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Hynecek

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(54) **IMAGE SENSOR WITH IMPROVED COLOR CROSSTALK**

(71) Applicant: **Intellectual Ventures II LLC**, Wilmington (DE)

(72) Inventor: **Jaroslav Hynecek**, Allen, TX (US)

(73) Assignee: **Intellectual Ventures II LLC**, Wilmington, DE (US)

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Related U.S. Application Data

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(30) **Foreign Application Priority Data**

Oct. 13, 2006 (KR) 10-2006-0099759

(51) **Int. Cl.**
H01L 21/00 (2006.01)

(52) **U.S. Cl.**
USPC **438/57**

(58) **Field of Classification Search**
USPC 438/57, 59, 60
See application file for complete search history.

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Primary Examiner — Bradley K Smith

(74) *Attorney, Agent, or Firm* — McAndrews, Held & Malloy, Ltd.

(57) **ABSTRACT**

An image sensor comprises a substrate of a first conductivity type. First and second pixels are arrayed over the substrate. A potential barrier is formed in a region of the substrate corresponding to the first pixel but not in a region of the substrate corresponding to the second pixel. The second pixel is responsive to a color having a wavelength longer than the color to which the first pixel is responsive. The potential barrier is doped with dopants by a high energy ion implantation dopants or by an ion implantation or diffusion during epitaxial growth of the P-type epitaxial layer.

19 Claims, 2 Drawing Sheets

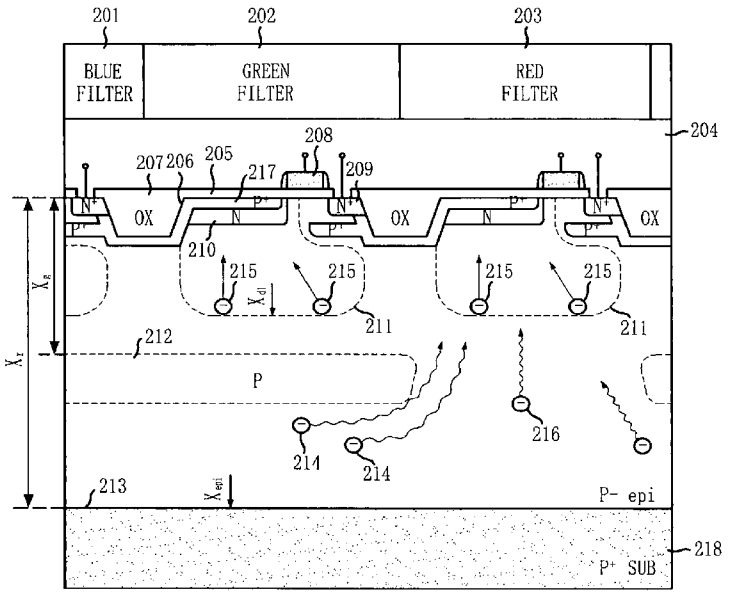

FIG. 1

RELATED ART

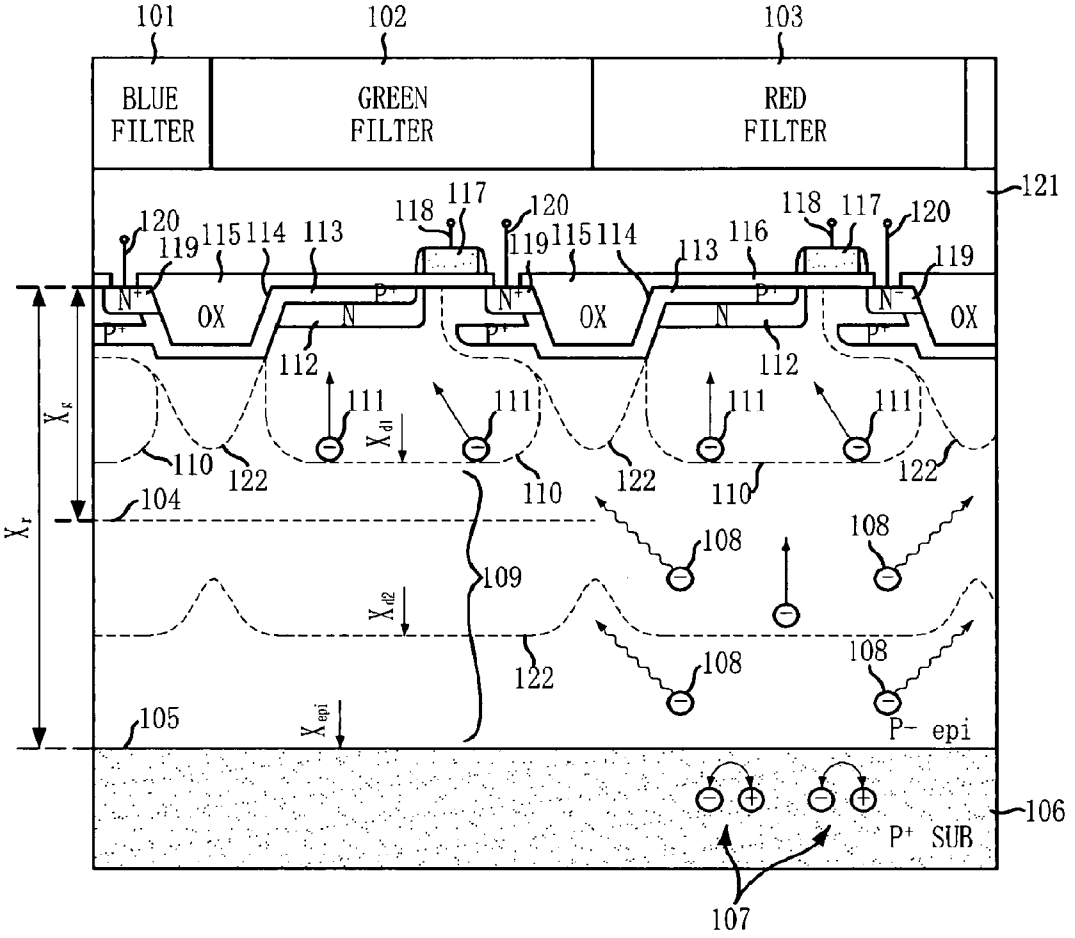

FIG. 2

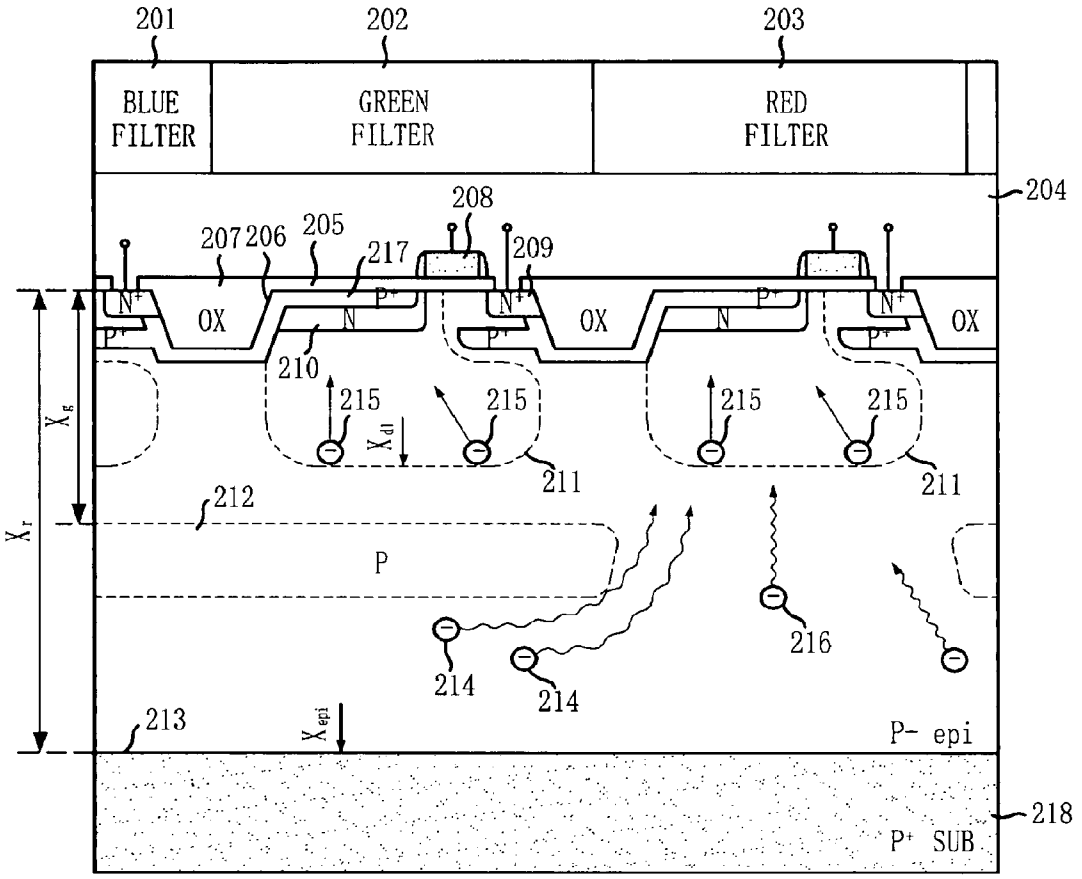
201
202
203
BLUE FILTER
GREEN FILTER
RED FILTER
204
208
207
206
205
217
209
N+
OX
P+
N
210
215
211
212
P
214
216
213
P- epi
218
P+ SUB

IMAGE SENSOR WITH IMPROVED COLOR CROSSTALK

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/077,104 filed on Mar. 31, 2011, which is a continuation of U.S. patent application Ser. No. 11/730,177 filed on Dec. 7, 2009 and issued as U.S. Pat. No. 7,928,478, and claims priority to Korean application 10-2006-0099759 filed on Oct. 13, 2006, all of which are hereby incorporated by reference in their entireties.

BACKGROUND OF THE INVENTION

The present invention relates to a solid-state image sensor, more particularly, to a complementary metal-oxide semiconductor (CMOS) image sensor including small pixels covered with light absorbing color filters.

A typical pixel of a modern CMOS image sensor includes a photodiode, more specifically, a pinned photodiode, and four transistors. The photodiode collects photo-generated charge that is later transferred onto a floating diffusion (FD) node at a suitable moment by a charge transfer transistor. The FD node functions as a charge detection node. Prior to the charge transfer, the FD node needs to be reset to a suitable reference voltage. The reset causes kTC noise, which would be normally added to a signal appearing on the FD node. Thus, it is necessary to read the voltage on the FD node twice, the first time before the charge transfer, and the second time after the charge transfer. This operation is called CDS (Correlated Double Sampling). The CDS operation allows sensing of only the voltage difference on the node caused by the transferred charge from the photodiode.

A source follower (SF) transistor senses the voltage on the FD node through a gate of the SF transistor connected to the FD node, a drain thereof connected to a power voltage (Vdd) terminal, and a source thereof connected to a common column sense line via addressing transistor. For this reason, incorporating 4 transistors in each pixel of a standard CMOS image sensor is generally necessary. U.S. Pat. No. 5,625,210 issued to Paul P. Lee et al. in the name of "Active Pixel Sensor Integrated with Pinned Photodiode" describes one exemplary 4T pixel circuit with a pinned photodiode.

In modern CMOS sensor designs, the circuitry for several photodiodes may be shared as can be found exemplarily in U.S. Pat. No. 6,657,665 B1, issued to R. M. Guidash et al., entitled "Active Pixel Sensor with Wired Floating Diffusions and Shared Amplifier." In this patent application, a dual pixel includes two photodiodes located in adjacent rows of a sensor image array and sharing the same circuitry.

The color sensing in most modern CMOS image sensors is accomplished by placing suitable color filters over the photodiodes as is shown in FIG. **1**. A blue color filter **101** absorbs green and red light and lets only the blue light photons to enter the photodiode area below. Similarly, a green color filter **102** absorbs blue and red light and lets only the green light photons to enter the silicon bulk below. Reference numeral **103** represents a red color filter. Blue light and green light photons have high energy and thus, are generally absorbed very quickly within a depth Xg defined from the surface of the silicon bulk to a certain region **104** thereof. On the other hand, red light photons have low energy and penetrate a region deeper than the above region **104**. More specifically, before generating any photoelectrons, the red light photons can penetrate to an interface **105** between an epitaxial substrate region, located at a depth Xepi, and a highly doped P^+-type substrate **106**. Reference letter 'Xr' denotes a depth of the interface **105** from the surface of the silicon bulk (i.e., highly doped P^+-type substrate **106**).

When electrons **107** are generated in the highly doped P^+-type substrate **106**, the electrons **107** recombine very quickly with the holes located in the highly doped P^+-type substrate **106** and cannot be collected in the "red" photodiode. Those electrons **108**, on the other hand, which are generated in an un-depleted epitaxial layer **109**, have much longer lifetime than the electrons **107**, and diffuse freely in the un-depleted epitaxial layer **109** both laterally and vertically until the electrons **108** reach the boundary of depletion regions **110**. The boundary of the depletion regions **110** is located at a depth Xd**1** from the surface of the silicon bulk.

When electrons **111** enter the depletion regions **110**, the electrons **111** are quickly swept into respective photodiode potential wells located in regions where N-type doped layers **112** are formed. The photodiodes are formed close to the surface of the silicon bulk by the N-type doped layers **112** and P^+-type pinning layers **113**. This structure is called the pinned photodiode. The P^+-type pinning layers **113** each extend along the sides and the bottom of respective shallow trench isolation (STI) regions **114**, each formed by etching the silicon bulk, to separate and isolate the photo sites and the corresponding electrical circuits from each other. The STI regions **114** are filled with silicon dioxide. The silicon dioxide also covers the photodiode surface area and extends under transfer gates **117**. Reference numeral **115** and **116** respectively represent the silicon dioxide filling the STI regions **114** and the silicon dioxide extending under the transfer gates **117** while covering the photodiode surface area. The transfer gates **117** are formed of polycrystalline silicon.

When a suitable bias is applied to each of the transfer gates **117** via corresponding connections **118** (shown only schematically), electron charge stored in the photodiode potential wells is transferred onto respective FD nodes **119** formed by doping N^+-type dopants. The FD nodes **119** usually experience a voltage change. This voltage change is then sensed by suitable amplifiers (SFs), which are connected individually to the FD nodes **119** by respective wires **120** (also shown only schematically). The voltage change represents a desired signal. The photodiodes and the transfer gates **117** are typically covered by another layer **121**, formed by silicon dioxide or multiple layers of silicon dioxide, and other transparent films before color filters are deposited on the top. Microlenses (not shown in the drawing) are then also deposited on top of the blue, green and red color filters **101**, **102** and **103** to focus the light on the surface area of the photodiodes.

As can be easily understood from FIG. **1**, those electrons generated by the red light in the un-depleted epitaxial layer **109** can also diffuse laterally and enter the depletion regions **110** of the neighboring photodiodes. This phenomenon often causes unwanted color crosstalk, since the red light-generated electrons usually end up in wrong photodiode potential wells of the "green" or "blue" photodiodes. This color crosstalk may be pronounced in small size pixels where the lateral dimension of the pixel is less than 2 μm, while the vertical dimension remains on the order of 5 μm. The color crosstalk can be reduced by decreasing the thickness of the epitaxial layer (i.e., the depth Xr of the interface **105**) and thus, reducing the thickness of the un-depleted epitaxial layer **109** or extending the boundary of the depletion regions **110** located at the depth Xd**1** to a depth Xd**2**.

However, the above-described two approaches may have some limitations. The shallow epitaxial thickness causes too many of the red light electrons to be generated in the highly

doped P^+-type substrate **106** and thus recombined with the holes in the highly doped P^+-type substrate **106**. As a result, the red light electrons may not contribute to the signal. It is usually desirable to have the epitaxial thickness on the order of 5.0 μm or larger to have a good "red" light response.

The thick depletion that extends all the way to the interface **105** may also cause limitations. The low doping of the epitaxial layer that is necessary to accomplish the thick depletion may increase the dark current generation, and may lead to the discontinuity and separation of the P^+-type pinning layers **113** located near the surface from the highly doped P^+-type substrate **106** as indicated by the separated depletion layer boundaries **122** for this level of epitaxial doping. When the discontinuous and separated P^+-type pinning layers **113** are observed, it is necessary to provide other electrical connections to the P^+-type pinning layers **113** by some other means such as metal wires placed over the top of the pixels. These electric connections may reduce the pixel aperture efficiency and consequently the final pixel Quantum efficiency.

SUMMARY OF THE INVENTION

Specific embodiments of the present invention provide an image sensor (e.g., complementary metal-oxide semiconductor (CMOS) image sensor) including small size pixels and improved in color crosstalk.

In accordance with one aspect of the present invention, there is provided an image sensor comprising a substrate of a first conductivity type, first and second pixels arrayed over the substrate, and a potential barrier formed in a region of the substrate corresponding to the first pixel but not in a region of the substrate corresponding to the second pixel.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a simplified cross-sectional view of conventional pixels overlaid with color filters in a CMOS image sensor.

FIG. **2** illustrates a simplified cross-sectional view of pixels overlaid with color filters in a CMOS image sensor in accordance with an embodiment of the present invention.

DESCRIPTION OF SPECIFIC EMBODIMENTS

According to various embodiments of the present invention, small pixel size sensors are improved in the performance, and the improved performance contributes to the reduction in color crosstalk. This effect can be achieved by incorporating a deep high energy Boron implantation under the pixels that receive the blue and green light but not under the pixels that receive the red light or by a low energy ion implantation applied during the P-type epitaxial growth.

The implanted doping creates a small potential barrier in a substrate structure that directs and focuses those carriers generated by the red light deep within the silicon bulk (i.e., the substrate structure) to flow into the "red" photodiodes (photodiodes under the red color filters) and are collected in the "red" photodiodes. The deep Boron implantation also redirects carriers generated by the residual red light penetrating through the imperfect blue and green color filters and generating carriers deep within the silicon bulk under the "blue" and "green" photodiodes, so as to make the carriers generated under the "blue" and "green" photodiodes flow into the "red" photodiodes.

In addition to the reduction in the color crosstalk caused by the red light-generated carriers, the color crosstalk caused by the imperfect blue and green color filters can also be reduced. As a result, it is possible to build CMOS sensor arrays of pixels with very small size, high performance and reduced color crosstalk.

FIG. **2** illustrates a simplified cross-sectional view of an image sensor including pixels with photodiodes and corresponding transfer transistors in accordance with an embodiment of the present invention. Blue, green and red color filters **201**, **202** and **203** are formed over an inter-level transparent dielectric structure **204**, which is formed over photodiode regions. P^+-type doped layers **217** form pinned photodiode regions together with N-type doped layers **210**. The P^+-type doped layers **217** each extend over the exposed surface of a silicon bulk (e.g., a highly doped P^+-type substrate **218**) including the sides and the bottom of shallow trench isolation (STI) regions **206**. The STI regions **206** are filled with an oxide-based material **207**. Oxide-based layers **205** each cover the surface of the silicon bulk and extend under the respective transfer gates **208**. The transfer gates **208** are formed of a conductive material such as polysilicon. The N^+-type doped layers **209** form FD regions connected to respective sense amplifiers (not shown).

When the photodiodes, more specifically, pinned photodiodes are depleted of all charge, depletion regions **211** are formed at a depth Xd**1** under the pinned photodiodes. A high energy Boron implantation is used to form a P-type doped layer **212** as a potential barrier. The P-type doped layer **212** is located at a depth Xg under "blue" and "green" photodiodes, where most of green and blue light photons have already been converted to electrons **215**. These electrons **215** drift upward for a short distance to the boundary of the depletion regions **211** and are quickly swept into photodiode potential wells located in the N-type doped layers **210**. Since the vertical diffusion distance can be made very short, there is a little chance of a lateral spread and thus a color crosstalk. Those red light-generated electrons **216** also diffuse directly upward, since the P-type doped layer **212** forms a small potential barrier for the red light-generated electrons **216** and prevents the lateral spread thereof. In addition, other red light-generated electrons **214** under the P-type doped layer **212** cannot also overcome the potential barrier and need to diffuse around the potential barrier to the "red" photodiode potential wells. As a result, the color crosstalk caused by the imperfect color filters can be improved.

For this reason, an epitaxial layer can have a suitable sufficient depth Xr for an efficient conversion of the red light into electrons without the need for a compromise to reduce the lateral spread into wrong photodiodes. An epitaxial-substrate interface **213** can be placed even deeper into the silicon bulk than the conventional epitaxial-substrate interface to further improve the red light conversion to electrons. Reference letter 'Xepi' denotes a depth at which the epitaxial-substrate interface **213** is located. The doping of the epitaxial layer can also be optimized for a minimum dark current and a good conductive connection of the P+-type doped layers **217** to a P+-type doped substrate **218**. Accordingly, a silicon bulk pixel aspect ratio, which is the effective pixel silicon thickness to the pixel horizontal dimension, can be increased without adverse effects on the color crosstalk in comparison to the conventional approach.

As is well known, the wavelength of red light is the largest, and descends in the order of green light and blue light. Therefore, the red light-generated charge can be generated at a depth deeper than that of the P-type epitaxial layer. Hence, in consideration of this fact, the P-type doped layer **212** is formed at a suitable depth Xg from the surface of the silicon bulk.

Since the description above did not discuss the pixel circuits and focused only on the photodiodes, it is understood that a shared pixel circuitry may also be used in this embodiment of the present invention. Each pixel may have a shared circuit to read the photo-generated charge as an electrical signal, and the shared circuit can read the photo-generated charge through a shared floating diffusion node.

It is also clear to those skilled in the art that this embodiment of the present invention can be easily adapted to the 3 T pixel structure, which represents another embodiment of this invention. Furthermore, it is clear to those skilled in the art that the P-type doped layer **212** does not have to be implanted by a high-energy ion implantation. Instead, the P-type doped layer **212** may be formed during the epitaxial layer growth. The epitaxial growth can be stopped at the depth defined between the depth Xr and the depth Xg. Boron may be implanted by a low energy ion implantation or deposited by some other means. Afterwards, the epitaxial growth can continue until reaching the original depth Xr. This approach represents another embodiment of the invention.

Additionally, it is clear to those skilled in the art that the P-type doped layer **212** can be formed at the depth Xg under the "green" photodiode, and another similar P-type doped layer can be formed at a shallower depth Xb (not shown) than the depth Xg under the "blue" photodiode. This approach represents another embodiment of the present invention.

In the present embodiment, the color crosstalk originating from the carriers generated in the deep region of the substrate structure (e.g., silicon bulk) can be minimized by placing the P-type doped layer, which functions as a potential barrier, under the "green" and "blue" photodiodes and not under the "red" photodiode. Accordingly, it is possible to provide a solid-state image sensor, more particularly, CMOS image sensor that has a small pixel size, good response to the red light, and less occurrence of color crosstalk.

Various embodiments of the present invention are directed toward the pixels that have an improved crosstalk for the small pixel size, which was accomplished by incorporating deep P-type layers under the "green" and "blue" photodiodes and not under the "red" photodiodes. However, this improvement is intended to be illustrative and not limiting, and it should be noted that the persons skilled in the art can make modifications and variations in light of the above teachings. It is therefore to be understood that changes may be made in the particular embodiments of the invention disclosed, which are within the scope and spirit of the invention as defined by appended claims.

The invention claimed is:

1. A method of forming an image sensor, the method comprising:

initiating a growth of an epitaxial layer;

stopping the growth of the epitaxial layer at a first depth;

while the growth of the epitaxial layer is stopped at the first depth, forming a portion of a potential barrier in the epitaxial layer at the first depth in a first pixel region, wherein the potential barrier includes a gap under a second pixel region; and

after forming the portion of the potential barrier, continuing the growth of the epitaxial layer until the epitaxial layer reaches a final depth;

wherein the gap is arranged to allow electrons to flow from a portion of the epitaxial layer below the potential barrier to a portion of the epitaxial layer above the potential barrier.

2. The method of claim **1**, wherein said forming a portion of a potential barrier in the epitaxial layer comprises performing a low-energy ion implantation.

3. The method of claim **2**, wherein said performing a low-energy ion implantation comprises implanting Boron.

4. The method of claim **1**, further comprising:

stopping the growth of the epitaxial layer at a second depth; and

while the growth of the epitaxial layer is stopped at the second depth, forming an additional portion of the potential barrier in the epitaxial layer at the second depth in a third pixel region.

5. The method of claim **1**, further comprising:

forming a first filter above the first pixel region, wherein the first filter is configured to pass light of a first color into the first pixel region; and

forming a second filter above the second pixel region, wherein the second filter is configured to pass light of a second color into the second pixel region.

6. The method of claim **5**, wherein:

the first color comprises at least one of green or blue; and

the second color comprises red.

7. The method of claim **1**, wherein the potential barrier comprises a P-type doped region.

8. A method of forming an image sensor, the method comprising:

initiating a growth of an epitaxial layer;

stopping the growth of the epitaxial layer at a first depth;

while the growth of the epitaxial layer is stopped at the first depth, forming a portion of a potential barrier in the epitaxial layer at the first depth in a first pixel region;

after forming the portion of the potential barrier, continuing the growth of the epitaxial layer until the epitaxial layer reaches a final depth;

forming a first photodiode in the first pixel region; and

forming a second photodiode in a second pixel region;

wherein the portion of the potential barrier is arranged to sweep electrons formed below the portion of the potential barrier to the second photodiode.

9. The method of claim **8**, wherein said forming a portion of a potential barrier in the epitaxial layer comprises performing a low-energy ion implantation.

10. The method of claim **9**, wherein said performing a low-energy ion implantation comprises implanting Boron.

11. The method of claim **8**, further comprising:

forming a first filter above the first pixel region, wherein the first filter is configured to pass light of a first color into the first pixel region; and

forming a second filter above the second pixel region, wherein the second filter is configured to pass light of a second color into the second pixel region.

12. The method of claim **11**, wherein:

the first color comprises at least one of green or blue; and

the second color comprises red.

13. The method of claim **8**, wherein the potential barrier comprises a P-type doped region.

14. A method of forming an image sensor, the method comprising:

initiating a growth of an epitaxial layer;

stopping the growth of the epitaxial layer at a first depth;

while the growth of the epitaxial layer is stopped at the first depth, forming a first portion of a potential barrier in the epitaxial layer at the first depth in a first pixel region, wherein the first portion of the potential barrier includes a gap under a second pixel region;

after forming the first portion of the potential barrier, continuing the growth of the epitaxial layer until the epitaxial layer reaches a second depth;

stopping the growth of the epitaxial layer at the second depth;

while the growth of the epitaxial layer is stopped at the second depth, forming a second portion of the potential barrier in the epitaxial layer at the second depth in a third pixel region;

after forming the second portion of the potential barrier, continuing the growth of the epitaxial layer until the epitaxial layer reaches a final depth;

forming a first photodiode in the first pixel region;

forming a second photodiode in a second pixel region; and

forming a third photodiode in the third pixel region;

wherein the gap is arranged to allow electrons to flow from a portion of the epitaxial layer below the potential barrier to a portion of the epitaxial layer above the potential barrier.

15. The method of claim **14**, wherein:

said forming a first portion of a potential barrier in the epitaxial layer comprises performing a low-energy ion implantation; and

said forming a second portion of the potential barrier in the epitaxial layer comprises performing a low-energy ion implantation.

16. The method of claim **15**, wherein said performing a low-energy ion implantation comprises implanting Boron.

17. The method of claim **14**, further comprising:

forming a first filter above the first pixel region, wherein the first filter is configured to pass light of a first color into the first pixel region;

forming a second filter above the second pixel region, wherein the second filter is configured to pass light of a second color into the second pixel region; and

forming a third filter above the third pixel region, wherein the third filter is configured to pass light of a third color into the third pixel region.

18. The method of claim **17**, wherein:

the first color comprises green;

the second color comprises red; and

the third color comprises blue.

19. The method of claim **14**, wherein the potential barrier comprises a P-type doped region.

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