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(54) Title: SEMICONDUCTOR DEVICE

**FIG. 1B**

(57) Abstract: An object is to stabilize electric characteristics of a semiconductor device including an oxide semiconductor to increase reliability. The semiconductor device includes an insulating film; a first metal oxide film on and in contact with the insulating film; an oxide semiconductor film partly in contact with the first metal oxide film; source and drain electrodes electrically connected to the oxide semiconductor film; a second metal oxide film partly in contact with the oxide semiconductor film; a gate insulating film on and in contact with the second metal oxide film; and a gate electrode over the gate insulating film.

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## DESCRIPTION

## SEMICONDUCTOR DEVICE

## 5 TECHNICAL FIELD

[0001]

The present invention relates to a semiconductor device and a manufacturing method thereof.

[0002]

10 In this specification, a semiconductor device means a general device which can function by utilizing semiconductor characteristics, and an electrooptic device, a semiconductor circuit, and an electronic device are all semiconductor devices.

## BACKGROUND ART

15 [0003]

A technique by which transistors are formed using semiconductor thin films formed over a substrate having an insulating surface has been attracting attention. Such transistors are applied to a wide range of electronic devices such as an integrated circuit (IC) and an image display device (display device). As semiconductor thin films applicable to the transistors, silicon-based semiconductor materials have been widely used, but oxide semiconductors have been attracting attention as alternative materials.

[0004]

20 For example, disclosed is a transistor whose active layer is formed using an amorphous oxide containing indium (In), gallium (Ga), and zinc (Zn) and having an electron carrier concentration of lower than  $10^{18} / \text{cm}^3$  (see Patent Document 1).

[0005]

25 A transistor including an oxide semiconductor is known to have a problem of low reliability because of high possibility of change in electric characteristics, although the transistor including an oxide semiconductor can be operated at higher speed than a transistor including amorphous silicon and can be manufactured more easily than a transistor including polycrystalline silicon. For example, the threshold voltage of the transistor fluctuates after a BT test performed under light. On the other hand, Patent

Documents 2 and 3 each disclose a technique of preventing charge trapping at the interface of an oxide semiconductor layer with the use of an interfacial stability layer, which is provided on at least one of the top surface and the bottom surface of the oxide semiconductor layer, in order to suppress the shift of the threshold voltage of the 5 transistor including an oxide semiconductor.

[Reference]

[0006]

[Patent Document 1] Japanese Published Patent Application No. 2006-165528

[Patent Document 2] Japanese Published Patent Application No. 2010-016347

10 [Patent Document 3] Japanese Published Patent Application No. 2010-016348

## DISCLOSURE OF INVENTION

[0007]

The transistor disclosed in Patent Document 2 or 3, however, includes as the 15 interfacial stability layer a layer having a property similar to those of a gate insulating layer and a protective layer, so that the state of the interface with an active layer cannot be kept favorably. This is why it is difficult to suppress charge trapping at the interface between the active layer and the interfacial stability layer. In particular, in the case where the interfacial stability layer and the active layer have equivalent band gaps, 20 charge is likely to be stored.

[0008]

Thus, a transistor including an oxide semiconductor cannot yet be said to have sufficiently high reliability.

[0009]

25 In view of the above problems, an object is to stabilize electric characteristics of a semiconductor device including an oxide semiconductor to increase reliability.

[0010]

One embodiment of the disclosed invention is based on the following technical 30 idea: an oxide semiconductor film as an active layer is not directly in contact with an insulating film such as a gate insulating film or a protective insulating film, and a metal oxide film is provided between and in contact with these films and contains a constituent similar to that of the oxide semiconductor film. In other words, one

embodiment of the disclosed invention includes a layered structure of an oxide semiconductor film, a metal oxide film, and an insulating film containing a different constituent from the oxide semiconductor film and the metal oxide film. Here, containing "a constituent similar to that of the oxide semiconductor film" means 5 containing one or more of metal elements selected from constituents of the oxide semiconductor film.

[0011]

Such a layered structure makes it possible to sufficiently suppress trapping of charge or the like, which is generated due to the operation of a semiconductor device, or 10 the like, at the interface of the insulating film and the oxide semiconductor film. This advantageous effect is brought by the following mechanism: the metal oxide film containing a material compatible with the oxide semiconductor film is provided in contact with the oxide semiconductor film, whereby suppressed is trapping of charge or the like, which can be generated due to the operation of a semiconductor device, at the 15 interface between the oxide semiconductor film and the metal oxide film. Meanwhile, the insulating film containing a material with which a charge trapping center can be formed at the interface is provided in contact with the metal oxide film, whereby the charge can be trapped at the interface between the metal oxide film and the insulating film.

20 [0012]

That is to say, in the case where a large amount of charge is generated, it is difficult to suppress trapping of charge at the interface between the oxide semiconductor film and the metal oxide film, only with the metal oxide film; however, when the insulating film is provided in contact with the metal oxide film, charge is trapped 25 preferentially at the interface between the metal oxide film and the insulating film, so that trapping of charge at the interface between the oxide semiconductor film and the metal oxide film can be suppressed. Thus, it can be said that the advantageous effect of one embodiment of the disclosed invention is attributed to the layered structure of the oxide semiconductor film, the metal oxide film, and the insulating film and is different 30 from an effect due to a layered structure of an oxide semiconductor film and a metal oxide film.

[0013]

Since trapping of charge at the interface of the oxide semiconductor film can be suppressed and a charge trapping center can be kept away from the oxide semiconductor film, operation malfunctions of the semiconductor device can be reduced to increase reliability of the semiconductor device.

5 [0014]

In the above mechanism, the metal oxide film desirably has an enough thickness. This is because the influence of charge trapped at the interface between the metal oxide film and the insulating film may be great when the metal oxide film is thin. For example, the metal oxide film is preferably thicker than the oxide semiconductor 10 film.

[0015]

The metal oxide film having an insulating property is formed so as not to hinder connection between the oxide semiconductor film and source and drain electrodes, so that resistance can be prevented from being increased as compared to the 15 case where a metal oxide film is provided between an oxide semiconductor film and a source electrode or a drain electrode. Thus, it is possible to suppress deterioration of electric characteristics of the transistor.

[0016]

When the composition of an oxide semiconductor differs from the 20 stoichiometric composition because of an excess or a deficiency of oxygen, or hydrogen or moisture which serves as an electron donor enters the oxide semiconductor in a thin film formation process, the conductivity of the oxide semiconductor is changed. Such a phenomenon is a factor of a change in electric characteristics of the transistor including such an oxide semiconductor. Therefore, an oxide semiconductor film is 25 highly purified to be electrically i-type (intrinsic) by intentionally removing impurities such as hydrogen, moisture, a hydroxyl group, and hydride (also referred to as a hydrogen compound) from the oxide semiconductor and supplying oxygen which is a major constituent of the oxide semiconductor and is simultaneously reduced in a step of removing impurities.

30 [0017]

An i-type (intrinsic) oxide semiconductor is an oxide semiconductor highly purified to be i-type (intrinsic) or substantially i-type (intrinsic) by removing hydrogen,

which is an n-type impurity, from the oxide semiconductor so that impurities that are not main components of the oxide semiconductor are contained as little as possible.

[0018]

Note that in the process of making an oxide semiconductor film intrinsic, a metal oxide film containing a constituent similar to that of the oxide semiconductor film may also be made intrinsic at the same time. According to one embodiment of the disclosed invention, metal oxide films provided on a top surface and a bottom surface of an oxide semiconductor film are desirably made electrically intrinsic by sufficiently reducing impurities such as moisture and hydrogen.

10 [0019]

The electric characteristics of a transistor including a highly-purified oxide semiconductor film, such as the threshold voltage and an off-state current, have almost no temperature dependence. Further, transistor characteristics are less likely to change due to light deterioration.

15 [0020]

One embodiment of the disclosed invention is a semiconductor device including an insulating film; a first metal oxide film on and in contact with the insulating film; an oxide semiconductor film partly in contact with the first metal oxide film; source and drain electrodes electrically connected to the oxide semiconductor film; a second metal oxide film partly in contact with the oxide semiconductor film; a gate insulating film on and in contact with the second metal oxide film; and a gate electrode over the gate insulating film.

[0021]

In the above, the first metal oxide film and the second metal oxide film may each contain a constituent element of the oxide semiconductor film. Further, the first metal oxide film and the second metal oxide film may each have a larger energy gap than the oxide semiconductor film. Energy at the bottom of the conduction band of each of the first metal oxide film and the second metal oxide film may be higher than that of the oxide semiconductor film.

30 [0022]

In the above, the first metal oxide film and the second metal oxide film may each contain a gallium oxide. The proportion of a constituent element of the first

metal oxide film may be equal to that of the second metal oxide film. The insulating film may contain a silicon oxide. The gate insulating film may contain a silicon oxide or a hafnium oxide.

[0023]

5 In the above, the second metal oxide film may be provided so as to cover the source and drain electrodes and contact the first metal oxide film. The oxide semiconductor film may be surrounded by the first metal oxide film and the second metal oxide film.

[0024]

10 In the above, side edges of the oxide semiconductor film in a channel length direction may be aligned with those of the first metal oxide film. Further, side edges of the oxide semiconductor film in a channel length direction may be aligned with those of the second metal oxide film.

[0025]

15 In the above, a second insulating film may be provided so as to cover the gate insulating film and the gate electrode. A conductive film may be provided below the oxide semiconductor film.

[0026]

20 In the above, the channel length  $L$  of the transistor, which depends on the distance between the source electrode and the drain electrode, can be longer than or equal to 10 nm and shorter than or equal to 10  $\mu\text{m}$ , for example, 0.1  $\mu\text{m}$  to 0.5  $\mu\text{m}$ . It is needless to say that the channel length  $L$  may be longer than or equal to 1  $\mu\text{m}$ . The channel width  $W$  may be longer than or equal to 10 nm.

[0027]

25 According to one embodiment of the present invention, a transistor having stable electric characteristics is provided.

[0028]

30 According to one embodiment of the present invention, a semiconductor device including a highly reliable transistor having favorable electric characteristics is provided.

## BRIEF DESCRIPTION OF DRAWINGS

[0029]

In the accompanying drawings:

FIGS. 1A to 1C are a plan view and cross-sectional views illustrating an embodiment of a semiconductor device;

FIG. 2 is a band diagram of a transistor including an oxide semiconductor film and a metal oxide film;

FIGS. 3A to 3G are cross-sectional views each illustrating an embodiment of a semiconductor device;

FIGS. 4A to 4E are cross-sectional views illustrating an example of a manufacturing process of the semiconductor device;

FIGS. 5A to 5E are cross-sectional views illustrating an example of a manufacturing process of the semiconductor device;

FIGS. 6A to 6C are views each illustrating an embodiment of a semiconductor device;

FIG. 7 is a cross-sectional view illustrating an embodiment of a semiconductor device;

FIG. 8 is a cross-sectional view illustrating an embodiment of a semiconductor device;

FIG. 9 is a cross-sectional view illustrating an embodiment of a semiconductor device; and

FIGS. 10A to 10F are views illustrating electronic devices.

## BEST MODE FOR CARRYING OUT THE INVENTION

[0030]

Hereinafter, embodiments of the present invention will be described in detail with reference to the drawings. Note that the present invention is not limited to the following description, and it will be easily understood by those skilled in the art that modes and details disclosed herein can be modified in various ways without departing from the spirit and the scope of the present invention. Thus, the present invention should not be construed as being limited to the following description of the embodiments.

## [0031]

Note that the ordinal numbers such as "first" and "second" in this specification are used for convenience and do not denote the order of steps or the stacking order of layers. In addition, the ordinal numbers in this specification do not denote particular names which specify the present invention.

## [0032]

(Embodiment 1)

In this embodiment, an embodiment of a semiconductor device and a manufacturing method thereof will be described with reference to FIGS. 1A to 1C, FIG. 10 2, FIGS. 3A to 3G, FIGS. 4A to 4E, and FIGS. 5A to 5E.

## [0033]

<Structural Example of Semiconductor Device>

FIGS. 1A to 1C are a plan view and cross-sectional views of a transistor 110 as an example of a semiconductor device according to an embodiment of the disclosed invention. Here, FIG. 1A is a plan view, FIG. 1B is a cross-sectional view along A-B of FIG. 1A, and FIG. 1C is a cross-sectional view along C-D of FIG. 1A. Note that part of components of the transistor 110 (e.g., a second metal oxide film 210) is omitted for brevity.

## [0034]

20 The transistor 110 in FIGS. 1A to 1C includes, over a substrate 200, an insulating film 202, a first metal oxide film 204, an oxide semiconductor film 206, a source electrode 208a, a drain electrode 208b, a second metal oxide film 210, a gate insulating film 212, and a gate electrode 214.

## [0035]

25 In the transistor in FIGS. 1A to 1C, the second metal oxide film 210 is formed so as to contact part of the first metal oxide film 204 and cover the source electrode 208a and the drain electrode 208b. In addition, in FIGS. 1A to 1C, the first metal oxide film 204 and the second metal oxide film 210 are in contact with each other in a region where the oxide semiconductor film 206 does not exist. In other words, the 30 oxide semiconductor film 206 is surrounded by the first metal oxide film 204 and the second metal oxide film 210.

## [0036]

Here, it is desirable to use an oxide containing a constituent similar to that of the oxide semiconductor film 206 for the first metal oxide film 204 and the second metal oxide film 210. Specifically, the first metal oxide film 204 and the second metal oxide film 210 are each a film containing an oxide containing one or more of metal elements selected from constituent elements of the oxide semiconductor film. Such a material is compatible with the oxide semiconductor film 206; thus, when it is used for the first metal oxide film 204 and the second metal oxide film 210, the state of the interface between the oxide semiconductor film and each of the first metal oxide film 204 and the second metal oxide film 210 can be kept favorably. That is to say, the use of the above material for the first metal oxide film 204 and the second metal oxide film 210 makes it possible to suppress trapping of charge at the interface between the oxide semiconductor film and the metal oxide film in contact with the oxide semiconductor film (here, the interface between the first metal oxide film 204 and the oxide semiconductor film 206 and the interface between the second metal oxide film 210 and the oxide semiconductor film 206).

[0037]

Note that the first metal oxide film 204 and the second metal oxide film 210 are each a film containing a constituent similar to that of the oxide semiconductor film. Therefore, in the case where the first metal oxide film 204 and the second metal oxide film 210 are in contact with each other in a region where the oxide semiconductor film 206 does not exist, the adhesion between the first metal oxide film 204 and the second metal oxide film 210 can be improved. Further, it is more desirable that the proportion of constituent elements of the first metal oxide film 204 be equal to that of the second metal oxide film 210.

[0038]

The first metal oxide film 204 and the second metal oxide film 210 each need to have a larger energy gap than the oxide semiconductor film 206 because the oxide semiconductor film 206 is used as an active layer. In addition, it is necessary that an energy barrier be formed between the first metal oxide film 204 and the oxide semiconductor film 206 or between the second metal oxide film 210 and the oxide semiconductor film 206 so that carriers do not flow from the oxide semiconductor film 206 at room temperature (20 °C). For example, the energy difference between the

bottom of the conduction band of the oxide semiconductor film 206 and the bottom of the conduction band of the first metal oxide film 204 or the second metal oxide film 210 or the energy difference between the top of the valence band of the oxide semiconductor film 206 and the top of the valence band of the first metal oxide film 204 or the second metal oxide film 210 is desirably 0.5 eV or more, more desirably 0.7 eV or more. In addition, the energy difference therebetween is desirably 1.5 eV or less.

[0039]

Specifically, for example, in the case where an In-Ga-Zn-O-based material is used for the oxide semiconductor film 206, the first metal oxide film 204 and the second metal oxide film 210 may be formed using a material containing gallium oxide, or the like. In the case where the gallium oxide is in contact with the In-Ga-Zn-O-based material, the energy barrier is about 0.8 eV on the conduction band side and about 0.9 eV on the valence band side.

[0040]

Note that a gallium oxide is also referred to as  $\text{GaO}_x$  and the value of  $x$  is preferably set so that the oxygen amount exceeds the stoichiometric proportion. For example, the value of  $x$  is preferably set to larger than or equal to 1.4 and smaller than or equal to 2.0, more preferably larger than or equal to 1.5 and smaller than or equal to 1.8. Note that a gallium oxide film may contain an impurity element other than hydrogen, e.g., an element belonging to Group 3 such as yttrium, an element belonging to Group 4 such as hafnium, an element belonging to Group 13 such as aluminum, an element belonging to Group 14 such as silicon, or nitrogen so that the energy gap of the gallium oxide is increased to improve the insulating property. The energy gap of a gallium oxide film which does not contain an impurity is 4.9 eV; however, when the gallium oxide film contains any of the above impurities at about greater than 0 atomic% and less than or equal to 20 atomic%, the energy gap can be increased to about 6 eV.

[0041]

Considering that charge sources and charge trapping centers should be reduced, it is desirable to sufficiently reduce impurities such as hydrogen and water in the metal oxide film. This idea is similar to the idea of reduction of impurities in an oxide semiconductor film.

## [0042]

It is desirable to use a material with which a charge trapping center can be formed at the interface with the first metal oxide film 204 or the second metal oxide film 210 when the material is in contact with the first metal oxide film 204 or the second metal oxide film 210, for the insulating film 202 or the gate insulating film 212. By using such a material for the insulating film 202 or the gate insulating film 212, charge is trapped at the interface between the insulating film 202 and the first metal oxide film 204 or the interface between the gate insulating film 212 and the second metal oxide film 210, so that it is possible to sufficiently suppress trapping of charge at the interface between the first metal oxide film 204 and the oxide semiconductor film 206 or the interface between the second metal oxide film 210 and the oxide semiconductor film 206. Note that in the case where many charge trapping centers are formed at the interface between the gate insulating film 212 and the second metal oxide film 210, transistor characteristics might possibly get worse; thus, it is favorable that charge trapping centers be slightly more likely to be formed at the interface between the gate insulating film 212 and the second metal oxide film 210 than at the interface between the oxide semiconductor film 206 and the second metal oxide film 210.

## [0043]

Specifically, the insulating film 202 and the gate insulating film 212 may each be formed using a silicon oxide, a silicon nitride, an aluminum oxide, an aluminum nitride, a mixed material of any of them, or the like. For example, in the case where a material containing a gallium oxide is used for the first metal oxide film 204 and the second metal oxide film 210, a silicon oxide, a silicon nitride, or the like is preferably used for the insulating film 202 and the gate insulating film 212. In addition, the energy gaps of the insulating film 202 and the gate insulating film 212 are desirably larger than those of the first metal oxide film 204 and the second metal oxide film 210, respectively, because the insulating film 202 and the gate insulating film 212 are in contact with the first metal oxide film 204 and the second metal oxide film 210, respectively.

## [0044]

Note that it is not necessary to limit the material of each of the insulating film 202 and the gate insulating film 212 to the above as long as a charge trapping center can

be formed at the interface between the insulating film 202 and the first metal oxide film 204 or the interface between the gate insulating film 212 and the second metal oxide film 210. Further, treatment through which a charge trapping center is formed may be performed on the interface between the insulating film 202 and the first metal oxide film 204 or the interface between the gate insulating film 212 and the second metal oxide film 210. As such treatment, plasma treatment and treatment for adding an element (ion implantation or the like) are given, for example.

[0045]

A second insulating film may further be formed over the transistor 110. Further, openings may be formed in the insulating film 202, the first metal oxide film 204, the second metal oxide film 210, the gate insulating film 212, and the like in order that the source electrode 208a and the drain electrode 208b may be electrically connected to a wiring. A second gate electrode may further be provided below the oxide semiconductor film 206. Note that it is not always necessary but desirable to process the oxide semiconductor film 206 into an island shape.

[0046]

FIG. 2 is an energy band diagram (schematic diagram) of the transistor 110, that is, an energy band diagram of the structure where the insulating film, the metal oxide film, the oxide semiconductor film, the metal oxide film, and the insulating film are bonded to each other from the gate electrode GE side, and  $E_F$  denotes the Fermi level of the oxide semiconductor film. FIG. 2 shows the case where a silicon oxide ( $SiO_x$ ) (with a band gap  $Eg$  of 8 eV to 9 eV), a gallium oxide ( $GaO_x$ ) (with a band gap  $Eg$  of 4.9 eV), and an In-Ga-Zn-O-based non-single-crystal film (with a band gap  $Eg$  of 3.15 eV) are used as the insulating film, the metal oxide film, and the oxide semiconductor (OS) film, respectively, on the assumption of the ideal state where the insulating films, the metal oxide films, and the oxide semiconductor film are all intrinsic. Note that the energy difference between the vacuum level and the bottom of the conduction band of the silicon oxide is 0.95 eV, the energy difference between the vacuum level and the bottom of the conduction band of the gallium oxide is 3.5 eV, and the energy difference between the vacuum level and the bottom of the conduction band of the In-Ga-Zn-O-based non-single-crystal film is 4.3 eV.

[0047]

As shown in FIG. 2, on the gate electrode side (the channel side) of the oxide semiconductor film, energy barriers of about 0.8 eV and about 0.95 eV exist at the interface between the oxide semiconductor and the metal oxide. On the back channel side (the side opposite to the gate electrode) of the oxide semiconductor film, similarly, 5 energy barriers of about 0.8 eV and about 0.95 eV exist at the interface between the oxide semiconductor and the metal oxide. When such energy barriers exist at the interface between the oxide semiconductor and the metal oxide, transport of carriers at the interface can be prevented; thus, the carriers travel through the oxide semiconductor and do not travel from the oxide semiconductor to the metal oxide. As shown in FIG. 10 2, these beneficial results may be obtained when the oxide semiconductor film, the metal oxide layers, and the insulating layers are arranged such that the oxide semiconductor film is sandwiched between materials having progressively larger band gaps (i.e., the band gaps of the insulating layers are larger than the band gaps of the metal oxide layers) that are each larger than the band gap of the oxide semiconductor.

15

[0048]

FIGS. 3A to 3G illustrate cross-sectional structures of transistors having different structures from that of the transistor 110. In FIGS. 3A to 3G, top-gate transistors are illustrated as transistors according to one embodiment of the disclosed 20 invention.

[0049]

A transistor 120 in FIG. 3A is the same as the transistor 110 in that it includes the insulating film 202, the first metal oxide film 204, the oxide semiconductor film 206, the source electrode 208a, the drain electrode 208b, the second metal oxide film 210, 25 the gate insulating film 212, and the gate electrode 214. The differences between the transistor 120 and the transistor 110 are the positions where the oxide semiconductor film 206 is connected to the source electrode 208a and the drain electrode 208b. That is, the source electrode 208a and the drain electrode 208b are in contact with bottom portions of the oxide semiconductor film 206 in the transistor 120. The other 30 components are the same as those of the transistor 110 in FIGS. 1A to 1C; thus, the description on FIGS. 1A to 1C can be referred to for the details.

[0050]

A transistor 130 in FIG. 3B is the same as the transistor 120 in FIG. 3A in that it includes the above components. The transistor 130 is different from the transistor 120 in that the insulating film 202 has a convex shape, and the oxide semiconductor film 206 is not completely covered with the first metal oxide film 204 and the second metal oxide film 210. The other components are the same as those in FIG. 3A.

5 [0051]

A transistor 140 in FIG. 3C is the same as the transistor 130 in FIG. 3B in that it includes the above components. The transistor 140 is different from the transistor 130 in that the insulating film 202 is flat, and the first metal oxide film 204 has a convex shape. Note that the insulating film 202 is not necessarily provided when the substrate 200 has a function of the insulating film 202. The other components are the same as those in FIG. 3B.

10 [0052]

A transistor 150 in FIG. 3D, a transistor 160 in FIG. 3E, a transistor 170 in FIG. 15 3F, and a transistor 180 in FIG. 3G are the same as the transistor 110 in FIGS. 1A to 1C, the transistor 120 in FIG. 3A, the transistor 130 in FIG. 3B, and the transistor 140 in FIG. 3C, respectively, in that they include the above components. The transistors 150, 160, 170, and 180 are different from the transistors 110, 120, 130, 140 in that the first metal oxide film 204 or the second metal oxide film 210 is processed to have an island shape.

20 The other components are the same as those in FIGS. 1A to 1C and FIGS. 3A to 3C.

[0053]

<Example of Manufacturing Process of Transistor>

Examples of a manufacturing process of the transistor in FIGS. 1A to 1C and a manufacturing process of the transistor in FIG. 3A will be described below with 25 reference to FIGS. 4A to 4E and FIGS. 5A to 5E.

[0054]

<Manufacturing Process of Transistor 110>

An example of a manufacturing process of the transistor 110 in FIGS. 1A to 1C will be described with reference to FIGS. 4A to 4E. A manufacturing process of the 30 transistor 150 in FIG. 3D is the same as that of the transistor 110 except that the first metal oxide film 204 and the like are processed in accordance with the shape of the

oxide semiconductor film 206.

[0055]

First, the insulating film 202 is formed over the substrate 200, and then, the first metal oxide film 204 is formed on and in contact with the insulating film 202 (see 5 FIG. 4A).

[0056]

There is no particular limitation on the property of a material and the like of the substrate 200 as long as the material has heat resistance high enough to withstand at least heat treatment performed later. For example, a glass substrate, a ceramic 10 substrate, a quartz substrate, or a sapphire substrate can be used as the substrate 200. Alternatively, a single crystal semiconductor substrate or a polycrystalline semiconductor substrate made of silicon, silicon carbide, or the like, a compound 15 semiconductor substrate made of silicon germanium or the like, an SOI substrate, or the like may be used as the substrate 200. Still alternatively, any of these substrates further provided with a semiconductor element may be used as the substrate 200.

[0057]

A flexible substrate may alternatively be used as the substrate 200. When a transistor is provided over the flexible substrate, the transistor may be formed directly on the flexible substrate, or the transistor may be formed over a different substrate and 20 then separated to be transferred to the flexible substrate. In order to separate the transistor to transfer it to the flexible substrate, a separation layer is preferably formed between the different substrate and the transistor.

[0058]

It is desirable to use a material with which a charge trapping center can be 25 formed at the interface with the first metal oxide film 204 when the material is in contact with the first metal oxide film 204, for the insulating film 202. By using such a material for the insulating film 202, charge is trapped at the interface between the insulating film 202 and the first metal oxide film 204, so that it is possible to sufficiently suppress trapping of charge at the interface between the first metal oxide 30 film 204 and the oxide semiconductor film 206.

[0059]

Specifically, the insulating film 202 may be formed using a silicon oxide, a

silicon nitride, an aluminum oxide, an aluminum nitride, a mixed material of any of them, or the like. For example, in the case where a material containing a gallium oxide is used for the first metal oxide film 204, a silicon oxide, a silicon nitride, or the like is preferably used for the insulating film 202. In addition, the energy gap of the 5 insulating film 202 is desirably larger than that of the first metal oxide film 204 because the insulating film 202 is in contact with the first metal oxide film 204.

[0060]

Note that it is not necessary to limit the material of the insulating film 202 to the above as long as a charge trapping center can be formed at the interface between the 10 insulating film 202 and the first metal oxide film 204. Further, treatment through which a charge trapping center is formed may be performed on the interface between the insulating film 202 and the first metal oxide film 204. As such treatment, plasma treatment and treatment for adding an element (ion implantation or the like) are given, for example.

15 [0061]

There is no particular limitation on the method for forming the insulating film 202, and for example, the insulating film 202 may be formed by a deposition method such as a plasma CVD method or a sputtering method. The insulating film 202 may have a single-layer structure or a layered structure using an insulating film including 20 any of the above materials.

[0062]

In the case where a substrate including any of the above insulating materials is used as the substrate 200, the substrate 200 can be handled as the insulating film 202. In other words, the insulating film 202 mentioned here may be omitted. In that case, it 25 is more desirable to use a silicon oxide or the like for the substrate 200.

[0063]

Here, it is desirable to use an oxide containing a constituent similar to that of the oxide semiconductor film 206 for the first metal oxide film 204. This is because such a material is compatible with the oxide semiconductor film 206 and thus, when it 30 is used for the first metal oxide film 204, the state of the interface with the oxide semiconductor film can be kept favorably. That is to say, the use of the above material for the first metal oxide film 204 makes it possible to suppress trapping of charge at the

interface between the oxide semiconductor film and the metal oxide film in contact with the oxide semiconductor film (here, the interface between the first metal oxide film 204 and the oxide semiconductor film 206).

[0064]

5 The first metal oxide film 204 needs to have a larger energy gap than the oxide semiconductor film 206 because the oxide semiconductor film 206 is used as an active layer. In addition, it is necessary that an energy barrier be formed between the first metal oxide film 204 and the oxide semiconductor film 206 so that carriers do not flow from the oxide semiconductor film 206 at room temperature (20 °C). For example, the  
10 energy difference between the bottom of the conduction band of the first metal oxide film 204 and the bottom of the conduction band of the oxide semiconductor film 206 or the energy difference between the top of the valence band of the first metal oxide film 204 and the top of the valence band of the oxide semiconductor film 206 is desirably 0.5 eV or more, more desirably 0.7 eV or more. In addition, the energy difference  
15 therebetween is desirably 1.5 eV or less.

[0065]

Considering that charge sources and charge trapping centers should be reduced, it is desirable to sufficiently reduce impurities such as hydrogen and water in the metal oxide film. This idea is similar to the idea of reduction of impurities in an oxide  
20 semiconductor film.

[0066]

There is no particular limitation on the method for forming the first metal oxide film 204. For example, the first metal oxide film 204 may be formed by a deposition method such as a plasma CVD method or a sputtering method. A sputtering method or  
25 the like is appropriate in terms of low possibility of entry of hydrogen, water, and the like. On the other hand, a plasma CVD method or the like is appropriate in terms of an advantage of improving film quality.

[0067]

Next, an oxide semiconductor film is formed over the first metal oxide film  
30 204 and then is processed to form the oxide semiconductor film 206 having an island shape (see FIG. 4B).

[0068]

The oxide semiconductor film is desirably formed by a method by which hydrogen, water, and the like do not easily enter the film, such as a sputtering method. The thickness of the oxide semiconductor film is desirably larger than or equal to 3 nm and smaller than or equal to 30 nm. This is because the transistor might possibly be normally on when the oxide semiconductor film is too thick (e.g., the thickness is 50 nm or more). Note that the insulating film 202, the first metal oxide film 204, and the oxide semiconductor film are preferably formed successively without being exposed to the air.

[0069]

As a material used for the oxide semiconductor film, any of the following materials can be used: a four-component metal oxide such as an In-Sn-Ga-Zn-O-based material; three-component metal oxides such as an In-Ga-Zn-O-based material, an In-Sn-Zn-O-based material, an In-Al-Zn-O-based material, a Sn-Ga-Zn-O-based material, an Al-Ga-Zn-O-based material, and a Sn-Al-Zn-O-based material; two-component metal oxides such as an In-Zn-O-based material, a Sn-Zn-O-based material, an Al-Zn-O-based material, a Zn-Mg-O-based material, a Sn-Mg-O-based material, an In-Mg-O-based material, and an In-Ga-O-based material; and single-component metal oxides such as an In-O-based material, a Sn-O-based material, and a Zn-O-based material. In addition, the above materials may contain  $\text{SiO}_2$ . Here, for example, an In-Ga-Zn-O-based material means an oxide film containing indium (In), gallium (Ga), and zinc (Zn), and there is no particular limitation on the composition ratio. Further, the In-Ga-Zn-O-based material may contain an element other than In, Ga, and Zn.

[0070]

The oxide semiconductor film may be a thin film formed using a material expressed by the chemical formula,  $\text{InMO}_3(\text{ZnO})_m$  ( $m > 0$ ). Here,  $M$  represents one or more metal elements selected from Ga, Al, Mn, and Co. For example,  $M$  may be Ga, Ga and Al, Ga and Mn, Ga and Co, or the like.

[0071]

In this embodiment, the oxide semiconductor film is formed by a sputtering method using an In-Ga-Zn-O-based oxide semiconductor deposition target.

[0072]

As the target used when an In-Ga-Zn-O-based material is used as the oxide semiconductor, for example, an oxide semiconductor deposition target with the following composition ratio may be used: the composition ratio of  $\text{In}_2\text{O}_3:\text{Ga}_2\text{O}_3:\text{ZnO}$  is 1:1:1 [molar ratio]. Note that it is not necessary to limit the material and the 5 composition ratio of the target to the above. For example, an oxide semiconductor deposition target with the following composition ratio may alternatively be used: the composition ratio of  $\text{In}_2\text{O}_3:\text{Ga}_2\text{O}_3:\text{ZnO}$  is 1:1:2 [molar ratio].

[0073]

In the case where an In-Zn-O-based material is used for the oxide 10 semiconductor, a target with the following composition ratio is used: the composition ratio of In: Zn is 50:1 to 1:2 in an atomic ratio ( $\text{In}_2\text{O}_3 : \text{ZnO} = 25:1$  to 1:4 in a molar ratio), preferably 20:1 to 1:1 in an atomic ratio ( $\text{In}_2\text{O}_3 : \text{ZnO} = 10:1$  to 1:2 in a molar ratio), more preferably 15:1 to 1.5:1 in an atomic ratio ( $\text{In}_2\text{O}_3 : \text{ZnO} = 15:2$  to 3:4 in a molar ratio). For example, a target used for the formation of an In-Zn-O-based oxide 15 semiconductor has the following atomic ratio: the atomic ratio of In : Zn : O is  $X : Y : Z$ , where  $Z > 1.5X + Y$ .

[0074]

The fill rate of the oxide target is higher than or equal to 90 % and lower than or equal to 100 %, preferably, higher than or equal to 95 % and lower than or equal to 20 99.9 %. With the use of the oxide semiconductor deposition target with high fill rate, a dense oxide semiconductor film can be formed.

[0075]

The deposition atmosphere may be a rare gas (typically argon) atmosphere, an oxygen atmosphere, or a mixed atmosphere containing a rare gas and oxygen. 25 Moreover, it is desirably an atmosphere using a high-purity gas in which impurities such as hydrogen, water, a hydroxyl group, and hydride are removed because entry of hydrogen, water, a hydroxyl group, and hydride into the oxide semiconductor film can be prevented.

[0076]

30 For example, the oxide semiconductor film can be formed as follows.

[0077]

First, the substrate 200 is placed in a deposition chamber kept under reduced pressure, and the substrate temperature is set to higher than or equal to 100 °C and lower than or equal to 600 °C, preferably higher than or equal to 200 °C and lower than or equal to 400 °C. This is because the concentration of an impurity contained in the 5 oxide semiconductor film can be reduced when deposition is performed while the substrate 200 is heated. This is also because damage to the oxide semiconductor film due to sputtering can be reduced.

[0078]

Then, a high-purity gas in which impurities such as hydrogen and moisture are 10 sufficiently removed is introduced into the deposition chamber from which remaining moisture is being removed, and the oxide semiconductor film is formed over the substrate 200 with the use of the target. To remove moisture remaining in the deposition chamber, an entrapment vacuum pump such as a cryopump, an ion pump, or a titanium sublimation pump is desirably used. Further, an evacuation means may be a 15 turbo pump provided with a cold trap. In the deposition chamber which is evacuated with the cryopump, a hydrogen molecule, a compound containing a hydrogen atom, such as water (H<sub>2</sub>O), (more preferably, also a compound containing a carbon atom), and the like are removed, whereby the concentration of an impurity in the oxide semiconductor film formed in the deposition chamber can be reduced.

20 [0079]

An example of the deposition condition is as follows: the distance between the substrate and the target is 100 mm, the pressure is 0.6 Pa, the direct-current (DC) power is 0.5 kW, and the deposition atmosphere is an oxygen atmosphere (the flow rate of the oxygen is 100 %). Note that a pulse direct current power source is preferable because 25 powdery substances (also referred to as particles or dust) generated in deposition can be reduced and unevenness in film thickness can be reduced.

[0080]

Note that before the oxide semiconductor film is formed by a sputtering method, powdery substances (also referred to as particles or dust) attached on a surface 30 of the first metal oxide film 204 are preferably removed by reverse sputtering in which an argon gas is introduced and plasma is generated. The reverse sputtering refers to a

method in which a voltage is applied to a substrate side to generate plasma in the vicinity of the substrate to modify a surface. Note that instead of argon, a gas such as nitrogen, helium, or oxygen may be used.

[0081]

5 The oxide semiconductor film can be processed by being etched after a mask having a desired shape is formed over the oxide semiconductor film. The mask may be formed by a method such as photolithography or an ink-jet method. The metal oxide film 204 and the like are also processed while the oxide semiconductor film is processed. Thus, the transistor 110 in FIG. 4E can be manufactured.

10 [0082]

For the etching of the oxide semiconductor film, either wet etching or dry etching may be employed. It is needless to say that both of them may be employed in combination.

[0083]

15 After that, heat treatment (first heat treatment) is desirably performed on the oxide semiconductor film. Excessive hydrogen (including water and a hydroxyl group) in the oxide semiconductor film is removed through the first heat treatment and the structure of the oxide semiconductor film is modified, so that defect levels in an energy gap can be reduced. The first heat treatment is performed at a temperature of  
20 higher than or equal to 250 °C and lower than or equal to 650 °C, preferably higher than or equal to 450 °C and lower than or equal to 600 °C. The temperature of the first heat treatment is preferably lower than the strain point of the substrate.

[0084]

25 Moreover, excessive hydrogen (including water and a hydroxyl group) in the first metal oxide film 204 can also be removed through the first heat treatment.

[0085]

30 The heat treatment may be performed, for example, in such a manner that an object to be processed is introduced into an electric furnace in which a resistance heating element or the like is used and heated in a nitrogen atmosphere at 450 °C for an hour. During the heat treatment, the oxide semiconductor film is not exposed to the air to prevent the entry of water and hydrogen.

[0086]

Note that a heat treatment apparatus is not limited to an electric furnace, and may include a device for heating an object to be processed by heat conduction or heat radiation from a medium such as a heated gas. For example, a rapid thermal anneal (RTA) apparatus such as a lamp rapid thermal anneal (LRTA) apparatus or a gas rapid thermal anneal (GRTA) apparatus can be used. An LRTA apparatus is an apparatus for heating an object to be processed by radiation of light (electromagnetic waves) emitted from a lamp such as a halogen lamp, a metal halide lamp, a xenon arc lamp, a carbon arc lamp, a high pressure sodium lamp, or a high pressure mercury lamp. A GRTA apparatus is an apparatus for heat treatment using a high temperature gas. As the high temperature gas, used is an inert gas which does not react with an object to be processed in heat treatment, such as nitrogen or a rare gas like argon.

[0087]

For example, as the first heat treatment, GRTA treatment may be performed as follows. The object is put in an inert gas atmosphere that has been heated, heated for several minutes, and then taken out of the inert gas atmosphere. GRTA treatment enables high-temperature heat treatment in a short time. Moreover, GRTA treatment can be employed even when the temperature exceeds the upper temperature limit of the object. Note that the inert gas may be switched to a gas containing oxygen during the treatment. This is because defect levels in an energy gap due to oxygen vacancy can be reduced by performing the first heat treatment in an atmosphere containing oxygen.

[0088]

Note that as the inert gas atmosphere, an atmosphere that contains nitrogen or a rare gas (e.g., helium, neon, or argon) as its main constituent and does not contain water, hydrogen, and the like is desirably used. For example, the purity of nitrogen or a rare gas such as helium, neon, or argon introduced into a heat treatment apparatus is 6N (99.9999 %) or higher, preferably 7N (99.99999 %) or higher (that is, the impurity concentration is 1 ppm or lower, preferably 0.1 ppm or lower).

[0089]

In any case, the i-type (intrinsic) or substantially i-type oxide semiconductor film in which impurities are reduced by the first heat treatment is formed, whereby a transistor having extremely excellent characteristics can be realized.

[0090]

The above heat treatment (first heat treatment) can be referred to as dehydration treatment, dehydrogenation treatment, or the like because of its advantageous effect of removing hydrogen, water, and the like. The dehydration treatment or dehydrogenation treatment may be performed at the timing, for example, after the oxide semiconductor film is processed to have an island shape. Such dehydration treatment or dehydrogenation treatment may be conducted once or plural times.

[0091]

Note that the case is described here in which after the oxide semiconductor film is processed to have an island shape, the first heat treatment is performed; however, one embodiment of the disclosed invention is not construed as being limited thereto. The oxide semiconductor film may be processed after the first heat treatment.

[0092]

Next, a conductive film for forming the source electrode and the drain electrode (including a wiring formed in the same layer as the source electrode and the drain electrode) is formed over the first metal oxide film 204 and the oxide semiconductor film 206 and processed to form the source electrode 208a and the drain electrode 208b (see FIG. 4C). The channel length  $L$  of the transistor depends on the distance between the edges of the source electrode 208a and the drain electrode 208b which are formed here.

[0093]

As the conductive film used for the source electrode 208a and the drain electrode 208b, for example, a metal film containing an element selected from Al, Cr, Cu, Ta, Ti, Mo, and W, or a metal nitride film containing any of the above elements as its constituent (e.g., a titanium nitride film, a molybdenum nitride film, or a tungsten nitride film) can be used. A high-melting-point metal film of Ti, Mo, W, or the like or a metal nitride film of any of these elements (a titanium nitride film, a molybdenum nitride film, or a tungsten nitride film) may be stacked on one of or both a bottom side and a top side of a metal film of Al, Cu, or the like.

[0094]

Alternatively, the conductive film used for the source electrode 208a and the

drain electrode 208b may be formed using a conductive metal oxide. As the conductive metal oxide, an indium oxide ( $\text{In}_2\text{O}_3$ ), a tin oxide ( $\text{SnO}_2$ ), a zinc oxide ( $\text{ZnO}$ ), an indium oxide-tin oxide alloy ( $\text{In}_2\text{O}_3\text{-SnO}_2$ , which is abbreviated to ITO), an indium oxide-zinc oxide alloy ( $\text{In}_2\text{O}_3\text{-ZnO}$ ), or any of these metal oxide materials containing a 5 silicon oxide may be used.

[0095]

The conductive film may be processed by etching with the use of a resist mask. Ultraviolet, a KrF laser light, an ArF laser light, or the like is preferably used for light exposure for forming a resist mask for the etching.

10 [0096]

In the case where the channel length  $L$  is less than 25 nm, the light exposure at the time of forming the resist mask is preferably performed using, for example, extreme ultraviolet having an extremely short wavelength of several nanometers to several tens of nanometers. In the light exposure using extreme ultraviolet, the resolution is high 15 and the focus depth is large. Thus, the channel length  $L$  of the transistor formed later can be reduced, whereby the operation speed of a circuit can be increased.

[0097]

An etching step may be performed with the use of a resist mask formed using a so-called multi-tone mask. A resist mask formed using a multi-tone mask has a 20 plurality of thicknesses and can be further changed in shape by ashing; thus, such a resist mask can be used in a plurality of etching steps for different patterns. Therefore, a resist mask for at least two kinds of patterns can be formed using a multi-tone mask, resulting in simplification of the process.

[0098]

25 Note that in etching of the conductive film, part of the oxide semiconductor film 206 is etched, so that the oxide semiconductor film having a groove (a recessed portion) is formed in some cases.

[0099]

30 After that, plasma treatment using a gas such as  $\text{N}_2\text{O}$ ,  $\text{N}_2$ , or  $\text{Ar}$  may be performed so that water or the like adsorbed onto a surface of an exposed portion of the oxide semiconductor film is removed. In the case where plasma treatment is performed, the second metal oxide film 210 which is to be in contact with part of the

oxide semiconductor film 206 is desirably formed without being exposed to the air, following the plasma treatment.

[0100]

Next, the second metal oxide film 210 is formed so as to contact part of the 5 oxide semiconductor film 206 and cover the source electrode 208a and the drain electrode 208b. Then, the gate insulating film 212 is formed in contact with the second metal oxide film 210 (see FIG. 4D).

[0101]

Since the second metal oxide film 210 is similar to the first metal oxide film 10 204, the detailed description thereof is omitted.

[0102]

The gate insulating film 212 is similar to the insulating film 202. Note that a material having a high dielectric constant, such as a hafnium oxide, may be used for the gate insulating film 212 considering the function of the gate insulating film of the 15 transistor. Note that also in that case, it is desirable to use a material with which a charge trapping center can be formed at the interface with the second metal oxide film 210 when the material is in contact with the second metal oxide film 210.

[0103]

Second heat treatment is desirably performed after formation of the second 20 metal oxide film 210 or after formation of the gate insulating film 212. The second heat treatment is performed at a temperature of higher than or equal to 250 °C and lower than or equal to 700 °C, preferably higher than or equal to 450 °C and lower than or equal to 600 °C. The temperature of the second heat treatment is preferably lower than the strain point of the substrate.

25 [0104]

The second heat treatment may be performed in an atmosphere of nitrogen, oxygen, ultra-dry air (air in which a water content is 20 ppm or less, preferably 1 ppm or less, more preferably 10 ppb or less), or a rare gas (argon, helium, or the like). Note that it is preferable that water, hydrogen, and the like be not contained in the atmosphere 30 of nitrogen, oxygen, ultra-dry air, or a rare gas. Further, the purity of nitrogen, oxygen, or a rare gas introduced into a heat treatment apparatus is 6N (99.9999 %) or higher,

preferably 7N (99.9999 %) or higher (that is, the impurity concentration is 1 ppm or lower, preferably 0.1 ppm or lower).

[0105]

The second heat treatment is performed while the oxide semiconductor film 206 and the second metal oxide film 210 are in contact with each other. Thus, oxygen which is one of main constituents of the oxide semiconductor film and may be reduced due to the dehydration (or dehydrogenation) treatment can be supplied from the second metal oxide film 210 to the oxide semiconductor film. Accordingly, charge trapping centers in the oxide semiconductor film can be decreased.

10 [0106]

Moreover, through this heat treatment, impurities in the first metal oxide film 204 or the second metal oxide film 210 can also be removed, resulting in high purification.

[0107]

15 Note that there is no particular limitation on the timing of the second heat treatment as long as it is after formation of the oxide semiconductor film 206. For example, the second heat treatment may be performed after the gate electrode 214 is formed. Alternatively, the second heat treatment may be performed following the first heat treatment, the first treatment may also serve as the second heat treatment, or the 20 second treatment may also serve as the first heat treatment.

[0108]

As described above, at least one of the first heat treatment and the second heat treatment is applied, whereby the oxide semiconductor film 206 can be highly purified so as to contain impurities other than main components of the oxide semiconductor film 25 206 as little as possible. The highly-purified oxide semiconductor film 206 contains extremely few (close to zero) carriers derived from a donor, and the carrier concentration thereof is lower than  $1 \times 10^{14} /cm^3$ , preferably lower than  $1 \times 10^{12} /cm^3$ , more preferably lower than  $1 \times 10^{11} /cm^3$ .

[0109]

30 Then, the gate electrode 214 is formed (see FIG. 4E). The gate electrode 214 can be formed using a metal material such as molybdenum, titanium, chromium,

tantalum, tungsten, aluminum, copper, neodymium, or scandium or an alloy material which contains any of these materials as its main component. Note that the gate electrode 214 may have a single-layer structure or a layered structure.

[0110]

5 Through the above process, the transistor 110 is formed.

[0111]

<Manufacturing Process of Transistor 120>

An example of a manufacturing process of the transistor 120 in FIG. 3A will be described with reference to FIGS. 5A to 5E. A manufacturing process of the transistor 10 160 in FIG. 3E is the same as that of the transistor 120 except that the second metal oxide film 210 is processed in accordance with the shape of the oxide semiconductor film 206.

[0112]

First, the insulating film 202 is formed over the substrate 200, and then, the 15 first metal oxide film 204 is formed on and in contact with the insulating film 202 (see FIG. 5A). The description on the manufacturing process of the transistor 110 can be referred to for the details.

[0113]

Next, a conductive film for forming the source electrode and the drain 20 electrode (including a wiring formed in the same layer as the source electrode and the drain electrode) is formed over the first metal oxide film 204 and processed to form the source electrode 208a and the drain electrode 208b (see FIG. 5B). The description on the manufacturing process of the transistor 110 can be referred to for the details.

[0114]

25 Next, an oxide semiconductor film is formed over the first metal oxide film 204 so as to be connected to the source electrode 208a and the drain electrode 208b and then is processed to form the oxide semiconductor film 206 having an island shape (see FIG. 5C). The description on the manufacturing process of the transistor 110 can be referred to for the details.

30 [0115]

Next, the second metal oxide film 210 is formed so as to contact part of the oxide semiconductor film 206 and cover the source electrode 208a and the drain

electrode 208b. Then, the gate insulating film 212 is formed in contact with the second metal oxide film 210 (see FIG. 5D). The description on the manufacturing process of the transistor 110 can be referred to for the details.

[0116]

5 Then, the gate electrode 214 is formed (see FIG. 5E). The description on the manufacturing process of the transistor 110 can be referred to for the details.

[0117]

Through the above process, the transistor 120 is formed.

[0118]

10 In the transistor according to this embodiment, the top surface portion and the bottom surface portion of the oxide semiconductor film are each provided with the metal oxide film containing a constituent similar to that of the oxide semiconductor film, and an insulating film containing a different constituent from the metal oxide film and the oxide semiconductor film is formed in contact with a surface of the metal oxide film, 15 which is opposite to the surface in contact with the oxide semiconductor film. Thus, the metal oxide film containing a material compatible with the oxide semiconductor film is provided in contact with the oxide semiconductor film, which suppresses trapping of charge or the like which can be generated due to the operation of a semiconductor device at the interface between the oxide semiconductor film and the 20 metal oxide film. Meanwhile, an insulator containing a material with which a charge trapping center can be formed at the interface is provided in contact with the metal oxide film, whereby the charge can be trapped at the interface between the metal oxide film and the insulator. Consequently, the oxide semiconductor film can be less adversely affected by charge, which suppresses fluctuation in the threshold voltage of 25 the transistor due to trapping of charge at the interface of the oxide semiconductor film.

[0119]

30 The oxide semiconductor film used for the active layer of the transistor is an oxide semiconductor film highly purified to be electrically i-type (intrinsic) by removing impurities such as hydrogen, moisture, a hydroxyl group, and hydride (also referred to as a hydrogen compound) from the oxide semiconductor through heat treatment and supplying oxygen which is a major constituent of the oxide semiconductor and is also reduced in a step of removing impurities. The transistor

including the oxide semiconductor film highly purified in such a manner has electric characteristics which are less likely to change, and thus is electrically stable.

[0120]

When charge is trapped at the interface of the oxide semiconductor film, the 5 threshold voltage of the transistor shifts (for example, when positive charge is trapped on the back channel side, the threshold voltage of the transistor shifts in a negative direction). As one of factors of such charge trapping, the model where cations (or atoms which are sources of the cations) travel and are trapped can be supposed. In the transistor including an oxide semiconductor, such cation sources may be hydrogen 10 atoms. In the disclosed invention, the highly-purified oxide semiconductor is used and is in contact with the stack of the metal oxide film and the insulating film, so that it is possible to suppress even charge trapping due to hydrogen, which may be caused in the above model. The above model is supposed to be realized when the ionization rate of hydrogen is, for example, about 10 %.

15 [0121]

Thus, a semiconductor device including an oxide semiconductor and having stable electric characteristics can be provided. Therefore, a semiconductor device with high reliability can be provided.

[0122]

20 The structures, the methods, and the like described in this embodiment can be combined as appropriate with any of the structures, the methods, and the like described in the other embodiments.

[0123]

(Embodiment 2)

25 A semiconductor device (also referred to as a display device) with a display function can be manufactured using the transistor an example of which is described in Embodiment 1. Some or all of driver circuits including the transistors can be formed over a substrate where a pixel portion is formed, whereby a system-on-panel can be obtained.

30 [0124]

In FIG. 6A, a sealant 4005 is provided to surround a pixel portion 4002 provided over a first substrate 4001, and the pixel portion 4002 is sealed with the

sealant 4005 and the second substrate 4006. In FIG. 6A, a scan line driver circuit 4004 and a signal line driver circuit 4003 each are formed using a single crystal semiconductor film or a polycrystalline semiconductor film over a substrate prepared separately, and mounted in a region different from the region surrounded by the sealant 4005 over the first substrate 4001. Various signals and potentials are supplied to the signal line driver circuit 4003 and the scan line driver circuit 4004 each of which is separately formed, and the pixel portion 4002, from flexible printed circuits (FPCs) 4018a and 4018b.

[0125]

10 In FIGS. 6B and 6C, the sealant 4005 is provided to surround the pixel portion 4002 and the scan line driver circuit 4004 which are provided over the first substrate 4001. The second substrate 4006 is provided over the pixel portion 4002 and the scan line driver circuit 4004. Thus, the pixel portion 4002 and the scan line driver circuit 4004 are sealed together with a display element, by the first substrate 4001, the sealant 4005, and the second substrate 4006. In FIGS. 6B and 6C, the signal line driver circuit 4003 is formed using a single crystal semiconductor film or a polycrystalline semiconductor film over a substrate prepared separately, and mounted in a region different from the region surrounded by the sealant 4005 over the first substrate 4001. In FIGS. 6B and 6C, various signals and potentials are supplied to the separately formed 15 signal line driver circuit 4003, the scan line driver circuit 4004, and the pixel portion 4002, from an FPC 4018. 20

[0126]

25 Although FIGS. 6B and 6C each show the example in which the signal line driver circuit 4003 is formed separately and mounted on the first substrate 4001, the present invention is not limited to this structure. The scan line driver circuit may be 30 separately formed and then mounted, or only part of the signal line driver circuit or part of the scan line driver circuit may be separately formed and then mounted.

[0127]

Note that a method for connecting a separately formed driver circuit is not particularly limited, and a chip on glass (COG) method, a wire bonding method, a tape automated bonding (TAB) method, or the like can be used. FIG. 6A shows an example in which the signal line driver circuit 4003 and the scan line driver circuit 4004 are

mounted by a COG method. FIG. 6B shows an example in which the signal line driver circuit 4003 is mounted by a COG method. FIG. 6C shows an example in which the signal line driver circuit 4003 is mounted by a TAB method.

[0128]

5 The display device includes in its category a panel in which a display element is sealed, and a module in which an IC such as a controller is mounted on the panel.

[0129]

10 Note that a display device in this specification means an image display device, a display device, or a light source (including a lighting device). The display device also includes the following modules in its category: a module to which a connector such as an FPC, a TAB tape, or a TCP is attached; a module having a TAB tape or a TCP at the tip of which a printed wiring board is provided; and a module in which an integrated circuit (IC) is directly mounted on a display element by a COG method.

[0130]

15 The pixel portion and the scan line driver circuit provided over the first substrate include a plurality of transistors and any of the transistors which are described in Embodiment 1 can be applied.

[0131]

20 As the display element provided in the display device, a liquid crystal element (also referred to as a liquid crystal display element) or a light-emitting element (also referred to as a light-emitting display element) can be used. The light-emitting element includes, in its category, an element whose luminance is controlled by a current or voltage, and specifically includes, in its category, an inorganic electroluminescent (EL) element, an organic EL element, and the like. Furthermore, a display medium 25 whose contrast is changed by an electric effect, such as electronic ink, can be used.

[0132]

One embodiment of the semiconductor device is described with reference to FIG. 7, FIG. 8, and FIG. 9. FIG. 7, FIG. 8, and FIG. 9 correspond to cross-sectional views taken along line M-N in FIG. 6B.

30 [0133]

As shown in FIG. 7, FIG. 8, and FIG. 9, the semiconductor device includes a connection terminal electrode 4015 and a terminal electrode 4016. The connection

terminal electrode 4015 and the terminal electrode 4016 are electrically connected to a terminal included in the FPC 4018 through an anisotropic conductive film 4019.

[0134]

The connection terminal electrode 4015 is formed of the same conductive film 5 as a first electrode layer 4030. The terminal electrode 4016 is formed of the same conductive film as a source electrode and a drain electrode of transistors 4010 and 4011.

[0135]

Each of the pixel portion 4002 and the scan line driver circuit 4004 provided over the first substrate 4001 includes a plurality of transistors. In FIG. 7, FIG. 8, and 10 FIG. 9, the transistor 4010 included in the pixel portion 4002 and the transistor 4011 included in the scan line driver circuit 4004 are shown as an example.

[0136]

In this embodiment, any of the transistors shown in Embodiment 1 can be applied to the transistors 4010 and 4011. Variation in the electric characteristics of the 15 transistors 4010 and 4011 is suppressed and the transistors 4010 and 4011 are electrically stable. As described above, a semiconductor device with high reliability as the semiconductor devices shown in FIG. 7, FIG. 8, and FIG. 9 can be obtained.

[0137]

The transistor 4010 provided in the pixel portion 4002 is electrically connected 20 to the display element to constitute a display panel. A variety of display elements can be used as the display element as long as display can be performed.

[0138]

An example of a liquid crystal display device using a liquid crystal element as a display element is shown in FIG. 7. In FIG. 7, a liquid crystal element 4013 is a 25 display element including the first electrode layer 4030, a second electrode layer 4031, and a liquid crystal layer 4008. Note that the insulating films 4032 and 4033 serving as alignment films are provided so that the liquid crystal layer 4008 is interposed therebetween. The second electrode layer 4031 is formed on the second substrate 4006 side. The first electrode layer 4030 and the second electrode layer 4031 are stacked 30 with the liquid crystal layer 4008 interposed therebetween.

[0139]

A columnar spacer 4035 is obtained by selective etching of an insulating film

and is provided in order to control the thickness (a cell gap) of the liquid crystal layer 4008. Alternatively, a spherical spacer may be used.

[0140]

In the case where a liquid crystal element is used as the display element, a 5 thermotropic liquid crystal, a low-molecular liquid crystal, a high-molecular liquid crystal, a polymer dispersed liquid crystal, a ferroelectric liquid crystal, an anti-ferroelectric liquid crystal, or the like can be used. Such a liquid crystal material exhibits a cholesteric phase, a smectic phase, a cubic phase, a chiral nematic phase, an isotropic phase, or the like depending on conditions.

10 [0141]

Alternatively, liquid crystal exhibiting a blue phase for which an alignment film is unnecessary may be used. A blue phase is one of liquid crystal phases generated just before a cholesteric phase changes into an isotropic phase while temperature of cholesteric liquid crystal is increased. Since the blue phase appears only in a narrow 15 temperature range, a liquid crystal composition in which several weight percent or more of a chiral material is mixed is used for the liquid crystal layer in order to improve the temperature range. The liquid crystal composition which includes a liquid crystal showing a blue phase and a chiral agent has a short response time of 1 msec or less, has optical isotropy, which makes the alignment process unneeded, and has a small viewing 20 angle dependence. In addition, since an alignment film does not need to be provided and rubbing treatment is unnecessary, electrostatic discharge damage caused by the rubbing treatment can be prevented and defects and damage of the liquid crystal display device can be reduced in the manufacturing process. Thus, productivity of the liquid crystal display device can be increased.

25 [0142]

The specific resistivity of the liquid crystal material is  $1 \times 10^9 \Omega\text{-cm}$  or more, preferably  $1 \times 10^{11} \Omega\text{-cm}$  or more, further preferably  $1 \times 10^{12} \Omega\text{-cm}$  or more. Note that the specific resistivity in this specification is measured at 20 °C.

[0143]

30 The size of a storage capacitor provided in the liquid crystal display device is set considering the leakage current of the transistor provided in the pixel portion or the

like so that charge can be held for a predetermined period. Since the transistor including a high-purity oxide semiconductor film is used, a storage capacitor having capacitance which is 1/3 or less, preferably 1/5 or less with respect to a liquid crystal capacitance of each pixel is sufficient to be provided.

5 [0144]

In the transistor used in this embodiment, which uses a highly-purified oxide semiconductor film, the current in an off state (the off-state current) can be made small. Therefore, an electrical signal such as an image signal can be held for a long period, and a writing interval can be set long when the power is on. Consequently, frequency of 10 refresh operation can be reduced, which leads to an effect of suppressing power consumption.

[0145]

The field-effect mobility of the transistor including a highly-purified oxide semiconductor film used in this embodiment can be relatively high, whereby high-speed 15 operation is possible. Thus, by using the transistor in a pixel portion of the liquid crystal display device, a high-quality image can be provided. In addition, since the transistors can be separately provided in a driver circuit portion and a pixel portion over one substrate, the number of components of the liquid crystal display device can be reduced.

20 [0146]

For the liquid crystal display device, a twisted nematic (TN) mode, an in-plane-switching (IPS) mode, a fringe field switching (FFS) mode, an axially 25 symmetric aligned micro-cell (ASM) mode, an optical compensated birefringence (OCB) mode, a ferroelectric liquid crystal (FLC) mode, an antiferroelectric liquid crystal (AFLC) mode, and the like can be used.

[0147]

A normally black liquid crystal display device such as a transmissive liquid crystal display device utilizing a vertical alignment (VA) mode is preferable. The vertical alignment mode is one of methods of controlling alignment of liquid crystal 30 molecules of a liquid crystal display panel. The vertical alignment mode is a mode in which liquid crystal molecules are aligned vertically to a panel surface when voltage is not applied. Some examples are given as the vertical alignment mode. For example,

a multi-domain vertical alignment (MVA) mode, a patterned vertical alignment (PVA) mode, an Advanced Super View (ASV) mode, and the like can be used. Moreover, it is possible to use a method called domain multiplication or multi-domain design, in which a pixel is divided into some regions (subpixels) and molecules are aligned in different 5 directions in their respective regions.

[0148]

In the display device, a black matrix (a light-blocking layer), an optical member (an optical substrate) such as a polarizing member, a retardation member, or an anti-reflection member, and the like are provided as appropriate. For example, circular 10 polarization may be employed by using a polarizing substrate and a retardation substrate. In addition, a backlight, a side light, or the like may be used as a light source.

[0149]

In addition, with the use of a plurality of light-emitting diodes (LEDs) as a backlight, a time-division display method (a field-sequential driving method) can be 15 employed. With the field-sequential driving method, color display can be performed without using a color filter.

[0150]

As a display method in the pixel portion, a progressive method, an interlace method, or the like can be employed. Color elements controlled in a pixel at the time 20 of color display are not limited to three colors: R, G, and B (R, G, and B correspond to red, green, and blue respectively). For example, R, G, B, and W (W corresponds to white), or R, G, B, and one or more of yellow, cyan, magenta, and the like can be used. The sizes of display regions may be different between respective dots of color elements. Note that the present invention is not limited to the application to a display device for 25 color display but can also be applied to a display device for monochrome display.

[0151]

Alternatively, as the display element included in the display device, a light-emitting element utilizing electroluminescence can be used. Light-emitting elements utilizing electroluminescence are classified according to whether a 30 light-emitting material is an organic compound or an inorganic compound. In general, the former is referred to as an organic EL element, and the latter is referred to as an inorganic EL element.

[0152]

In an organic EL element, by application of voltage to a light-emitting element, electrons and holes are separately injected from a pair of electrodes into a layer containing a light-emitting organic compound, and current flows. The carriers 5 (electrons and holes) are recombined, and thus the light-emitting organic compound is excited. The light-emitting organic compound returns to a ground state from the excited state, thereby emitting light. Owing to such a mechanism, such a light-emitting element is referred to as a current-excitation light-emitting element.

[0153]

10 The inorganic EL elements are classified according to their element structures into a dispersion-type inorganic EL element and a thin-film inorganic EL element. A dispersion-type inorganic EL element has a light-emitting layer where particles of a light-emitting material are dispersed in a binder, and its light emission mechanism is donor-acceptor recombination type light emission that utilizes a donor level and an 15 acceptor level. A thin-film inorganic EL element has a structure where a light-emitting layer is sandwiched between dielectric layers, which are further sandwiched between electrodes, and its light emission mechanism is localized type light emission that utilizes inner-shell electron transition of metal ions. Note that an example of an organic EL element as a light-emitting element is described here.

20 [0154]

In order to extract light emitted from the light-emitting element, it is acceptable as long as at least one of a pair of electrodes is transparent. Then a transistor and a light-emitting element are formed over a substrate. The light-emitting element can have any of the following structure: a top emission structure in which light is extracted 25 through the surface opposite to the substrate; a bottom emission structure in which light is extracted through the surface on the substrate side; or a dual emission structure in which light is extracted through the surface opposite to the substrate and the surface on the substrate side.

[0155]

30 An example of a light-emitting device using a light-emitting element as a display element is shown in FIG. 8. A light-emitting element 4513 which is a display element is electrically connected to the transistor 4010 provided in the pixel portion

4002. The light-emitting element 4513 has a stacked-layer structure of the first electrode layer 4030, an electroluminescent layer 4511, and the second electrode layer 4031 but is not limited to this structure. The structure of the light-emitting element 4513 can be changed as appropriate depending on a direction in which light is extracted 5 from the light-emitting element 4513, or the like.

[0156]

A partition wall 4510 can be formed using an organic insulating material or an inorganic insulating material. It is particularly preferable that the partition wall 4510 be formed using a photosensitive resin material to have an opening portion over the first 10 electrode layer 4030 so that a sidewall of the opening portion is formed as a tilted surface with continuous curvature.

[0157]

The electroluminescent layer 4511 may be formed with either a single layer or a stacked layer of a plurality of layers.

15 [0158]

A protective film may be formed over the second electrode layer 4031 and the partition wall 4510 in order to prevent entry of oxygen, hydrogen, moisture, carbon dioxide, or the like into the light-emitting element 4513. As the protective film, a silicon nitride film, a silicon nitride oxide film, a diamond like carbon (DLC) film, or 20 the like can be formed. In a space sealed with the first substrate 4001, the second substrate 4006, and the sealant 4005, a filler 4514 is provided and tightly sealed. It is preferable that the light-emitting element be packaged (sealed) with a cover material with high air-tightness and little degasification or a protective film (such as a laminate film or an ultraviolet curable resin film) so that the light-emitting element is not 25 exposed to the outside air, in this manner.

[0159]

As the filler 4514, an ultraviolet curable resin or a thermosetting resin can be used as well as an inert gas such as nitrogen or argon, and polyvinyl chloride (PVC), acrylic, polyimide, an epoxy resin, a silicone resin, polyvinyl butyral (PVB), ethylene 30 vinyl acetate (EVA), or the like can be used. For example, nitrogen is used for the filler.

[0160]

If needed, an optical film, such as a polarizing plate, a circularly polarizing plate (including an elliptically polarizing plate), a retardation plate (a quarter-wave plate or a half-wave plate), or a color filter, may be provided as appropriate on a light-emitting surface of the light-emitting element. Further, the polarizing plate or the 5 circularly polarizing plate may be provided with an anti-reflection film. For example, anti-glare treatment by which reflected light can be diffused by projections and depressions on the surface so as to reduce the glare can be performed.

[0161]

An electronic paper in which electronic ink is driven can be provided as the 10 display device. The electronic paper is also called an electrophoretic display device (electrophoretic display) and has advantages in that it has the same level of readability as regular paper, it has less power consumption than other display devices, and it can be set to have a thin and light form.

[0162]

An electrophoretic display device can have various modes. An 15 electrophoretic display device contains a plurality of microcapsules dispersed in a solvent or a solute, each microcapsule containing first particles which are positively charged and second particles which are negatively charged. By applying an electric field to the microcapsules, the particles in the microcapsules move in opposite 20 directions to each other and only the color of the particles gathering on one side is displayed. Note that the first particles and the second particles each contain pigment and do not move without an electric field. Moreover, the first particles and the second particles have different colors (which may be colorless).

[0163]

25 Thus, an electrophoretic display device is a display device that utilizes a so-called dielectrophoretic effect by which a substance having a high dielectric constant moves to a high-electric field region.

[0164]

A solution in which the above microcapsules are dispersed in a solvent is 30 referred to as electronic ink. This electronic ink can be printed on a surface of glass, plastic, cloth, paper, or the like. Furthermore, by using a color filter or particles that have a pigment, color display can also be achieved.

[0165]

Note that the first particles and the second particles in the microcapsules may each be formed of a single material selected from a conductive material, an insulating material, a semiconductor material, a magnetic material, a liquid crystal material, a ferroelectric material, an electroluminescent material, an electrochromic material, and a magnetophoretic material, or formed of a composite material of any of these.

[0166]

As an electronic paper, a display device using a twisting ball display method can be used. The twisting ball display method refers to a method in which spherical particles each colored in white and black are arranged between a first electrode layer and a second electrode layer which are electrode layers used for a display element, and a potential difference is generated between the first electrode layer and the second electrode layer to control orientation of the spherical particles, so that display is performed.

[0167]

FIG. 9 shows an active matrix electronic paper as one embodiment of a semiconductor device. The electronic paper in FIG. 9 is an example of a display device using a twisting ball display method.

[0168]

Between the first electrode layer 4030 connected to the transistor 4010 and the second electrode layer 4031 provided on the second substrate 4006, spherical particles 4613 each of which includes a black region 4615a, a white region 4615b, and a cavity 4612 around the regions which is filled with liquid, are provided. A space around the spherical particles 4613 is filled with a filler 4614 such as a resin. The second electrode layer 4031 corresponds to a common electrode (counter electrode). The second electrode layer 4031 is electrically connected to a common potential line.

[0169]

Note that in FIG. 7, FIG. 8, and FIG. 9, a flexible substrate as well as a glass substrate can be used as the first substrate 4001 and the second substrate 4006. For example, a plastic substrate having light-transmitting properties can be used. For plastic, a fiberglass-reinforced plastics (FRP) plate, a polyvinyl fluoride (PVF) film, a polyester film, or an acrylic resin film can be used. A sheet with a structure in which

an aluminum foil is sandwiched between PVF films or polyester films can also be used.

[0170]

The insulating layer 4021 can be formed using an organic insulating material or an inorganic insulating material. Note that an organic insulating material having heat 5 resistance, such as an acrylic resin, a polyimide, a benzocyclobutene-based resin, a polyamide, or an epoxy resin is preferably used as a planarizing insulating film. Other than such organic insulating materials, it is possible to use a low-dielectric constant material (a low-k material), a siloxane-based resin, phosphosilicate glass (PSG), borophosphosilicate glass (BPSG), or the like. The insulating layer may be formed by 10 stacking a plurality of insulating films formed of these materials.

[0171]

There is no particular limitation on the method for forming the insulating layer 4021, and the insulating layer 4021 can be formed, depending on a material thereof, by a sputtering method, a spin coating method, a dipping method, a spray coating method, 15 a droplet discharging method (e.g., an ink jet method, a screen printing method, or an offset printing method), a roll coating method, a curtain coating method, a knife coating method, or the like.

[0172]

The display device performs display by transmitting light from a light source or 20 a display element. Thus, the substrates and the thin films such as insulating films and conductive films provided in the pixel portion where light is transmitted have light-transmitting properties with respect to light in the visible-light wavelength range.

[0173]

The first electrode layer and the second electrode layer (each of which may be 25 called a pixel electrode layer, a common electrode layer, a counter electrode layer, or the like) for applying voltage to the display element may have light-transmitting properties or light-reflecting properties, which depends on the direction in which light is extracted, the position where the electrode layer is provided, and the pattern structure of the electrode layer.

30 [0174]

A light-transmitting conductive material such as indium oxide containing tungsten oxide, indium zinc oxide containing tungsten oxide, indium oxide containing

titanium oxide, indium tin oxide containing titanium oxide, indium tin oxide (hereinafter referred to as ITO), indium zinc oxide, or indium tin oxide to which silicon oxide is added, can be used for the first electrode layer 4030 and the second electrode layer 4031.

5 [0175]

The first electrode layer 4030 and the second electrode layer 4031 can be formed using one kind or plural kinds selected from metal such as tungsten (W), molybdenum (Mo), zirconium (Zr), hafnium (Hf), vanadium (V), niobium (Nb), tantalum (Ta), chromium (Cr), cobalt (Co), nickel (Ni), titanium (Ti), platinum (Pt), 10 aluminum (Al), copper (Cu), or silver (Ag); an alloy thereof; and a nitride thereof.

[0176]

A conductive composition containing a conductive high molecule (also referred to as a conductive polymer) can be used for the first electrode layer 4030 and the second electrode layer 4031. As the conductive high molecule, a so-called  $\pi$ -electron conjugated conductive polymer can be used. For example, polyaniline or a derivative thereof, polypyrrole or a derivative thereof, polythiophene or a derivative thereof, and a copolymer of two or more of aniline, pyrrole, and thiophene or a derivative thereof can be given.

[0177]

20 Since the transistor is easily broken due to static electricity or the like, a protective circuit for protecting the driver circuit is preferably provided. The protective circuit is preferably formed using a nonlinear element.

[0178]

As described above, by using any of the transistors shown in Embodiment 1, a 25 semiconductor device having a high reliability can be provided. Note that the transistors described in Embodiment 1 can be applied to not only semiconductor devices having the display functions described above but also semiconductor devices having a variety of functions, such as a power device which is mounted on a power supply circuit, a semiconductor integrated circuit such as an LSI, and a semiconductor device having 30 an image sensor function of reading information of an object.

[0179]

The structures, the methods, and the like described in this embodiment can be

combined as appropriate with any of the structures, the methods, and the like described in the other embodiments.

[0180]

(Embodiment 3)

5 A semiconductor device disclosed in this specification can be applied to a variety of electronic appliances (including game machines). Examples of electronic appliances are a television set (also referred to as a television or a television receiver), a monitor of a computer or the like, a camera such as a digital camera or a digital video camera, a digital photo frame, a mobile phone handset (also referred to as a mobile phone or a mobile phone device), a portable game machine, a portable information terminal, an audio reproducing device, a large-sized game machine such as a pachinko machine, and the like. Examples of electronic appliances each including the semiconductor device described in the above embodiment are described.

10

[0181]

15 FIG. 10A illustrates a laptop personal computer, which includes a main body 3001, a housing 3002, a display portion 3003, a keyboard 3004, and the like. By applying the semiconductor device described in Embodiment 1 or 2, the laptop personal computer can have high reliability.

[0182]

20 FIG. 10B is a portable information terminal (PDA) which includes a display portion 3023, an external interface 3025, an operation button 3024, and the like in a main body 3021. A stylus 3022 is included as an accessory for operation. By applying the semiconductor device described in Embodiment 1 or 2, the portable information terminal (PDA) can have higher reliability.

25 [0183]

FIG. 10C illustrates an example of an electronic book reader. For example, an electronic book reader 2700 includes two housings, a housing 2701 and a housing 2703. The housing 2701 and the housing 2703 are combined with a hinge 2711 so that the electronic book reader 2700 can be opened and closed with the hinge 2711 as an axis.

30 With such a structure, the electronic book reader 2700 can operate like a paper book.

[0184]

A display portion 2705 and a display portion 2707 are incorporated in the

housing 2701 and the housing 2703, respectively. The display portion 2705 and the display portion 2707 may display one image or different images. When the display portion 2705 and the display portion 2707 display different images, for example, text can be displayed on a display portion on the right side (the display portion 2705 in FIG. 5 10C) and graphics can be displayed on a display portion on the left side (the display portion 2707 in FIG. 10C). By applying the semiconductor device described in Embodiment 1 or 2, the electronic book reader 2700 can have high reliability.

[0185]

FIG. 10C illustrates an example in which the housing 2701 is provided with an 10 operation portion and the like. For example, the housing 2701 is provided with a power switch 2721, operation keys 2723, a speaker 2725, and the like. With the operation key 2723, pages can be turned. Note that a keyboard, a pointing device, or the like may also be provided on the surface of the housing, on which the display portion is provided. Furthermore, an external connection terminal (an earphone 15 terminal, a USB terminal, or the like), a recording medium insertion portion, and the like may be provided on the back surface or the side surface of the housing. Moreover, the electronic book reader 2700 may have a function of an electronic dictionary.

[0186]

The electronic book reader 2700 may have a configuration capable of 20 wirelessly transmitting and receiving data. Through wireless communication, desired book data or the like can be purchased and downloaded from an electronic book server.

[0187]

FIG. 10D illustrates a mobile phone, which includes two housings, a housing 2800 and a housing 2801. The housing 2801 includes a display panel 2802, a speaker 25 2803, a microphone 2804, a pointing device 2806, a camera lens 2807, an external connection terminal 2808, and the like. In addition, the housing 2800 includes a solar cell 2810 having a function of charge of the mobile phone, an external memory slot 2811, and the like. Further, an antenna is incorporated in the housing 2801. By applying the semiconductor device described in Embodiment 1 or 2, the mobile phone 30 can have high reliability.

[0188]

Further, the display panel 2802 is provided with a touch panel. A plurality of

operation keys 2805 which are displayed as images is illustrated by dashed lines in FIG. 10D. Note that a boosting circuit by which a voltage output from the solar cell 2810 is increased to be sufficiently high for each circuit is also included.

[0189]

5 In the display panel 2802, the display orientation can be appropriately changed depending on a usage pattern. Further, the display device is provided with the camera lens 2807 on the same surface as the display panel 2802, and thus it can be used as a video phone. The speaker 2803 and the microphone 2804 can be used for videophone calls, recording and playing sound, and the like as well as voice calls. Moreover, the 10 housings 2800 and 2801 in a state where they are opened as illustrated in FIG. 10D can be slid so that one overlaps the other; therefore, the size of the mobile phone can be reduced, which makes the mobile phone suitable for being carried.

[0190]

15 The external connection terminal 2808 can be connected to an AC adapter and various types of cables such as a USB cable, and charging and data communication with a personal computer are possible. Moreover, a larger amount of data can be saved and moved by inserting a recording medium to the external memory slot 2811.

[0191]

20 Further, in addition to the above functions, an infrared communication function, a television reception function, or the like may be provided.

[0192]

FIG. 10E illustrates a digital video camera which includes a main body 3051, a display portion A 3057, an eyepiece 3053, an operation switch 3054, a display portion B 3055, a battery 3056, and the like. By applying the semiconductor device described in 25 Embodiment 1 or 2, the digital video camera can have high reliability.

[0193]

FIG. 10F illustrates an example of a television set. In a television set 9600, a display portion 9603 is incorporated in a housing 9601. The display portion 9603 can display images. Here, the housing 9601 is supported by a stand 9605. By applying 30 the semiconductor device described in Embodiment 1 or 2, the television set can have high reliability.

[0194]

The television set 9600 can be operated by an operation switch of the housing 9601 or a separate remote controller. Further, the remote controller may be provided with a display portion for displaying data output from the remote controller.

[0195]

5 Note that the television set 9600 is provided with a receiver, a modem, and the like. With the use of the receiver, general television broadcasting can be received. Furthermore, when the display device is connected to a communication network with or without wires via the modem, one-way (from a sender to a receiver) or two-way (between a sender and a receiver or between receivers) information communication can  
10 be performed.

[0196]

The structures, the methods, and the like described in this embodiment can be combined as appropriate with any of the structures, the methods, and the like described in the other embodiments.

15

This application is based on Japanese Patent Application serial no. 2010-086407 filed with the Japan Patent Office on April 2, 2010, the entire contents of which are hereby incorporated by reference.

## CLAIMS

1. A semiconductor device comprising:  
an insulating film;  
a first metal oxide film on and in contact with the insulating film;  
5 an oxide semiconductor film partly in contact with the first metal oxide film;  
source and drain electrodes electrically connected to the oxide semiconductor  
film;  
a second metal oxide film partly in contact with the oxide semiconductor film;  
a gate insulating film on and in contact with the second metal oxide film; and  
10 a gate electrode over the gate insulating film.

2. The semiconductor device according to claim 1,  
wherein the first metal oxide film and the second metal oxide film each contain  
a constituent element of the oxide semiconductor film.

15 3. The semiconductor device according to claim 1,  
wherein the first metal oxide film and the second metal oxide film each have a  
larger energy gap than the oxide semiconductor film.

20 4. The semiconductor device according to claim 1,  
wherein energy at a bottom of a conduction band of each of the first metal  
oxide film and the second metal oxide film is higher than energy at a bottom of a  
conduction band of the oxide semiconductor film.

25 5. The semiconductor device according to claim 1,  
wherein the first metal oxide film and the second metal oxide film each contain  
a gallium oxide.

6. The semiconductor device according to claim 1,  
30 wherein a proportion of a constituent element of the first metal oxide film is  
equal to a proportion of a constituent element of the second metal oxide film.

7. The semiconductor device according to claim 1,  
wherein the insulating film contains a silicon oxide.

5 8. The semiconductor device according to claim 1,  
wherein the gate insulating film contains a silicon oxide or a hafnium oxide.

9. The semiconductor device according to claim 1,  
wherein the second metal oxide film is provided so as to cover the source and  
drain electrodes and contact the first metal oxide film.

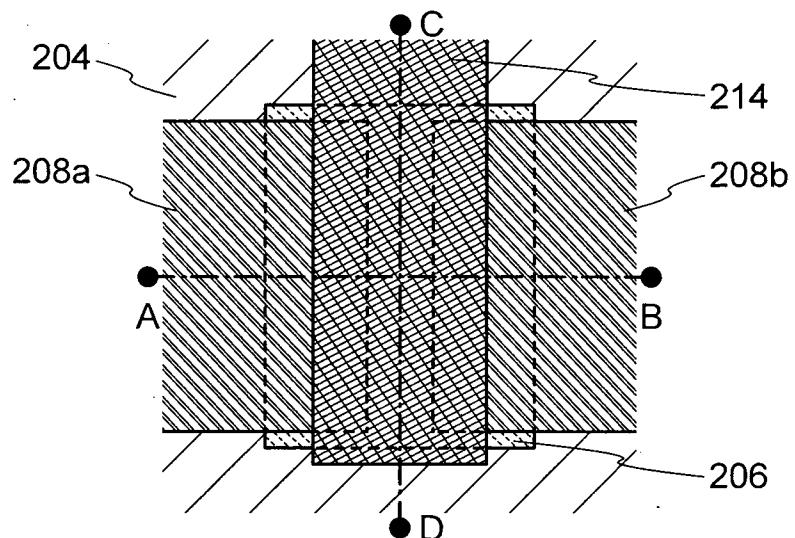
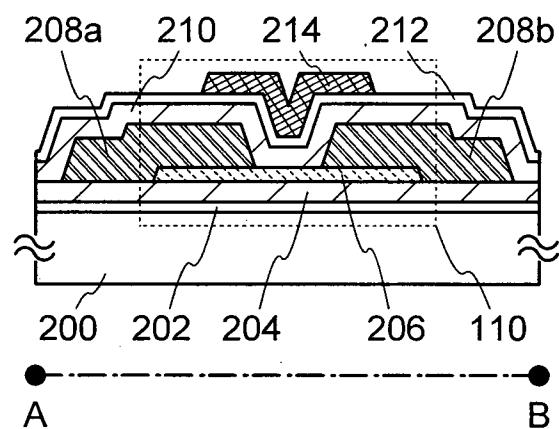
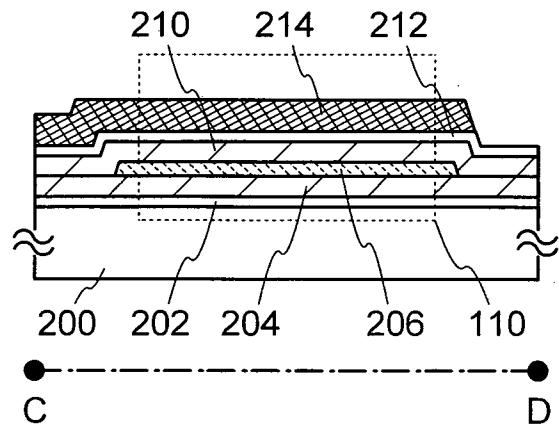
10 10. The semiconductor device according to claim 9,  
wherein the oxide semiconductor film is surrounded by the first metal oxide  
film and the second metal oxide film.

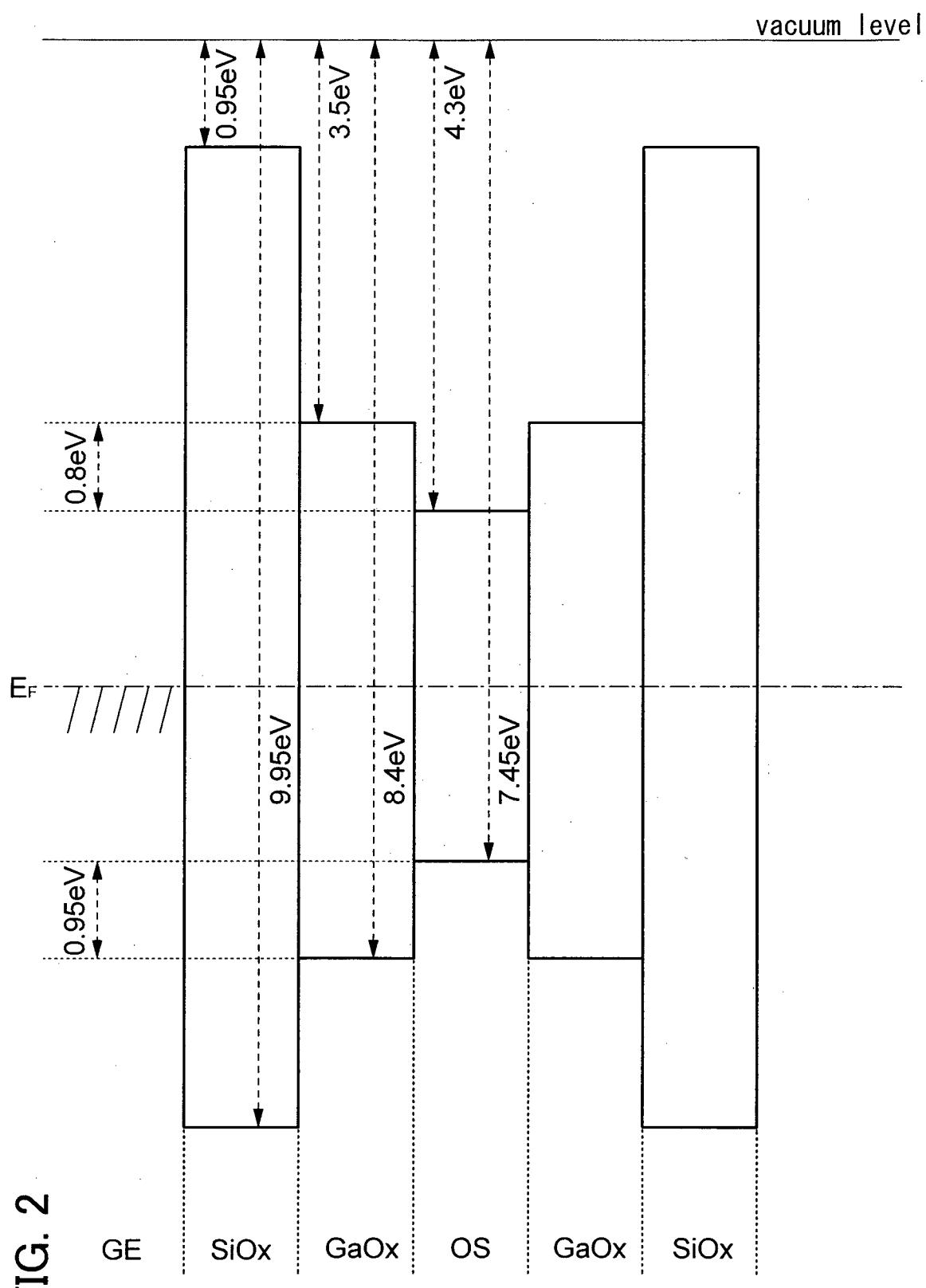
15 11. The semiconductor device according to claim 1,  
wherein side edges of the oxide semiconductor film in a channel length  
direction are aligned with side edges of the first metal oxide film in a channel length  
direction.

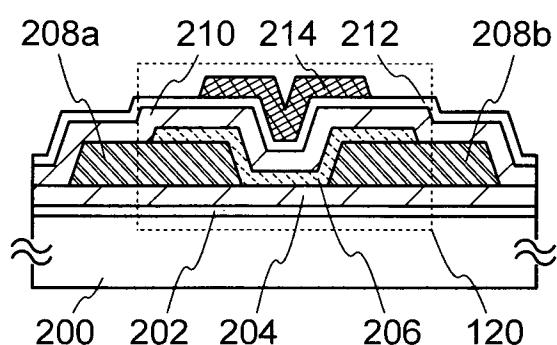
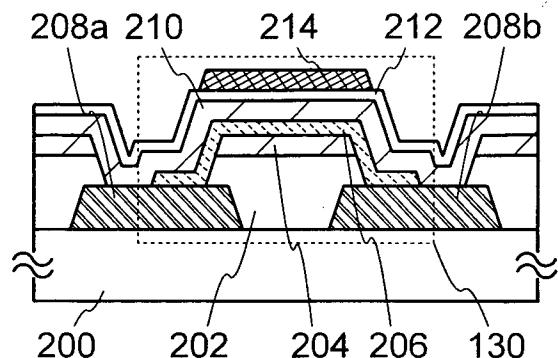
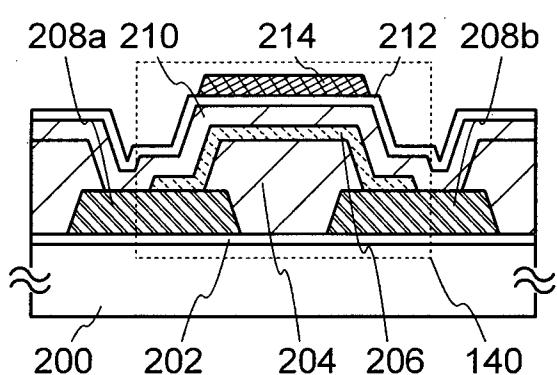
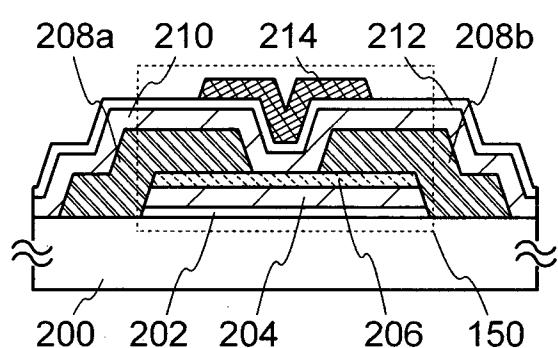
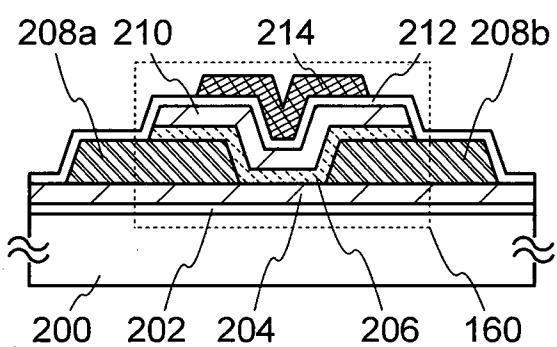
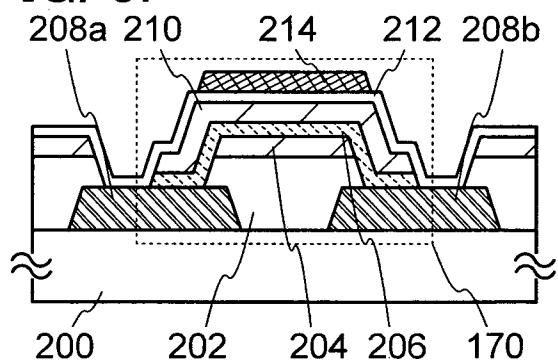
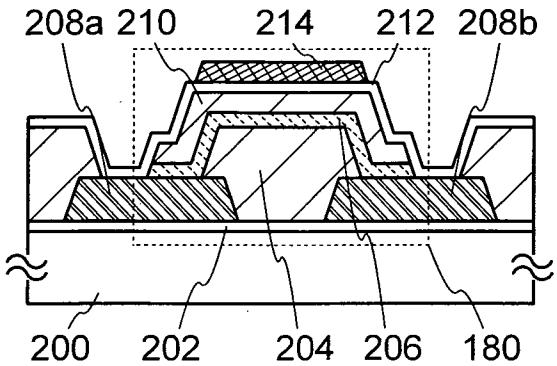
20 12. The semiconductor device according to claim 1,  
wherein side edges of the oxide semiconductor film in a channel length  
direction are aligned with side edges of the second metal oxide film in a channel length  
direction.

25 13. The semiconductor device according to claim 1,  
wherein a first insulating film is provided so as to cover the gate insulating film  
and the gate electrode.

30 14. The semiconductor device according to claim 1,  
wherein a conductive film is provided below the oxide semiconductor film.

**FIG. 1A****FIG. 1B****FIG. 1C**



**FIG. 3A****FIG. 3B****FIG. 3C****FIG. 3D****FIG. 3E****FIG. 3F****FIG. 3G**

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FIG. 4A

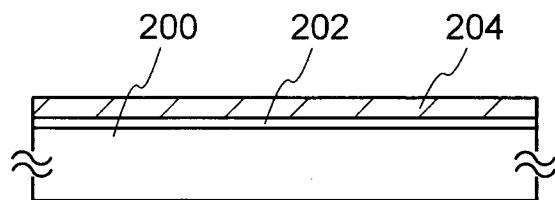


FIG. 4B

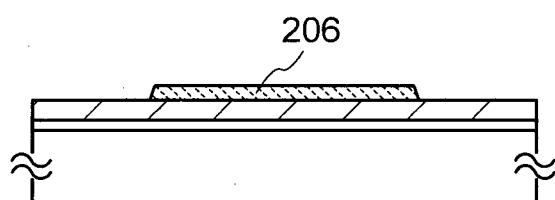


FIG. 4C

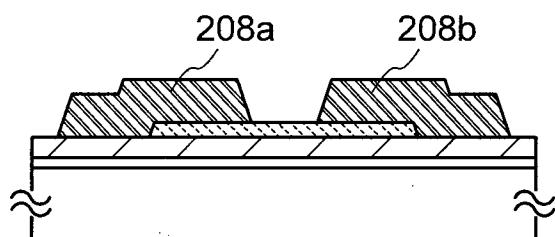


FIG. 4D

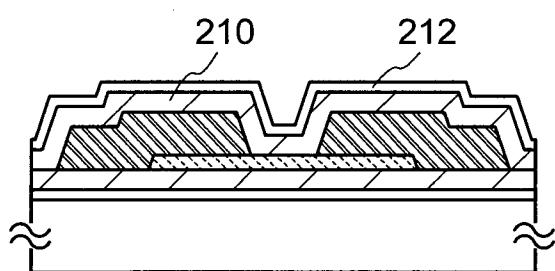
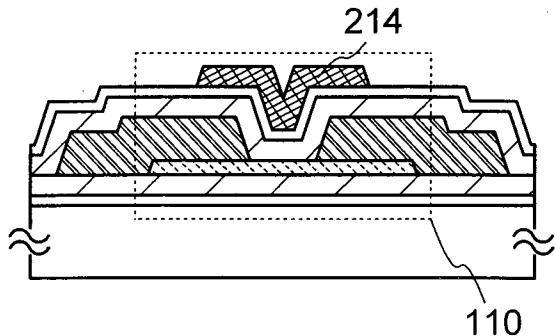


FIG. 4E



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FIG. 5A

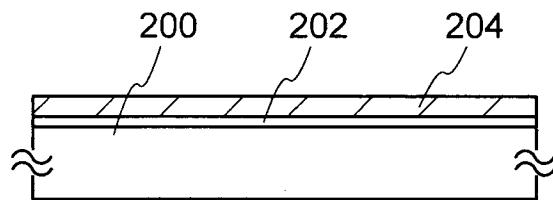


FIG. 5B

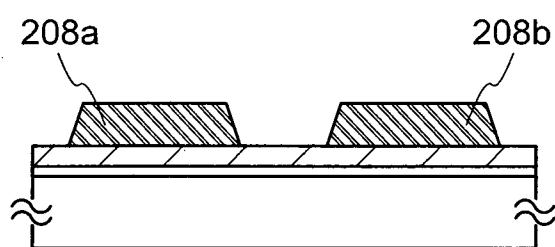


FIG. 5C

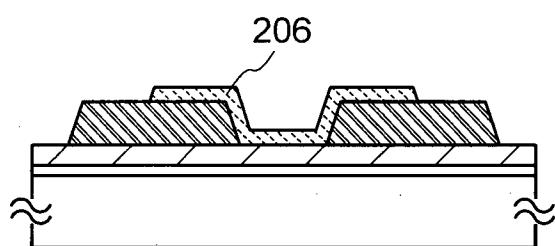


FIG. 5D

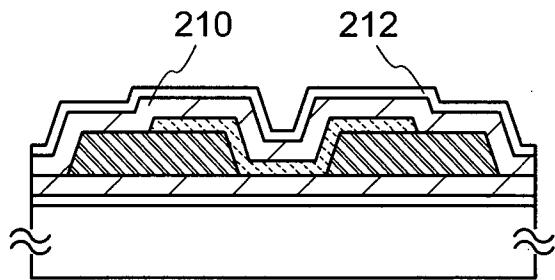
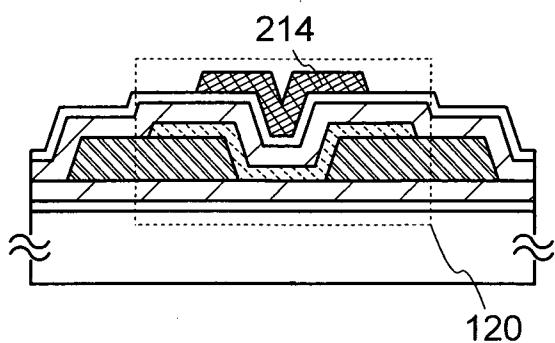


FIG. 5E



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FIG. 6A

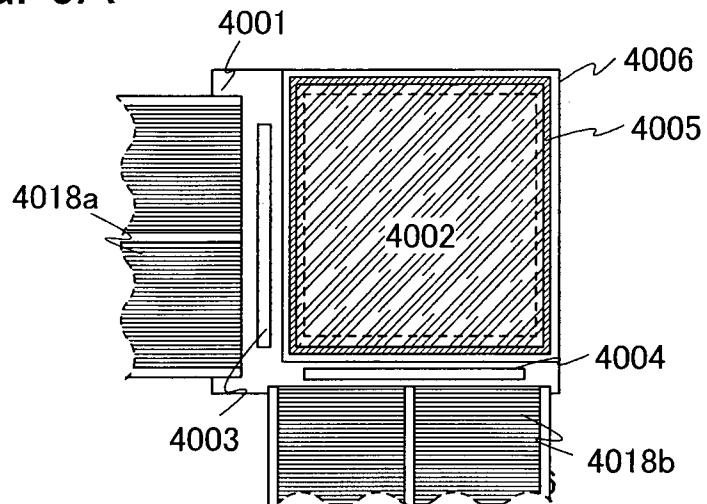


FIG. 6B

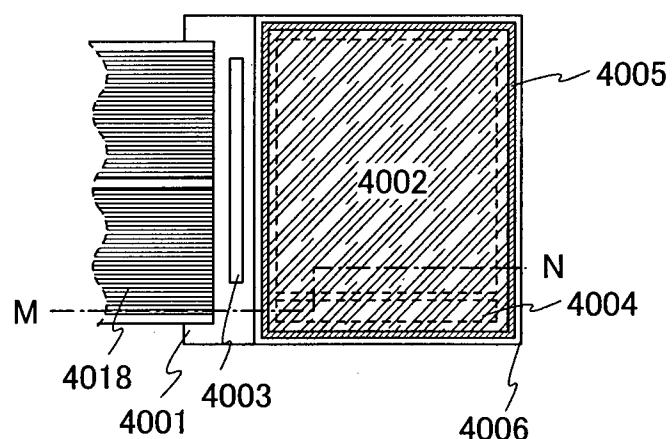
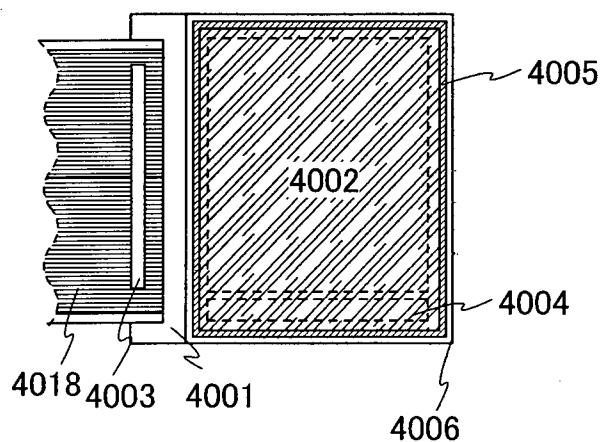


FIG. 6C



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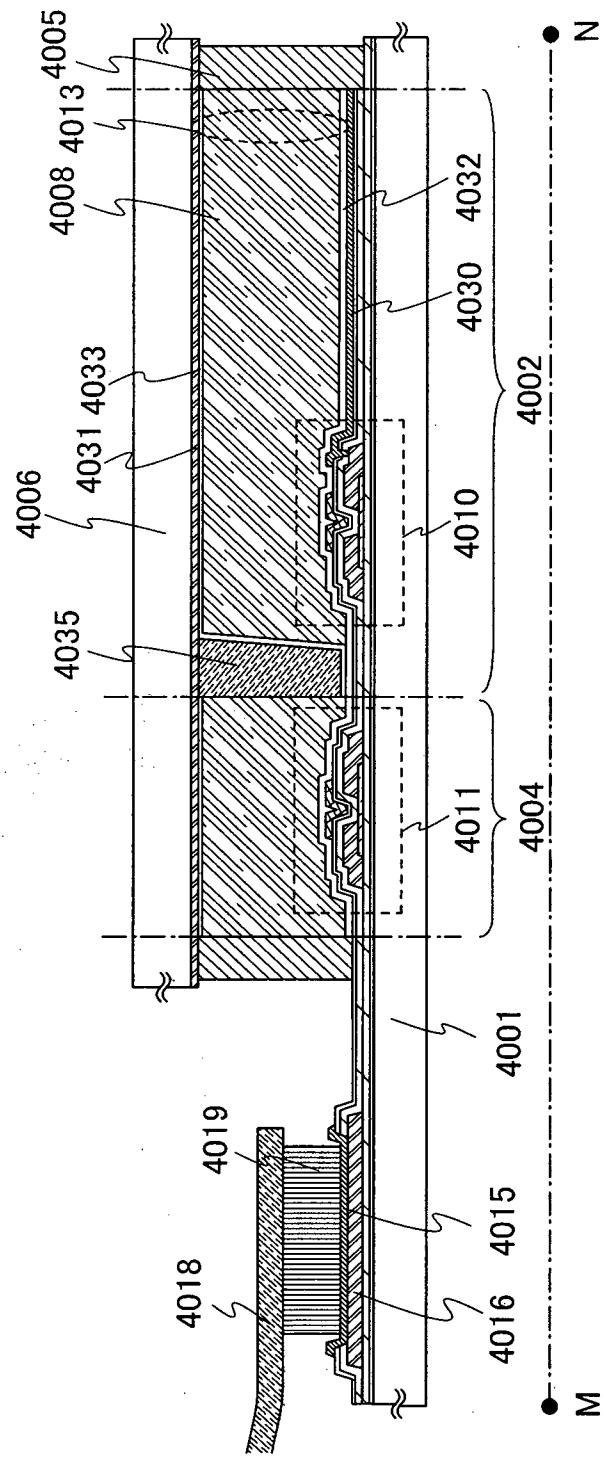
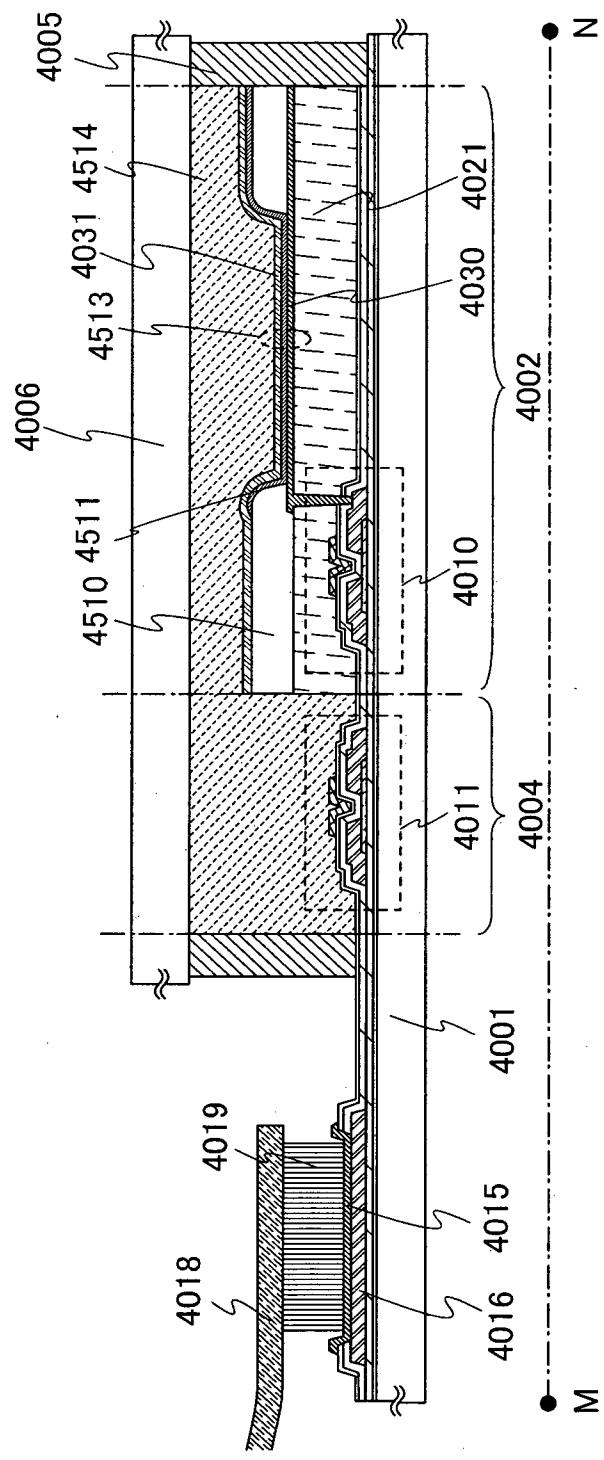


FIG. 7

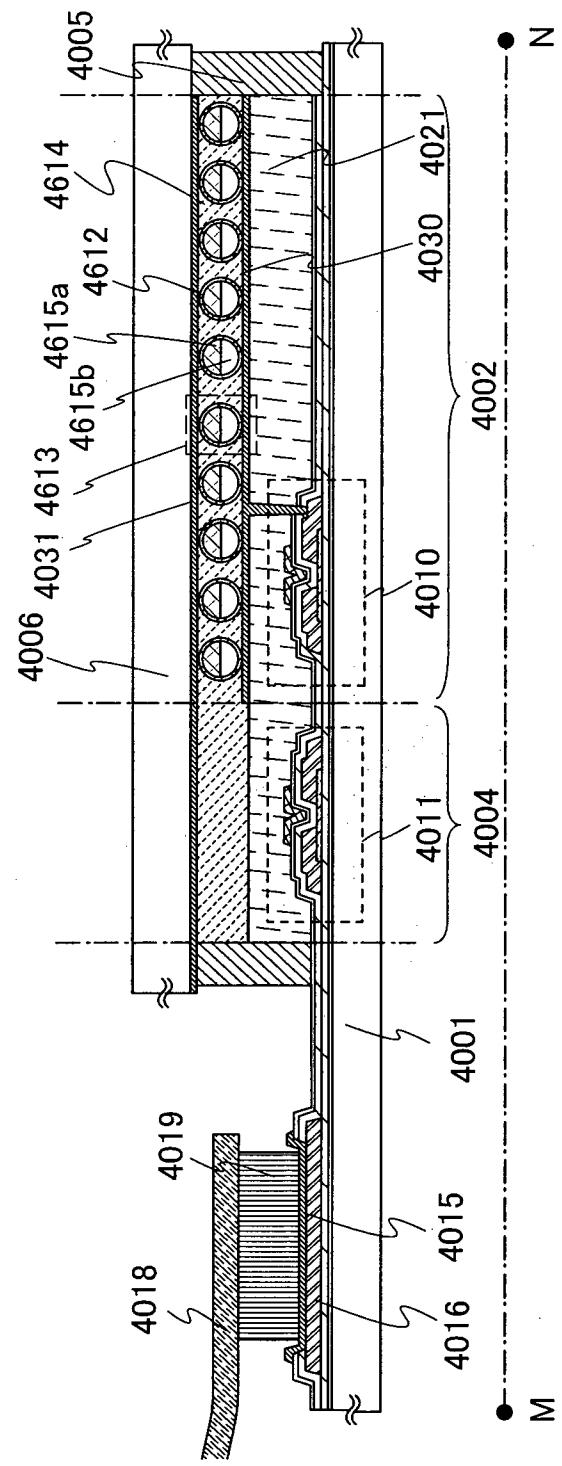
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FIG. 8



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FIG. 9



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FIG. 10A

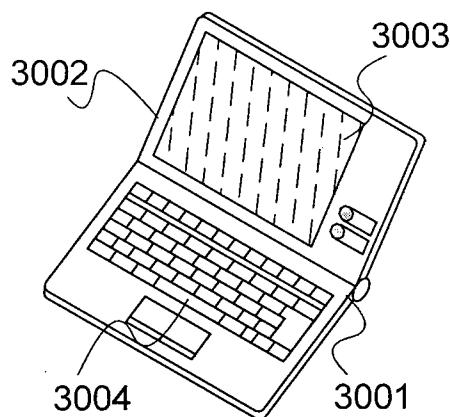


FIG. 10B

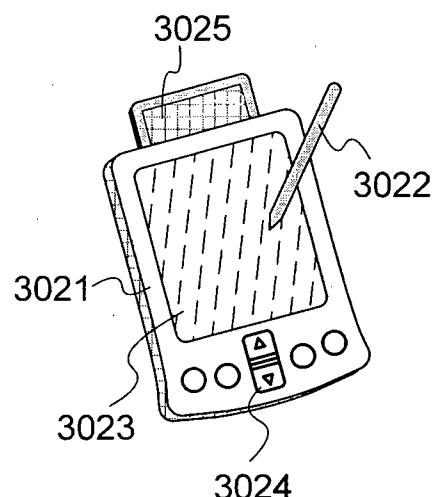


FIG. 10C

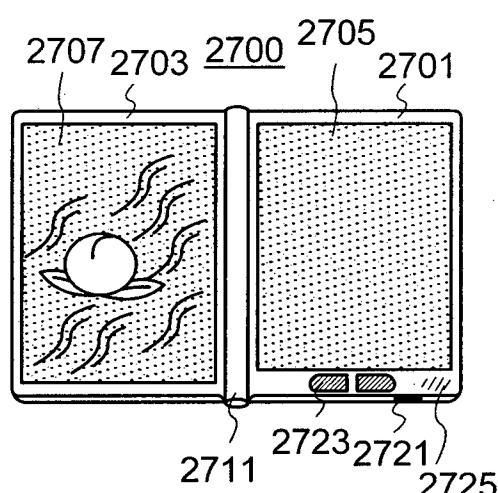


FIG. 10D

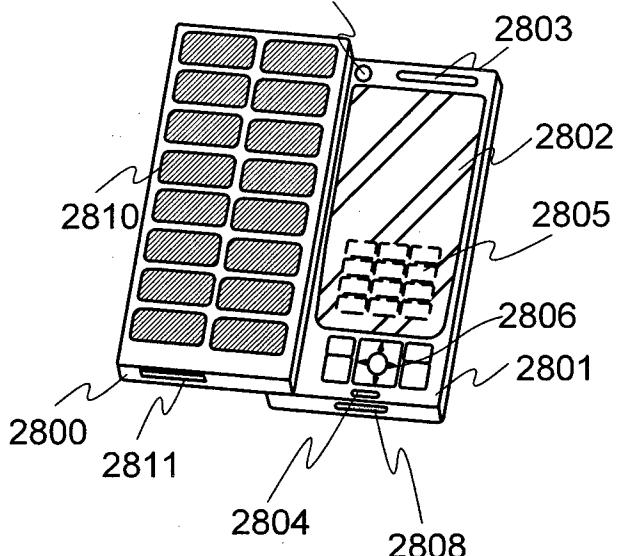


FIG. 10E

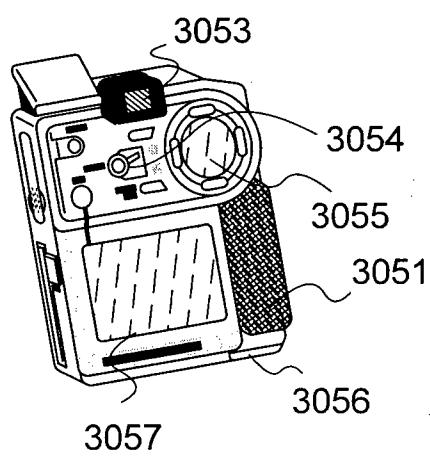
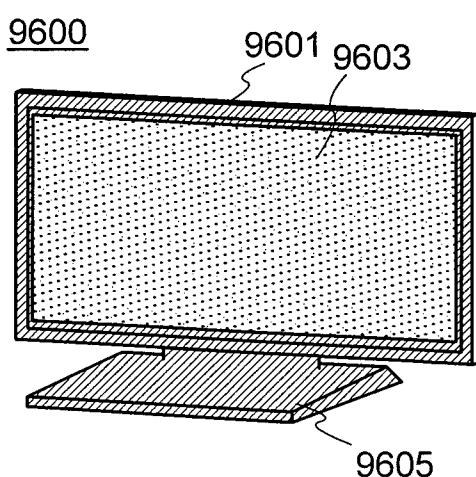


FIG. 10F



## EXPLANATION OF REFERENCE

[0197]

110: transistor, 120: transistor, 130: transistor, 140: transistor, 150: transistor, 160: transistor, 170: transistor, 180: transistor, 200: substrate, 202: insulating film, 204: metal oxide film, 206: oxide semiconductor film, 208a: source electrode, 208b: drain electrode, 210: metal oxide film, 212: gate insulating film, 214: gate electrode, 2700: electronic book reader, 2701: housing, 2703: housing, 2705: display portion, 2707: display portion, 2711: hinge, 2721: power switch, 2723: operation key, 2725: speaker, 2800: housing, 2801: housing, 2802: display panel, 2803: speaker, 2804: microphone, 2805: operation key, 2806: pointing device, 2807: camera lens, 2808: external connection terminal, 2810: solar cell, 2811: external memory slot, 3001: main body, 3002: housing, 3003: display portion, 3004: keyboard, 3021: main body, 3022: stylus, 3023: display portion, 3024: operation button, 3025: external interface, 3051: main body, 3053: eyepiece, 3054: operation switch, 3055: display portion B, 3056: battery, 3057: display portion A, 4001: substrate, 4002: pixel portion, 4003: signal line driver circuit, 4004: scan line driver circuit, 4005: sealant, 4006: substrate, 4008: liquid crystal layer, 4010: transistor, 4011: transistor, 4013: liquid crystal element, 4015: connection terminal electrode, 4016: terminal electrode, 4018: FPC, 4018a: FPC, 4018b: FPC, 4019: anisotropic conductive film, 4021: insulating layer, 4030: electrode layer, 4031: electrode layer, 4032: insulating film, 4033: insulating film, 4035: spacer, 4510: partition wall, 4511: electroluminescent layer, 4513: light-emitting element, 4514: filler, 4612: cavity, 4613: spherical particle, 4614: filler, 4615a: black region, 4615b: white region, 9600: television set, 9601: housing, 9603: display portion, and 9605: stand.

**INTERNATIONAL SEARCH REPORT**

International application No.  
PCT/JP2011/056493

**A. CLASSIFICATION OF SUBJECT MATTER**

Int.Cl. H01L29/786 (2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. H01L29/786

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996  
Published unexamined utility model applications of Japan 1971-2011  
Registered utility model specifications of Japan 1996-2011  
Published registered utility model applications of Japan 1994-2011

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2009/0321732 A1 (Samsung Mobile Display Co., Ltd.) 2009.12.31, Par. Nos. [0036] to [0048] & JP 2010-16347 A & EP 2141744 A1 & KR 10-2010-0002503 A & CN 101621076 A	1-8, 11-14 9, 10
X A	US 2010/0038641 A1 (FUJIFILM CORPORATION) 2010.02.18, Par. Nos. [0054] to [0186] & JP 2010-67954 A	1-8, 11-14 9, 10

Further documents are listed in the continuation of Box C.

See patent family annex.

\* Special categories of cited documents:

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“&” document member of the same patent family

Date of the actual completion of the international search

03.06.2011

Date of mailing of the international search report

14.06.2011

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