0047] Please referring to FIG. 7, which is a schematic view of a semiconductor image-sensing structure in accordance with some embodiments of the present disclosure. In some embodiments, when the semiconductor image-sensing structure **110** is integrated with a 3D stacking approach, some transistors may be located in another semiconductor substrate. For example, a source follower transistor SF and a row selector transistor RSL may be formed in another semiconductor substrate **202** or wafer, such as an application specific integrated circuit (ASIC) wafer. In such embodiments, spaces are conserved and is thus available for disposing additional reflective structure **140**, and thus QE may be further improved. The semiconductor substrate **202** accommodating the source follower transistor SF, the row selector transistor RSL and other devices can be bonded to the semiconductor substrate **102** accommodating the photo-sensing element **112**, the reset transistor RST, the transfer transistor Tx, the reflective structure **142** and other devices to realize a 3D-stacking sensor device **100**.

[0048] The present disclosure therefore provides a semiconductor image-sensing structure having a reflective structure formed by front-end-of-line (FEOL) manufacturing operations. The reflective structure helps reflect light back into image sensors before entering a BEOL metallization structure. Accordingly, light quantum efficiency (QE) is improved for longer wavelengths of light. In addition, because the reflective structure is formed by the FEOL operations, design and manufacturing of the BEOL metallization structure are simplified. Further, the forming of the reflective structure is integrated with the forming of a semiconductor gate structure or a metal gate structure; therefore, the reflective structure provides an advantage of various options for materials. Accordingly, process flexibility is improved.

[0049] In some embodiments, a semiconductor image-sensing structure is provided. The semiconductor image-sensing structure includes a semiconductor substrate having a front side and a back side, a pixel sensor disposed in the semiconductor substrate, a transistor disposed over the front side of the semiconductor substrate, and a reflective structure disposed over the front side of the semiconductor substrate. A gate structure of the transistor and the reflective structure include a same material. A top surface of the gate structure of the transistor and a top surface of the reflective structure are aligned with each other.

[0050] In some embodiments, a semiconductor image-sensing structure is provided. The semiconductor image-sensing structure includes a semiconductor substrate having a front side and a back side, a pixel sensor disposed in the semiconductor substrate, a transistor disposed over the front side of the semiconductor substrate, and a reflective structure disposed over the front side of the semiconductor substrate. A gate structure of the transistor and the reflective structure include different materials. A top surface of the gate structure of the transistor and a top surface of the reflective structure are aligned with each other.

[0051] In some embodiments, a semiconductor image-sensing structure is provided. The semiconductor image-sensing structure includes a semiconductor substrate having a sensing region,

a gate structure disposed over the sensing region, and a reflective structure disposed over the sensing region. A ratio of an area of the reflective structure to an area of the sensing region is between approximately 65% and approximately 80%.

[0052] In some embodiments, a semiconductor image-sensing structure is provided. The semiconductor image-sensing structure includes a semiconductor substrate having a front side and a back side, a photo-sensing element disposed in the semiconductor substrate, a transistor disposed over the front side of the semiconductor substrate, and a metal reflector disposed over the front side of the semiconductor substrate. The metal reflector surrounds a gate structure of the transistor from a plan view on the front side of the semiconductor substrate.

[0053] In some embodiments, a semiconductor image-sensing structure is provided. The semiconductor image-sensing structure includes a semiconductor substrate having a front side and a back side, a photo-sensing element disposed in the semiconductor substrate, a transistor disposed over the front side of the semiconductor substrate, and a semiconductor reflector disposed over the front side of the semiconductor substrate. The semiconductor reflector surrounds a gate structure of the transistor from a plan view on the front side of the semiconductor substrate.

[0054] In some embodiments, a semiconductor image-sensing structure is provided. The semiconductor image-sensing structure includes a semiconductor substrate having a sensing region, a plurality of first gate structures disposed inside the sensing region, and a first reflective structure disposed inside the sensing region. The first reflective structure surrounds the plurality of first gate structures from a plan view.

[0055] The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled 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 skilled 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.

## Claims

1. A semiconductor image-sensing structure, comprising: a semiconductor substrate having a front side and a back side; a photo-sensing element disposed in the semiconductor substrate; a transistor disposed over the front side of the semiconductor substrate; and a metal reflector disposed over the front side of the semiconductor substrate, wherein the metal reflector surrounds a gate structure of the transistor from a plan view on the front side of the semiconductor substrate.
2. The semiconductor image-sensing structure of claim 1, wherein the gate structure of the transistor comprises a semiconductor material.
3. The semiconductor image-sensing structure of claim 1, wherein the gate structure of the transistor and the metal reflector comprise a same metal material.
4. The semiconductor image-sensing structure of claim 1, wherein the metal reflector overlaps at least a portion of the photo-sensing element.
5. The semiconductor image-sensing structure of claim 1, further comprising: a dielectric layer disposed over the front side of the semiconductor substrate; and a metallization layer disposed in the dielectric layer.
6. The semiconductor image-sensing structure of claim 5, wherein the metal reflector is electrically isolated from the metallization layer by the dielectric layer.
7. The semiconductor image-sensing structure of claim 1, further comprising a deep trench isolation (DTI) structure surrounding the photo-sensing element.
8. A semiconductor image-sensing structure, comprising: a semiconductor substrate having a front

side and a back side; a photo-sensing element disposed in the semiconductor substrate; a transistor disposed over the front side of the semiconductor substrate; and a semiconductor reflector disposed over the front side of the semiconductor substrate, wherein the semiconductor reflector surrounds a gate structure of the transistor from a plan view on the front side of the semiconductor substrate.

**9.** The semiconductor image-sensing structure of claim 8, wherein the gate structure of the transistor comprises a metal material.

**10.** The semiconductor image-sensing structure of claim 8, wherein the gate structure of the transistor and the semiconductor reflector comprise a same semiconductor material.

**11.** The semiconductor image-sensing structure of claim 8, wherein the semiconductor reflector overlaps at least a portion of the photo-sensing element.

**12.** The semiconductor image-sensing structure of claim 8, further comprising: a dielectric layer disposed over the front side of the semiconductor substrate; and a metallization layer disposed in the dielectric layer.

**13.** The semiconductor image-sensing structure of claim 12, wherein the semiconductor reflector is separated from the metallization layer by the dielectric layer.

**14.** The semiconductor image-sensing structure of claim 8, further comprising a DTI structure surrounding the photo-sensing element.

**15.** A semiconductor image-sensing structure, comprising: a semiconductor substrate having a sensing region; a plurality of first gate structures disposed inside the sensing region; and a first reflective structure disposed inside the sensing region, wherein the first reflective structure surrounds the plurality of first gate structures from a plan view.

**16.** The semiconductor image-sensing structure of claim 15, wherein the first reflective structure is separated from each of the plurality of gate structures from a plan view.

**17.** The semiconductor image-sensing structure of claim 15, wherein the plurality of first gate structures are separated from each other.

**18.** The semiconductor image-sensing structure of claim 15, further comprising at least one second gate structure disposed outside the sensing region and separated from the plurality of first gate structure.

**19.** The semiconductor image-sensing structure of claim 18, wherein the first reflective structure is separated from the at least one second gate structure.

**20.** The semiconductor image-sensing structure of claim 15, further comprising a second reflective structure disposed outside the sensing region.

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