



US010720483B2

(12) **United States Patent**
Lee et al.

(10) **Patent No.:** **US 10,720,483 B2**
(45) **Date of Patent:** **Jul. 21, 2020**

(54) **THIN FILM TRANSISTOR ARRAY
SUBSTRATE AND ORGANIC
LIGHT-EMITTING DIODE DISPLAY**

(71) Applicant: **Samsung Display Co., Ltd.**, Yongin-si,
Gyeonggi-do (KR)

(72) Inventors: **Won-Se Lee**, Yongin-si (KR);
Won-Kyu Kwak, Yongin-si (KR);
Se-Ho Kim, Yongin-si (KR)

(73) Assignee: **Samsung Display Co., Ltd.**, Yongin-si
(KR)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 88 days.

(21) Appl. No.: **15/707,884**

(22) Filed: **Sep. 18, 2017**

(65) **Prior Publication Data**
US 2018/0006103 A1 Jan. 4, 2018

Related U.S. Application Data

(63) Continuation of application No. 15/064,526, filed on
Mar. 8, 2016, now Pat. No. 9,768,241, which is a
(Continued)

Foreign Application Priority Data

Sep. 19, 2012 (KR) 10-2012-0104215

(51) **Int. Cl.**
H01L 27/32 (2006.01)
H01L 27/12 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC **H01L 27/3265** (2013.01); **H01L 27/1255**
(2013.01); **H01L 27/3262** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H01L 27/3265; H01L 27/1255
See application file for complete search history.

References Cited

U.S. PATENT DOCUMENTS

6,664,569 B2 12/2003 Moon
7,858,974 B2 12/2010 Yoon et al.
(Continued)

FOREIGN PATENT DOCUMENTS

KR 2001-0111328 12/2001
KR 10-2008-0001106 A 1/2008
(Continued)

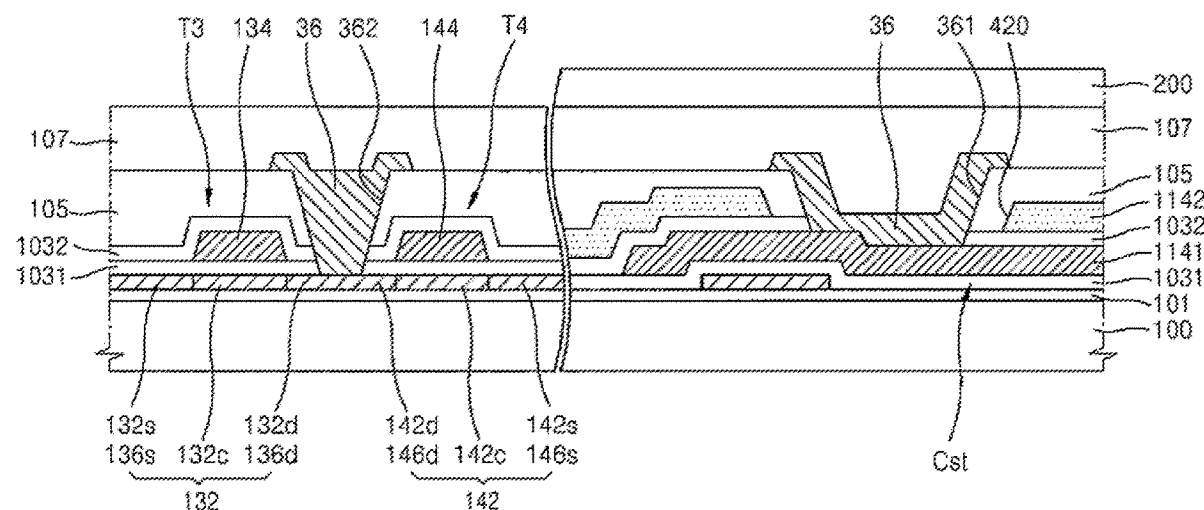
Primary Examiner — Mark V Prenty

(74) *Attorney, Agent, or Firm* — Lewis Roca Rothgerber
Christie LLP

(57) ABSTRACT

A thin film transistor (TFT) array substrate includes: a substrate; a first insulation layer on the substrate; a capacitor including a lower electrode on the first insulation layer, and an upper electrode arranged to overlap with the whole lower electrode and having an opening, and the upper electrode is insulated from the lower electrode by a second insulation layer; an inter-layer insulation film covering the capacitor; a node contact hole in the inter-layer insulation film and the second insulation layer, and within the opening; and a connection node on the inter-layer insulation film and electrically coupling the lower electrode and at least one TFT to each other through the node contact hole.

29 Claims, 7 Drawing Sheets



Related U.S. Application Data

continuation of application No. 13/801,937, filed on
Mar. 13, 2013, now Pat. No. 9,299,730.

(51) **Int. Cl.**

H01L 51/50 (2006.01)

H01L 49/02 (2006.01)

(52) **U.S. Cl.**

CPC **H01L 27/3276** (2013.01); **H01L 51/50**
(2013.01); **H01L 28/40** (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,299,730 B2	3/2016	Lee et al.
9,768,241 B2 *	9/2017	Lee H01L 27/3262
2008/0079005 A1	4/2008	Tseng
2011/0025585 A1	2/2011	Kim et al.
2012/0105388 A1	5/2012	Han et al.
2012/0146004 A1	6/2012	Lee et al.
2013/0063330 A1	3/2013	Eom

FOREIGN PATENT DOCUMENTS

KR	10-2008-0050704 A	6/2008
KR	10-2008-0085411	9/2008
KR	10-2011-0012710	2/2011
KR	10-2011-0113040	10/2011
KR	10-2012-0044657	5/2012
KR	10-2012-0066491 A	6/2012

* cited by examiner

FIG. 1

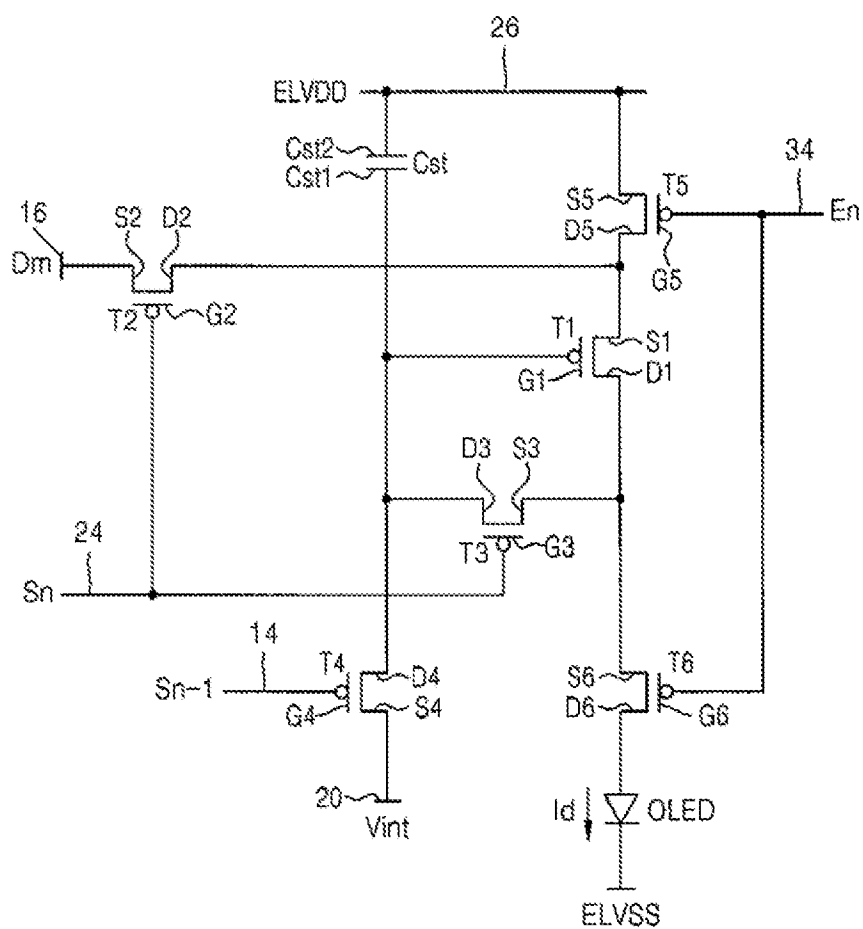


FIG. 2

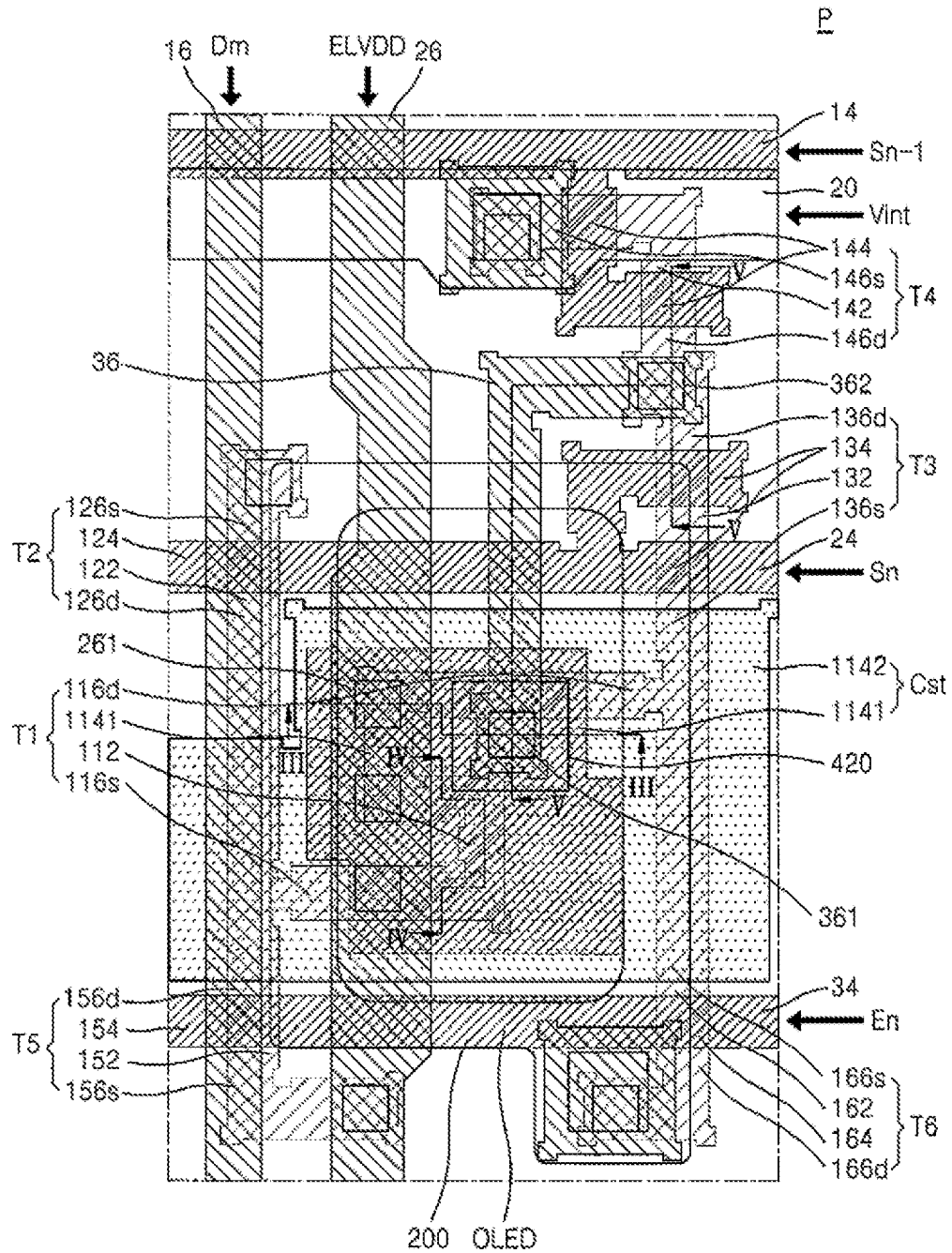


FIG. 4

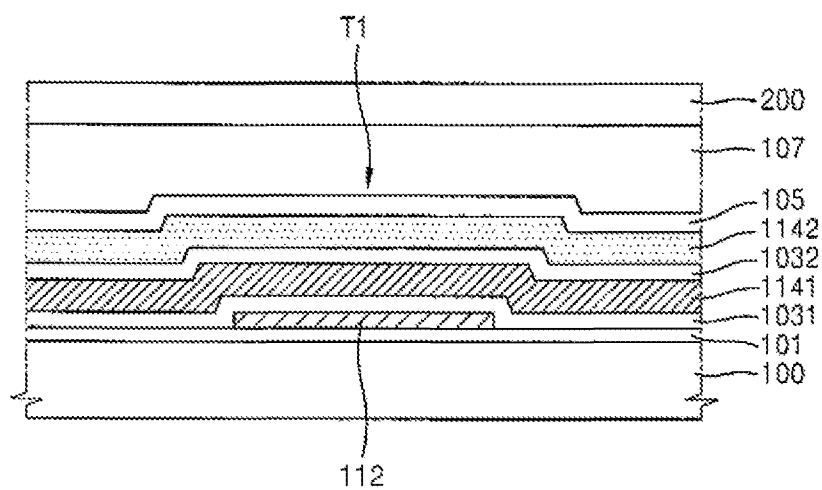


FIG. 5

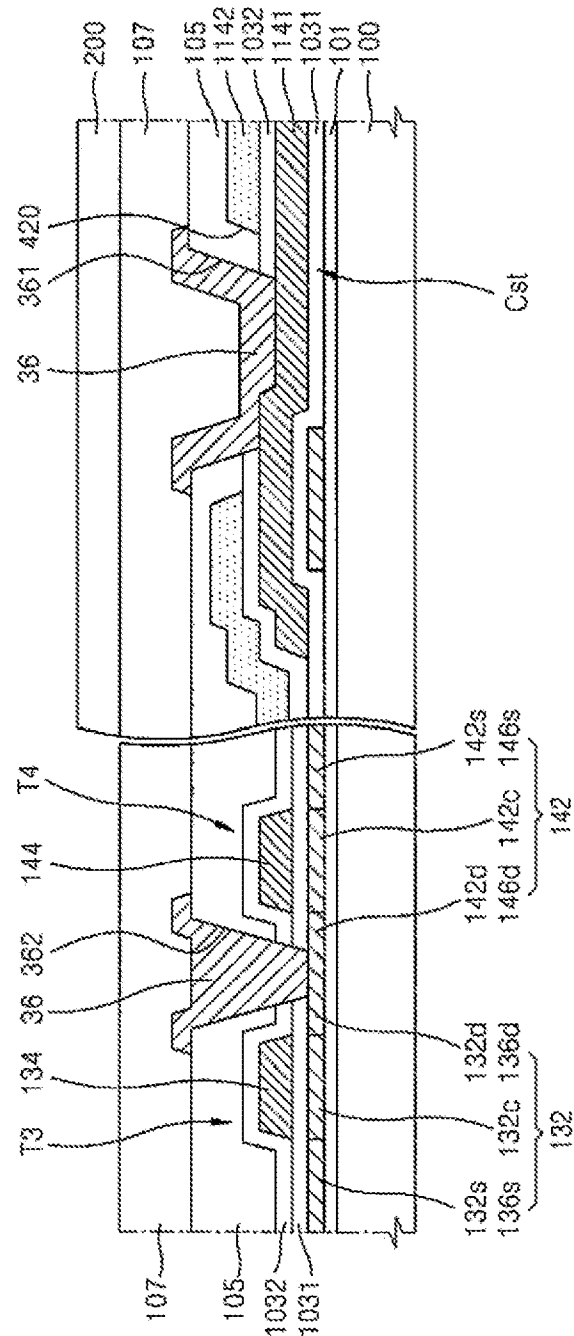
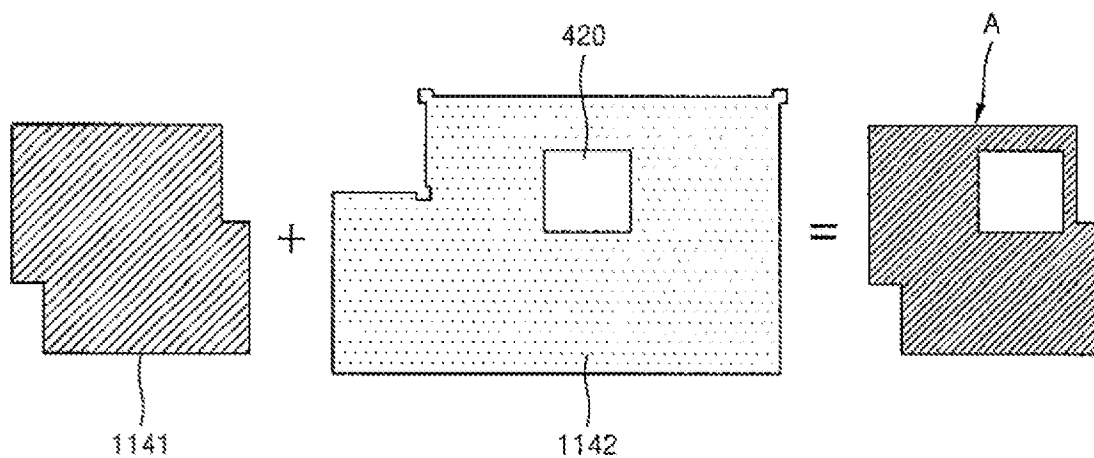


FIG. 6



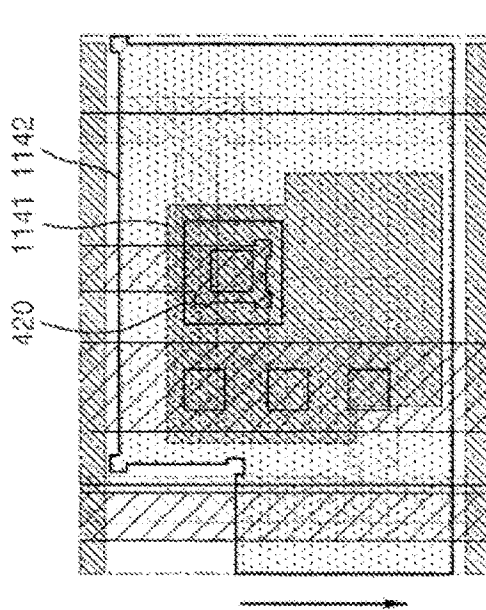


FIG. 7B

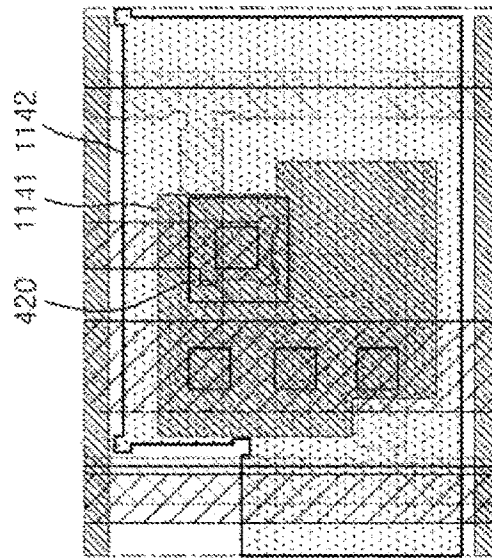


FIG. 7D

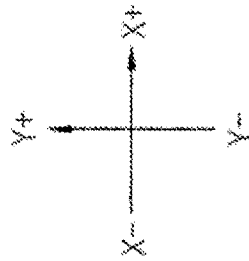
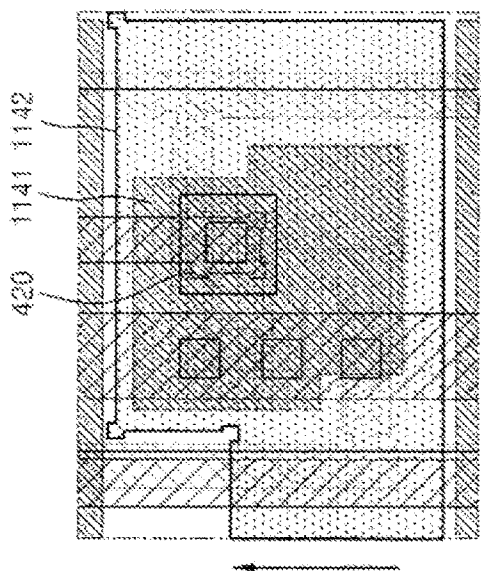


FIG. 7A

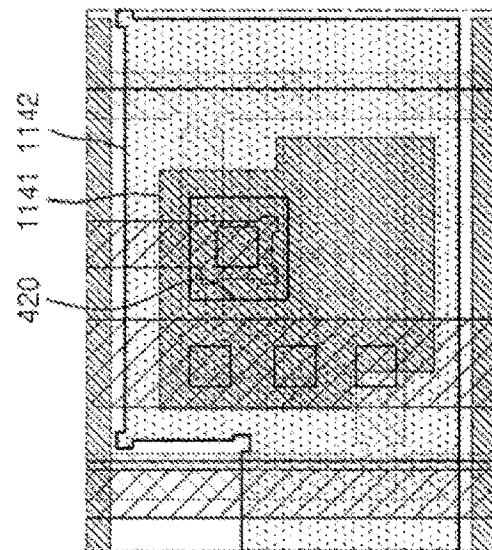


FIG. 7C

1

THIN FILM TRANSISTOR ARRAY SUBSTRATE AND ORGANIC LIGHT-EMITTING DIODE DISPLAY

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. application Ser. No. 15/064,526, filed Mar. 8, 2016, which is a continuation of U.S. application Ser. No. 13/801,937, filed Mar. 13, 2013, now U.S. Pat. No. 9,299,730, which claims priority to and the benefit of Korean Patent Application No. 10-2012-0104215, filed on Sep. 19, 2012, in the Korean Intellectual Property Office, the entire contents of all of which are incorporated herein by reference.

BACKGROUND

1. Field

Embodiments of the present invention relate to a thin film transistor (TFT) array substrate including at least one TFT and one storage capacitor, and an organic light-emitting diode (OLED) display.

2. Description of Related Art

An organic light-emitting diode (OLED) display may include two electrodes and an organic light-emitting layer interposed therebetween, wherein electrons injected from one electrode and holes injected from the other electrode are combined to form excitons that release energy, thereby emitting light.

Such an OLED display may also include a plurality of pixels, each pixel including an OLED, which is a self light-emitting device, a plurality of thin film transistors (TFTs), and a capacitor for driving the OLED.

The capacitor may include lower and upper electrodes and a dielectric interposed therebetween. Each electrode may be patterned through a photolithography process after a conductive layer is formed on the whole surface of a substrate. In a system in which a great number of large-sized panels are manufactured at the same time, a misalignment may occur between a substrate and a mask or a light exposure device within a tolerance (or tolerance level) of process equipment during a patterning process. Contrary to an intention of the design, an overlay deviation may occur between both of the electrodes of the capacitor due to the misalignment. Due to the overlay deviation, a capacitance may be generated that is different from a designed value, thereby resulting in low-gradation spots, abnormal colors, or the like.

SUMMARY

Aspects of embodiments of the present invention provide a thin film transistor (TFT) array substrate including a storage capacitor structure for maintaining a capacitance to be substantially constant even though an overlay deviation occurs, and an organic light-emitting diode (OLED) display employing the same.

According to an aspect of the present invention, a TFT array substrate includes: a substrate; a first insulation layer on the substrate; a capacitor including a lower electrode on the first insulation layer, and an upper electrode arranged to overlap with the whole lower electrode and having an opening, and the upper electrode is insulated from the lower electrode by a second insulation layer; an inter-layer insu-

2

lation film covering the capacitor; a node contact hole in the inter-layer insulation film and the second insulation layer, and within the opening; and a connection node on the inter-layer insulation film and electrically coupling the lower electrode and at least one TFT to each other through the node contact hole.

The opening may overlap with the lower electrode.

The upper electrode may be configured to receive a driving voltage through a driving voltage line formed from the same layer as the connection node.

The driving voltage line may be coupled to the upper electrode through another contact hole in the inter-layer insulation film.

The TFT array substrate may further include a driving TFT arranged to overlap with the capacitor. A driving gate electrode of the driving TFT may include the lower electrode.

The at least one TFT may include a compensation TFT coupled to the driving TFT and electrically coupled to the lower electrode through the connection node, and the compensation TFT may be configured to compensate for a threshold voltage of the driving TFT.

A compensation gate electrode of the compensation TFT may be formed from the same layer as the lower electrode.

The at least one TFT may include an initialization TFT electrically coupled to the lower electrode through the connection node, and the initialization TFT may be configured to provide an initialization voltage to the driving gate electrode of the driving TFT by being turned on in response to a previous scan signal.

An initialization gate electrode of the initialization TFT may be formed from the same layer as the lower electrode.

According to another aspect of the present invention, an OLED display includes: a substrate; a first insulation layer on the substrate; a scan line on the first insulation layer and configured to deliver a scan signal; a data line and a driving voltage line crossing the scan line, the data line and the driving voltage line being insulated by a second insulation layer and an inter-layer insulation film and configured to respectively deliver a data signal and a driving voltage; a pixel circuit coupled to the scan line and the data line and including at least one thin film transistor (TFT) and a capacitor; an OLED for emitting light by receiving the driving voltage from the pixel circuit, and the capacitor includes a lower electrode on the first insulation layer, and an upper electrode arranged to overlap with the whole lower electrode and having an opening, and the upper electrode is insulated from the lower electrode by the second insulation layer; a node contact hole in the inter-layer insulation film and the second insulation layer, and within the opening; and a connection node on the inter-layer insulation film and electrically coupling the lower electrode and the at least one TFT to each other through the node contact hole.

The opening may overlap with the lower electrode.

The upper electrode may be configured to receive a driving voltage through a driving voltage line formed from the same layer as the connection node.

The driving voltage line may be coupled to the upper electrode through another contact hole in the inter-layer insulation film.

The OLED display may further include a driving TFT arranged to overlap with the capacitor. A driving gate electrode of the driving TFT may include the lower electrode.

The at least one TFT may include a compensation TFT coupled to the driving TFT and electrically coupled to the lower electrode through the connection node, and the com-

3

compensation TFT may be configured to compensate for a threshold voltage of the driving TFT.

A compensation gate electrode of the compensation TFT may be formed from the same layer as the lower electrode.

The at least one TFT may include an initialization TFT electrically coupled to the lower electrode through the connection node, and the initialization TFT may be configured to provide an initialization voltage to the driving gate electrode of the driving TFT by being turned on in response to a previous scan signal.

An initialization gate electrode of the initialization TFT may be formed from the same layer as the lower electrode.

The OLED display may further include a switching TFT for delivering the data signal to the driving TFT by being turned on by the scan signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and aspects of the present invention will become more apparent by describing in detail exemplary embodiments thereof with reference to the attached drawings in which:

FIG. 1 is an equivalent circuit diagram of one pixel in an organic light-emitting diode (OLED) display according to an embodiment of the present invention;

FIG. 2 is a top view of the pixel in the OLED display of FIG. 1;

FIG. 3 is a cross-sectional view through line of FIG. 2;

FIG. 4 is a cross-sectional view through line W-W of FIG. 2;

FIG. 5 is a cross-sectional view through line V-V of FIG. 2;

FIG. 6 is a top view schematically showing an overlapping region of a storage capacitor in the pixel of FIG. 2; and

FIGS. 7A to 7D are top views showing cases where an overlay deviation occurs between both electrodes of the storage capacitor in the pixel of FIG. 2.

DETAILED DESCRIPTION

Embodiments of the present invention will be described in detail with reference to the attached drawings, so that one of ordinary skill in the art may implement the spirit and scope of the present invention. The present invention can be implemented in various different forms and is not limited to the embodiments described below.

Parts irrelevant to the description may have been omitted to more clearly describe the present invention, and like reference numerals denote like elements throughout the specification.

In addition, since the sizes and thicknesses of components in the drawings are arbitrarily shown for convenience of description, the present invention is not necessarily limited to the shown sizes and thicknesses.

In the drawings, the thicknesses of layers and regions are magnified for clarity. In addition, the thicknesses of some layers and regions are exaggerated for convenience of description. When it is described that a certain component, such as a layer, a film, a region, or a plate, is “above” or “on” another component, the certain component may be directly above another component, or a third component may be interposed therebetween.

In the specification, when a certain part “includes” a certain component, this indicates that the part may further include another component instead of excluding another component unless there is no different disclosure. In addition, the term “on” indicates that a certain part is located

4

above or below another part and does not necessarily indicate that the certain part is located above another part based on a direction of gravity.

As used herein, expressions such as “at least one of,” when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

An organic light-emitting diode (OLED) display according to an embodiment will now be described in detail with reference to FIGS. 1 to 5.

FIG. 1 is an equivalent circuit diagram of one pixel in an OLED display according to an embodiment of the present invention.

As shown in FIG. 1, the pixel in the OLED display includes a plurality of lines (or signal lines) 14, 24, 34, 16, 26, and 20 and a pixel circuit, which includes a plurality of thin film transistors (TFTs) T1, T2, T3, T4, T5, and T6 that are coupled to the plurality of signal lines 14, 24, 34, 16, 26, and 20 and a storage capacitor Cst. In addition, the pixel further includes an OLED for emitting light by receiving a driving voltage from the pixel circuit.

The plurality of TFTs T1, T2, T3, T4, T5, and T6 includes a driving TFT T1, a switching TFT T2, a compensation TFT T3, an initialization TFT T4, an operation control TFT T5, and a light-emitting control TFT T6.

The plurality of lines 14, 24, 34, 16, 26, and 20 includes a scan line 24 for delivering a scan signal Sn, a previous scan line 14 for delivering a previous scan signal Sn-1, a light-emitting control line 34 for delivering a light-emitting control signal En to the operation control TFT T5 and the light-emitting control TFT T6, a data line 16, which crosses the scan line 24 and delivers a data signal Dm, a driving voltage line 26, which delivers a driving voltage ELVDD and is formed to be almost parallel to the data line 16, and an initialization voltage line 20 for delivering an initialization voltage Vint for initializing the driving TFT T1.

A gate electrode G1 of the driving TFT T1 is coupled to one electrode Cst1 of the storage capacitor Cst, a source electrode S1 thereof is coupled to the driving voltage line 26 via the operation control TFT T5, and a drain electrode D1 thereof is electrically coupled to an anode of the OLED via the light-emitting control TFT T6. In response to a switching operation of the switching TFT T2, the driving TFT T1 receives the data signal Dm and provides a driving current Id to the OLED.

A gate electrode G2 of the switching TFT T2 is coupled to the scan line 24, a source electrode S2 thereof is coupled to the data line 16, and a drain electrode D2 thereof is coupled to the source electrode S1 of the driving TFT T1 and is also coupled to the driving voltage line 26 via the operation control TFT T5. The switching TFT T2 performs a switching operation for delivering the data signal Dm received through the data line 16 to the source electrode S1 of the driving TFT T1 by being turned on in response to the scan signal Sn received through the scan line 24.

A gate electrode G3 of the compensation TFT T3 is coupled to the scan line 24, a source electrode S3 thereof is coupled to the drain electrode D1 of the driving TFT T1 and is also coupled to the anode of the OLED via the light-emitting control TFT T6, and a drain electrode D3 thereof is coupled to the one electrode Cst1 of the storage capacitor Cst, a drain electrode D4 of the initialization TFT T4, and the gate electrode G1 of the driving TFT T1. The compensation TFT T3 couples the gate electrode G1 and the drain electrode D1 of the driving TFT T1 to each other by being turned on in response to the scan signal Sn received through the scan line 24 so that the driving TFT T1 is diode-coupled.

5

A gate electrode G4 of the initialization TFT T4 is coupled to the previous scan line 14, a source electrode S4 thereof is coupled to the initialization voltage line 20, and the drain electrode D4 thereof is coupled to the one electrode Cst1 of the storage capacitor Cst, the drain electrode D3 of the compensation TFT T3, and the gate electrode G1 of the driving TFT T1. The initialization TFT T4 delivers the initialization voltage Vint to the gate electrode G1 of the driving TFT T1 by being turned on in response to the previous scan signal Sn-1 received through the previous scan line 14 to perform an initialization operation for initializing a voltage of the gate electrode G1 of the driving TFT T1.

A gate electrode G5 of the operation control TFT T5 is coupled to the light-emitting control line 34, a source electrode S5 thereof is coupled to the driving voltage line 26, and a drain electrode D5 thereof is coupled to the source electrode S1 of the driving TFT T1 and the drain electrode D2 of the switching TFT T2.

A gate electrode G6 of the light-emitting control TFT T6 is coupled to light-emitting control line 34, a source electrode S6 thereof is coupled to the drain electrode D1 of the driving TFT T1 and the source electrode S3 of the compensation TFT T3, and a drain electrode D6 thereof is electrically coupled to the anode of the OLED. The operation control TFT T5 and the light-emitting control TFT T6 are concurrently (e.g., simultaneously) turned on in response to the light-emitting control signal En received through the light-emitting control line 34 to deliver the driving voltage ELVDD to the OLED so that the driving current Id flows through the OLED.

The other electrode Cst 2 of the storage capacitor Cst is coupled to the driving voltage line 26. The one electrode Cst1 of the storage capacitor Cst is coupled to the gate electrode G1 of the driving TFT T1, the drain electrode D3 of the compensation TFT T3, and the drain electrode D4 of the initialization TFT T4 via a connection node.

A cathode of the OLED is coupled to a common voltage ELVSS. Accordingly, the OLED emits light by receiving the driving current Id from the driving TFT T1 so that an image is displayed.

An operation of the pixel in the OLED display of FIG. 1 will now be described in detail.

During an initialization period, the previous scan signal Sn-1 at a low level is provided through the previous scan line 14. In response to the previous scan signal Sn-1 at a low level, the initialization TFT T4 is turned on, thereby providing the initialization voltage Vint to the gate electrode G1 of the driving TFT T1 via the initialization TFT T4 through the initialization voltage line 20. The driving TFT T1 is initialized by the initialization voltage Vint.

During a data programming period, the scan signal Sn at a low level is supplied through the scan line 24. In response to the scan signal Sn, the switching TFT T2 and the compensation TFT T3 are turned on.

Due to the turn-on state of the compensation TFT T3, the driving TFT T1 is diode-coupled and biased in a forward direction.

In this case, a compensation voltage $Dm + V_{th}$ (V_{th} has a negative value) obtained by subtracting a threshold voltage V_{th} of the driving TFT T1 from the data signal Dm input through the data line 16 is applied to the gate electrode G1 of the driving TFT T1.

Then, the driving voltage ELVDD and the compensation voltage $Dm + V_{th}$ are applied to both of the electrodes of the storage capacitor Cst, thereby storing charges corresponding to a voltage difference between both of the electrodes of the

6

storage capacitor Cst in the storage capacitor Cst. During a light-emitting period, the light-emitting control signal En provided through the light-emitting control line 34 is changed from a high level to a low level, thereby turning on the operation control TFT T5 and the light-emitting control TFT T6.

Then, the driving current Id is generated due to a voltage difference between a voltage at the gate electrode G1 of the driving TFT T1 and the driving voltage ELVDD and is supplied to the OLED through the light-emitting control TFT T6. During the light-emitting period, a gate-source voltage Vgs of the driving TFT T1 is maintained as $(Dm + V_{th}) - ELVDD$ by the storage capacitor Cst, and according to a current-voltage relationship of the driving TFT T1, the driving current Id is determined regardless of the threshold voltage Vth of the driving TFT T1.

A structure of the pixel in the OLED display of FIG. 1 will now be described in detail with reference to FIGS. 2 to 5, which are based on FIG. 1. FIG. 2 is a top view of a pixel P in the OLED display of FIG. 1. FIG. 3 is a cross-sectional view through the line III-III of FIG. 2. FIG. 4 is a cross-sectional view through the line IV-IV of FIG. 2. FIG. 5 is a cross-sectional view through the line V-V of FIG. 2.

As shown in FIGS. 2 to 5, according to an embodiment, the pixel P in the OLED display includes the scan line 24, the previous scan line 14, the light-emitting control line 34, and the initialization voltage line 20, which apply the scan signal Sn, the previous scan signal Sn-1, the light-emitting control signal En, and the initialization voltage Vint, respectively, along a row direction, and includes the data line 16 and the driving voltage line 26, which cross each of the scan line 24, the previous scan line 14, the light-emitting control line 34, and the initialization voltage line 20, and apply the data signal Dm and the driving voltage ELVDD, respectively.

In addition, the pixel P includes the driving TFT T1, the switching TFT T2, the compensation TFT T3, the initialization TFT T4, the operation control TFT T5, the light-emitting control TFT T6, the storage capacitor Cst, and the OLED.

The driving TFT T1, the switching TFT T2, the compensation TFT T3, the initialization TFT T4, the operation control TFT T5, and the light-emitting control TFT T6 are formed along semiconductor layers 112, 122, 132, 142, 152, and 162, which are formed bent in various shapes, respectively. Each of the semiconductor layers 112, 122, 132, 142, 152, and 162 is formed of polysilicon. Each of the semiconductor layers 112, 122, 132, 142, 152, and 162 includes a channel region not doped with impurities, and a source region and a drain region, doped with impurities, formed at both sides of the channel region. The impurities vary according to types of the TFTs and may include N-type impurities and/or P-type impurities.

The semiconductor layers 112, 122, 132, 142, 152, and 162 include a driving semiconductor layer 112 formed in the driving TFT T1, a switching semiconductor layer 122 formed in the switching TFT T2, a compensation semiconductor layer 132 formed in the compensation TFT T3, an initialization semiconductor layer 142 formed in the initialization TFT T4, an operation control semiconductor layer 152 formed in the operation control TFT T5, and a light-emitting control semiconductor layer 162 formed in the light-emitting control TFT T6.

The driving TFT T1 includes the driving semiconductor layer 112, a driving gate electrode 1141, a driving source electrode 116s, and a driving drain electrode 116d. The driving semiconductor layer 112 is bent. The driving source

7

electrode **116s** corresponds to a driving source region **116s** doped with impurities in the driving semiconductor layer **112**, and the driving drain electrode **116d** corresponds to a driving drain region **116d** doped with impurities in the driving semiconductor layer **112**. The storage capacitor **Cst** is formed on the driving TFT **T1** to overlap with the driving TFT **T1**.

The storage capacitor **Cst** includes lower and upper electrodes **1141** and **1142** with a second gate insulation film **1032** interposed therebetween. The driving gate electrode **1141** also functions as the lower electrode **1141**. That is, the driving gate electrode **1141** includes the lower electrode **1141**. The second gate insulation film **1032** is formed of a dielectric, and a storage capacitance is determined by charges accumulated in the storage capacitor **Cst** and a voltage between the lower and upper electrodes **1141** and **1142**.

According to an embodiment, the lower electrode **1141** is formed as a floating electrode having an island shape and is formed of the same material layers as the scan line **24**, the previous scan line **14**, the light-emitting control line **34**, a switching gate electrode **124**, a compensation gate electrode **134**, an initialization gate electrode **144**, an operation control gate electrode **154**, and a light-emitting control gate electrode **164**.

The upper electrode **1142** may be formed on the second gate insulation film **1032** as a floating electrode having an island shape. In one embodiment, the upper electrode **1142** is arranged to overlap with the whole lower electrode **1141** and has a storage opening **420**. The storage opening **420** may have a shape of a simple closed curve penetrating the upper electrode **1142**. According to one embodiment, the simple closed curve refers to a closed figure in which a start point and an end point are the same when the closed curve is traced from the start point of the traced curve to draw a polygon, a circle, or the like. The upper electrode **1142** having the storage opening **420** may have a doughnut shape.

According to an embodiment of the present invention, by using the storage capacitor **Cst** including the upper electrode **1142**, which overlaps with the whole lower electrode **1141** and has the storage opening **420** having a simple closed curve, even though an overlay deviation occurs between the lower electrode **1141** and the upper electrode **1142** during a method of manufacturing the OLED display, the capacitance of the storage capacitor **Cst** may be maintained (e.g., always be maintained) to be substantially constant. This feature will be described in detail below with reference to FIGS. **6** and **7**.

The switching TFT **T2** includes the switching semiconductor layer **122**, the switching gate electrode **124**, a switching source electrode **126s**, and a switching drain electrode **126d**. The switching source electrode **126s** protrudes from the data line **16**, and the switching drain electrode **126d** corresponds to a switching drain region **126d** doped with impurities in the switching semiconductor layer **122**.

The compensation TFT **T3** includes the compensation semiconductor layer **132**, the compensation gate electrode **134**, a compensation source electrode **136s**, and a compensation drain electrode **136d**, wherein the compensation source electrode **136s** corresponds to a compensation source region **136s** doped with impurities in the compensation semiconductor layer **132**, and the compensation drain electrode **136d** corresponds to a compensation drain region **136d** doped with impurities in the compensation semiconductor layer **132**. The compensation drain electrode **136d** may be coupled to the lower electrode **1141** via a connection node

8

36. In one embodiment, the compensation gate electrode **134** prevents a leakage current by forming a separate dual gate electrode.

The initialization TFT **T4** includes the initialization semiconductor layer **142**, the initialization gate electrode **144**, an initialization source electrode **146s**, and an initialization drain electrode **146d**. The initialization drain electrode **146d** corresponds to an initialization drain region **146d** doped with impurities in the initialization semiconductor layer **142**. The initialization drain electrode **146d** may be coupled to the lower electrode **1141** via the connection node **36**. The initialization source electrode **146s** may be coupled to the initialization voltage line **20** via a connection member.

The operation control TFT **T5** includes the operation control semiconductor layer **152**, the operation control gate electrode **154**, an operation control source electrode **156s**, and an operation control drain electrode **156d**. The operation control source electrode **156s** is a portion of the driving voltage line **26**, and the operation control drain electrode **156d** corresponds to an operation control drain region **156d** doped with impurities in the operation control semiconductor layer **152**.

The light-emitting control TFT **T6** includes the light-emitting control semiconductor layer **162**, the light-emitting control gate electrode **164**, a light-emitting control source electrode **166s**, and a light-emitting control drain electrode **166d**. The light-emitting control source electrode **166s** corresponds to a light-emitting control source region **166s** doped with impurities in the light-emitting control semiconductor layer **162**, and the light-emitting control drain electrode **166d** may be coupled to a pixel electrode **200** via a connection member.

According to one embodiment, one end of the driving semiconductor layer **112** of the driving TFT **T1** is coupled to the switching semiconductor layer **122** and the operation control semiconductor layer **152**, and the other end thereof is coupled to the compensation semiconductor layer **132** and the light-emitting control semiconductor layer **162**. Thus, the driving source electrode **116s** is coupled to the switching drain electrode **126d** and the operation control drain electrode **156d**, and the driving drain electrode **116d** is coupled to the compensation source electrode **136s** and the light-emitting control source electrode **166s**.

The lower electrode **1141** of the storage capacitor **Cst** may be coupled to the compensation TFT **T3** and the initialization TFT **T4** via the connection node **36**. The connection node **36** may be formed in the same layer as the data line **16**. One end of the connection node **36** may be coupled to the lower electrode **1141** via a first node contact hole **361** formed in the second gate insulation film **1032** and an inter-layer insulation film **105**. The first node contact hole **361** may be formed within the storage opening **420** of the upper electrode **1142**. The other end of the connection node **36** may be coupled to the compensation drain electrode **136d** and the initialization drain electrode **146d** via a second node contact hole **362** formed in a first gate insulation film **1031**, the second gate insulation film **1032**, and the inter-layer insulation film **105**.

The upper electrode **1142** of the storage capacitor **Cst** may be used as a switching device for selecting a pixel from which light is emitted. In one embodiment, the switching gate electrode **124** is coupled to the scan line **24**, the switching source electrode **126s** is coupled to the data line **16**, and the switching drain electrode **126d** is coupled to the driving TFT **T1** and the operation control TFT **T5**.

The light-emitting control drain electrode **166d** of the light-emitting control TFT **T6** is directly coupled to the pixel

electrode **200** of the OLED via a via hole (not shown) formed on a protection film **107**.

A structure of an OLED display according to an embodiment of the present invention will now be described in detail in a layered order with reference to FIGS. **3** to **5**. For convenience of description, FIGS. **3** to **5** show only layers from a substrate **100** to the pixel electrode **200**. In FIGS. **3** to **5**, a structure of the driving TFT **T1**, the compensation TFT **T3**, and the initialization TFT **T4** is mainly described. The storage capacitor **Cst** is described together with them. Since the other TFTs **T2**, **T5**, and **T6** substantially have a similar (or the same) structure as the driving TFT **T1**, the compensation TFT **T3**, and the initialization TFT **T4**, a detailed description thereof is omitted.

In one embodiment, a buffer layer **101** is formed on the substrate **100**, which may be an insulation substrate formed of glass, quartz, ceramic, plastic, or the like.

The driving semiconductor layer **112**, the compensation semiconductor layer **132**, and the initialization semiconductor layer **142** are formed on the buffer layer **101**.

Although not shown, the driving semiconductor layer **112** may include a driving channel region, and a driving source region and a driving drain region facing each other with the driving channel region therebetween. The compensation semiconductor layer **132** also includes a compensation channel region **132c**, and the compensation source region **136s** and the compensation drain region **136d** facing each other with the compensation channel region **132c** therebetween. The initialization semiconductor layer **142** also includes an initialization channel region **142c**, and an initialization source region **146s** and the initialization drain region **146d** facing each other with the initialization channel region **142c** therebetween.

The first gate insulation film **1031** is formed on the driving semiconductor layer **112**, the compensation semiconductor layer **132**, and the initialization semiconductor layer **142**. The first gate insulation film **1031** may be formed of silicon nitride (SiN_x), silicon oxide (SiO_2), or the like.

A first gate conductive layer, parts of which form the driving gate electrode **1141** including the lower electrode **1141** of the storage capacitor **Cst**, the scan line **24** including the compensation gate electrode **134**, the previous scan line **14** including the initialization gate electrode **144**, and the light-emitting control line **34** including the operation control gate electrode **154** and the light-emitting control gate electrode **164**, is formed on the first gate insulation film **1031**.

In one embodiment, the driving gate electrode **1141** or the lower electrode **1141** are separated from the previous scan line **14**, the scan line **24**, and the light-emitting control line **34** and overlap with the driving channel region of the driving semiconductor layer **112**. The compensation gate electrode **134** is coupled to the scan line **24** and overlaps with the compensation channel region **132c** of the compensation semiconductor layer **132**. The initialization gate electrode **144** is coupled to the previous scan line **14** and overlaps with the initialization channel region **142c** of the initialization semiconductor layer **142**.

The second gate insulation film **1032** covers the first gate conductive layer and the first gate insulation film **1031**. The second gate insulation film **1032** may be formed of SiN_x , SiO_2 , or the like.

A second gate conductive layer **1142** including the upper electrode **1142** of the storage capacitor **Cst** is formed on the second gate insulation film **1032**. The upper electrode **1142**, which operates as a floating electrode, overlaps with the whole lower electrode **1141** to form the storage capacitor **Cst** and has the storage opening **420** overlapping with the lower

electrode **1141**. The storage opening **420** may have a shape of a simple closed curve penetrating the upper electrode **1142**.

The inter-layer insulation film **105** is formed on the second gate insulation film **1032** and the upper electrode **1142**. Like the first gate insulation film **1031** and the second gate insulation film **1032**, the inter-layer insulation film **105** is formed of a ceramic series material, such as SiN_x , SiO_2 , or the like.

The first node contact hole **361** is formed in the second gate insulation film **1032** and the inter-layer insulation film **105**, within the storage opening **420** of the upper electrode **1142** to expose the lower electrode **1141** to the outside. In addition, the second node contact hole **362** is formed in the first gate insulation film **1031**, the second gate insulation film **1032**, and the inter-layer insulation film **105** to expose the compensation drain region **136d** of the compensation semiconductor layer **132** and the initialization drain region **146d** of the initialization semiconductor layer **142**.

The driving voltage line **26**, the connection node **36**, and the data line **16** are formed on the inter-layer insulation film **105**. The driving voltage line **26** is coupled to the upper electrode **1142** of the storage capacitor **Cst** through a driving voltage line contact hole **261** so that the upper electrode **1142** receives the driving voltage **ELVDD** through the driving voltage line **26**. One end of the connection node **36** is coupled to the lower electrode **1141** of the storage capacitor **Cst** via the first node contact hole **361**, and the other end of the connection node **36** is coupled to the compensation drain electrode **136d** of the compensation TFT **T3** and the initialization drain electrode **146d** of the initialization TFT **T4** via the second node contact hole **362**. As described above, the compensation drain electrode **136d** and the initialization drain electrode **146d** correspond to the compensation drain region **136d** and the initialization drain region **146d**, respectively.

The protection film **107** covering the data line **16**, the driving voltage line **26**, and the connection node **36** is formed on the inter-layer insulation film **105**, and the pixel electrode **200** is formed on the protection film **107**.

Although not shown, the pixel electrode **200** may be coupled to the light-emitting control drain electrode **166d** through a via hole formed in the protection film **107**. A pixel-defining film (not shown) may be formed on the edge of the pixel electrode **200** and the protection film **107** and may have a pixel opening (not shown) to expose the pixel electrode **200**. The pixel-defining film may be formed of an organic material, such as a polyacrylate resin or polyimides, or a silica series inorganic material. An organic light-emitting layer (not shown) may be formed on the pixel electrode **200** exposed through the pixel opening, and a common electrode (not shown) may be formed on the organic light-emitting layer. As such, an OLED, including the pixel electrode **200**, the organic light-emitting layer, and the common electrode, may be formed.

In one embodiment, the pixel electrode **200** is an anode that is a hole injection electrode, and the common electrode is a cathode that is an electron injection electrode. However, the present invention is not necessarily limited thereto, and according to a driving method of the OLED display, the pixel electrode **200** may be cathode, and the common electrode may be an anode. Light is emitted when holes and electrons are injected from the pixel electrode **200** and the common electrode, respectively, and excitons generated by combining the injected holes and electrons to transition from an excited state to a ground state.

11

The organic light-emitting layer may be formed of a low-molecular weight organic material or a high-molecular weight organic material, such as Poly 3,4-ethylenedioxythiophene (PEDOT). In addition, the organic light-emitting layer may be formed of a multi-film structure including at least one of a hole injection layer (HIL), a hole transporting layer (HTL), an electron transporting layer (ETL), and an electron injection layer (EIL). In one embodiment, when the multi-film structure includes all of the HIL, the HTL, the ETL, and the EIL, the HIL is arranged on the pixel electrode 200 that is the anode, and then the HTL, the ETL, and the EIL are sequentially layered on the HIL. When the common electrode is formed of a reflection-type conductive material, the OLED display may be a rear-surface light-emitting type display. Examples of the reflection-type conductive material include lithium (Li), calcium (Ca), lithium fluoride/calcium (LiF/Ca), lithium fluoride/aluminum (LiF/Al), Al, silver (Ag), magnesium (Mg), and gold (Au).

FIG. 6 is a top view schematically showing an overlapping region of the storage capacitor Cst in the OLED display of FIG. 2. FIGS. 7A to 7D are top views showing cases where an overlay deviation occurs between the lower and upper electrodes 1141 and 1142 of the storage capacitor Cst in the OLED display of FIG. 2.

Referring to FIGS. 6 to 7D, the OLED display is characterized in that a capacitance of the storage capacitor Cst may be maintained (e.g., always maintained) to be substantially constant even though an overlay deviation occurs between the lower and upper electrodes 1141 and 1142 during a manufacturing process of the OLED display. The storage capacitor Cst includes the upper electrode 1142, which overlaps with the whole lower electrode 1141 and has the storage opening 420 in a simple closed curve shape.

When the two or more layers overlapping each other are formed, if each of the two or more layers overlapping each other is shifted to the top, bottom, left, or right, an overlapping region due to the shift differs from an initially designed overlapping region, and this overlapping region difference is the overlay deviation. The overlay deviation may occur due to a misalignment between a substrate and a mask or a light exposure device when a conductive layer is formed on the whole substrate and is patterned by a photolithography process. This overlay deviation may have a high probability of occurring within a tolerance (or tolerance level) of process equipment in a system for concurrently (e.g., simultaneously) producing a great number of large panels.

Referring to FIG. 6, a capacitance between the lower and upper electrodes 1141 and 1142 of the storage capacitor Cst is determined by Equation 1. In Equation 1, C denotes a capacitance, c denotes a dielectric constant, A denotes an area of an overlapping region of the lower and upper electrodes 1141 and 1142, and d denotes a distance between the lower and upper electrodes 1141 and 1142.

$$C = \varepsilon \frac{A}{d} \quad (1)$$

That is, the capacitance of the storage capacitor Cst may be determined by a dielectric constant c of the second gate insulation layer 1032, the distance d between the lower and upper electrodes 1141 and 1142, and the area A of the overlapping region of the lower and upper electrodes 1141 and 1142. Thus, when the area A of the overlapping region of the lower and upper electrodes 1141 and 1142 varies, the capacitance also varies. In other words, when an overlay

12

deviation between the lower and upper electrodes 1141 and 1142 occurs, the capacitance may be different from a designed value. If the capacitance is different from the designed value, problems, such as low-gradation spots and abnormal colors, may occur, thereby degrading the quality of the OLED display.

To address these problems, an OLED display according to embodiments of the present invention is characterized in that the capacitance of the storage capacitor Cst may be maintained (e.g., always maintained) to be substantially constant even though an overlay deviation occurs between the lower and upper electrodes 1141 and 1142. In one embodiment, the storage capacitor Cst includes the upper electrode 1142 having the storage opening 420 in a simple closed curve shape.

For example, FIG. 7A shows a case where the lower electrode 1141 is shifted to the top (in a +Y direction) rather than a designed location. FIG. 7B shows a case where the lower electrode 1141 is shifted to the bottom (in a -Y direction) rather than the designed location. FIG. 7C shows a case where the lower electrode 1141 is shifted to the right (in a +X direction) rather than the designed location, and FIG. 7D shows a case where the lower electrode 1141 is shifted to the left (in a -X direction) rather than the designed location.

A shift (or shift level) may be generated within a tolerance (or tolerance level) of process equipment, and the tolerance may be at most within a range in which the opening 420 of the upper electrode 1142 overlaps with the lower electrode 1141. When a shift occurs to a region in which the opening 420 of the upper electrode 1142 does not overlap with the lower electrode 1141, a problem may occur in forming the connection node 36 and the first node contact hole 361, thereby making the pixel circuit inoperable. Thus, aspects of embodiments of the present invention do not deal with the case that the tolerance (or tolerance level) exceeds the range in which the opening 420 of the upper electrode 1142 overlaps with the lower electrode 1141. So that the whole lower electrode 1141 and the upper electrode 1142 overlap each other, an area of the upper electrode 1142 may be equal to or greater than that of the lower electrode 1141. For example, the area of the upper electrode 1142 may be as large as that of the lower electrode 1141 so that the capacitance may be maintained (e.g., always maintained) to be substantially constant even though a shift occurs.

According to each case of FIGS. 7A to 7D, even though the lower electrode 1141 is shifted to the top, bottom, left, and right from the designed location, the upper electrode 1142 overlaps (or always overlaps) with the whole lower electrode 1141, and the opening 420 of the upper electrode 1142 overlaps (or always overlaps) with the lower electrode 1141, and thus, the capacitance may be maintained to be substantially constant.

Although the lower electrode 1141 is shifted in FIGS. 7A to 7D, the present invention is not limited thereto, and the capacitance may be maintained to be substantially constant even though the upper electrode 1142 is shifted.

According to an embodiment of the present invention, the whole lower electrode and an upper electrode of a storage capacitor overlap each other, and an opening is formed in the upper electrode to overlap with the lower electrode, and thus even though an overlay deviation occurs between the two electrodes, a capacitance may be maintained (e.g., always maintained) to be substantially constant. Accordingly, low-gradation spots and abnormal colors due to a capacitance change may be prevented.

13

While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by one of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the following claims and their equivalents.

What is claimed is:

1. A thin film transistor (TFT) array substrate comprising:
 - a substrate;
 - a first thin film transistor including a first channel region and a first gate electrode overlapping the first channel region, the first gate electrode and the first channel region being spaced apart from each other with a first insulating layer therebetween;
 - a second thin film transistor including a second channel region and a second gate electrode overlapping the second channel region, the second gate electrode and the second channel region being spaced apart from each other with the first insulating layer therebetween;
 - a second insulating layer disposed on the first and second gate electrode;
 - a first metal pattern overlapping the first gate electrode, the first metal pattern and the first gate electrode being spaced apart from each other with the second insulating layer therebetween;
 - a third insulating layer disposed on the first metal pattern; and
 - a connection member disposed on the third insulating layer and electrically connecting the first gate electrode and the second thin film transistor.
2. The TFT array substrate of claim 1, wherein the first metal pattern includes an opening, and a portion of the connection member overlaps the opening in a plan view.
3. The TFT array substrate of claim 2, wherein at least one of the second and third insulating layers includes a node contact hole overlapping the opening, and the portion of the connection member is connected with the first gate electrode through the node contact hole.
4. The TFT array substrate of claim 3, wherein a size of the opening is greater than a size of the node contact hole in the plan view.
5. The TFT array substrate of claim 4, wherein the second and third insulating layers contact each other in a region between the first metal pattern and the portion of the connection member in a cross-sectional view.
6. The TFT array substrate of claim 2, wherein an entire area of the opening overlaps the first gate electrode in the plan view.
7. The TFT array substrate of claim 1, wherein the first channel region includes a bent portion.
8. The TFT array substrate of claim 7, wherein the first channel region includes at least two bent portions.
9. The TFT array substrate of claim 7, wherein the first channel region is curved in an "S" shape.
10. The TFT array substrate of claim 7, wherein the first channel region is curved in a zigzag shape.
11. The TFT array substrate of claim 1, further comprising a driving voltage line on the third insulating layer, wherein the driving voltage line is connected to the first metal pattern through a first contact hole of the third insulating layer.
12. The TFT array substrate of claim 11, wherein the first contact hole includes a plurality of first-sub contact holes.
13. The TFT array substrate of claim 12, wherein at least one of the plurality of first-sub contact holes overlaps the first channel region in a plan view.

14

14. The TFT array substrate of claim 1, further comprising a first gate line electrically connected to the second gate electrode.

15. The TFT array substrate of claim 14, wherein the second thin film transistor further comprises a first region adjacent to a side of the second channel region and a second region adjacent to another side of the second channel region, and the first region is electrically connected to the first gate electrode via the connection member.

16. The TFT array substrate of claim 15, wherein the first thin film transistor further comprises a third region adjacent to a side of the first channel region and a fourth region adjacent to another side of the first channel region, and the second region is electrically connected to the fourth region.

17. The TFT array substrate of claim 14, further comprising a second gate line, and a third thin film transistor, the third thin film transistor including a third gate electrode and a third channel region overlapping the third gate electrode, the third gate electrode and the third channel region being spaced apart from each other with the first insulating layer therebetween, and wherein the second gate line is electrically connected to the third gate electrode.

18. The TFT array substrate of claim 17, further comprising an initialization voltage line, wherein the third thin film transistor further comprises a fifth region adjacent to a side of the third channel region and a sixth region adjacent to another side of the third channel region, and the sixth region is electrically connected to the initialization voltage line.

19. The TFT array substrate of claim 18, wherein the fifth region is electrically connected to the first gate electrode via the connection member.

20. The TFT array substrate of claim 18, wherein the initialization voltage line extends in the same direction as the first gate line.

21. The TFT array substrate of claim 18, wherein the initialization voltage line is formed of a different layer from the first gate line.

22. A thin film transistor (TFT) array substrate comprising:

- a substrate;
- a first thin film transistor including a first channel region and a first gate electrode overlapping the first channel region, the first gate electrode and the first channel region being spaced apart from each other with a first insulating layer therebetween;
- a second thin film transistor including a second channel region and a second gate electrode overlapping the second channel region, the second gate electrode and the second channel region being spaced apart from each other with the first insulating layer therebetween;
- a second insulating layer disposed on the first and second gate electrode;
- a first metal pattern overlapping the first gate electrode, the first metal pattern and the first gate electrode being spaced apart from each other with the second insulating layer therebetween;
- a third insulating layer disposed on the first metal pattern; and
- a connection member disposed on the third insulating layer and electrically connecting the first gate electrode and the second thin film transistor, the connection member overlapping a portion of the first channel region in a plan view.

23. The TFT array substrate of claim 22, wherein the first metal pattern includes an opening, and a portion of the connection member overlaps the opening in the plan view.

15

24. The TFT array substrate of claim 23, wherein at least one of the second and third insulating layers includes a node contact hole overlapping the opening, and the portion of the connection member is connected with the first gate electrode through the node contact hole.

5

25. The TFT array substrate of claim 22, wherein the first channel region includes a bent portion.

26. The TFT array substrate of claim 25, wherein the first channel region is curved in a zigzag shape.

27. The TFT array substrate of claim 22, further comprising a driving voltage line on the third insulating layer, the driving voltage line is connected to the first metal pattern through a first contact hole of the third insulating layer.

10

28. The TFT array substrate of claim 27, wherein the first contact hole includes a plurality of first-sub contact holes.

15

29. The TFT array substrate of claim 28, wherein at least one of the plurality of first-sub contact holes overlaps the first channel region in the plan view.

* * * * *

16