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(54) **IMAGE PICKUP DEVICE AND METHOD FOR MANUFACTURING IMAGE PICKUP DEVICE**

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(57) **ABSTRACT**

An image pickup device having a pixel region in which pixels are arranged, and in which a multilayer wiring structure is disposed. Each pixel includes a photoelectric conversion unit, a charge accumulation unit, a floating diffusion, a light shielding portion covering the charge accumulation unit and opening above the photoelectric conversion unit, and a waveguide which overlaps at least partially a portion at which the light shielding portion opens in a plan view. The device includes an insulating film disposed below the optical waveguide. The insulating film has a refractive index higher than that of an interlayer insulating film. The insulating film is disposed closer to the photoelectric conversion unit than to the lowermost wiring layer among wiring layers of the multilayer wiring structure. The insulating film extends to a portion above the light shielding portion. The insulating film is wider than a lower portion of the optical waveguide.

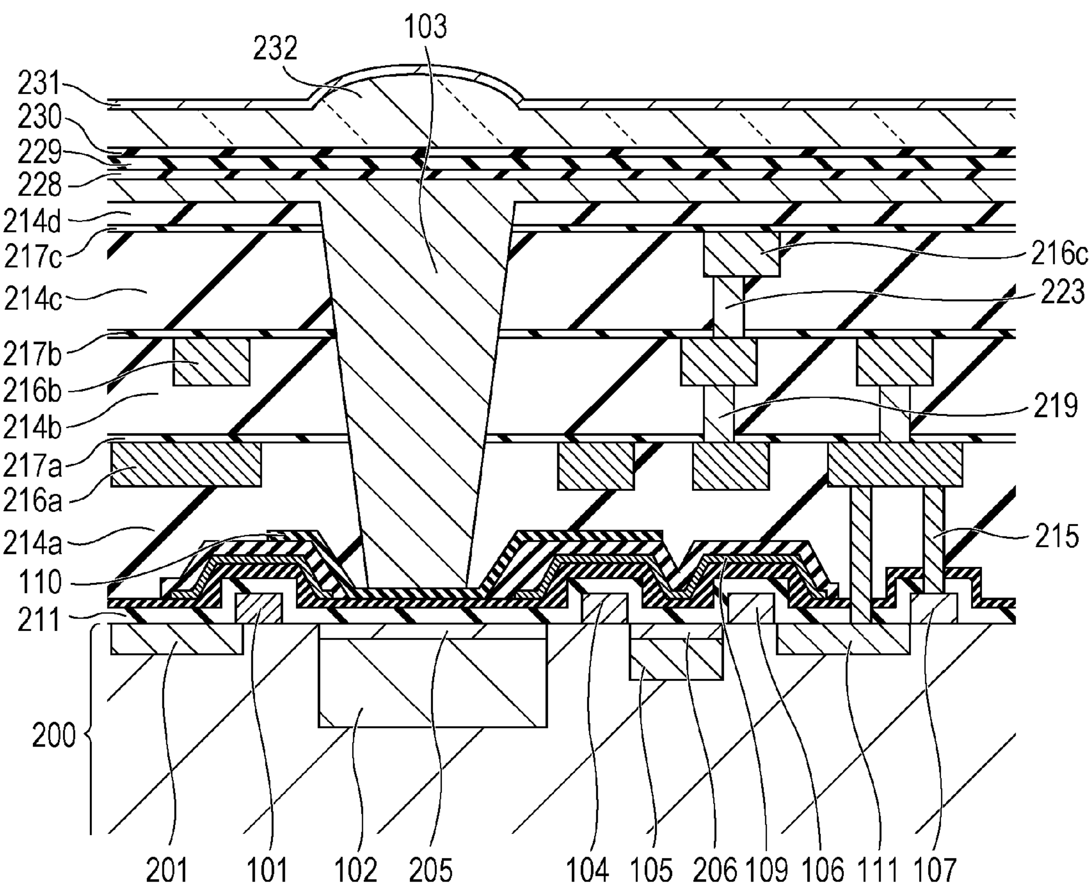


FIG. 1

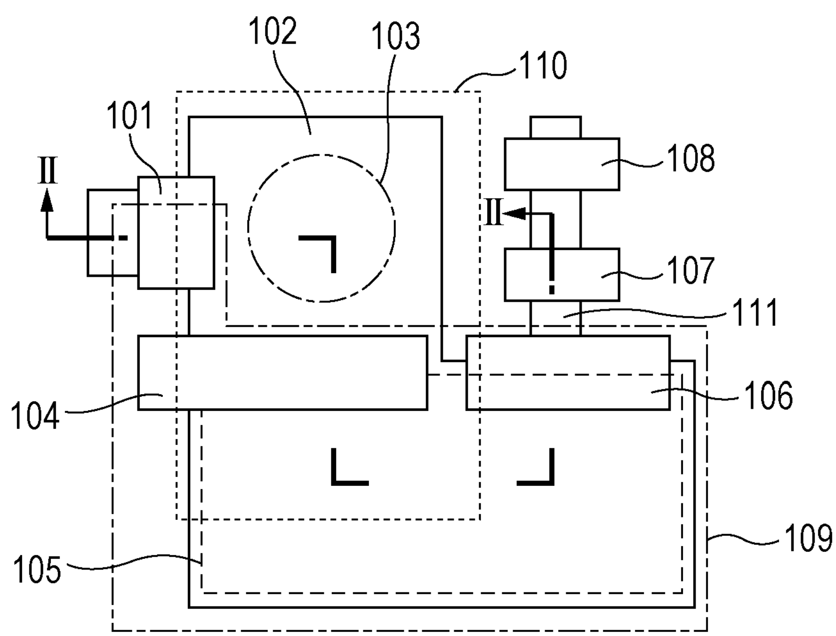
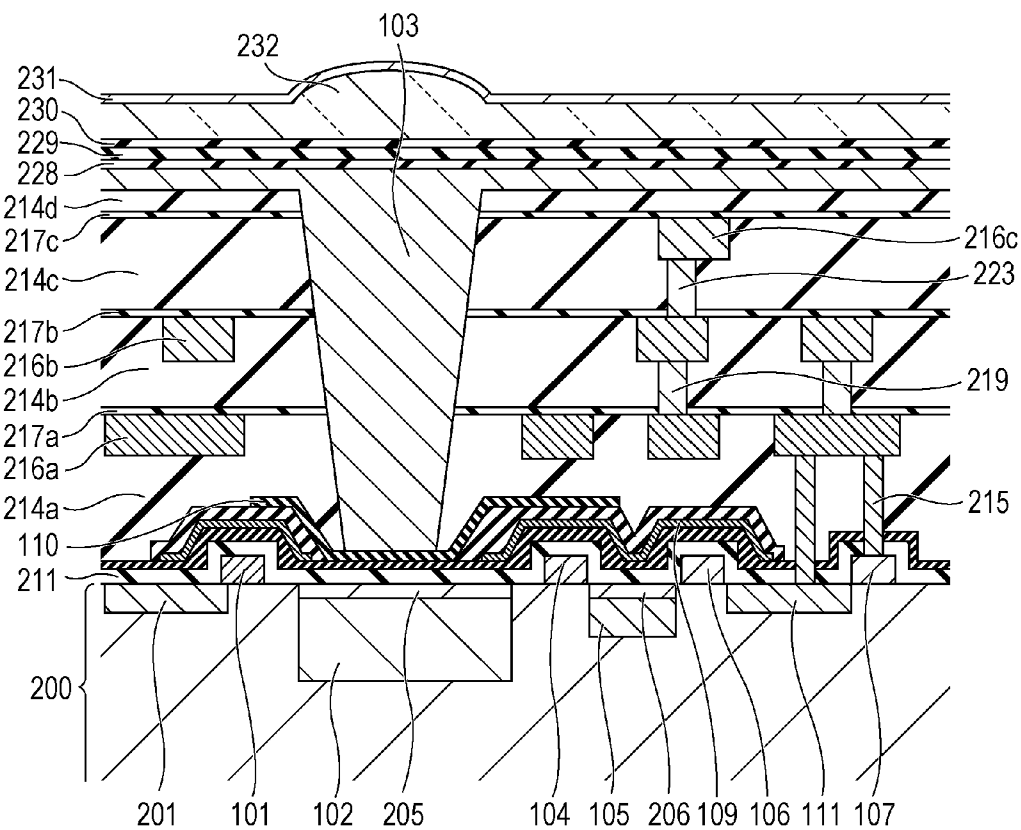


FIG. 2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232
231
230
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228
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219
217a
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110
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200
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FIG. 3A

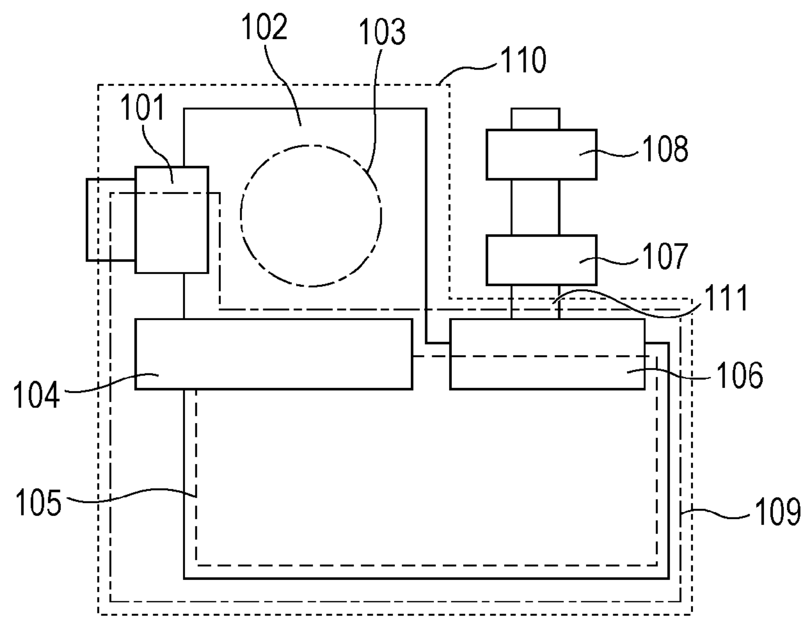
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FIG. 3B

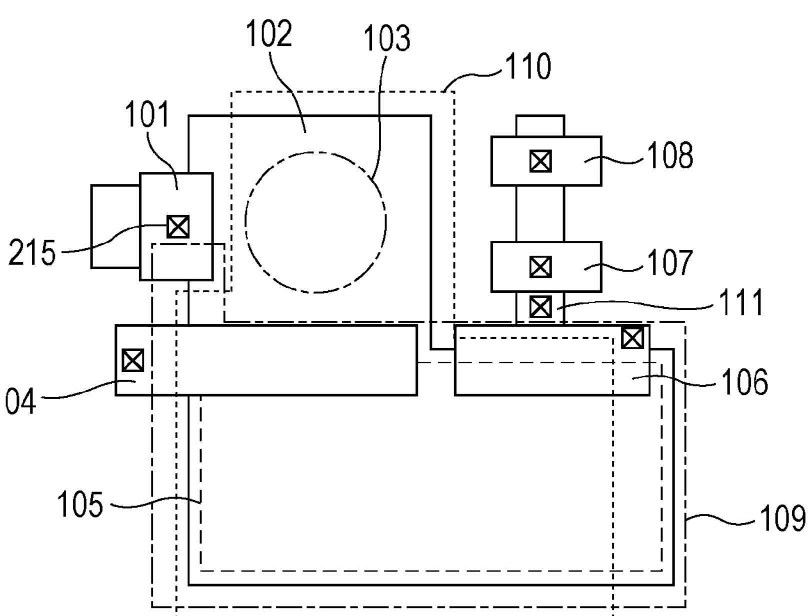
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FIG. 4A

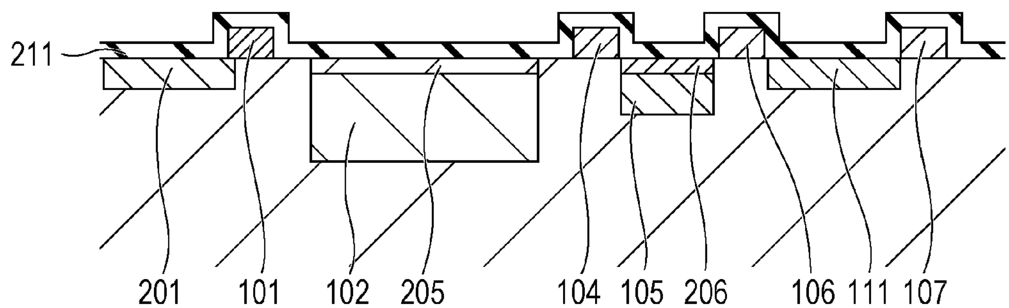

FIG. 4B

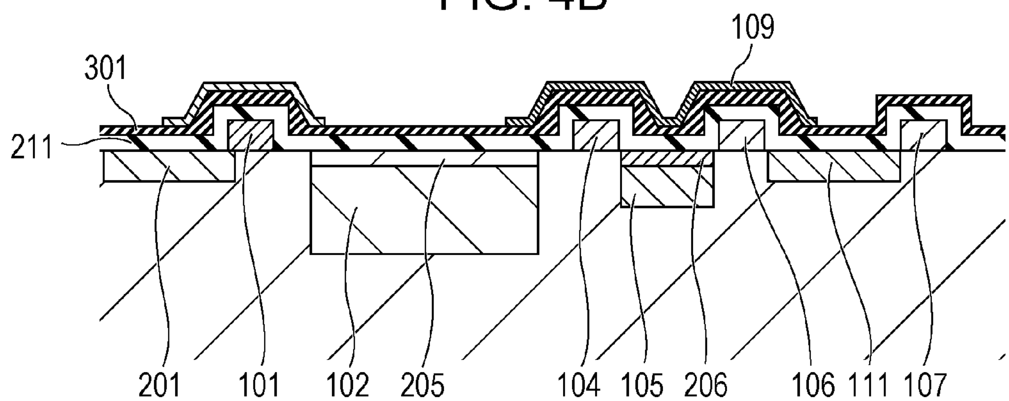

FIG. 4C

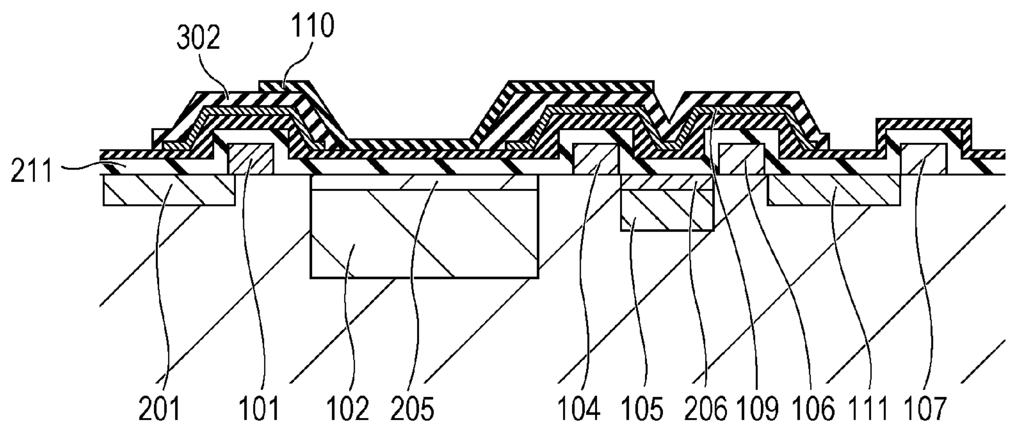

FIG. 5A

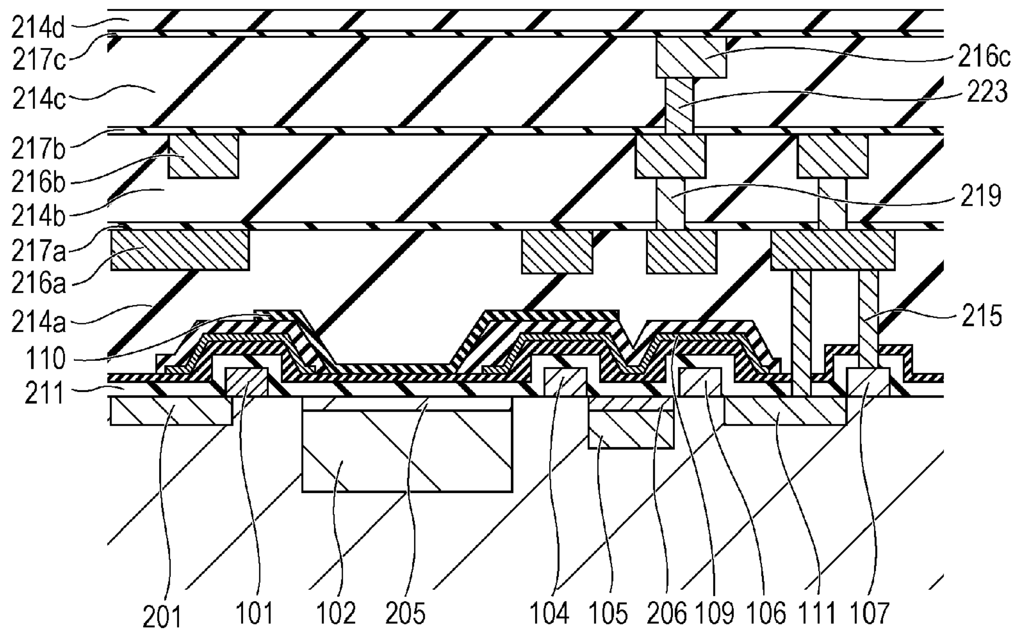
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FIG. 5B

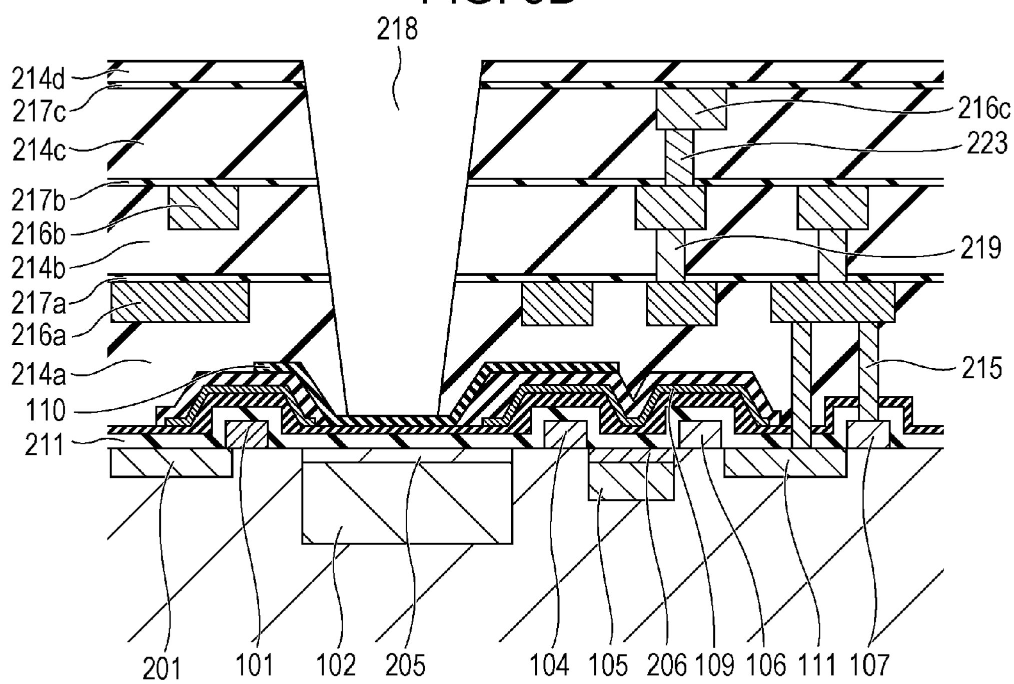
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FIG. 6A

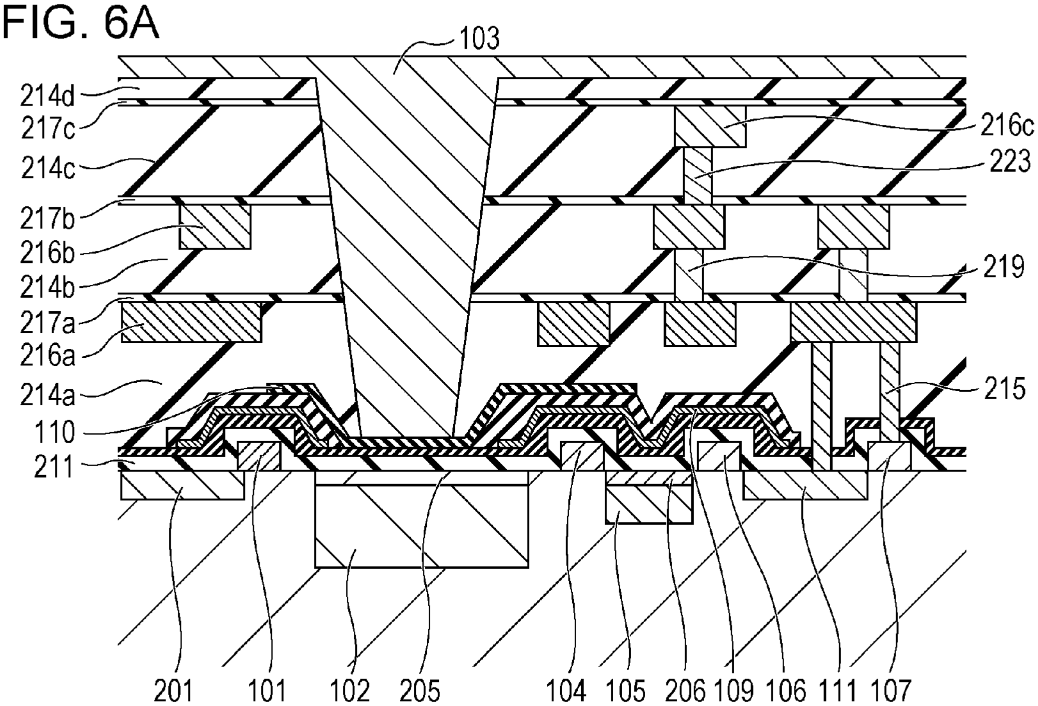
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FIG. 6B

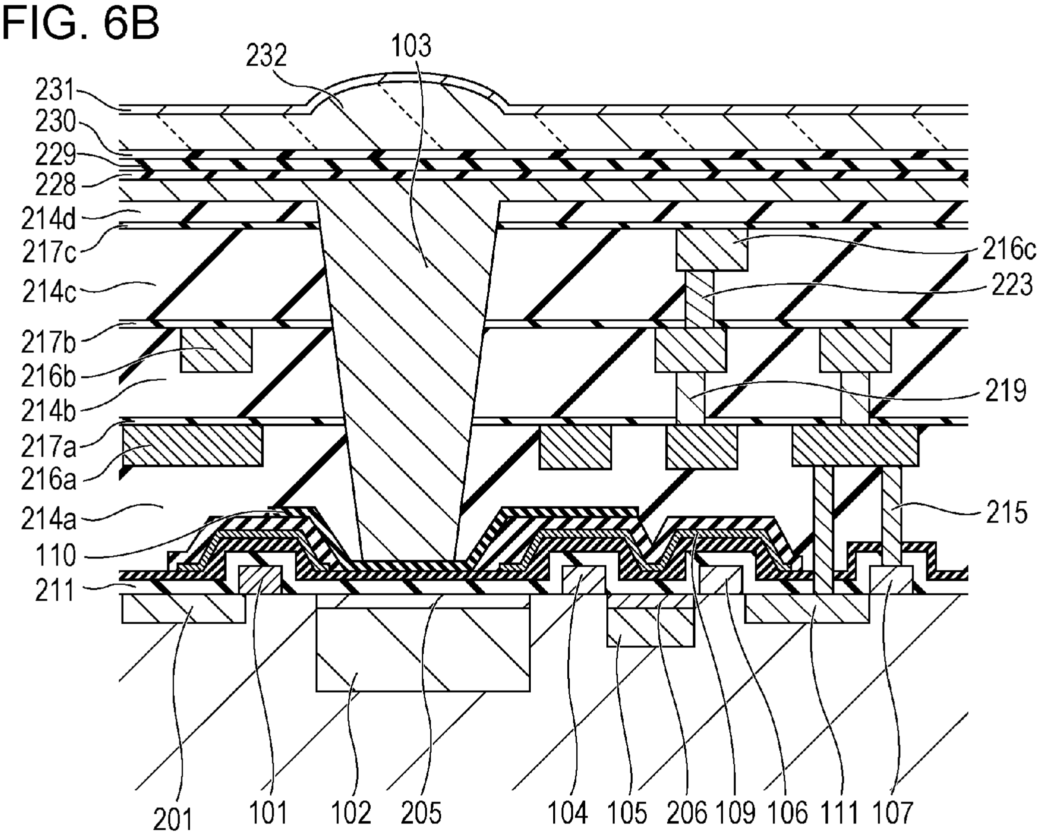
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FIG. 7

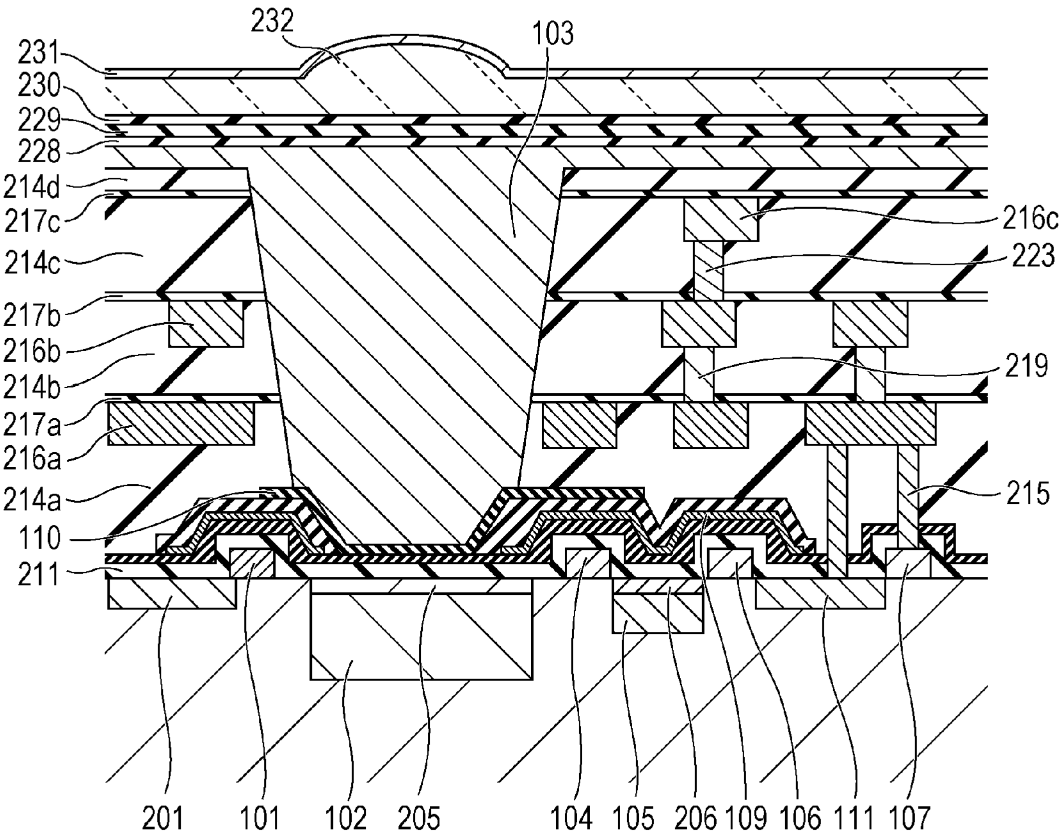

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FIG. 8

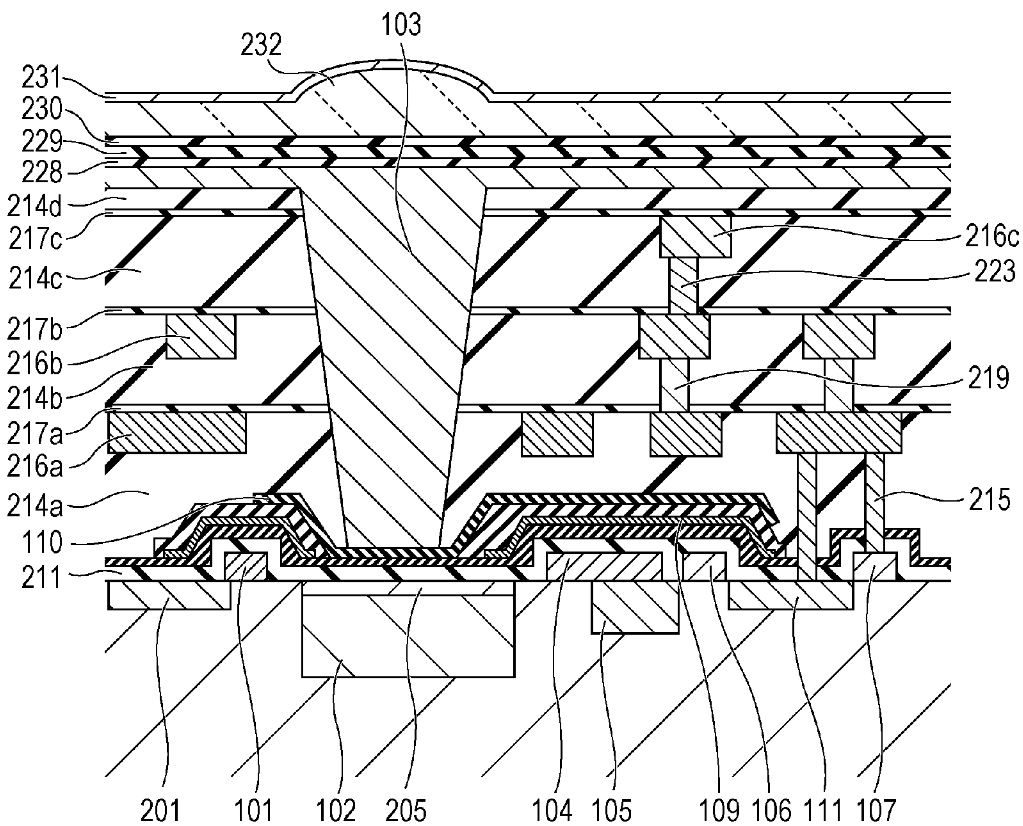
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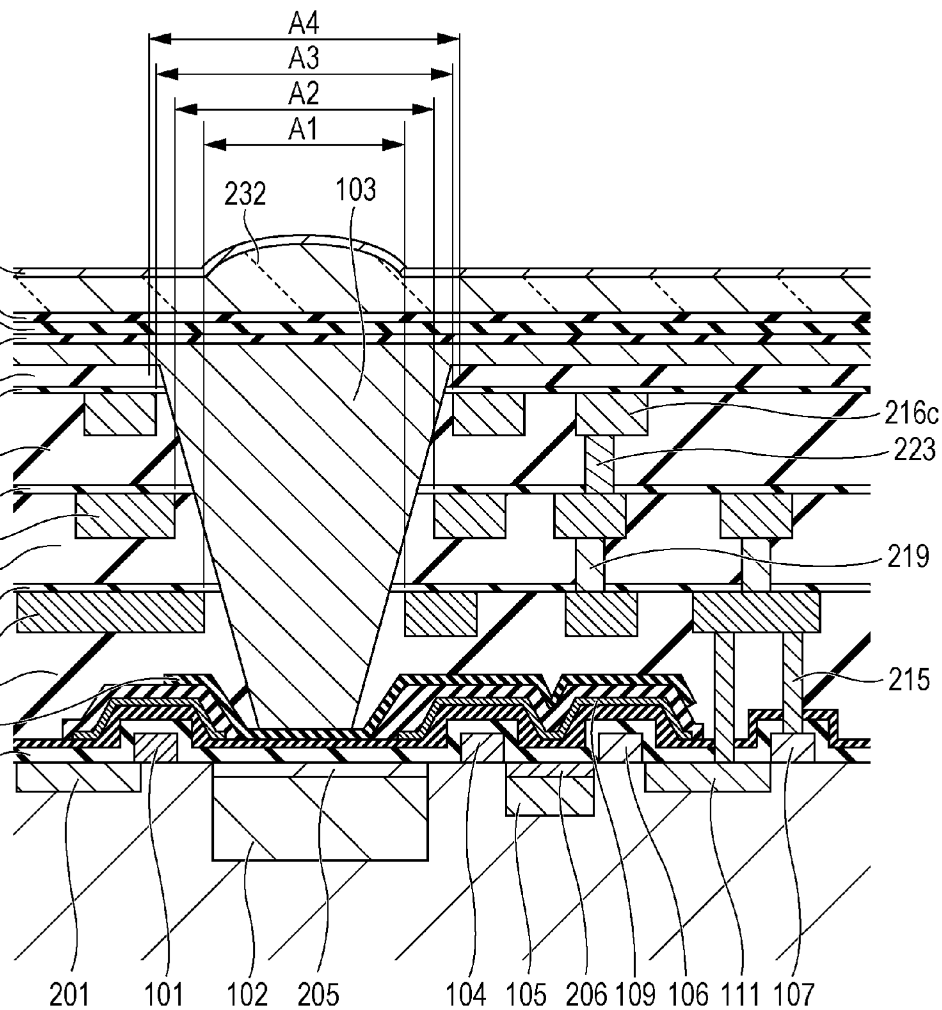
FIG. 9



A4
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FIG. 10

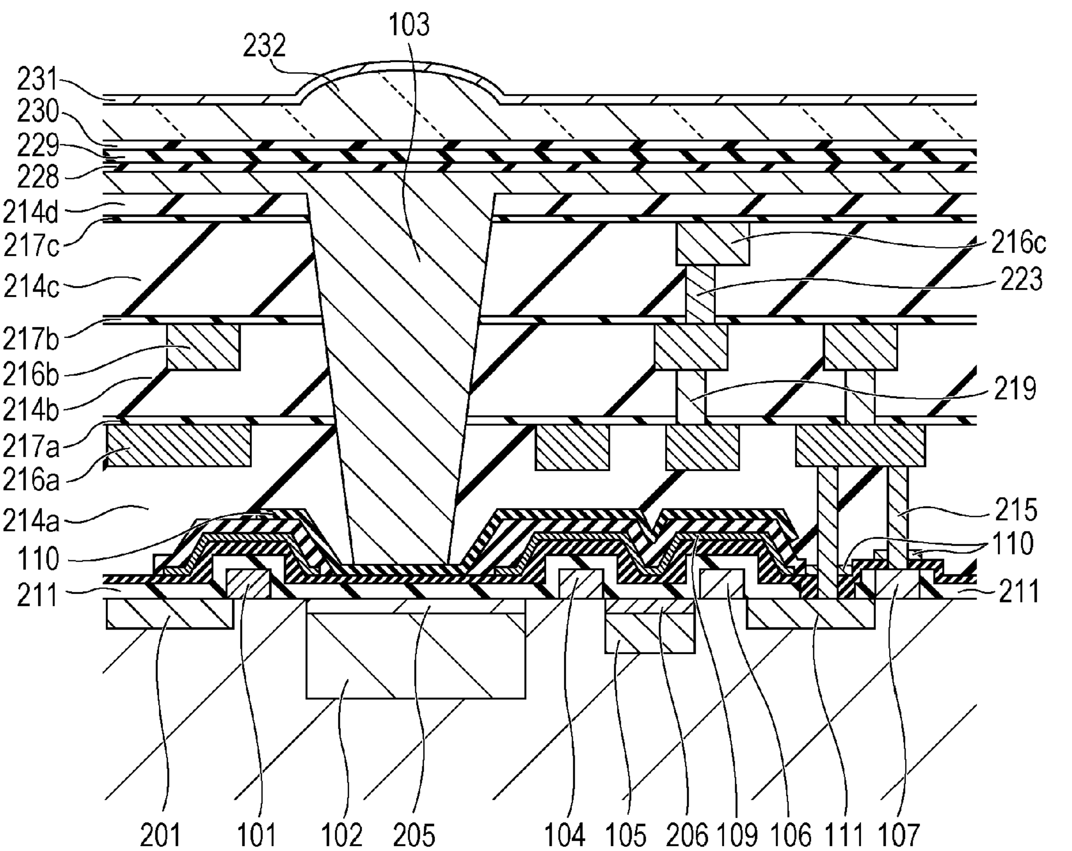
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FIG. 11

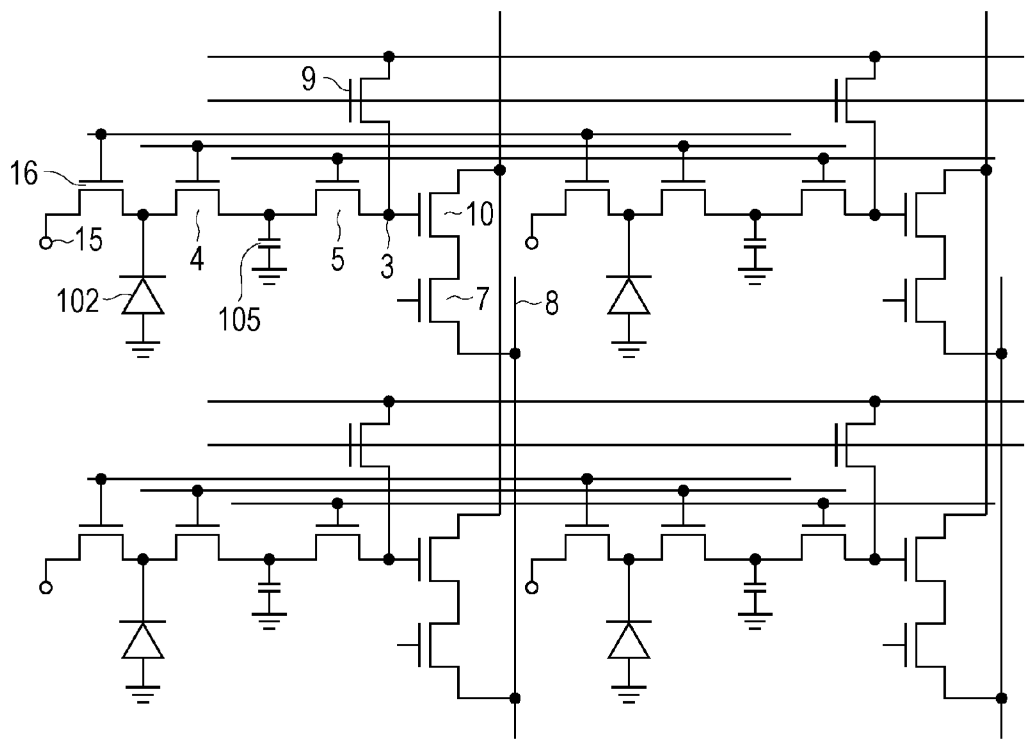

IMAGE PICKUP DEVICE AND METHOD FOR MANUFACTURING IMAGE PICKUP DEVICE

BACKGROUND

[0001] Field

[0002] Aspects of the present invention generally relate to an image pickup device and, more particularly, to a configuration which includes an optical waveguide on a photoelectric conversion unit.

[0003] Description of the Related Art

[0004] A CMOS sensor in which a pixel includes an optical waveguide for guiding light to a photoelectric conversion unit and a charge accumulation unit for accumulating signal charge generated by the photoelectric conversion unit is proposed (see, for example, Japanese Patent Laid-Open No. 2013-168546). In an image pickup device disclosed in Japanese Patent Laid-Open No. 2013-168546, the charge accumulation unit is covered with a light shielding portion (a metal light shielding film) disposed above the charge accumulation unit via an insulating film. A lower surface of the light shielding portion, a lower surface of an optical waveguide, and an upper surface of the insulating film disposed above the charge accumulation unit coincide with one another. An antireflection film is disposed on an upper surface of the light shielding portion.

[0005] The technique disclosed in Japanese Patent Laid-Open No. 2013-168546 has the following two problems.

[0006] The first problem is that, in the configuration disclosed in Japanese Patent Laid-Open No. 2013-168546, light incident upon the optical waveguide can enter the charge accumulation unit via the insulating film below the light shielding portion. The light incident upon the charge accumulation unit may cause noise to signals in a previous accumulation period in the charge accumulation unit.

[0007] The second problem is related to a method for manufacturing the image pickup device disclosed in Japanese Patent Laid-Open No. 2013-168546. In Japanese Patent Laid-Open No. 2013-168546, an interlayer insulating film is etched to form an opening and a core material which becomes the optical waveguide is formed in the opening. The interlayer insulating film and the antireflection film are etched to form an opening using the light shielding portion as an etching stop film, and an opening is further formed by self alignment with respect to the opening of the interlayer insulating film and the antireflection film.

SUMMARY

[0008] In this manufacturing method, the photoelectric conversion unit is easily damaged and noise may be increased. Aspects of the present invention provide an imaging phase value of low noise.

[0009] According to an aspect of the present invention, an image pickup device which has a pixel region in which a plurality of pixels are arranged, and a multilayer wiring structure is disposed in a pixel region. Each of the pixels includes a photoelectric conversion unit, a charge accumulation unit configured to accumulate signal charge transferred from the photoelectric conversion unit, a floating diffusion to which the signal charge of the charge accumulation unit is transferred, a light shielding portion configured to cover the charge accumulation unit and opening above the photoelectric conversion unit, and an optical waveguide disposed above the photoelectric conversion unit. The device includes an insulating film disposed below the optical waveguide, wherein the insulating film has larger refractive index than interlayer insulating film of the multilayer wiring structure, the insulating film extends from below the optical waveguide to a portion above the light shielding portion at a portion closer to the photoelectric conversion unit than to the lowermost wiring layer among wiring layers of the multilayer wiring structure, and an area of the insulating film is larger than an emission surface area of the optical waveguide in a plan view.

[0010] Further features of aspects of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a plan view of a pixel.

[0012] FIG. **2** is a cross-sectional view of Example 1 of the present invention.

[0013] FIGS. **3**A and **3**B are plan views of a pixel of another example.

[0014] FIGS. **4**A to **4**C are cross-sectional views of a manufacturing method of Example 2.

[0015] FIGS. **5**A and **5**B are cross-sectional views of the manufacturing method of Example 2.

[0016] FIGS. **6**A and **6**B are cross-sectional views of the manufacturing method of Example 2.

[0017] FIG. **7** is a cross-sectional view of an image pickup device of Example 3.

[0018] FIG. **8** is a cross-sectional view of an image pickup device of Example 4.

[0019] FIG. **9** is a cross-sectional view of an image pickup device of Example 5.

[0020] FIG. **10** is a cross-sectional view of an image pickup device of Example 6.

[0021] FIG. **11** is an equivalent circuit diagram of a pixel.

DESCRIPTION OF THE EMBODIMENTS

[0022] Embodiments of the present invention are described in detail with reference to Examples. Embodiments of the present invention are desirably applicable to a CMOS sensor. Embodiments of the present invention are also desirably applicable to an image pickup device in which a multilayer wiring structure is disposed in a pixel region in which a plurality of pixels are arranged. FIG. **11** is an equivalent circuit diagram of a pixel of the image pickup device of an embodiment of the present invention.

[0023] The pixel includes a photoelectric conversion unit **102**, a charge accumulation unit **105**, a floating diffusion unit (FD unit) **3**, a signal line **8**, and an overflow drain unit (OFD unit) **15**. The pixel further includes a first transfer transistor **4**, a second transfer transistor **5**, a selection transistor **7**, a reset transistor **9**, a source follower transistor **10**, and an OFD transistor **16** for the switching between connection/disconnection among the photoelectric conversion unit **102**, the charge accumulation unit **105**, the FD unit **3**, the signal line **8**, and the OFD unit **15** or the signal amplification. Each transistor is formed from, for example, a MOSFET and includes a gate electrode provided as a control electrode between drain and source.

[0024] The photoelectric conversion unit **102** is an element which generates signal charge in accordance with an amount of incident light. A photodiode may be used as the photoelectric conversion unit **102**. The charge accumulation unit **105** is connected to the photoelectric conversion unit **102** via the first transfer transistor **4**. The charge accumulation unit **105** functions as a grounding capacity and temporarily accumulates the charge transferred from the photoelectric conversion unit **102**.

[0025] The FD unit **3** converts the charge transferred from the charge accumulation unit **105** into voltage signals. The FD unit **3** includes a semiconductor region disposed in a semiconductor substrate described later, and a FD capacitance designates a capacitance including parasitic capacitance produced in the node. The FD unit **3** is connected to the charge accumulation unit **105** via the second transfer transistor **5**. The FD unit **3** is connected also to a source terminal of the reset transistor **9** and to a gate terminal of the source follower transistor **10**. A power supply voltage is supplied to a drain terminal of the reset transistor **9**. A voltage of the FD unit **3** is reset to the power supply voltage when the reset transistor **9** is turned on. At this time, a reset signal voltage is output to a source terminal of the source follower transistor **10**.

[0026] When the second transfer transistor **5** is turned on and the charge is transferred to a FD from the charge accumulation unit **105**, a pixel signal voltage corresponding to the transferred amount of charge is output to the source terminal of the source follower transistor **10**.

[0027] The source terminal of the source follower transistor **10** is connected to a drain terminal of the selection transistor **7**. The source terminal of the selection transistor **7** is connected to a vertical output line **8**. When the selection transistor **7** is turned on, a reset signal or a pixel signal is output to the vertical output line **8**. The signal is thus read out of the pixel.

[0028] The OFD unit **15** is further connected to the photoelectric conversion unit **102** via the OFD transistor **16**. When the OFD transistor **16** is turned on, the charge accumulated in the photoelectric conversion unit **102** is discharged to the OFD unit **15**. In all the pixels, the charge is discharged to the OFD units **15** simultaneously and then the accumulated charge is transferred to the charge accumulation units **105**. In this manner, an electronic shutter which sets simultaneous and constant exposure time to all the pixels is implemented. The electronic shutter reduces time lag in the exposure timing caused by sequential reading of the charge from each pixel, whereby distortion of an image is avoided.

[0029] The equivalent circuit diagram illustrated in FIG. **11** is applicable to all the following examples.

Example 1

[0030] FIG. **1** is a plan view of a pixel of Example 1. The same components are denoted by the same reference numerals through the drawings referred to in each Example below and FIG. **11**.

[0031] A gate electrode **104** of the first transfer transistor **4** is disposed between the photoelectric conversion unit **102** and the charge accumulation unit **105**. A gate electrode **106** of the second transfer transistor **5** is disposed between the charge accumulation unit **105** and the FD **111**.

[0032] A gate electrode **107** of the reset transistor **9** is disposed adjacent to the FD **111**. A drain region of the reset transistor **9** is disposed on the opposite side of the FD **111** via the gate electrode **107**. The drain region of the reset transistor **9** is common to a drain region of the source follower transistor **10**. A gate electrode **108** of the source follower transistor **10** is disposed adjacent to the drain region. A source region of the source follower transistor **10** is disposed on the opposite side of the drain region of the source follower transistor **10** via the gate electrode **108**. The selection transistor **7** is not illustrated in FIG. **1**. The selection transistor **7** may be disposed, for example, on the opposite side of the reset transistor **9** via the source follower transistor **10**.

[0033] A gate electrode **101** of the OFD transistor **16** is disposed adjacent to the photoelectric conversion unit **102**. The gate electrode **101** is disposed at a different portion on the side on which the gate electrode **104** of the photoelectric conversion unit **102** is disposed. A semiconductor region which constitutes a part of the OFD unit **15** is disposed on the opposite side of the photoelectric conversion unit **102** via the gate electrode **101**. The semiconductor region becomes a drain region of the OFD transistor **16**.

[0034] An optical waveguide **103** is disposed above the photoelectric conversion unit **102** so as to at least partially overlap the photoelectric conversion unit **102**. Although the entire optical waveguide **103** is included in the photoelectric conversion unit **102** in a plan view in FIG. **1**, it is only necessary that at least a part of the optical waveguide **103** overlaps the photoelectric conversion unit **102**.

[0035] The light shielding portion **109** covers the charge accumulation unit **105**, and opens above the photoelectric conversion unit **102**. An insulating film **110** is disposed to cover the entire photoelectric conversion unit **102**, a part of the charge accumulation unit **105**, and a part of the gate electrodes **101** and **104**. The insulating film **110** is described later. An element isolation region formed from an insulating material is disposed at portions other than those illustrated by the solid line. A part of the insulating film **110** overlaps the element isolation region.

[0036] FIG. **2** is a cross-sectional view along line II-II of FIG. **1**. In FIG. **2**, the photoelectric conversion unit **102** in a semiconductor substrate **200** is, for example, an n-type semiconductor region, in which a p-type semiconductor region **205** is disposed above the photoelectric conversion unit **102**. Therefore, an embedded type photodiode structure is provided. With this configuration, noise generated on an interface between the semiconductor substrate **200** and the insulating film **110** disposed on the semiconductor substrate **200** can be reduced. The charge accumulation unit **105** is, for example, an n-type semiconductor region, and a p-type semiconductor region **206** is disposed above the charge accumulation unit **105**. Therefore, an embedded type structure is provided. This structure can reduce noise.

[0037] An antireflection film **211** is disposed above the photoelectric conversion unit **102**. A film having a refractive index between that of an interlayer insulating film **214** and that of the semiconductor substrate **200** may be used as the antireflection film **211**. A silicon nitride film (SiN) of which refractive index is about 2.0 is used as the antireflection film **211**.

[0038] The light shielding portion **109** is disposed to overlap a part of the photoelectric conversion unit **102** in a plan view, and opens at a portion which overlaps other part of the photoelectric conversion unit **102** in a plan view. The light shielding portion **109** is disposed to cover the charge accumulation unit **105** and at least a part of the gate electrode **104** of the transistor which transfers charge to the charge accumulation unit **105** from the photoelectric conversion unit **102**. A portion of the light shielding portion **109** which overlaps the photoelectric conversion unit **102** includes a portion extended from a portion above the gate electrode **104** and a portion extended from a portion above the gate electrode **101**. The light shielding portion **109** reduces light incident upon the charge accumulation unit **105**, and reduces generation of charge by the incident light in the charge accumulation unit **105** and occurrence of noise.

[0039] The light shielding portion **109** is desirably formed from a material which hardly transmits visible light. For example, tungsten, tungsten silicide, tungsten oxide film, aluminum, or an alloy film thereof are used. A desirable film thickness d of the light shielding portion **109** is, for example, 100≤d≤200 nm. Since the light shielding portion **109** is formed on the gate electrode and other portions simultaneously, the light shielding portion **109** has unevenness caused by the film thickness of the gate electrode.

[0040] Wires **216***a* to **216***c*, a contact **215**, and vias **219** and **223** are disposed above the semiconductor substrate **200**. Although three wiring layers are illustrated in FIG. **2**, a greater or smaller number of wiring layers may be provided. Although a plurality of wiring layers, interlayer insulating films, and diffusion preventing films are formed here, these layers and films will be described collectively with no alphabet added to the reference numerals if it is unnecessary to distinguish them. A diffusion preventing film **217** is used especially when the wire **216** is formed mainly from Cu.

[0041] The wire which constitutes each wire **216** may be formed from copper, aluminum, and an alloy film thereof. The wire **216** and the light shielding portion **109** may be connected with each other by the contact **215** to apply a voltage to the light shielding portion **109**. Alternatively, a contact (not illustrated) may be formed between the light shielding portion **109** and the semiconductor substrate **200**.

[0042] Diffusion preventing films **217***a* to **217***c* formed from a wiring material may be provided above the wires **216***a* to **216***c*. The diffusion preventing films **217***a* to **217***c* may be formed from, for example, a silicon nitride film (SiN) and a silicon carbide (SiC).

[0043] Each pixel further includes the optical waveguide **103** and an innerlayer lens **232** as an optical system disposed immediately above the photoelectric conversion unit **102**. Although the optical waveguide **103** is round in a plan view, the optical waveguide **103** may be square, rectangular, ellipse, polygon, and the like. An unillustrated color filter and a microlens may be provided above the innerlayer lens **232**.

[0044] The optical waveguide **103** has a function to condense the incident light on the photoelectric conversion unit **102**. Since the amount of light incident upon the photoelectric conversion unit **102** is increased by the optical waveguide **103**, sensitivity improves as compared with the case in which no optical waveguide **103** is provided. Sensitivity may decrease especially when an area of the photoelectric conversion unit **102** is small or when the F number of a lens of a camera is large if the image pickup device is used for the camera. This influence can be reduced by providing the optical waveguide **103**.

[0045] Interlayer insulating films **214***a* to **214***c* are disposed between the wire **216**. The interlayer insulating film **214** is desirably formed from a material having a refractive index lower than that of a material constituting the optical waveguide **103**. For example, the interlayer insulating film **214** may be formed from a silicon oxide film (SiO) having a refractive index of about 1.5, and the optical waveguide **103** may be formed from a silicon oxynitride film (SiON) having a refractive index of about 1.8. The light incident obliquely at a predetermined angle upon each interface between the optical waveguide **103** and each of the insulating films **214***a* to **214***c* is totally reflected on each of the interfaces. Therefore, leakage of light incident upon the optical waveguide **103** into the interlayer insulating film **214** is reduced, and a greater amount of incident light reaches the photoelectric conversion unit **102**. The materials of the interlayer insulating film **214** and the optical waveguide **103** are not limited to the combination of the silicon oxide film and the silicon oxynitride film. Any materials may be used in combination so that the refractive index of the optical waveguide **103** becomes higher than the refractive index of the interlayer insulating film **214**. For example, the interlayer insulating film **214** may be a silicon oxide film and the optical waveguide **103** may be a silicon nitride film (SiN) having a refractive index of about 2.0. An organic film material and a material in which titanium oxide particles or the like are mixed in an organic film material may be used. The interlayer insulating films **214***a* to **214***c* may be laminated films of different materials. In that case, the refractive index of the optical waveguide **103** is set to be higher than the refractive indices of the interlayer insulating films **214***a* to **214***c* around the optical waveguide **103**. The optical waveguide **103** has a descending taper shape in which an incident surface area is larger than an emission surface area. Therefore, it is possible to condense a greater amount of incident light on the photoelectric conversion unit **102** via the optical waveguide **103**.

[0046] An antireflection film **228**, an interlayer insulating film **229**, and an antireflection film **230** are disposed between the optical waveguide **103** and the innerlayer lens **232**. A silicon oxynitride film (SiON) having a refractive index of about 1.6 may be used, for example, as the antireflection films **228** and **230**, and a silicon oxide film (SiO) having a refractive index of about 1.5 may be used as the interlayer insulating film **229**. The interlayer insulating film **229** may be used as the interlayer insulating film in a peripheral circuit region.

[0047] An antireflection film **231** may further be formed above the innerlayer lens **232**. This antireflection structure can increase transmittance of the incident light, thereby increasing sensitivity.

[0048] In Example 1, a multilayer wiring structure including the wire **216** and the interlayer insulating film **214** is disposed above the semiconductor substrate **200** in the pixel region. The optical waveguide **103** is desirably formed by embedding the above-described high refractive index member in an opening formed by penetrating each insulating film **214** of the multilayer wiring structure.

[0049] The insulating film **110** is provided to extend from below the optical waveguide **103** to reach a portion above the light shielding portion **109**. The insulating film **110** includes a material having a refractive index higher than that of the interlayer insulating film **214**. It is especially desirable that the insulating film **110** has a refractive index higher than the refractive index of a portion of the interlayer insulating film **214** disposed above the charge accumulation unit. This configuration prevents entrance of light leaked from the optical waveguide **103** into the charge accumulation unit **105**. The reason thereof will be described below.

[0050] A case in which the insulating film **110** does not extend to a portion above the light shielding portion **109**, that is, a case in which an end portion of the insulating film **110** faces an end portion of the light shielding portion **109** at substantially the same height in a cross-sectional view is considered. A part of the light incident upon the optical waveguide **103** propagates through the insulating film **110**, and a part of the light leaks into the interlayer insulating film **214** above the charge holding portion at the end portion of the insulating film **110** and becomes stray light. The stray light enters the charge accumulation unit **105** through the insulating film between the light shielding portion **109** and the semiconductor substrate **200** and causes noise. If the insulating film **110** extends to a portion above the light shielding portion **109** as illustrated in FIG. **2**, the light propagating from the optical waveguide **103** to the insulating film **110** reaches to a portion above the light shielding portion **109** along the insulating film **110**. In this case, existence of the light shielding portion **109** prevents the light leaked from the end portion of the insulating film **110** from entering the charge accumulation unit **105**. An area of the insulating film **110** is desirably larger than the emission surface area of the optical waveguide in a plan view.

[0051] Since the insulating film **110** extends to a portion above the light shielding portion **109**, the light leaked from the optical waveguide **103** into the interlayer insulating film **214** and the light which did not enter an upper opening of the optical waveguide **103** can be condensed on the optical waveguide **103** through the insulating film **110** which has a refractive index higher than that of the interlayer insulating film **214**. Also in this case, since the stray light in the interlayer insulating film **214** is reduced, entrance of light into the charge accumulation unit **105** can be reduced. The shape of the insulating film **110** in a plan view is not limited to that illustrated in FIG. **1** but may be various shapes.

[0052] FIG. **3**A illustrates a first another example of the shape of the insulating film **110** of Example 1. FIG. **3**A differs from FIG. **1** in that the insulating film **110** covers the entire light shielding portion **109**. In FIG. **1**, a portion in which the insulating film **110** and the light shielding portion **109** are not laminated together in the vertical direction above the charge accumulation unit **105** exists, whereas the first another example has a laminated structure in which the insulating film **110** is located above the entire light shielding portion **109**. In the laminated films, since reflection of the incident light from above generally occurs on the interfaces, transmittance of the incident light from above can be decreased. That is, in the first another example, as compared with the example illustrated in FIG. **2**, a ratio of the stray light, among the stray light which does not enter the upper opening of the optical waveguide **103** but enters the interlayer insulating film **214**, which penetrates the light shielding portion **109** and reaches the charge accumulation unit **105** can be decreased. Although FIG. **3**A is a plan view of a unit pixel, the light shielding portion **109** and the insulating film **110** may be connected to those of adjacent pixels.

[0053] FIG. **3**B illustrates a second another example of the insulating film **110** of Example 1. In FIG. **3**B, the second another example differs from Example 1 of FIGS. **1** and **2** in that the insulating film **110** does not extend to a portion above the light shielding portion **109** on the gate electrode **101** of the OFD transistor **16**. The second another example is suitable if the contact plug **215** does not overlap neither the light shielding portion **109** nor the insulating film **110** in a plan view for the reason of the manufacturing process. Also in the second another example, since the insulating film **110** extends to a portion above the light shielding portion **109** between the optical waveguide **103** and the charge accumulation unit **105**, shielding performance against the charge accumulation unit **105** can be improved by the mechanism described above.

[0054] The effect of Example 1 is provided if the insulating film **110** extends to the portion above the light shielding portion **109** at least a part of the pixel, desirably between the optical waveguide **103** and the charge accumulation unit **105**. At which portion the insulating film **110** extends to a portion above the light shielding portion **109** can be suitably designed in consideration of a pixel layout, desired pixel characteristics, and a manufacturing process.

Example 2

[0055] FIGS. **4**A to **4**C, **5**A, **5**B, **6**A and **6**B are cross-sectional views illustrating a method for manufacturing an image pickup device of Example 2.

[0056] In FIG. **4**A, after preparing a semiconductor substrate, an OFD unit **201**, a photoelectric conversion unit **102**, a charge accumulation unit **105**, a FD **111**, and gate electrodes **101**, **104**, **106** and **107** of each transistor are formed.

[0057] Next, an antireflection film **211** is formed on the photoelectric conversion unit **102**, a gate electrode of each transistor, and a source region and a drain region of each transistor. A silicon nitride film may be used as the antireflection film **211**. The antireflection film **211** may be used as an unillustrated film for forming a side spacer of the transistor disposed in a peripheral circuit region outside a pixel region.

[0058] Next, as illustrated in FIG. **4**B, an insulating film **301** is formed in the entire pixel region. On the insulating film **301**, a shielding member which becomes a light shielding portion **109** is formed to cover at least the photoelectric conversion unit **102**, the gate electrode **104**, and the charge accumulation unit **105**. A portion of the shielding member which overlaps the photoelectric conversion unit **102** in a plan view is removed so that the light shielding portion **109** which covers a part of the photoelectric conversion unit **102** and the charge accumulation unit **105** is formed. The insulating film **301** may be formed from a silicon oxide film. The shielding member may be removed by dry etching. Desirably, the insulating film **301** partially remains in the opening of the light shielding portion **109**. This is because, if the insulating film **301** is removed completely, a part of the antireflection film **211** is also removed, whereby an antireflection effect can be decreased and sensitivity can be lowered.

[0059] Next, as illustrated in FIG. **4**C, an insulating film **302** is formed in the pixel region. Then, the insulating film **110** is formed in the opening of the light shielding portion **109** on the photoelectric conversion unit **102**, on the gate electrode **104**, and on at least a part of the charge accumulation unit **105**. The shape of the insulating film **110** in a plan view is described later.

[0060] Patterning of the insulating film **110** may be performed by dry etching. In the region in which the insulating film **110** is removed, it is desirable to make the insulating film **302** partially remain. This is because, if the insulating film **302** is removed completely, a part of the light shielding portion **109** is also removed in the region in which the light shielding portion **109** is disposed below the insulating film **302**.

[0061] Next, as illustrated in FIG. **5**A, wires **216***a* to **216***c*, a contact plug **215**, via plugs **219***a* and **219***b*, interlayer insulating films **214***a* to **214***d*, and diffusion preventing films **217***a* to **217***c* are formed by publicly known methods. Although three wiring layers are illustrated in FIG. **5**A, a greater or smaller number of wiring layers may be provided. Although a plurality of wiring layers, interlayer insulating films, and diffusion preventing films are formed here, these layers and films will be described collectively with no alphabet added to the reference numerals if it is unnecessary to distinguish them. The diffusion preventing film **217** is not necessarily that used when the wire **216** is formed mainly from Cu.

[0062] Then, as illustrated in FIG. **5**B, an opening **218** is formed at a portion of the interlayer insulating film **214** and the diffusion preventing film **217** at which the optical waveguide is to be formed. The opening is formed by, for example, dry etching. During formation of the opening, the insulating film **110** functions as an etching stop film. Since etching is stopped by the insulating film **110**, exposure of the photoelectric conversion unit **102** to the etching damage is reduced and an increase of noise is avoided. It is not necessary that etching is stopped completely by the insulating film **110**. It is only necessary that the material is less easily etched than the interlayer insulating film **214** to the etching condition during etching of the interlayer insulating film **214**. If the interlayer insulating film **214** is formed from a silicon oxide film or a glass-based material made mainly of silicon oxide, such as BPSG, PSG and NSG, the insulating film **110** may be formed from a film including a silicon nitride film and a silicon carbide film.

[0063] A part or the entire insulating film **110** may be removed by further etching.

[0064] Next, as illustrated in FIG. **6**A, a high refractive index material having a refractive index higher than that of the interlayer insulating film **214** is embedded in the opening **208** to conduct planarization, and the optical waveguide **103** is formed. The high refractive index material may be embedded by, for example, high density plasma chemical vapor deposition or spin coating of an organic material. Planarization may be conducted by, for example, chemical mechanical polishing (CMP) or etch back.

[0065] Next, as illustrated in FIG. **6**B, an interlayer insulating film **229** and antireflection films **228** and **230** located on the upper and lower sides of the interlayer insulating film **229** are formed. A silicon oxide film may be used as the interlayer insulating film **229**, and a silicon oxynitride film may be used as the antireflection film **228**. As compared with a configuration in which the interlayer insulating film **229** is provided in contact with a member which constitutes the optical waveguide **103**, the antireflection film **228** can increase the amount of light incident upon the photoelectric conversion unit **102**.

[0066] As compared with a configuration in which a later-described innerlayer lens **232** and the insulating film **229** are disposed in contact with each other, the antireflection film **230** can increase the amount of light incident upon the photoelectric conversion unit **102**.

[0067] The innerlayer lens **232** is formed above the antireflection film **230** and the antireflection film **231** is formed above the innerlayer lens **232**.

[0068] As described above, in the manufacturing method of Example 2, the insulating film **110** which functions as the etching stop film is formed to extend continuously from at least a part of the photoelectric conversion unit **102** to at least a part of a portion above the light shielding portion in a plan view. This configuration prevents the light which leaks out of a side surface of the insulating film **110** from entering the semiconductor substrate **200** below the light shielding portion **109**, and improves shielding performance of the charge accumulation unit **105**.

[0069] As another effect, during formation of the opening **218** in the interlayer insulating film **214**, the opening **218** can be formed wider on the side of the charge accumulation unit **105**. This is because, even if the opening **218** is disposed to overlap the light shielding portion **109** in a plan view, the light shielding portion **109** is protected by the insulating film **110** during etching of the opening **218**.

Example 3

[0070] FIG. **7** is a cross-sectional view of an image pickup device of Example 3. The same components as those of Example 1 will be denoted by the same reference numerals and detailed description thereof will be omitted.

[0071] Example 3 differs from Examples 1 and 2 in the planar shape of the insulating film **110**. In Example 3, an end portion of an optical waveguide **103** is located outside an opening portion of a light shielding portion **109**. In Example 3, since the optical waveguide **103** has an emission surface and an incident surface wider than those of Examples 1 and 2, it is possible to condense a greater amount of light on a photoelectric conversion unit **102**.

[0072] Also in the configuration illustrated in FIG. **7**, since an insulating film **110** extends to a portion above the light shielding portion **109**, light leaking on an interlayer insulating film **214** and light which did not enter an incident surface of the optical waveguide **103** are condensed on the optical waveguide **103** through the insulating film **110** of which refractive index is higher than that of the interlayer insulating film **214**. Therefore, stray light in the interlayer insulating film **214** is reduced and noise generated in a charge accumulation unit **105** is reduced.

Example 4

[0073] FIG. **8** is a cross-sectional view illustrating Example 4. In Example 4, as compared with Example 3, no p-type semiconductor region **205** exists above a charge accumulation unit **105** whereas a gate electrode **104** of a first transfer transistor extends to a portion above the charge accumulation unit **105**.

[0074] In Example 4, noise generated near a surface of the semiconductor substrate **200** is reduced using a voltage applied to the gate electrode **104** in the charge accumulation unit **105**. Since a volume of a p-type semiconductor portion of the silicon substrate surface can be reduced as compared with a case in which the p-type semiconductor region **205** is formed by ion implantation, it is possible to increase the number of electrons that can be accumulated in the charge accumulation unit **105**.

Example 5

[0075] FIG. **9** is a cross-sectional view illustrating Example 5. Example 5 differs from Example 1 in that an opening region A4 above the optical waveguide **103** is larger than opening regions A1, A2 and A3 of wiring layers. In Examples of the present invention, since the charge accumulation unit **105** also exists in the semiconductor substrate **200** in addition to the photoelectric conversion unit **102**, an area occupied by the photoelectric conversion unit **102** becomes relatively smaller. As in Example 5, by increasing the upper opening of the optical waveguide **103** greatly, it is possible to let a greater amount of light enter a photoelectric conversion unit **102** of relatively small area, thereby increasing sensitivity.

Example 6

[0076] FIG. **10** is a cross-sectional view illustrating Example 6. In FIG. **10**, as compared with Example 1, an antireflection film **211** opens at a location at which a contact **215** to a gate electrode **107** of a FD **111** and a source follower transistor is to be formed. Further, an insulating film **110** remains at a location at which the contact **215** is to be formed. The insulating film **110** is made to function as an etching stop film when the contact **215** is opened by dry etching.

[0077] The antireflection film **211** can reduce diffusion of hydrogen in a semiconductor substrate **200** during a hydrogen sinter process, whereas the antireflection film **211** can diffuse a greater amount of hydrogen in the semiconductor substrate **200** through the opening of the antireflection film **211** in Example 6. This increases an effect of terminating tangling bond which exists on the silicon substrate surface, and further reduces noise.

[0078] The location at which the opening of the antireflection film **211** is formed is not limited to the location at which the contact **215** to the gate electrode **107** of the FD **111** and the source follower transistor is to be formed. The opening of the antireflection film **211** may be formed at a location at which other contact (not illustrated) is to be formed. Regarding the contact to the FD **111** and the gate electrode **107** of an SF transistor, the antireflection film **211** may be left and used as an etching stop film.

[0079] Although the present invention is described with reference to Examples, combinations and changes may be made without departing from the concept of the invention.

[0080] While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

[0081] This application claims the benefit of Japanese Patent Application No. 2015-180068, filed 11 Sep. 2015, which is hereby incorporated by reference herein in its entirety.

What is claimed is:

1. An image pickup device which has a pixel region in which a plurality of pixels are arranged, and a multilayer wiring structure is disposed in a pixel region, each of the pixels including

a photoelectric conversion unit,

a charge accumulation unit configured to accumulate signal charge transferred from the photoelectric conversion unit,

a floating diffusion to which the signal charge of the charge accumulation unit is transferred,

a light shielding portion configured to cover at least a part of the charge accumulation unit and opening above the photoelectric conversion unit, and

an optical waveguide disposed above the photoelectric conversion unit,

the device comprising an insulating film disposed below the optical waveguide,

wherein the insulating film has a refractive index higher than that of a portion of an interlayer insulating film of the multilayer wiring structure disposed above the charge holding portion, and the insulating film extends from below the optical waveguide to a portion above the light shielding portion at a portion closer to the photoelectric conversion unit than to the lowermost wiring layer among wiring layers of the multilayer wiring structure.

2. The image pickup device according to claim **1**, wherein the insulating film covers the entire charge accumulation unit.

3. The image pickup device according to claim **1**, wherein an incident surface area of an upper portion of the optical waveguide is larger than an emission surface area.

4. The image pickup device according to claim **1**, wherein an antireflection film is disposed above the photoelectric conversion unit, the antireflection film has an opening, and the insulating film is disposed above the opening of the antireflection film.

5. A method for manufacturing an image pickup device which has a pixel region in which a plurality of pixels are arranged, each of the pixels including

a photoelectric conversion unit,

a charge accumulation unit configured to accumulate signal charge transferred from the photoelectric conversion unit,

a floating diffusion to which the signal charge of the charge accumulation unit is transferred,

a light shielding portion configured to cover at least a part of the charge accumulation unit and opening above the photoelectric conversion unit, and

a waveguide disposed above the photoelectric conversion unit,

the method comprising:

preparing a semiconductor substrate on which the charge accumulation unit and the photoelectric conversion unit are arranged;

forming the light shielding portion;

forming an interlayer insulating film so as to cover the light shielding portion and the photoelectric conversion unit;

forming an opening which at least partially overlaps the photoelectric conversion unit in the interlayer insulating film by etching; and

forming the optical waveguide in the opening,

wherein an etching stop film used in the etching is formed to extend continuously from at least a part of a portion above the photoelectric conversion unit to at least a part of a portion above the light shielding portion in a plan view.

6. The method for manufacturing an image pickup device according to claim **5**, further comprising forming a multilayer wiring structure on the pixel region,

wherein the etching stop film is removed in a region in which a contact plug which connects between the semiconductor substrate and a wire included in the wiring layer of the multilayer wiring structure exists.

7. The method for manufacturing an image pickup device according to claim **5**, further comprising forming an insulating film between the light shielding portion and the etching stop film.

8. The method for manufacturing an image pickup device according to claim **7**, further comprising removing at least a part of the insulating film, wherein the etching stop film is left in a region from which the insulating film is removed.

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