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LIGHT-EMITTING DEVICE, IMAGE FORMING DEVICE, IMAGE CAPTURING DEVICE, DISPLAY DEVICE, ELECTRONIC APPARATUS, ILLUMINATION DEVICE, MOVING BODY, AND WEARABLE DEVICE

Abstract

A light emitting device in which a plurality of pixels are arranged in a matrix in a semiconductor substrate. Each of the plurality of pixels includes a light-emitting element, a driving transistor configured to supply a current to the light-emitting element, and a switching transistor configured to control the light-emitting element. A gate electrode of the switching transistor is provided on at least two faces of four faces surrounding a cross section of a region to be a channel.

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Background/Summary

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] One disclosed aspect of the embodiments relates to a light-emitting device, for example, a light-emitting device including an organic light-emitting element, and an image forming device, an image capturing device, a display device, an electronic apparatus, an illumination device, a moving body, and a wearable device to each of which the light-emitting device is applied.

Description of the Related Art

[0002] As a light-emitting element, for example, an organic light-emitting element is used. Japanese Patent Laid-Open No. 2022-85287 discloses that a switching transistor configured to control light emission and non-light emission of a light-emitting element is provided between the anode and cathode as two terminals of the light-emitting element.

[0003] If the source-drain voltage or the well voltage fluctuates, the switching transistor can be incompletely turned on/off, causing incomplete control of light emission and non-light emission of the light-emitting element. As a result, the light emission amount may vary, and the light emission quality may deteriorate.

SUMMARY OF THE INVENTION

[0004] One disclosed embodiment has been made in consideration of the above-described problem, and provides a light-emitting device having an arrangement advantageous in suppressing deterioration of light emission quality.

[0005] According to one aspect of the disclosure, there is provided a light-emitting device in which a plurality of pixels are arranged in a matrix in a semiconductor substrate. Each of the plurality of pixels includes a light-emitting element, a driving transistor configured to supply a current to the light-emitting element, and a switching transistor configured to control the light-emitting element. A gate electrode of the switching transistor is provided on at least two faces of four faces surrounding a cross section of a region to be a channel.

[0006] Further features of the disclosure will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a block diagram of a light-emitting device;

[0008] FIG. **2** is a schematic view showing the arrangement of a pixel;

[0009] FIG. **3** is a plan view of pixels according to the first embodiment;

[0010] FIGS. **4**A and **4**B are cross-sectional views of the pixel according to the first embodiment;

[0011] FIGS. **5**A to **5**D are views for explaining formation of a pixel circuit according to the first embodiment;

[0012] FIGS. **6**A to **6**D are views for explaining formation of the pixel circuit according to the first embodiment;

[0013] FIGS. **7**A to **7**D are views for explaining formation of the pixel circuit according to the first embodiment;

[0014] FIG. **8** is a plan view of pixels according to the second embodiment;

[0015] FIGS. **9**A and **9**B are cross-sectional views of the pixel according to the second embodiment;

[0016] FIGS. **10**A to **10**D are views for explaining formation of a pixel circuit according to the second embodiment;

[0017] FIGS. **11**A to **11**D are views for explaining formation of the pixel circuit according to the second embodiment;
[0018] FIGS. **12**A to **12**D are views for explaining formation of the pixel circuit according to the second embodiment;
[0019] FIGS. **13**A to **13**C are schematic views showing an example of an image forming device;
[0020] FIG. **14** is a schematic view showing an example of a display device;
[0021] FIG. **15**A is a schematic view showing an example of an image capturing device;
[0022] FIG. **15**B is a schematic view showing an example of an electronic apparatus;
[0023] FIG. **16**A is a schematic view showing an example of a display device;
[0024] FIG. **16**B is a schematic view showing an example of a display device;
[0025] FIG. **17**A is a schematic view showing an example of an illumination device;
[0026] FIG. **17**B is a schematic view showing an example of an automobile including a vehicle lighting appliance; and
[0027] FIGS. **18**A and **18**B are schematic views each showing an example of a wearable device.

DESCRIPTION OF THE EMBODIMENTS

[0028] Hereinafter, embodiments will be described in detail with reference to the attached drawings. Note, the following embodiments are not intended to limit the scope of the claimed invention. Multiple features are described in the embodiments, but limitation is not made to an invention that requires all such features, and multiple such features may be combined as appropriate. Furthermore, in the attached drawings, the same reference numerals are given to the same or similar configurations, and redundant description thereof is omitted.

First Embodiment

[0029] FIG. **1** is a block diagram of a light-emitting device **101** according to this embodiment. This embodiment will be described here by taking an active matrix display device as an example. As shown in FIG. **1**, the light-emitting device **101** includes a pixel array portion **103**, and a driver arranged around the pixel array portion **103**. The pixel array portion **103** includes a plurality of pixels **102** two-dimensionally arranged in a matrix, and each pixel **102** includes a circuit including a light-emitting element **201** and transistors arranged around the light-emitting element shown in FIG. **2**.

[0030] The light-emitting device **101** includes a driver configured to drive each pixel. The driver includes a vertical scanning circuit **104** and a signal output circuit **105**. The driver can be controlled by a controller to operate the light-emitting device as a display device. In FIG. **1**, in the pixel array portion **103** where the pixels **102** are arranged in a matrix, a first scanning line **106** and a second scanning line **107** are arranged for each pixel row along a row direction. Further, a signal line **108** is arranged for each pixel column along a column direction.

[0031] Each of the first scanning line **106** and the second scanning line **107** is connected to the output terminal in the corresponding row in the vertical scanning circuit **104**. Each signal line **108** is connected to the output terminal in the corresponding column in the signal output circuit **105**.

[0032] The vertical scanning circuit **104** can be formed from a shift resistor, which sequentially shifts a start pulse in synchronization with a clock pulse, or the like. When writing a video signal in each pixel **102** in the pixel array portion **103**, the vertical scanning circuit **104** supplies a write control signal to the first scanning line **106**. In a non-light emission period, the vertical scanning circuit **104** supplies a reset signal to the second scanning line **107**.

[0033] The signal output circuit **105** outputs a signal voltage (luminance signal) corresponding to luminance information supplied from the outside. The signal voltage output from the signal output circuit **105** is supplied to the corresponding pixel **102** via the signal line **108**.

[0034] In the pixel where the write signal from the first scanning line **106** is set at active level, the light-emitting element **201** can emit light in accordance with the signal voltage supplied from the signal line **108**. In the pixel to which the reset signal is supplied from the second scanning line, the light-emitting element can be controlled to be set in a non-light emission state. The vertical scanning circuit **104** can sequentially output the write control signal and the reset signal for each row.

[0035] Note that the driver need not be arranged in the same substrate as the pixel array portion **103**. The pixel array portion **103** may be arranged in the first substrate, and at least a part of the driver may be arranged in the second substrate, thereby stacking the first substrate and the second substrate.

[0036] In this specification, when the light-emitting device **101** is a monochrome display compatible display device, one pixel as a unit for forming a monochrome image corresponds to the pixel **102**. On the other hand, when the light-emitting device **101** is a color display compatible display device, one pixel as a unit for forming a color image may be formed from a plurality of sub-pixels, and the plurality of sub-pixels may correspond to the pixel **102**. More specifically, in the color display compatible display device, one pixel may be formed from three sub-pixels including a sub-pixel that emits red (R) light, a sub-pixel that emits green (G) light, and a sub-pixel that emits blue (B) light.

[0037] One pixel is not limited to a combination of the sub-pixels of the three primary colors of RGB. That is, it is also possible to form one pixel by adding one or a plurality of color sub-pixels to the sub-pixels of the three primary colors. More specifically, it is also possible to form one pixel by adding a sub-pixel that emits white (W) light to improve luminance, or form one pixel by adding at least one sub-pixel that emits complementary color light to extend the color reproduction range.

[0038] FIG. **2** is a circuit diagram showing an example of the arrangement of the pixel **102** of the light-emitting device **101** shown in FIG. **1**. For the light-emitting element **201**, a current-driven electro-optical element whose light emission luminance changes in accordance with the value of a current flowing through the element, for example, an organic light emitting diode (OLED) element can be used. A case in which the electro-optical element is an OLED element will be described below. The light-emitting element **201** includes an organic layer including a light emitting layer between an anode electrode and a cathode electrode. The organic layer may include at least one of a hole injection layer, a hole transport layer, an electron injection layer, and an electron transport layer, in addition to the light emitting layer.

[0039] The pixel **102** may include an OLED element functioning as the light-emitting element **201**, and a driving circuit for driving the light-emitting element **201**. The pixel **102** includes the light-emitting element **201**, a driving transistor **202**, and a write transistor **203**. One of the drain and source of the driving transistor **202** is connected to a power supply potential Vdd, and the other is connected to one main terminal of the light-emitting element **201**.

[0040] In this example, the driving transistor **202** is connected to the anode electrode of the light-emitting element **201**. The pixel **102** further includes a switching transistor **204** and a first capacitive element **205**.

[0041] In this embodiment, one of the drain and source of the switching transistor **204** is connected to a connection portion between the driving transistor **202** and the light-emitting element **201**. In this example, the other of the drain and source of the switching transistor **204** is connected to a power supply potential Vss serving as a reference. In this embodiment, the power supply potential Vdd is higher than the power supply potential Vss.

[0042] Here, the total number of transistors and the capacitive element and the combination of the conductivity types of the transistors are merely examples, and not limited to this arrangement. The total number of the transistors and the capacitive element may be the same for the plurality of pixels, or pixels different in the total number of the transistors and the capacitive element may be included in the light-emitting device.

[0043] When the light-emitting device is used as a color display compatible display device, the arrangement may be changed in accordance with each color. The capacitance value of the first capacitive element **205** in the sub-pixel that emits blue light may be larger than the capacitance value of the first capacitive element **205** in the sub-pixel that emits green light. In the following description, when a transistor is connected between an element A and an element B, one terminal (one of the source region and drain region) of the transistor is connected to the element A, and the other terminal (the other of the source region and drain region) of the transistor is connected to the element B.

[0044] A circuit operation of the pixel **102** will be described. In this embodiment, one end of a current path including the light-emitting element **201**, the driving transistor **202**, and the switching transistor **204** is connected to the power supply potential Vss, and the other end is connected to the power supply potential Vdd.

[0045] More specifically, one (the cathode in the example shown in FIG. **2**) of the main terminals of the light-emitting element **201** and one (the drain region in the example shown in FIG. **2**) of the drain and source of the switching transistor **204** are connected to the power supply potential Vss. The other (anode) of the main terminals of the light-emitting element **201** and the other (the source region in the example shown in FIG. **2**) of the drain and source of the switching transistor **204** are connected to the power supply potential Vdd via the driving transistor **202**.

[0046] One (the drain region in the example shown in FIG. **2**) of the drain and source of the write transistor **203** is connected to the gate of the driving transistor **202**, and the other (the source region in the example shown in FIG. **2**) of the drain and source of the write transistor **203** is connected to the signal line **108**. The gate of the write transistor **203** is connected to the first scanning line **106**.

[0047] One (the drain region in the example shown in FIG. **2**) of the drain and source of the switching transistor **204** is connected to the power supply potential Vss **207**. The gate of the switching transistor **204** is connected to the second scanning line **107**. The cathode electrode of the light-emitting element **201** is also connected to the power supply potential Vss. Therefore, when the switching transistor **204** is controlled to become conductive, the two main terminals (anode and cathode) of the light-emitting element **201** are short-circuited. To control the light-emitting element **201** to set it in a non-light emission state, the switching transistor **204** is turned on in a non-light emission period. With this, the anode of the light-emitting element **201** can be connected to the power supply potential Vss **207**, thereby setting the light-emitting element **201** in the non-light emission state. The one terminal of the drain and source of the switching transistor **204** may be connected a predetermined potential that can set the light-emitting element **201** in the non-light emission state when the switching transistor is controlled to be conductive (if the Vdd is a positive potential, the predetermined potential is preferably a more negative potential than the Vss).

[0048] The first capacitive element **205** is connected between a node connected to the gate of the driving transistor **202** and a node connected to one (the source in the example shown in FIG. **2**) of the drain and source of the driving transistor **202**. The first capacitive element **205** can be selected from a parasitic capacitance, a Metal-Insulator-Metal (MIM) structure, a Metal-Oxide-Semiconductor (MOS) structure, and the like.

[0049] The driving transistor **202** supplies a current from the power supply potential Vdd **206** to the light-emitting element **201**, thereby causing it to emit light. More specifically, the driving transistor **202** supplies, to the light-emitting element **201**, a current corresponding to the signal voltage of the signal line **108**. This causes the light-emitting element **201** to emit light by current driving.

[0050] The write control signal is supplied to the gate of the write transistor **203** from the vertical scanning circuit **104** via the first scanning line **106**. The write transistor **203** controls a conductive state and a non-conductive state in accordance with the write control signal. The write transistor **203** can transmit the luminance signal to the light-emitting element **201**. When the write transistor **203** is set in the conductive state, the write transistor **203** samples the signal voltage of the luminance signal corresponding to the luminance information supplied from the signal output circuit **105** via the signal line **108**, and writes it in the pixel **102**. The written signal voltage is applied to the gate of the driving transistor **202**.

[0051] In this embodiment, the description will be continued for the example in which the OLED element is used as the light-emitting element **201**. When the light-emitting element **201** emits light,

the amount of current flowing through the driving transistor **202** changes in accordance with the signal voltage applied to the gate of the driving transistor **202** from the signal line **108** via the write transistor **203**. This charges the electric capacitance between the anode and cathode of the light-emitting element **201** up to a predetermined potential, and a current corresponding to the potential difference flows. Thus, the light-emitting element **201** emits light with a predetermined luminance.
[0052] FIG. **3** is a schematic plan view showing a part of the pixel array portion **103** where the plurality of pixels **102** are arranged. A description will be given here using a p-channel MOSFET as an example of the transistor, but an n-channel MOSFET may be used. An arrangement in which a p-channel MOSFET and an n-channel MOSFET are mixed may be used.
[0053] The driving transistor **202** is formed from a gate electrode **301**, a p-type diffusion region **302** functioning as one of a source region and a drain region, and a p-type diffusion region **303** functioning as the other of the source region and the drain region. In FIG. **3**, the gate electrode **301** is connected to one terminal of the first capacitive element **205** shown in FIG. **2**, and the diffusion region **303** is connected to the other terminal of the first capacitive element **205**. Furthermore, the diffusion region **303** is connected to the power supply potential Vdd **206**. The diffusion region **302** is connected to the anode of the light-emitting element **201**.
[0054] The write transistor **203** is formed from a gate electrode **304**, a p-type diffusion region **305** functioning as one of a source region and a drain region, and a p-type diffusion region **306** functioning the other of the source region and the drain region. In the example shown in FIG. **3**, the diffusion region **305** can function as the drain region, and the diffusion region **306** can function as the source region. The diffusion region **305** is connected to the gate electrode **301** of the driving transistor **202**, and holds the signal voltage. When the write transistor **203** is in the OFF state, the potential of the diffusion region **305** functioning as the drain region of the write transistor **203** and the potential of the gate electrode of the driving transistor **202** are in a floating state.
[0055] The potential of the gate electrode **301** of the driving transistor **202** and the potential of the diffusion region **305** functioning as the drain region of the write transistor **203** are equipotential. The potential of the gate electrode **301** of the driving transistor **202** decides the drain current of the driving transistor **202**, thereby deciding the luminance of the light-emitting element **201**. The diffusion region **306** is connected to the signal line **108**, and the gate electrode **304** is connected to the first scanning line **106**.
[0056] The switching transistor **204** is formed from a gate electrode **307**, the p-type diffusion region **302** functioning as one of a source region and a drain region, and a p-type diffusion region **308** functioning the other of the source region and the drain region. The gate electrode **307** is connected to the second scanning line **107**. The diffusion region **302** is shared by the driving transistor **202** and the switching transistor **204**. However, the present invention is not limited to this, and each of the driving transistor **202** and the switching transistor **204** may have an independent diffusion region. The diffusion region **308** is connected to the power supply potential Vss **207**. In a planar view, the diffusion region closest to the diffusion region **308** is the diffusion region **305**.
[0057] A contact plug **309** is connected to each of the source regions and the drain regions. Each of the source regions and the drain regions may have a Lightly Doped Drain (LDD) structure, and this can be expected to suppress a leakage current.
[0058] The region connected to the contact plug **309** may have a higher impurity concentration than in the source region and the drain region around it. In the source region and the drain region, the portion connected to the contact plug may have a higher impurity concentration than in a portion forming an interface with a well **402**. If a silicide containing tungsten (W), cobalt (Co) or the like is formed in the region connected to the contact plug **309**, the electric resistance can be reduced.
[0059] The structure of the switching transistor **204** and the structure of the driving transistor **202** will be described with reference to FIGS. **4**A and **4**B. FIG. **4**A is a cross-sectional view taken along

a line X**1**-X**1**′ shown in FIG. **3**, which is a view for explaining the cross-sectional structure of the switching transistor **204**. Explaining FIGS. **4**A and **4**B in relation to FIG. **3**, each of the section taken along the line X**1**-X**1**′ and the section taken along a line X**2**-X**2**′ is a cross section perpendicular to a current flowing between the drain and the source.

[0060] A substrate **400** is a semiconductor substrate, and a single crystal silicon substrate will be described as an example in this embodiment. The n-type well **402** is formed on a p-type substrate **401**. An element isolation portion **403** is formed in a part of the n-type well **402**. The element isolation portion **403** is a shallow trench isolation (STI), a local oxidation of silicon (LOCOS), or the like, and made of an insulator such as silicon oxide. A channel region **404** is a part of the n-type well **402**, and arranged between the element isolation portions **403**.

[0061] The gate electrode **307** is arranged on the channel region **404**. The gate electrode **307** is made of polysilicon in this example, but may be formed of another conductor material. An interlayer film **601** is arranged on the gate electrode **307**. The interlayer film **601** is made of an insulator such as silicon oxide.

[0062] A gate insulating film **405** is arranged between the gate electrode **307** and the channel region **404**. Silicon oxide can be used for the gate insulating film **405**. To ensure the breakdown voltage, the film thickness is preferably selected in accordance with the voltage used in the circuit. To drive the light-emitting element **201**, the switching transistor **204** needs to be used with a relatively high voltage. More specifically, the voltage is, for example, about 5 to 20 V. When used with such a voltage, the film thickness of the gate insulating film **405** of about 10 to 40 nm can ensure the breakdown voltage. For the same region, the gate length needs to have a length that can ensure the breakdown voltage. More specifically, the gate length is, for example, 0.5 μm or more.

[0063] The gate electrode **307** includes not only a portion on the substrate **400** but also a portion embedded in the substrate **400**, thereby having a vertical gate electrode structure. The gate electrode **307** is formed from a portion **307***a* on the substrate **400** and a portion **307***b* embedded in a groove of the substrate **400**, thereby surrounding the channel region **404** not only from above the substrate **400** but also from both sides. The gate electrode **307** can have an inverted U-shape or a U-shape with respect to the bottom surface of the substrate **400** when viewed in a cross section perpendicular to the current flow direction. With respect to the channel region surrounded by the gate electrode **307**, the element isolation portion **403** can be located outside the gate electrode **307** so as to be adjacent to the gate electrode **307**.

[0064] Such a trench gate structure including a gate electrode in a groove of a substrate allows the electric field of the gate electrode **307** to influence the channel region **404** from more faces than a gate electrode of a conventional planar structure. This can improve the controllability of the ON/OFF operation caused by forming a channel between the source and the drain due to the gate voltage. Here, improvement in controllability refers to an increase in current in the ON state and a reduction in leakage current in the OFF state.

[0065] In the circuit arrangement of the pixel **102**, the switching transistor **204** has a role of controlling light emission and non-light emission of the light-emitting element **201**. Therefore, it is required to be reliably turned on/off even in a situation where the source-drain voltage or the well voltage fluctuates. If the switching transistor **204** is incompletely turned on/off, this can cause incomplete control of light emission and non-light emission of the light-emitting element **201** and variation of the light emission amount of the light-emitting element **201**, leading to deterioration of image quality. If the switching transistor **204** has the structure according to this embodiment, the controllability of the ON/OFF operation due to the gate voltage can be improved, and an improvement in image quality can be expected.

[0066] In this embodiment, the portion **307***b* of the gate electrode is shown as being embedded in a part of the element isolation portion **403**. However, the gate electrode may be embedded in a part of the channel region **404**, or may be embedded across a part of the element isolation portion **403** and a part of the channel region **404**.

[0067] In this embodiment, when the channel region **404** through which a current flows between the source and the drain is viewed in a cross section cut perpendicularly to the current flow direction, the portions **307***a* and **307***b* of the gate electrode are arranged on three faces of four faces surrounding the cross section. More specifically, the gate electrode is arranged, along the current flow direction, on three faces in total including one face on the front surface side of the substrate and two faces on both sides of the region to be the channel. However, the gate electrode may be provided on two faces including a face on the front surface side of the substrate and a face on one side of the region surrounding the channel. Alternatively, the gate electrode in the groove may be embedded in the central portion of the channel region **404**.
[0068] By making the depth of the portion **307***b* of the gate electrode shallower than the depth of the element isolation portion **403**, it becomes easy to process the groove for embedding the portion **307***b* of the gate electrode when forming the transistor. The depth of the portion **307***b* of the gate electrode is preferably more than twice the film thickness of the gate insulating film **405**. In this case, parts of the portion **307***b* of the gate electrode face each other on the side surfaces of the channel region **404**, and it can be expected that the electric field from the portion **307***b* of the gate electrode influences the side surface of the channel region **404** more effectively. This can further improve the controllability of the ON/OFF operation (channel formation) due to the gate voltage.
[0069] FIG. **4**B is a cross-sectional view of the driving transistor **202** taken along the line X**2**-X**2**′ in FIG. **3**. The difference from FIG. **4**A is that the gate electrode **301** has a planar structure in which the gate electrode **301** is arranged only on the substrate **400** and is not embedded in the substrate **400**.
[0070] When the light-emitting element **201** emits light, the amount of current flowing through the driving transistor **202** changes in accordance with the signal voltage applied to the gate of the driving transistor **202** from the signal line **108** via the writing transistor **203**. Therefore, if the characteristics of the driving transistor **202** vary among the pixels, deterioration of image quality such as a rough image can occur.
[0071] If a trench gate structure as shown in FIG. **4**A is applied to the driving transistor **202**, a groove for embedding the gate electrode **301** needs to be formed in the element isolation portion **403**, and this can cause processing variation in the shape of the gate electrode **301**. The processing variation can result in the characteristic variation of the driving transistor **202**.
[0072] On the other hand, with a planar structure as shown in FIG. **4**B, it is easy to suppress the characteristic variation caused by the variation in the shape of the gate electrode **301**, and deterioration of image quality can be minimized. If the characteristic variation of the driving transistor **202** is allowed, a transistor having a trench gate structure as shown in FIG. **4**A may be used. The write transistor **203** may have a trench gate structure or a planar structure, and can be appropriately selected depending on the circuit design, pixel circuit layout, and the like.
[0073] FIGS. **5**A to **5**D, **6**A to **6**D, and **7**A to **7**D are views for explaining the process of forming each transistor that constitutes the pixel circuit while comparing the cross-sectional structures of the switching transistor **204** and the driving transistor **202**. The method of forming transistors according to this embodiment will be described below. Each of FIGS. **5**A, **5**C, **6**A, **6**C, **7**A, and **7**C is a cross-sectional view of the switching transistor **204** shown in FIG. **3** taken along the line X**1**-X**1**′. Each of FIGS. **5**B, **5**D, **6**B, **6**D, **7**B, and **7**D is a cross-sectional view of the driving transistor **202** taken along line the X**2**-X**2**′.
[0074] As shown in FIGS. **5**A and **5**B, the element isolation portion **403** is formed in the substrate **400** formed from the p-type substrate **401** and the n-type well **402**. The element isolation portion **403** can be made of silicon oxide or the like. The element isolation portion **403** can have an STI structure, a LOCOS structure, or the like. A region of the n-type well **402** sandwiched between the element isolation portions **403** is to be the channel region **404**.
[0075] Then, as shown in FIGS. **5**C and **5**D, a resist mask **501** for the switching transistor **204** is formed on the substrate **400**, and the element isolation portion **403** is partially removed by dry

etching or the like to form a groove **502**. In this embodiment, the groove **502** is formed between the n-type well **402** to be the channel region **404** and the element isolation portion **403**. The gate electrode **307** is to be formed in the groove **502**. Here, since the driving transistor **202** has a planar structure, no groove is formed. In order to form the gate electrode of the switching transistor **204** having a trench gate structure, the groove **502** is formed only in the region of the switching transistor **204**. The groove **502** may be formed using wet etching. The width of the groove **502** is about **100** to **400** nm.

[0076] After the groove **502** is formed, the resist mask **501** is removed. Thereafter, sacrificial oxidation may be performed to remove a layer damaged by etching of the groove **502**. Isotropic etching may also be performed to round the bottom shape of the groove **502** to ensure the embedding characteristic of a polysilicon film. To adjust the threshold value of the transistor, channel doping may be performed by ion implantation or the like.

[0077] As shown in FIGS. **6**A and **6**B, the gate insulating film **405** is formed on the substrate **400**. The gate insulating film **405** can be made of silicon oxide. The silicon oxide film can be formed by thermal oxidation, In situ steam generation (ISSG) oxidation, or the like. The gate insulating film **405** can be formed on a portion of the groove **502** including the sidewall of the region to be the channel and on the surface of the substrate **400** including the top face of the region to be the channel. The film thickness of the gate insulating film **405** is about **10** to **40** nm, and can be appropriately selected in accordance with the voltage to be applied to the transistor.

[0078] As shown in FIGS. **6**C and **6**D, an electrode made of a polysilicon film **503** is formed on the surface of the substrate **400**. At this time, an electrode is also formed in the groove **502** of the switching transistor **204**. The material of the electrodes is not limited to polysilicon. The film thickness of the polysilicon film **503** is about 100 to 400 nm. If the width of the above-described groove **502** is set to be equal to or less than twice the film thickness of the polysilicon film **503**, the embedding characteristic of the polysilicon film **503** in the groove **502** is improved. Furthermore, if the width of the groove **502** is set to be equal to or less than the film thickness of the polysilicon film **503**, it is possible to suppress a step of the polysilicon film **503** generated above the groove **502**.

[0079] As shown in FIGS. **7**A and **7**B, a resist mask **504** is formed on the polysilicon film **503**, and the gate electrodes **301** and **307** are formed by dry etching or the like.

[0080] As shown in FIGS. **7**C and **7**D, after the resist mask **504** is removed, the interlayer film **601** is formed. Before forming the interlayer film **601**, it is possible to form the source region and the drain region by ion implantation or the like, and to form a silicide containing W, Co, or the like in the region to be connected to the contact plug **309**, as appropriate.

[0081] In this manner, the gate electrode is formed that has an inverted U-shape or U-shape in the cross section of the switching transistor **204** taken along the line X**1**-X**1**′. The channel region **404** can be formed inside the gate electrode having the inverted U-shaped or U-shaped cross section. The driving transistor **202** includes the planar type gate electrode formed therein. According to the above-described formation method, it is possible to simultaneously form, on the same substrate, a transistor including a gate electrode having a trench gate structure and a transistor including a gate electrode having a planar structure.

Second Embodiment

[0082] A light-emitting device **101** according to this embodiment will be described with reference to FIGS. **8**, **9**A and **9**B, **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D. The arrangement of the light-emitting device and the circuit arrangement of the pixel **102** shown in FIGS. **1** and **2** apply to the second embodiment. FIG. **8** is a schematic plan view of a plurality of pixels **102** according to this embodiment. FIG. **9**A is a cross-sectional view taken along a line X**3**-X**3**′ shown in FIG. **8**, which is a view for explaining the cross-sectional structure of a switching transistor **204**. FIG. **9**B is a cross-sectional view taken along a line X**4**-X**4**′ shown in FIG. **8**, which is a view for explaining the cross-sectional structure of a driving transistor **202**.

[0083] The difference from the first embodiment is that the switching transistor **204** has a fin gate structure protruding from the base portion of a substrate **400**. The gate electrode of the switching transistor **204** is formed in a convex shape relative to the substrate **400**, and most of an element isolation portion **403** around a channel region **404** has been removed. The periphery of the channel region **404** is covered with a gate insulating film **405**, and a gate electrode **307** is arranged outside the gate insulating film **405** so as to surround the channel region **404**. The space between adjacent switching transistors **204** is filled with an interlayer film **601**.
[0084] In the switching transistor **204** having the structure as described above, most of the channel region **404** except for the lower part can be surrounded by the gate electrode **307**, so that it can be expected that the electric field of the gate electrode **307** effectively acts on the channel region **404**. This can improve the controllability of the ON/OFF operation (channel formation) due to the gate voltage, and an improvement in image quality can be expected.
[0085] The driving transistor **202** has a planar structure as in the first embodiment. When a fin gate structure is applied as the gate electrode of the driving transistor **202**, it is necessary to form a space around the channel region **404** for a processing purpose. If shape variation occurs during processing the space, this can result in the characteristic variation of the driving transistor **202**. With the planar structure as shown in FIG. **9**B, the shape variation caused by formation of the space can be suppressed, so that deterioration of image quality can be minimized. If the characteristic variation of the driving transistor **202** is allowed, the driving transistor **202** having a fin gate structure as shown in FIG. **9**A may be used. A write transistor **203** may have a fin gate structure or a planar structure, and can be appropriately selected depending on the convenience of the circuit design, pixel circuit layout, and the like.
[0086] The method of forming transistors constituting the pixel circuit according to this embodiment will be described with reference to FIGS. **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D. FIGS. **10**A to **12**D are cross-sectional views taken along a line X**3**-X**3**′ or a line X**4**-X**4**′ shown in FIG. **8**, which are views for explaining the cross-sectional structures of the switching transistor **204** and the driving transistor **202**. Each of FIGS. **10**A, **10**C, **11**A, **11**C, **12**A, and **12**C is a cross-sectional view of the switching transistor **204** taken along the line X**3**-X**3**′. Each of FIGS. **10**B, **10**D, **11**B, **11**D, **12**B, and **12**D is a cross-sectional view of the driving transistor **202** taken along the line X**4**-X**4**′.
[0087] As shown in FIGS. **10**A and **10**B, the element isolation portion **403** is formed in the substrate **400** formed from a p-type substrate **401** and an n-type well **402**. The element isolation portion **403** can be made of silicon oxide or the like. The element isolation portion **403** can have an STI structure, a LOCOS structure, or the like. A region of the n-type well **402** sandwiched between the element isolation portions **403** is to be the channel region **404**. Up to this point, this embodiment is the same as the first embodiment.
[0088] As shown in FIGS. **10**C and **10**D, a resist mask **501** is formed on the substrate **400**, and the element isolation portion **403** is partially removed by dry etching or the like to form a space **801**. In this example, the driving transistor **202** has a planar structure and the switching transistor **204** has a fin gate structure, so that the space **801** is formed only in the region of the switching transistor **204**. The element isolation portion **403** is partially left under the space **801**. The space **801** may be formed using wet etching.
[0089] After the space **801** is formed, the resist mask **501** is removed. Thereafter, sacrificial oxidation may be performed to remove a layer damaged by etching of the space **801**. Isotropic etching may also be performed to round the bottom shape of the space **801** to ensure the embedding characteristic of a polysilicon film. To adjust the threshold value of the transistor, channel doping may be performed by ion implantation or the like.
[0090] As shown in FIGS. **11**A and **11**B, the gate insulating film **405** is formed on the substrate **400**. The gate insulating film **405** is preferably made of silicon oxide. The silicon oxide film can be formed by thermal oxidation, ISSG oxidation, or the like. Through the steps described above, the

gate insulating film **405** is formed on the surface of the substrate **400** including the space **801**. The film thickness of the gate insulating film **405** is about 10 to 40 nm, and can be appropriately selected in accordance with the voltage to be applied to the transistor.

[0091] Then, as shown in FIGS. **11**C and **11**D, a polysilicon film **503** is formed on the surface of the substrate **400**. The film thickness of the polysilicon film **503** is about 100 to 400 nm. The film thickness of the polysilicon film **503** is desirably equal to or less than ¼ the interval between the channel regions **404** of the switching transistors **204**. With this structure, the space **801** is not filled with the polysilicon film **503**, and gate electrodes **301** and **307** to be described below can be easily formed.

[0092] Then, as shown in FIGS. **12**A and **12**B, a resist mask **504** is formed on the polysilicon film **503**, and the gate electrodes **301** and **307** are formed by dry etching or the like.

[0093] As shown in FIGS. **12**C and **12**D, after the resist mask **504** is removed, the interlayer film **601** is formed. Before forming the interlayer film **601**, it is possible to form the source region and the drain region by ion implantation or the like, and to form a silicide containing W, Co, or the like in the region to be connected to the contact plug **309**, as appropriate.

[0094] The above-described method can simultaneously form, on the same substrate, a transistor including a gate electrode having a fin gate structure and a transistor including a gate electrode having a planar structure.

Application Examples of Light-Emitting Device

[0095] Examples in which the light-emitting device according to each of the above-described first and second embodiments is applied to an apparatus will be described below. An organic light-emitting element is preferably used as the light-emitting element. FIGS. **13**A to **13**C show an image forming device according to this embodiment. FIG. **13**A is a schematic view of an image forming device **926** according to this embodiment. The image forming device includes a photosensitive member **927**, an exposure light source **928**, a developing device **931**, a charging unit **930**, a transfer device **932**, a conveyance unit **933**, and a fixing device **935**.

[0096] Light **929** is emitted from the exposure light source **928**, and an electrostatic latent image is formed on the surface of the photosensitive member **927**. The exposure light source includes the light-emitting device according to each of the first and second embodiments. The developing device **931** includes a developing agent such as a toner, and applies the developing agent to the exposed photosensitive member **927**. The charging unit **930** charges the photosensitive member **927**. The transfer device **932** transfers the developed image to a print medium **934**. The conveyance unit **933** conveys the print medium **934**. The print medium **934** is, for example, paper. A fixing device **935** fixes the image formed on the print medium.

[0097] Each of FIGS. **13**B and **13**C is a schematic view showing a form in which a plurality of light emitting portions **936** are arranged in the exposure light source **928** on a long substrate. Arrow **937** indicates a direction parallel to the axis of the photosensitive member, which represents a column direction in which light-emitting elements are arrayed. An organic light-emitting element can be used as the light-emitting element. This column direction matches the direction of the axis upon rotating the photosensitive member **927**. This direction can also be referred to as the long-axis direction of the photosensitive member.

[0098] FIG. **13**B shows a form in which the light emitting portions are arranged along the long-axis direction of the photosensitive member. FIG. **13**C shows a form which is different from that shown in FIG. **13**B and in which the light emitting portions are arranged in the column direction alternately between the first column and the second column. The light emitting portions are arranged at different positions in the row direction between the first column and the second column.

[0099] As for the light emitting portions shown in FIG. **13**C, the plurality of light emitting portions are arranged apart from each other in the first column. In the second column, the light emitting portion is arranged at the position corresponding to the space between the light emitting portions in the first column. That is, in the row direction as well, the plurality of light emitting portions are arranged apart from each other. The arrangement shown in FIG. **13**C can be referred to as, for example, an arrangement in a grid pattern, an arrangement in a staggered pattern, or an arrangement in a checkered pattern.

[0100] FIG. **14** is a schematic view showing an example of a display device that can use the light-emitting device according to each of the above-described first and second embodiments. A display device **1000** can include a touch panel **1003**, a display panel **1005**, a frame **1006**, a circuit board **1007**, and a battery **1008** between an upper cover **1001** and a lower cover **1009**. Flexible printed circuits (FPCs) **1002** and **1004** are respectively connected to the touch panel **1003** and the display panel **1005**. Transistors are arranged on the circuit board **1007**. The battery **1008** is unnecessary if the display device is not a portable apparatus. Even when the display device is a portable apparatus, the battery **1008** may be provided at another position.

[0101] The display device according to this embodiment can include color filters of red, green, and blue. The color filters of red, green, and blue can be arranged in a delta array.

[0102] The display device according to this embodiment can also be used for a display unit of a portable terminal. At this time, the display unit can have both a display function and an operation function. Examples of the portable terminal are a portable phone such as a smartphone, a tablet, and a head mounted display.

[0103] The display device according to this embodiment can be used for a display unit of an image capturing device including an optical unit having a plurality of lenses, and an image capturing element for receiving light having passed through the optical unit. The image capturing device can include a display unit for displaying information acquired by the image capturing element. In addition, the display unit can be either a display unit exposed outside the image capturing device, or a display unit arranged in the finder. The image capturing device can be a digital camera or a digital video camera.

[0104] FIG. **15**A is a schematic view showing an example of an image capturing device according to this embodiment. An image capturing device **1100** can include a viewfinder **1101**, a rear display **1102**, an operation unit **1103**, and a housing **1104**. The viewfinder **1101** may include the display device using the light-emitting device according to each of the first and second embodiments. In this case, the display device can display not only an image to be captured but also environment information, image capturing instructions, and the like. Examples of the environment information are the intensity and direction of external light, the moving velocity of an object, and the possibility that an object is covered with an obstacle.

[0105] The timing suitable for image capturing is a very short time, so the information is preferably displayed as soon as possible. Therefore, an organic light-emitting element is preferably used for the light-emitting element. This is so because the organic light-emitting element has a high response speed. The display device using the organic light-emitting element can be used for the devices that require a high display speed more preferably than for the liquid crystal display device.

[0106] The image capturing device **1100** includes an optical unit (not shown). This optical unit has a plurality of lenses, and forms an image on an image capturing element that is accommodated in the housing **1104**. The focal points of the plurality of lenses can be adjusted by adjusting the relative positions. This operation can also automatically be performed. The image capturing device may be called a photoelectric conversion device. Instead of sequentially capturing an image, the photoelectric conversion device can include, as an image capturing method, a method of detecting the difference from a previous image, a method of extracting an image from an always recorded image, or the like.

[0107] FIG. **15**B is a schematic view showing an example of an electronic apparatus according to this embodiment. An electronic apparatus **1200** includes a display unit **1201**, an operation unit **1202**, and a housing **1203**. The housing **1203** can accommodate a circuit, a printed board having this circuit, a battery, and a communication unit. The operation unit **1202** can be a button or a touch-panel-type reaction unit. The operation unit can also be a biometric authentication unit that performs unlocking or the like by authenticating the fingerprint. The electronic apparatus including the communication unit can also be regarded as a communication apparatus. The electronic apparatus can further have a camera function by including a lens and an image capturing element. An image captured by the camera function is displayed on the display unit. Examples of the electronic apparatus are a smartphone and a notebook computer.

[0108] FIGS. **16**A and **16**B are schematic views showing examples of a display device using the light-emitting device according to each of the first and second embodiments. FIG. **16**A shows a display device such as a television monitor or a PC monitor. A display device **1300** includes a frame **1301** and a display unit **1302**. When the light-emitting device according to each of the above-described first and second embodiments is used for the display unit **1302**, deterioration of a displayed image can be suppressed.

[0109] The display device **1300** includes a base **1303** that supports the frame **1301** and the display unit **1302**. The base **1303** is not limited to the form shown in FIG. **16**A. The lower side of the frame **1301** may also function as the base.

[0110] In addition, the frame **1301** and the display unit **1302** can be bent. The radius of curvature in this case can be 5,000 (inclusive) mm to 6,000 (inclusive) mm.

[0111] FIG. **16**B is a schematic view showing another example of the display device. A display device **1310** shown in FIG. **16**B can be folded, that is, the display device **1310** is a so-called foldable display device. The display device **1310** includes a first display unit **1311**, a second display unit **1312**, a housing **1313**, and a bending point **1314**. The first display unit **1311** and the second display unit **1312** may include the light-emitting device according to each of the first and second embodiments. The first display unit **1311** and the second display unit **1312** can also be one seamless display device. The first display unit **1311** and the second display unit **1312** can be divided by the bending point. The first display unit **1311** and the second display unit **1312** can display different images, and can also display one image together.

[0112] FIG. **17**A is a schematic view showing an example of an illumination device using the light-emitting device according to each of the first and second embodiments. An illumination device **1400** may include a housing **1401**, a light source **1402**, a circuit board **1403**, an optical film **1404**, and a light diffusing unit **1405**. The light source may include the light-emitting device according to each of the first and second embodiments. An organic light emitting element is preferably used for the light-emitting element. The optical film **1404** may be a filter that transmits light and improves the color rendering of the light source. When performing lighting-up or the like, the light diffusing unit can throw the light of the light source over a broad range by effectively diffusing the light. The optical film **1404** and the light diffusing unit **1405** may be provided on the illumination light emission side. The illumination device may also include a cover on the outermost portion, as needed.

[0113] The illumination device is, for example, a device for illuminating the interior of the room. The illumination device may emit white light, natural white light, or light of another color from blue to red. The illumination device may include a light control circuit for controlling these light components. The illumination device may include the light-emitting device according to each of the first and second embodiments and a power supply circuit connected thereto. An organic light-emitting element can be used as the light-emitting element of the light-emitting device. The power supply circuit is a circuit for converting an AC voltage into a DC voltage. White has a color temperature of 4,200 K, and natural white has a color temperature of 5,000 K. The illumination device may also include a color filter.

[0114] In addition, the illumination device according to this embodiment may include a heat radiation unit. The heat radiation unit radiates the internal heat of the device to the outside of the device, and examples are a metal having a high specific heat and liquid silicon.

[0115] FIG. **17**B is a schematic view of an automobile as an example of a moving body according to this embodiment, that uses the light-emitting device according to each of the first and second embodiments. The automobile has a taillight as an example of the lighting appliance. An automobile **1500** has a taillight **1501**, and may have a form in which the taillight is turned on when performing a braking operation or the like.

[0116] The taillight **1501** can include the light-emitting device according to each of the first and second embodiments. The taillight may include a protection member for protecting the light-emitting device. The material of the protection member is not limited as long as the material is a transparent material with a strength that is high to some extent, and is preferably, for example, polycarbonate or the like. A furandicarboxylic acid derivative, an acrylonitrile derivative, or the like may be mixed in polycarbonate.

[0117] The automobile **1500** may include a vehicle body **1503**, and a window **1502** attached to the vehicle body **1503**. The window may be a transparent display as long as it is not a window for checking the front or rear of the automobile. This transparent display may include the light-emitting device according to each of the first and second embodiments. In this case, the constituent materials of the electrodes and the like of the light-emitting device are formed from transparent members.

[0118] The moving body according to this embodiment may be a ship, an airplane, a drone, or the like. The moving body may include a main body and a lighting appliance provided on the main body. The lighting appliance may emit light for making a notification of the position of the main body. The lighting appliance includes the light-emitting device according to each of the first and second embodiments.

[0119] An application example of a display device using the light-emitting device according to each of the first and second embodiments will be described with reference to FIGS. **18**A and **18**B. The display device can be applied to a system that can be worn as a wearable device such as smartglasses, an HMD, or a smart contact lens. The display device used for such applications can include an image capturing device capable of photoelectrically converting visible light and a display device capable of emitting visible light.

[0120] Glasses **1600** (smartglasses) according to one application example will be described with reference to FIG. **18**A. An image capturing device **1602** such as a CMOS sensor or an SPAD is provided on the surface side of a lens **1601** of the glasses **1600**. In addition, the display device of each of the above-described embodiments is provided on the back surface side of the lens **1601**.

[0121] The glasses **1600** can further include a control device **1603**. The control device **1603** can function as a power supply that supplies power to the image capturing device **1602** and the display device according to each embodiment. In addition, the control device **1603** can control the operations of the image capturing device **1602** and the display device. An optical system configured to condense light to the image capturing device **1602** is formed on the lens **1601**.

[0122] Glasses **1610** (smartglasses) according to one application example will be described with reference to FIG. **18**B. The glasses **1610** includes a control device **1612**. An image capturing device corresponding to the image capturing device **1602** and a display device are mounted on the control device **1612**. An optical system configured to project light emitted from the display device in the control device **1612** is formed in a lens **1611**, and an image is projected to the lens **1611**. The control device **1612** functions as a power supply that supplies power to the image capturing device and the display device, and controls the operations of the image capturing device and the display device.

[0123] The control device may include a line-of-sight detection unit that detects the line of sight of a wearer. The detection of a line of sight may be done using infrared rays. An infrared ray emitting unit emits infrared rays to an eyeball of the user who is gazing at a displayed image. An image capturing unit including a light receiving element detects reflected light of the emitted infrared rays from the eyeball, thereby obtaining a captured image of the eyeball. A reduction unit for reducing light from the infrared ray emitting unit to the display unit in a planar view is provided, thereby

reducing deterioration of image quality.
[0124] The line of sight of the user to the displayed image is detected from the captured image of the eyeball obtained by capturing the infrared rays. An arbitrary known method can be applied to the line-of-sight detection using the captured image of the eyeball. As an example, a line-of-sight detection method based on a Purkinje image obtained by reflection of irradiation light by a cornea can be used.
[0125] More specifically, line-of-sight detection processing based on pupil corneal reflection method is performed. Using pupil corneal reflection method, a line-of-sight vector representing the direction (rotation angle) of the eyeball is calculated based on the image of the pupil and the Purkinje image included in the captured image of the eyeball, thereby detecting the line-of-sight of the user.
[0126] The display device according to this embodiment can include an image capturing device including a light receiving element, and a displayed image on the display device can be controlled based on the line-of-sight information of the user from the image capturing device.
[0127] More specifically, the display device can decide a first display region at which the user is gazing and a second display region other than the first display region based on the line-of-sight information. The first display region and the second display region may be decided by the control device of the display device, or those decided by an external control device may be received. In the display region of the display device, the display resolution of the first display region may be controlled to be higher than the display resolution of the second display region. That is, the resolution of the second display region may be lower than that of the first display region.
[0128] In addition, the display region includes a first display region and a second display region different from the first display region, and a region of higher priority is decided from the first display region and the second display region based on line-of-sight information. The first display region and the second display region may be decided by the control device of the display device, or those decided by an external control device may be received. The resolution of the region of higher priority may be controlled to be higher than the resolution of the region other than the region of higher priority. That is, the resolution of the region of relatively low priority may be low.
[0129] Note that AI may be used to decide the first display region or the region of higher priority. The AI may be a model configured to estimate the angle of the line of sight and the distance to a target ahead the line of sight from the image of the eyeball using the image of the eyeball and the direction of actual viewing of the eyeball in the image as supervised data. The AI program may be held by the display device, the image capturing device, or an external device. If the external device holds the AI program, it is transmitted to the display device via communication.
[0130] When performing display control based on line-of-sight detection, this can be applied to smartglasses further including an image capturing device configured to capture the outside. The smartglasses can display captured outside information in real time.
[0131] As has been described above, by using the light-emitting device according to the embodiment in an apparatus, display with fine image quality and stable even for a long period of time is possible.
[0132] 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.
[0133] This application claims the benefit of Japanese Patent Application No.2024-021448 filed Feb. 15, 2024, which is hereby incorporated by reference herein in their entirety.

Claims

1. A light-emitting device in which a plurality of pixels are arranged in a matrix in a semiconductor substrate, wherein each of the plurality of pixels includes a light-emitting element, a driving transistor configured to supply a current to the light-emitting element, and a switching transistor configured to control the light-emitting element, and a gate electrode of the switching transistor is provided on at least two faces of four faces surrounding a cross section of a region to be a channel.
2. The device according to claim 1, wherein a part of the gate electrode is provided in a groove of the semiconductor substrate, and a depth of the groove is larger than twice a thickness of a gate insulating film.
3. The device according to claim 2, wherein the depth of the groove is shallower than a depth of an element insulation portion.
4. The device according to claim 2, wherein a width of the groove is not more than twice a thickness of the gate electrode on a surface of the semiconductor substrate.
5. The device according to claim 1, wherein the gate electrode includes two faces facing with respect to the region to be the channel, and one face between the two faces.
6. The device according to claim 1, wherein the gate electrode of the switching transistor has an inverted U-shape with respect to a bottom surface of the semiconductor substrate in a cross section perpendicular to a direction of a current flowing through the channel.
7. The device according to claim 1, wherein one of a source and a drain of the switching transistor is connected to a connection portion between a first main terminal of the light-emitting element and one of a source and a drain of the driving transistor, and the other of the source and the drain of the switching transistor is connected to a predetermined potential.
8. The device according to claim 7, wherein a region functioning as one of the source and the drain of the switching transistor and a region functioning as one of the source and the drain of the driving transistor share a diffusion region of the semiconductor substrate.
9. The device according to claim 1, wherein a gate electrode of the driving transistor has a planar structure.
10. The device according to claim 1, wherein the driving transistor has an LDD structure.
11. The device according to claim 1, wherein at least one of the driving transistor and the switching transistor includes a silicide in a region where at least one of a source and a drain is arranged.
12. An image forming device comprising a photosensitive member, an exposure light source configured to expose the photosensitive member, a developing device configured to apply a developing agent to the exposed photosensitive member, and a transfer device configured to transfer an image developed by the developing device to a print medium, wherein the exposure light source includes a light-emitting device defined in claim 1.
13. An image capturing device comprising an optical unit including a plurality of lenses, an image capturing element configured to receive light having passed through the optical unit, and a display unit configured to display an image captured by the image capturing element, wherein the display unit includes a light-emitting device defined in claim
1.
14. A display device comprising a display unit including a light-emitting device defined in claim 1, and a housing provided with the display unit.
15. An electronic apparatus comprising a display unit including a light-emitting device defined in claim 1, a housing provided with the display unit, and a communication unit provided in the housing and configured to perform external communication.
16. An illumination device comprising a light source including a light-emitting device defined in claim 1, and one of a light diffusing unit and an optical film configured to transmit light emitted by the light source.
17. A mobile body comprising a lighting appliance including a light-emitting device defined in claim 1, and a body provided with the lighting appliance.

18. A wearable device including a display device configured to display an image, wherein the display device includes a light-emitting device defined in claim 1.