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(54) **MICRO LIGHT-EMITTING DIODE DISPLAY DEVICE AND MICRO LIGHT-EMITTING DIODE DRIVING CIRCUIT**

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H01L 33/62	(2010.01)
H01L 49/02	(2006.01)
H01L 33/36	(2010.01)
H01L 33/14	(2010.01)

(52) **U.S. Cl.**
CPC ***H01L 27/15*** (2013.01); ***H01L 28/40*** (2013.01); ***H01L 29/42364*** (2013.01); ***H01L 29/42384*** (2013.01); ***H01L 29/78648*** (2013.01); ***H01L 29/78669*** (2013.01); ***H01L 29/78696*** (2013.01); ***H01L 33/14*** (2013.01); ***H01L 33/36*** (2013.01); ***H01L 33/62*** (2013.01)

(58) **Field of Classification Search**
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USPC 257/71
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2016/0013170 A1* 1/2016 Sakariya H01L 33/42 257/13
2016/0197232 A1* 7/2016 Bour H01L 33/24 257/13
2018/0174519 A1* 6/2018 Kim G09G 3/3233

* cited by examiner

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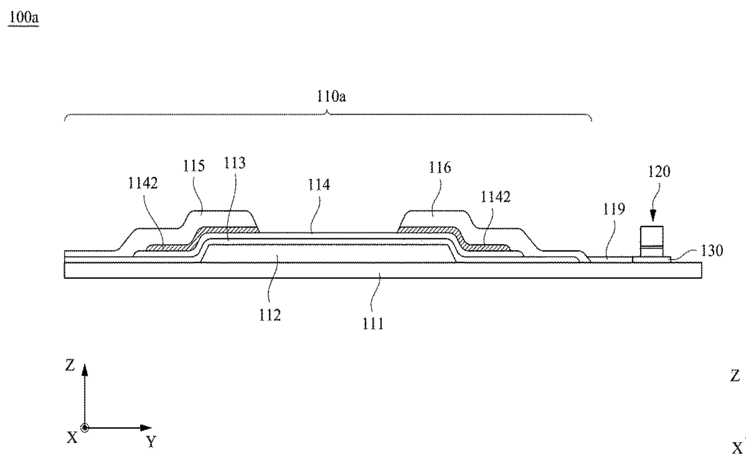
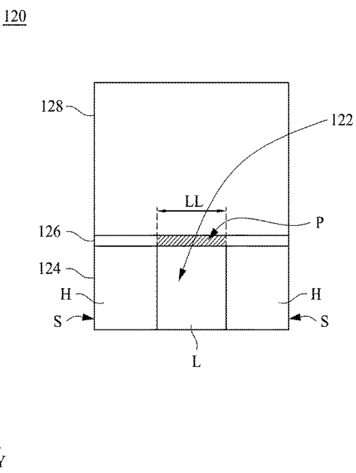
(57) **ABSTRACT**

A micro light-emitting diode display device including a driving transistor and a micro light-emitting diode is provided. The driving transistor includes a substrate, a gate, a gate insulator, a semiconductor layer, a drain electrode, and a source electrode. The gate insulator has a thickness less than or equal to about 500 angstroms. The micro light-emitting diode has a lateral length less than or equal to about 50 μm and is electrically connected to one of the source electrode and the drain electrode. A current injection channel is extended within one of a first type semiconductor layer and a second type semiconductor layer of the micro light-emitting diode and is spaced apart from a side surface of the micro light-emitting diode. A lateral length a light-emitting portion of an active layer of the micro light-emitting diode is less than or equal to about 10 μm.

12 Claims, 9 Drawing Sheets





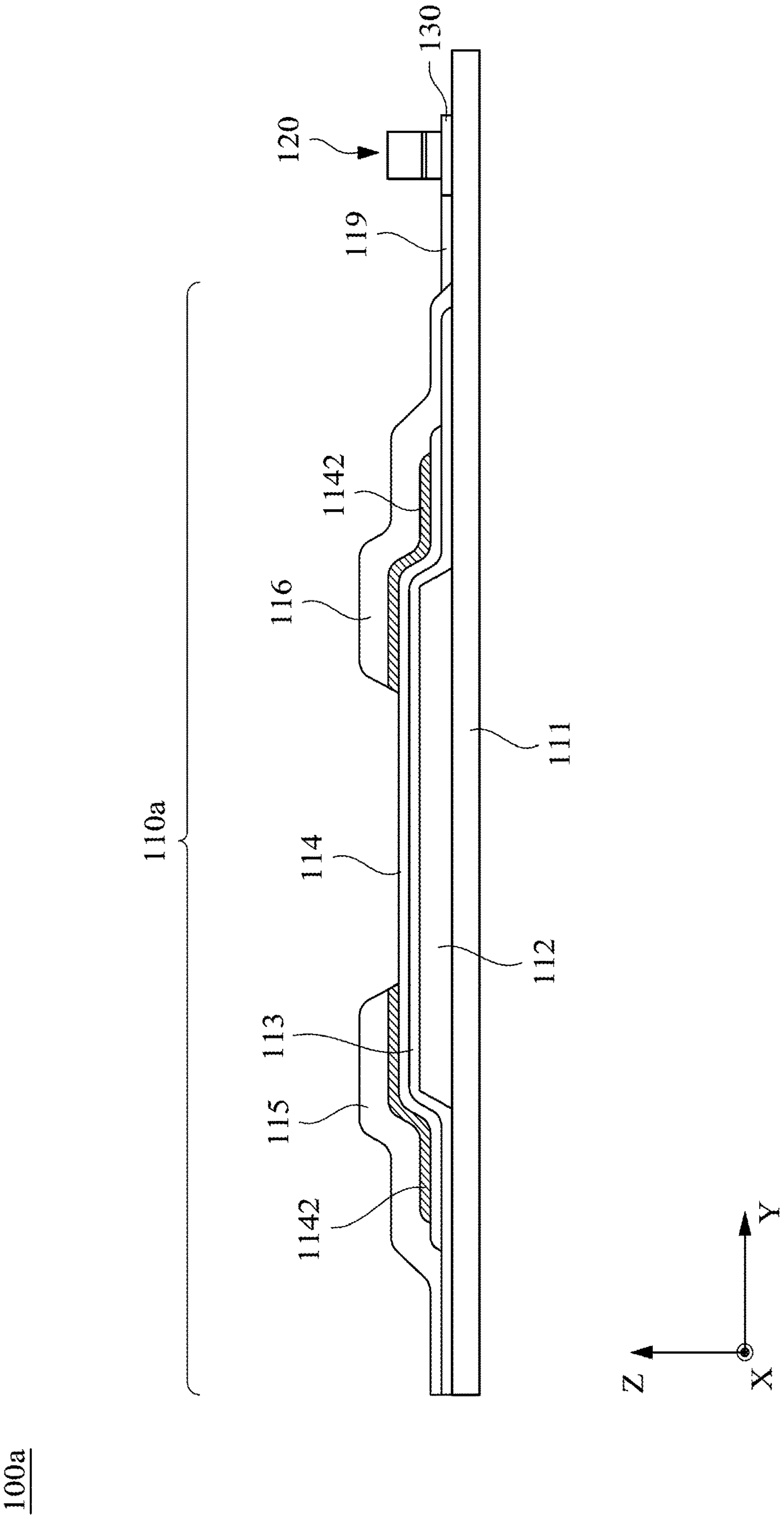


Fig. 1A

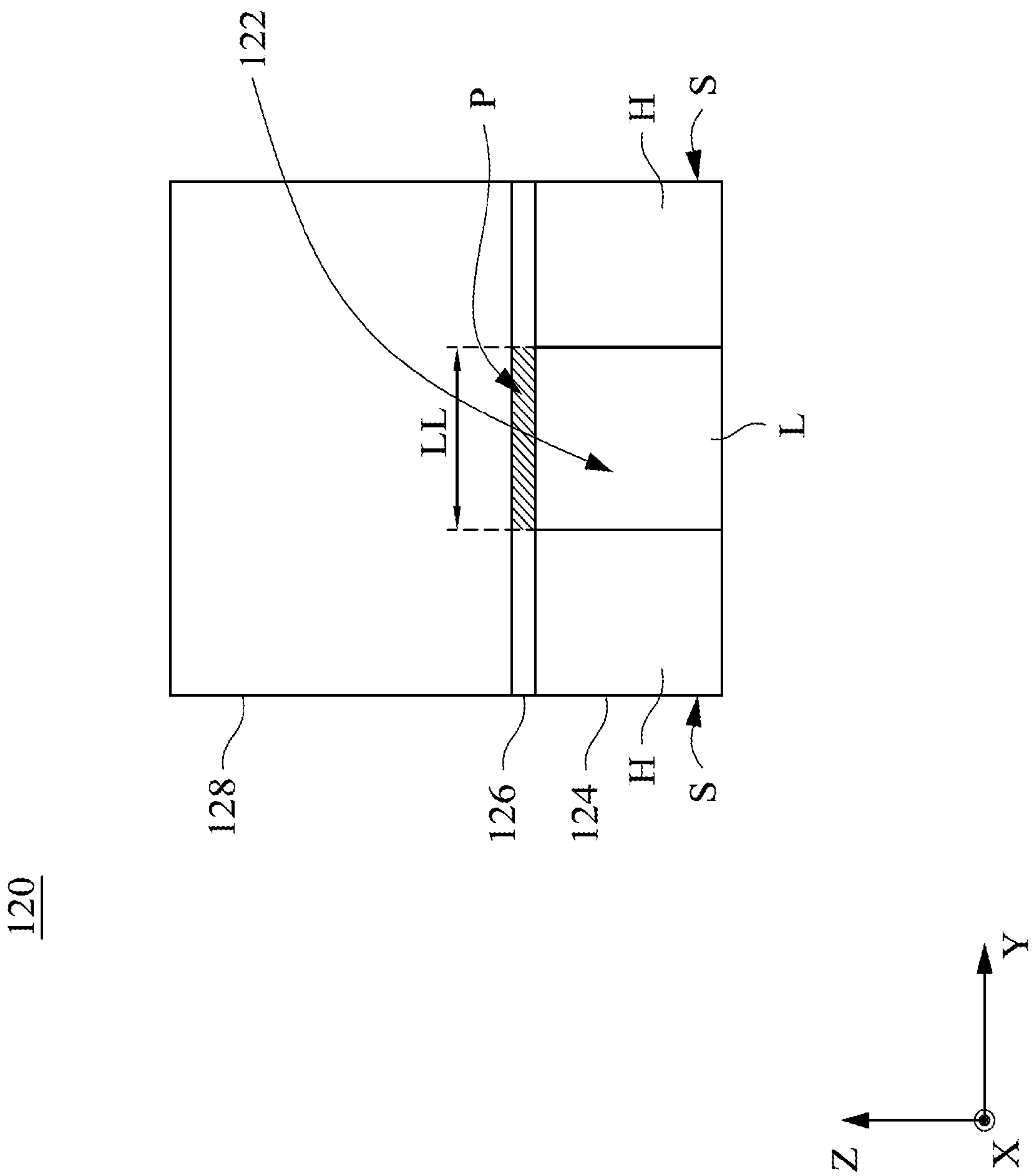


Fig. 1B

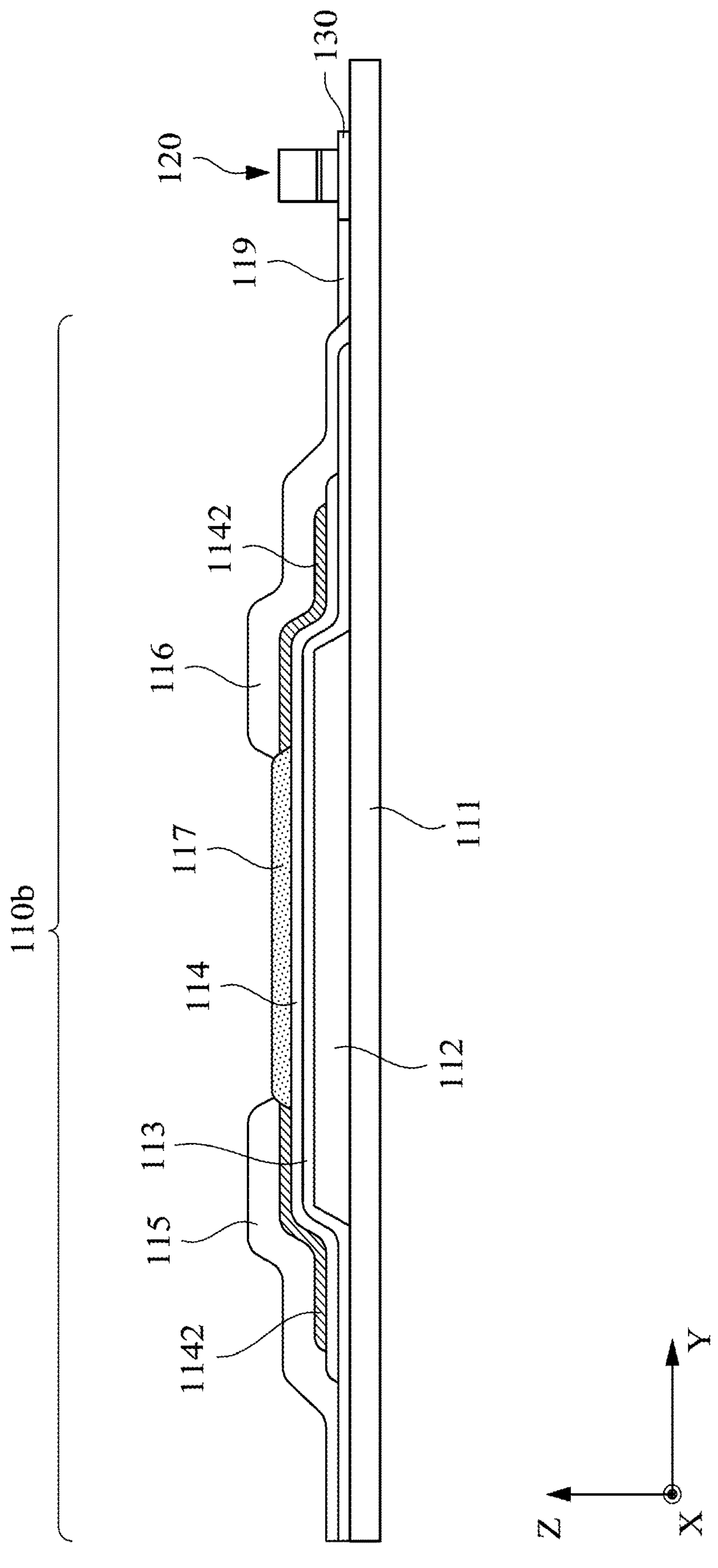


Fig. 2

100b

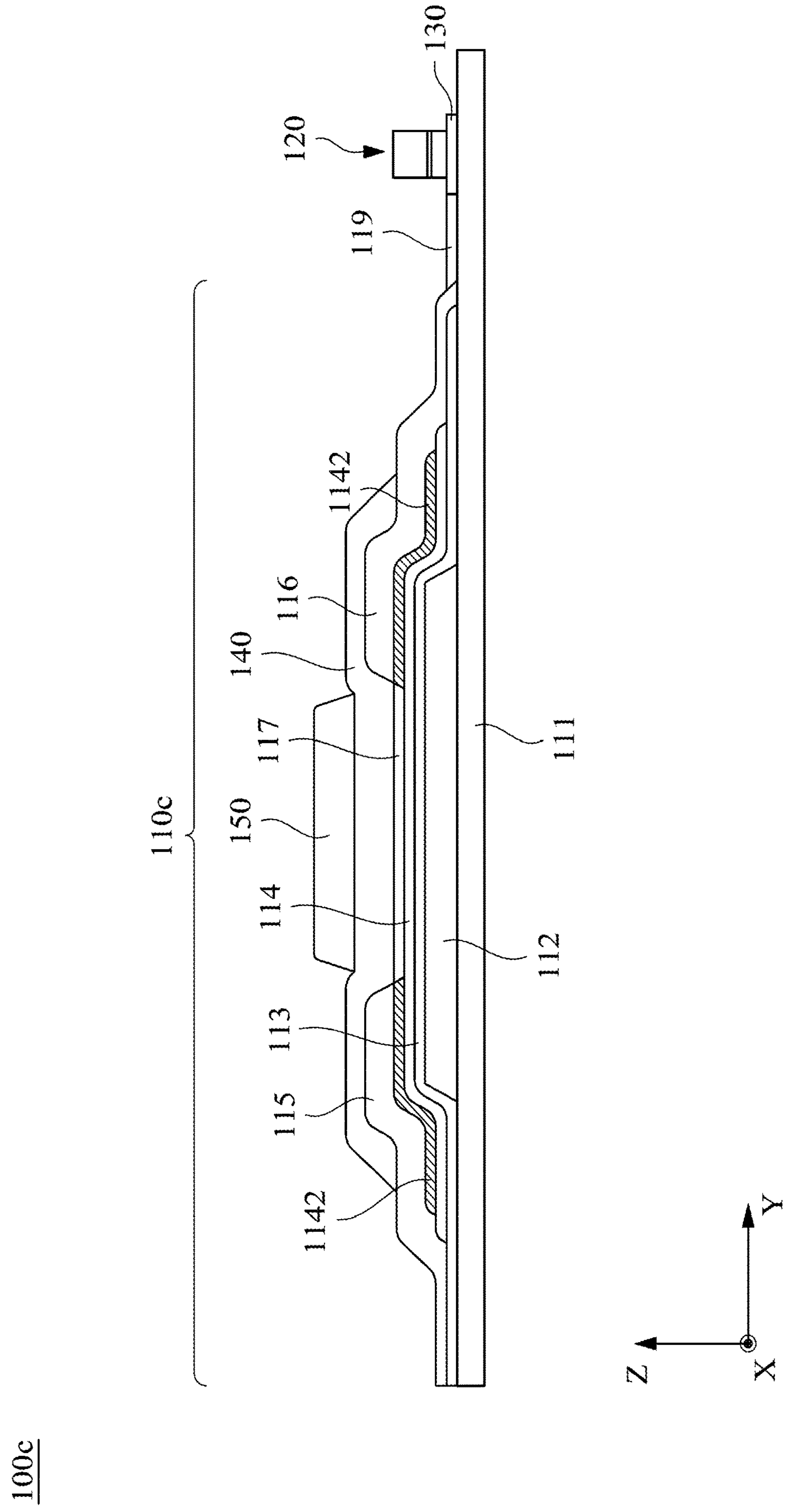

100c
110c
130
120
119
1142
116
140
117
150
114
113
115
1142
111
112
Y
Z
X

Fig. 3

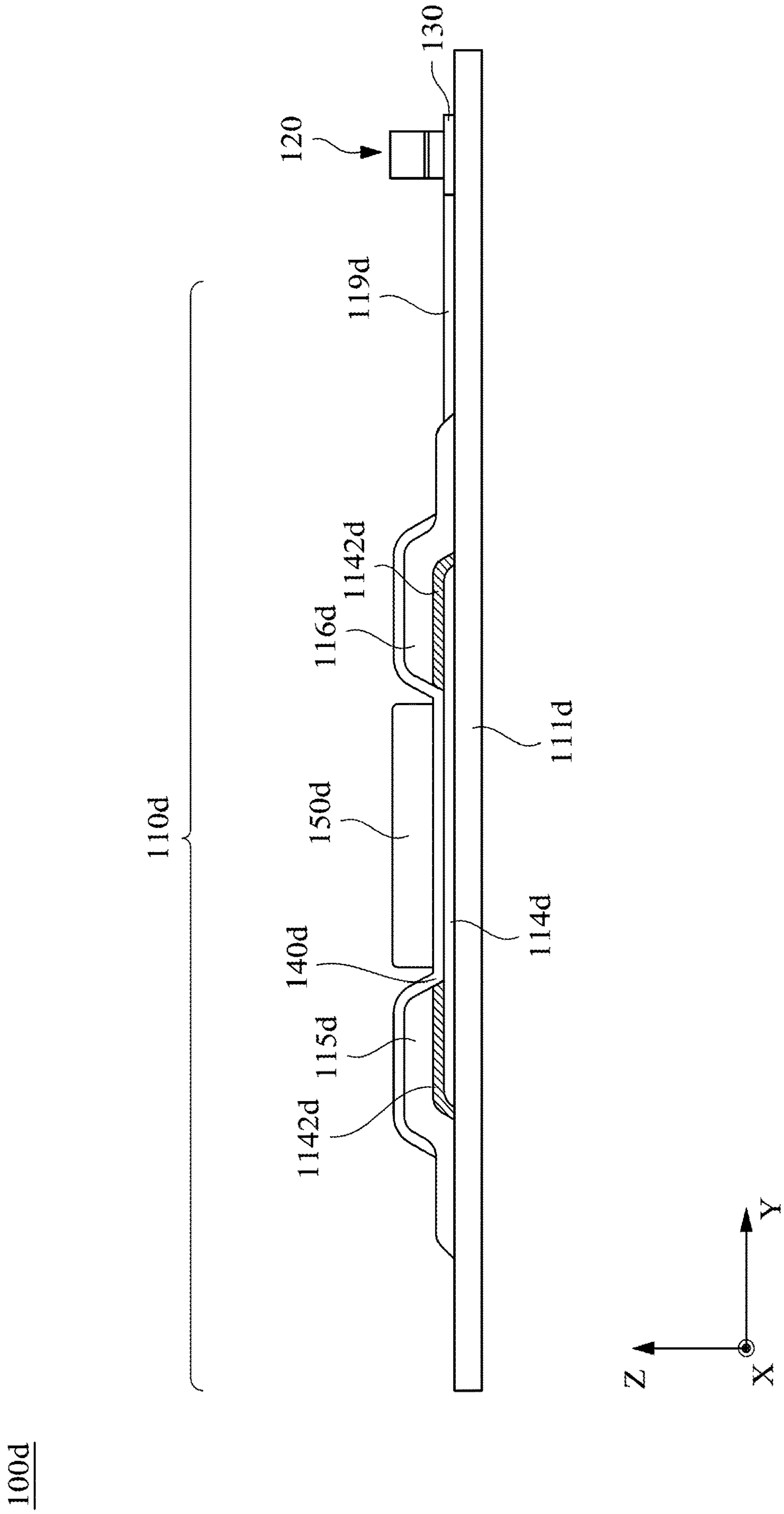

130
120
119d
1142d
116d
111d
150d
110d
114d
140d
115d
1142d
Y
Z
X
100d

Fig. 4

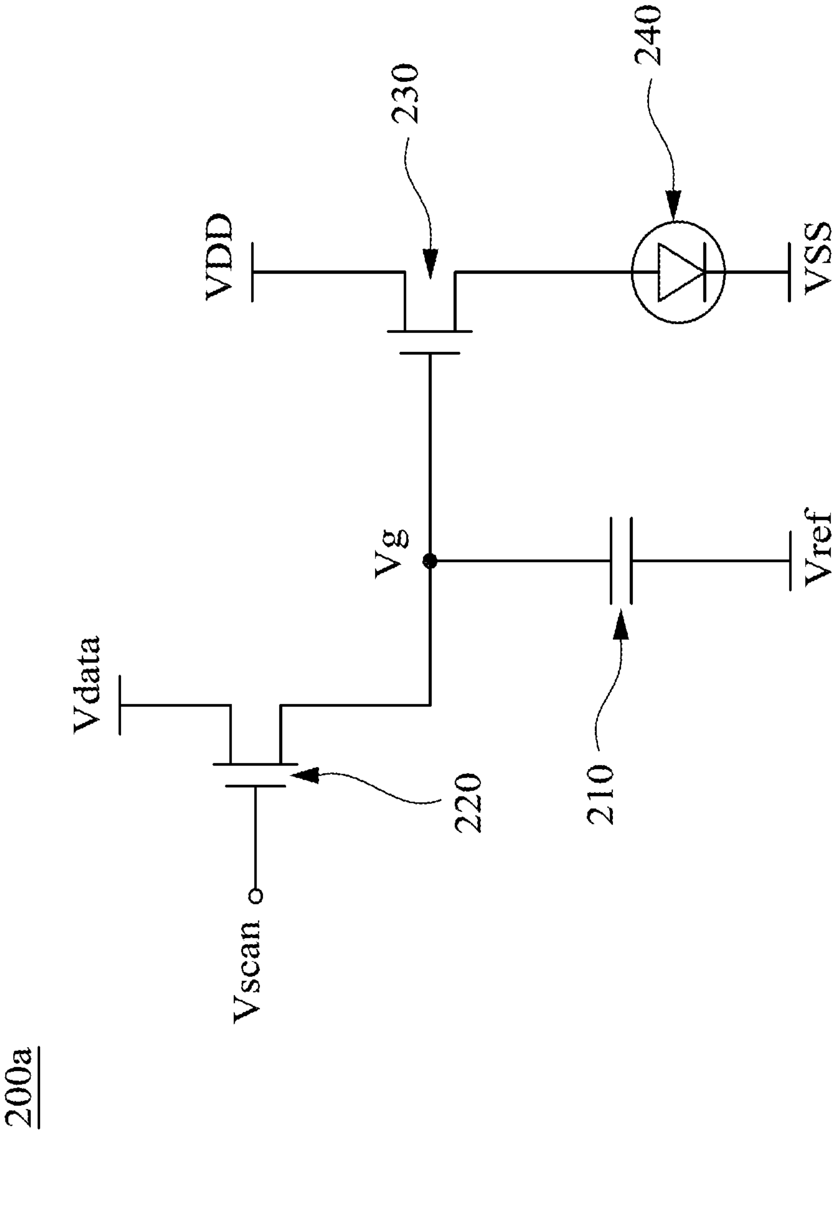


Fig. 5

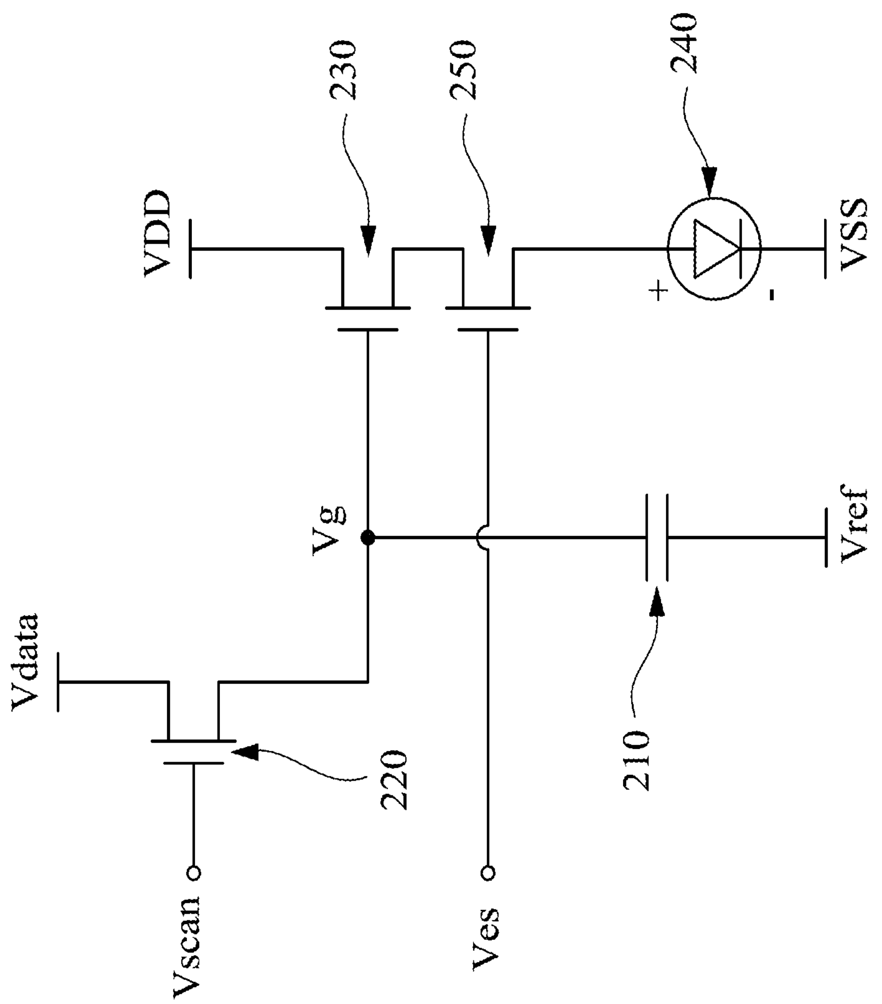


Fig. 6

200b

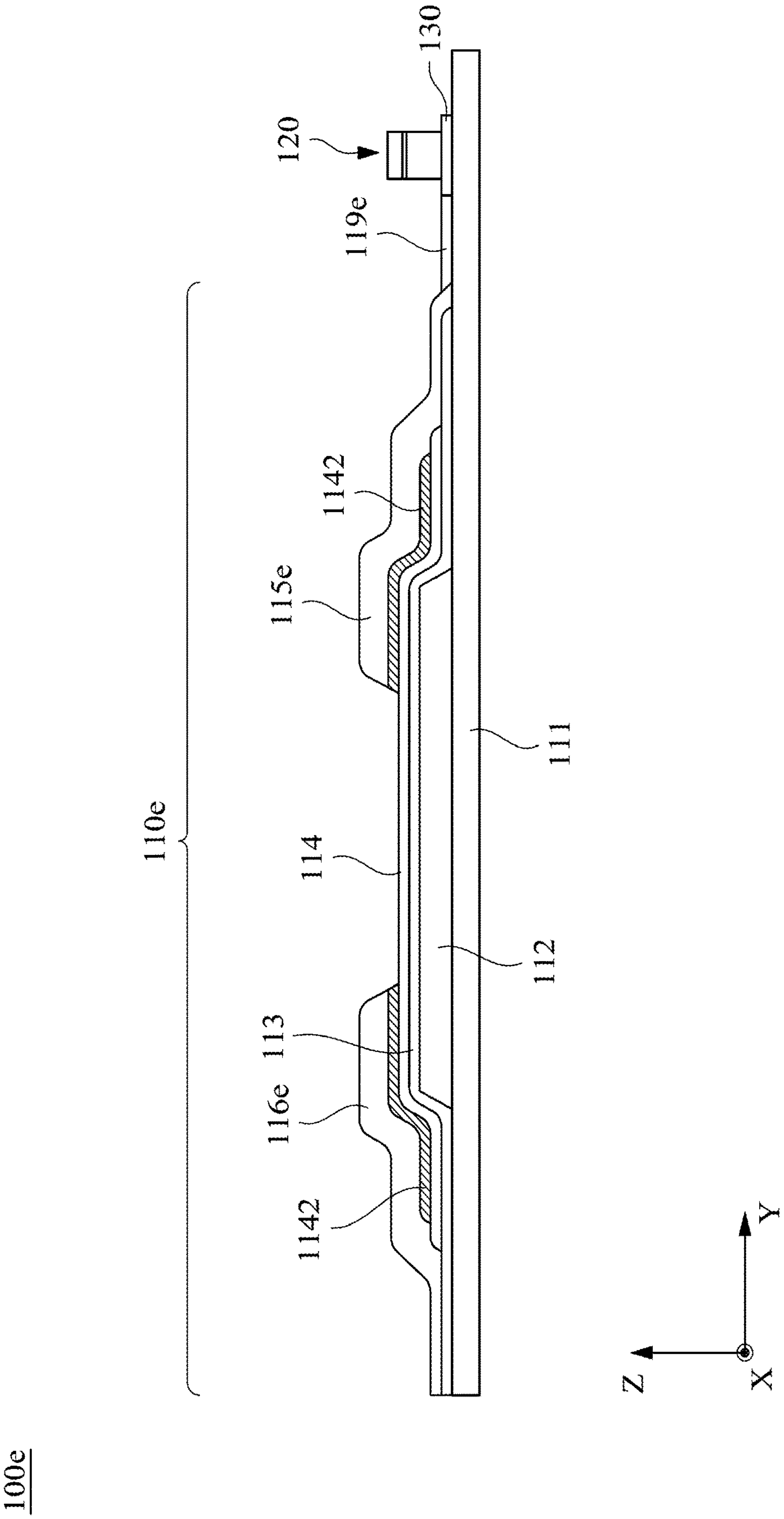


Fig. 7A

200c

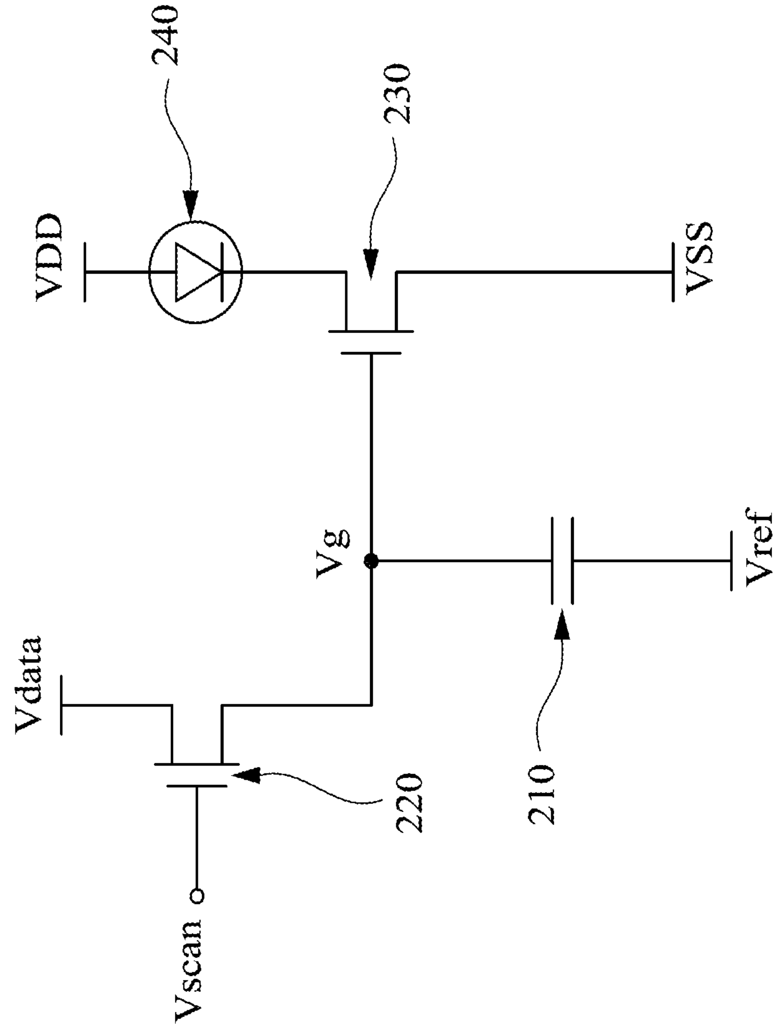


Fig. 7B

MICRO LIGHT-EMITTING DIODE DISPLAY DEVICE AND MICRO LIGHT-EMITTING DIODE DRIVING CIRCUIT

BACKGROUND

Field of Invention

The present disclosure relates to a low power micro light-emitting diode display device and a low power micro light-emitting diode driving circuit.

Description of Related Art

The statements in this section merely provide background information related to the present disclosure and do not necessarily constitute prior art.

In recent years, micro devices have become popular in various applications. One of the promising subfields is micro light-emitting diode devices, and one of the important issues of said subfield is the power consumption of a micro light-emitting diode driving circuit.

SUMMARY

According to some embodiments of the present disclosure, a micro light-emitting diode display device including a driving transistor and a micro light-emitting diode is provided. The driving transistor includes a substrate, a gate, a gate insulator, a semiconductor layer, a drain electrode, and a source electrode. The gate is on the substrate. The gate insulator has a thickness less than or equal to about 500 angstroms and is on the gate and the substrate. The semiconductor layer is on the gate insulator. The drain electrode is on the semiconductor layer. The source electrode is on the semiconductor layer and is spaced apart from the drain electrode. The micro light-emitting diode has a lateral length less than or equal to about 50 μm and is electrically connected to one of the source electrode and the drain electrode. The micro light-emitting diode includes a first type semiconductor layer, an active layer, and a second type semiconductor layer. The active layer is on and joined with the first type semiconductor layer. The second type semiconductor layer is on and joined with the active layer. A current injection channel is extended within one of the first type semiconductor layer and the second type semiconductor layer and is spaced apart from a side surface of the micro light-emitting diode, and the active layer has a portion in contact with the current injection channel and having a lateral length less than or equal to about 10 μm.

According to some embodiments of the present disclosure, a micro light-emitting diode display device including a driving transistor and a micro light-emitting diode is provided. The driving transistor includes a substrate, a semiconductor layer, a drain electrode, a source electrode, a gate insulator, and a gate. The semiconductor layer is on the substrate. The drain electrode is on the semiconductor layer. The source electrode is on the semiconductor layer and is spaced apart from the drain electrode. The gate insulator has a thickness less than or equal to about 500 angstroms and is on the semiconductor layer. The gate is on the gate insulator. The micro light-emitting diode has a lateral length less than or equal to about 50 μm and is electrically connected to one of the source electrode and the drain electrode. The micro light-emitting diode includes a first type semiconductor layer, an active layer, and a second type semiconductor layer. The active layer is on and joined with the first type semiconductor layer. The second type semiconductor layer is on and joined with the active layer. A current injection channel is extended within one of the first type semiconductor layer and the second type semiconductor layer and is spaced apart from a side surface of the micro light-emitting diode, and the active layer has a portion in contact with the current injection channel and having a lateral length less than or equal to about 10 μm.

According to some embodiments of the present disclosure, a micro light-emitting diode driving circuit including a storage capacitor, a switching transistor, a micro light-emitting diode, and a driving transistor is provided. The storage capacitor has two ends. The switching transistor has a gate terminal connected to a scan line, a drain terminal connected to a data line, and a source terminal connected to one end of the storage capacitor. The micro light-emitting diode has a lateral length less than or equal to about 50 μm and includes a first type semiconductor layer, an active layer, and a second type semiconductor layer. The active layer is on and joined with the first type semiconductor layer. The second type semiconductor layer is on and joined with the active layer. A current injection channel is extended within one of the first type semiconductor layer and the second type semiconductor layer and is spaced apart from a side surface of the micro light-emitting diode, and the active layer has a portion in contact with the current injection channel and having a lateral length less than or equal to about 10 μm. The micro light-emitting diode has an anode and a cathode respectively connected to the first type semiconductor layer and the second type semiconductor layer. The micro light-emitting diode receives a first driving voltage from a driving voltage source. The micro light-emitting diode is electrically connected to a low voltage source. The driving transistor has a gate terminal, a drain terminal, and a source terminal. The gate terminal is connected to the source terminal of the switching transistor. The micro light-emitting diode is electrically connected to one of the source terminal and the drain terminal of the driving transistor. The driving transistor receives a second driving voltage from a driving voltage source and is electrically connected to the low voltage source. The driving transistor is one of a first structure, a second structure and a third structure. The first structure includes a first substrate, a first gate, a first gate insulator, a first semiconductor layer, a first drain electrode, and a first source electrode. The first gate is on the first substrate. The first gate insulator having a thickness less than or equal to about 500 angstroms is on the first gate and the first substrate. The first semiconductor layer is on the first gate insulator. The first drain electrode is on the first semiconductor layer. The first source electrode is on the first semiconductor layer and is spaced apart from the first drain electrode. The second structure includes a second substrate, a second gate, a second gate insulator, a second semiconductor layer, a second drain electrode, a second source electrode, a top gate insulator, and a top gate. The second gate is on the second substrate. The second gate insulator having a thickness less than or equal to about 500 angstroms is on the second gate and the second substrate. The second semiconductor layer is on the second gate insulator. The second drain electrode is on the second semiconductor layer. The second source electrode is on the second semiconductor layer and is spaced apart from the second drain electrode. The top gate insulator is on the second semiconductor layer. The top gate is on the top gate insulator. The third structure includes a third substrate, a third semiconductor layer, a third drain electrode, a third source electrode, a third gate insulator, and a third gate. The third semiconductor layer is on the third substrate. The third drain electrode is on the third semiconductor layer. The third source electrode is on the third semiconductor layer and is spaced apart from the third drain electrode. The third gate insulator having a thickness less than or equal to about 500 angstroms is on the third semiconductor layer. The third gate is on the third gate insulator.

It is to be understood that both the foregoing general description and the following detailed description are by examples, and are intended to provide further explanation of the disclosure as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure can be more fully understood by reading the following detailed description of the embodiment, with reference made to the accompanying drawings as follows:

FIG. **1**A is a cross-sectional view of a micro light-emitting diode display device according to some embodiments of the present disclosure;

FIG. **1**B is an enlarged cross-sectional view of a micro light-emitting diode according to some embodiments of the present disclosure;

FIG. **2** is a cross-sectional view of a micro light-emitting diode display device according to some embodiments of the present disclosure;

FIG. **3** is a cross-sectional view of a micro light-emitting diode display device according to some embodiments of the present disclosure;

FIG. **4** is a cross-sectional view of a micro light-emitting diode display device according to some embodiments of the present disclosure;

FIG. **5** is a schematic diagram of a micro light-emitting diode driving circuit in some embodiments of the present disclosure;

FIG. **6** is a schematic diagram of a micro light-emitting diode driving circuit in some embodiments of the present disclosure;

FIG. **7**A is a cross-sectional view of a micro light-emitting diode display device according to some embodiments of the present disclosure; and

FIG. **7**B is a schematic diagram of a micro light-emitting diode driving circuit in some embodiments of the present disclosure.

DETAILED DESCRIPTION

Reference will now be made in detail to the present embodiments of the disclosure, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the description to refer to the same or like parts.

In various embodiments, description is made with reference to figures. However, certain embodiments may be practiced without one or more of these specific details, or in combination with other known methods and configurations. In the following description, numerous specific details are set forth, such as specific configurations, dimensions, and processes, etc., in order to provide a thorough understanding of the present disclosure. In other instances, well-known semiconductor processes and manufacturing techniques have not been described in particular detail in order to not unnecessarily obscure the present disclosure. Reference throughout this specification to "one embodiment," "an embodiment", "some embodiments" or the like means that a particular feature, structure, configuration, or characteristic described in connection with the embodiment is included in at least one embodiment of the disclosure. Thus, the appearances of the phrase "in one embodiment," "in an embodiment", "in some embodiments" or the like in various places throughout this specification are not necessarily referring to the same embodiment of the disclosure. Furthermore, the particular features, structures, configurations, or characteristics may be combined in any suitable manner in one or more embodiments.

The terms "over," "to," "between" and "on" as used herein may refer to a relative position of one layer with respect to other layers. One layer "over" or "on" another layer or bonded "to" another layer may be directly in contact with the other layer or may have one or more intervening layers. One layer "between" layers may be directly in contact with the layers or may have one or more intervening layers. Although most of terms described in the following disclosure use singular nouns, said terms may also be plural in accordance with figures or practical applications.

Reference is made to FIGS. **1**A and **1**B. FIG. **1**A is a cross-sectional view of a micro light-emitting diode display device **100*a*** according to some embodiments of the present disclosure. FIG. **1**B is an enlarged cross-sectional view of a micro light-emitting diode **120** according to some embodiments of the present disclosure. In some embodiments, a micro light-emitting diode display device **100*a*** includes a driving transistor **110*a*** and a micro light-emitting diode **120**. The driving transistor **110*a*** includes a substrate **111**, a gate **112**, a gate insulator **113**, a semiconductor layer **114**, a drain electrode **115**, and a source electrode **116**. The substrate **111** can be a glass substrate, or a quartz substrate. The gate **112** is on the substrate **111**. In some embodiments, the gate insulator **113** is on and in contact with the substrate **111** and the gate **112**. The gate insulator **113** has a thickness less than or equal to about 500 angstroms (Å), such that a threshold voltage of the driving transistor **110*a*** is significantly decreased compared to a threshold voltage of a conventional thin film transistor. Specifically, the threshold voltage of the conventional thin film transistor is about 6 volts (V) with a conventional gate insulator having a thickness about 1500 Å, while the threshold voltage of the driving transistor **110*a*** can be lowered to about 0.8 V when the thickness of the gate insulator **113** is about 200 Å. The gate insulator **113** can be a low-k dielectric layer or a high-k dielectric layer. The semiconductor layer **114** is on the gate insulator **113**. A material of the semiconductor layer **114** can include (hydrogenated) amorphous silicon (a-Si:H), indium gallium zinc oxide (IGZO), gallium zinc oxide (GZO), or indium zinc oxide (IZO), but should not be limited thereto. A vertical projection of at least a portion of the semiconductor layer **114** on the substrate **111** is overlapped with a vertical projection of the gate **112** on the substrate **111**. The drain electrode **115** is on the semiconductor layer **114**. The source electrode **116** is on the semiconductor layer **114** and is spaced apart from the drain electrode **115**. In order to reach ohmic contacts between the drain electrode **115** and the semiconductor layer **114** and between the source electrode **116** and the semiconductor layer **114**, contact portions thereof can be heavily doped. Said heavy doping can also have a hole blocking function to prevent a hole leakage through the contact portions. Therefore, in some embodiments, the semiconductor layer **114** further includes highly conductive n+a-Si:H films **1142**, especially when the semiconductor layer **114** is a-Si:H as mentioned. The highly conductive n+a-Si:H films **1142** are between the drain electrode **115** and the semiconductor layer **114** and between the source electrode **116** and the semiconductor layer **114**. Normally, the highly conductive n+a-Si:H films **1142** have a resistivity which is about seven orders magnitude lower than that of the intrinsic a-Si:H. In some other embodiments, such as the semiconductor layer **114** being an IGZO layer, said n+ doped films may not be necessary since the IGZO layer has much fewer hole carriers than that of a-Si:H, and the contact between the IGZO layer and the drain/source electrodes **115**/**116** is much better (i.e., closer to the ohmic contact) than that between the a-Si:H and the drain/source electrodes **115**/**116**.

In some embodiments, the micro light-emitting diode **120** has a lateral length less than or equal to about 50 μm and is electrically connected to one of the source electrode **116** and the drain electrode **115**. The micro light-emitting diode **120** includes a first type semiconductor layer **124**, an active layer **126**, and a second type semiconductor layer **128**. The active layer **126** is on and joined with the first type semiconductor layer **124**. The second type semiconductor layer **128** is on and joined with the active layer **126**. A current injection channel **122** is extended within one of the first type semiconductor layer **124** and the second type semiconductor layer **128** and is spaced apart from a side surface S of the micro light-emitting diode **120**, and the active layer **126** has a portion P in contact with the current injection channel **122**. The portion P has a lateral length LL less than or equal to about 10 μm (i.e., a lateral length or a diameter of a light-emitting portion is less than or equal to about 10 μm). The current injection channel **122** and the portion P of the active layer **126** can be constructed by at least the following structure. One of the first type semiconductor layer **124** and the second type semiconductor layer **128** includes a low resistance portion L and a high resistance portion H. The low resistance portion L is separated from at least one side surface S of said one of the first type semiconductor layer **124** and the second type semiconductor layer **128** by the high resistance portion H. The resistivity of said one of the first type semiconductor layer **124** and the second type semiconductor layer **128** increases from the low resistance portion L toward the high resistance portion H. The low resistance portion L can thus form the current injection channel **122**. The formation of the high resistance portion H can be performed by a metal diffusive doping such as silicon (Si) or titanium (Ti) doping, but should not be limited thereto. Lateral lengths (in a direction parallel to extensions of the substrate **111**, or in a direction parallel to an X-Y plane, which is perpendicular to a thickness direction Z) of the first type semiconductor layer **124**, the active layer **126**, and the second type semiconductor layer **128** are less than or equal to about 50 μm.

With the existence of the current injection channel **122** and a restricted light-emitting area of the active layer **126** formed by the portion P in contact with the current injection channel **122**, a current density flowing through the micro light-emitting diode **120** increases due to a reduction of a light-emitting area of the active layer **126**. Besides, a surface recombination (which is a non-radiative recombination) is avoided due to an isolation of the current injection channel **122** from the side surface S of the micro light-emitting diode **120**, so as to decrease the current leakage. As a result, a voltage needed to light up the micro light-emitting diode **120** can be reduced.

In some embodiments, the micro light-emitting diode display device **100***a* further includes a connecting electrode **119** on the substrate **111** and in contact with one of the source electrode **116** and the drain electrode **115**. In the embodiments as shown in FIG. **1**A, the connecting electrode **119** is in contact with the source electrode **116**. In some embodiments, the micro light-emitting diode display device **100***a* further includes a bottom electrode **130** on the substrate **111**. The bottom electrode **130** is in contact with the connecting electrode **119** of the driving transistor **110***a*. In some embodiments, the first type semiconductor layer **124** is on and in contact with the bottom electrode **130**. With the combination of said driving transistor **110***a* and the light-emitting diode **120**, a low power driving scheme can be realized. The low power driving scheme will be mentioned again later with more details.

Reference is made to FIG. **2**. FIG. **2** is a cross-sectional view of a micro light-emitting diode display device **100***b* according to some embodiments of the present disclosure. In some embodiments, the driving transistor **110***b* further includes an etch stopper **117** on the semiconductor layer **114** as compared to the driving transistor **110***a* as shown in FIG. 1A. The etch stopper **117** is in contact with the drain electrode **115** and the source electrode **116**. In some embodiments, at least a portion of the etch stopper **117** between the drain electrode **115** and the source electrode **116** is exposed and not covered by the drain electrode **115** and the source electrode **116**. The etch stopper **117** can protect the underlying semiconductor layer **114** from damages during an etching process, so as to maintain the quality of the semiconductor layer **114**.

Reference is made to FIG. **3**. FIG. **3** is a cross-sectional view of a micro light-emitting diode display device **100***c* according to some embodiments of the present disclosure. In some embodiments, the driving transistor **110***c* further includes a top gate insulator **140** and a top gate **150** as compared to the driving transistor **110***a* as shown in FIG. 1A. The top gate insulator **140** is on the semiconductor layer **117**. The top gate **150** is on the top gate insulator **140**. In some embodiments, the top gate insulator **140** has a thickness less than or equal to about 500 Å, but should not be limited thereto. In some embodiments, a vertical projection of the top gate **150** on the substrate **111** is overlapped with a vertical projection of at least a portion of the gate **112** on the substrate **111**, such that a gate voltage of at least a part of semiconductor layer **114** can be modified simultaneously by the top gate **150** and the gate **112**. In this dual gate configuration, carriers can be induced in the semiconductor layer **114** on both sides respectively facing the top gate **150** and the gate **112**, and thicknesses of channels for carriers to flow through on surfaces of two opposite sides of the semiconductor layer **114** also increase compared to single gate (gate or top gate) configurations because one channel is influenced by both the gate **112** and the top gate **150**. As a result, resistivities of the channels decreases, and the reliability increases compared to the single gate configurations.

Reference is made to FIG. **4**. FIG. **4** is a cross-sectional view of a micro light-emitting diode display device **100***d* according to some embodiments of the present disclosure. In some embodiments, the micro light-emitting diode display device **100***d* including a driving transistor **110***d* and the micro light-emitting diode **120** is provided. The driving transistor **110***d* includes a substrate **111***d*, a semiconductor layer **114***d*, a drain electrode **115***d*, a source electrode **116***d*, a gate insulator **140***d*, and a gate **150***d*. The semiconductor layer **114***d* is on the substrate **111***d*. A material of the semiconductor layer **114***d* can be a low temperature polysilicon (LTPS), but should not be limited thereto. The drain electrode **115***d* is on the semiconductor layer **114***d*. The source electrode **116***d* is on the semiconductor layer **114***d* and is spaced apart from the drain electrode **115***d*. The gate insulator **140***d* has a thickness less than or equal to about 500 Å and is on the semiconductor layer **114***d*, the drain electrode **115***d*, and the source electrode **116***d*. The gate **150***d* is on the gate insulator **140***d*. Briefly speaking, the embodiments illustrated by FIG. **4** are top gate cases without any bottom gate.

In some embodiments, the micro light-emitting diode display device **100***d* further includes a connecting electrode **119***d* on the substrate **111***d* and is in contact with the source electrode **116***d*. The gate **150***d* is electrically isolated from the source electrode **116***d* and the drain electrode **115***d* by the gate insulator **140***d*. In some embodiments, the micro light-emitting diode display device **100***d* further includes a bottom electrode **130** on the substrate **111***d* and is in contact with the connecting electrode **119***d* of the driving transistor **110***d*. In some embodiments, the micro light-emitting diode **120** is in contact with the bottom electrode **130**.

Reference is made to FIG. **5**. FIG. **5** is a schematic diagram of a micro light-emitting diode driving circuit **200***a* in some embodiments of the present disclosure. The micro light-emitting diode driving circuit **200***a* includes a storage capacitor **210**, a switching transistor **220**, a driving transistor **230**, and a micro light-emitting diode **240**. The storage capacitor **210** has two ends, and one of the two ends can be connected to a reference signal Vref. The switching transistor **220** has three terminals. One of the three terminals is a gate terminal connected to a scan line Vscan, another one of the three terminals is a drain terminal connected to a data line Vdata, and a remaining one of the three terminals is a source terminal connected to the other end of the storage capacitor **210**. The driving transistor **230** has a gate terminal configured to receive an applied gate voltage Vg and is connected to the source terminal of the switching transistor **220**. The driving transistor **230** has a drain terminal and a source terminal. The drain terminal of the driving transistor **230** is connected to a driving voltage source VDD. It should be noted that the driving transistor **230** described herein is intended for the driving transistors as illustrated by the embodiments shown in FIG. **1**A and FIGS. **2** to **4**. Specifically, the drain terminal and the source terminal of the driving transistor **230** respectively correspond to (i.e., serve as) the drain electrode (e.g., the drain electrodes **115**,**115***d*) and the source electrode (e.g., the source electrodes **116**, **116***d*), and the gate terminal of the driving transistor corresponds to (i.e., serves as) the gates or the top gate (e.g., the gates **112**, **150***d* or the top gate **150**).

The micro light-emitting diode driving circuit **200***a* also includes a micro light-emitting diode **240**. The micro light-emitting diode **240** has an anode connected to the source terminal of the driving transistor **230** and a cathode connected to a low voltage source VSS. It should be noted that the micro light-emitting diode **240** described herein is intended for the micro light-emitting diode (e.g., the micro light-emitting diode **120**) as illustrated by the embodiment shown in FIGS. **1**A, **1**B, and **2** to **4**. In some embodiments, the anode can correspond to (i.e., serve as) the bottom electrode **130** of the micro light-emitting diode **120**.

From the embodiments such as FIGS. **1**A, **1**B and **5** which include the combination of the driving transistor **110***a* (acts as the driving transistor **230**) and the micro light-emitting diode **120** with the current injection channel **122** therein (acts as the micro light-emitting diode **240**) in the micro light-emitting diode driving circuit **200***a* as shown above, a voltage applied by the driving voltage source VDD can be lowered to be less than about 6 V but still in the working range of light-emitting mode of the micro light-emitting diode **120**, so that a low power micro light-emitting diode driving circuit can be realized compared to a thin film transistor with a conventional organic light-emitting diodes (OLED). Specifically, since a driving voltage applied in a circuit with a conventional transistor and an OLED therein shall be at least higher than or equal to 7 V to light up the OLED and a working range of the OLED is equal to or greater than about 5V, as a comparison, the embodiments of the present disclosure can reduce the power consumption of a circuit. There are two structural features in combination which shall be satisfied to achieve said reduction of power consumption. One is the gate insulator (e.g. the gate insulator **113**) having the thickness less than or equal to about 500 Å, such that the threshold voltage of the driving transistor **110***a* can be lowered (to about 0.8 V when said thickness is about 200 Å), and a saturation region on current-to-voltage curves of the driving transistor **110***a* which is normally adopted to drive a light-emitting device extends to a lower voltage compared to a conventional thin film transistor. However, it is still not suitable for the low power consumption because the driving voltage VDD depends on not only a drain-to-source voltage VDS of the driving transistor **230** but also a voltage across the micro light-emitting diode **240** as expressed in an equation I: VDD=VDS+Vd. The equation I can be directly derived from the circuitry illustrated by FIG. **5**. From the equation I, although VDS is reduced by said thinner gate insulator **113**, Vd still dominates the power consumption. Therefore, a second structural feature in which the current injection channel **122** in the micro light-emitting diode **120** is provided to solve the problem. The current injection channel **122** shall be separated from the side surface S of the micro light-emitting diode **120**, such as embodiments illustrated by FIG. **1**B. In such a configuration, a current density flowing through the micro light-emitting diode **120** increases due to a reduction of a light-emitting area of the active layer **126**, and the surface recombination is substantially avoided, such that a voltage needed to light up the micro light-emitting diode can be reduced to be less than about 3 V, and a working range of said micro light-emitting diode **120** is about 2 V (e.g., from about 2.5 V to about 4 V). As a result, the driving voltage source VDD less than about 6 V can be realized. In some embodiments, the driving voltage source VDD is less than about 5 V.

Reference is made to FIG. **6**. FIG. **6** is a schematic diagram of a micro light-emitting diode driving circuit **200***b* in some embodiments of the present disclosure. In some embodiments, the micro light-emitting diode driving circuit **200***b* as shown in FIG. **6** further includes an emission control transistor **250** as compared to the micro light-emitting diode driving circuit **200***a* as shown in FIG. **5**. The emission control transistor **250** has three terminals. One of the three terminals is a gate terminal connected to an emission signal Ves. The emission control transistor **250** is electrically connected to the driving transistor **230** and the micro light-emitting diode **240** in series as shown in FIG. **6**. In some embodiments, another one of the three terminals is a drain terminal connected to the source terminal of the driving transistor **230**, and a remaining one of the three terminals is a source terminal connected to the anode of the micro light-emitting diode **240**, as shown in FIG. **6**. The emission control transistor **250** can give an ON/OFF function in a specified frequency to modify the brightness of the micro light-emitting diode **120**. It should be noted that other equivalent connecting ways performing similar functions of said emission control transistor **250** does not depart the scope of the present disclosure. In some embodiments, each of the switching transistor **220** and the emission control transistor **250** can also have a gate insulator having a thickness less than or equal to about 500 Å, such that voltages applied to the switching transistor **220** and the emission control transistor **250** can be respectively reduced and thus low power consumptions of the switching transistor **220** and the emission control transistor **250** are achieved.

It should be noted that some minor modifications on a sequence of circuit elements in circuitries as mentioned in the embodiments of the present disclosure do not depart from the claimed scope. An example is shown below. Reference is made to FIGS. **7**A and **7**B. FIG. **7**A is a cross-sectional view of a micro light-emitting diode display device **100***e* according to some embodiments of the present disclosure. FIG. **7**B is a schematic diagram of a micro light-emitting diode driving circuit **200***c* in some embodiments of the present disclosure. In some embodiments, the connecting electrode **119***e* is electrically connected to the drain electrode **115***e*, and is electrically isolated from the source electrode **116***e*. The configuration is shown in FIG. **7**A, and the corresponding micro light-emitting diode driving circuit **200***c* is shown in FIG. **7**B. Specifically, in the above configuration, since the connecting electrode **119***e* is electrically connected to the drain electrode **115***e*, the micro light-emitting diode **120** shall be in an upside-down way compared to that in FIG. **1**A. That is, the second type semiconductor layer **128** (e.g., the n-type semiconductor layer) is in contact with the bottom electrode **130**, and the bottom electrode **130** is in contact with the connecting electrode **119***e*. The above structure is reflected on the micro light-emitting diode driving circuit **200***c* by interchanging positions of the driving transistor **230** and the micro light-emitting diode **240**, such that the anode of the micro light-emitting diode **240** is connected to the driving voltage source VDD, and the cathode of the micro light-emitting diode **240** is connected to the drain electrode **115***e* of the driving transistor **230**. The source electrode **116***e* of the driving transistor **230** is connected to the low voltage source VSS, as shown in FIG. **7**B.

It should also be noted that the above advantages cannot be achieved by a driving circuit based on a conventional OLED since a minimum voltage to light up an OLED (i.e., forward voltage of the OLED) shall generally be higher than or equal to about 7 V, and the working range of the OLED is equal to or greater than about 5 V. It is the design of the current injection channel plus the ultra-thin gate insulator (e.g., with a thickness less than or equal to about 500 Å) that makes the low power driving feasible.

In summary, a micro light-emitting diode display device including a driving transistor with a gate insulator having a thickness less than or equal to about 500 Å and a micro light-emitting diode with a current injection channel and a light-emitting portion of an active layer having lateral length less than or equal to about 10 μm is provided in some embodiments of the present disclosure to realize a low power consumption micro light-emitting diode display device and a low power consumption micro light-emitting diode driving circuit.

Although the present disclosure has been described in considerable detail with reference to certain embodiments thereof, other embodiments are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the embodiments contained herein.

It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present disclosure without departing from the scope or spirit of the disclosure. In view of the foregoing, it is intended that the present disclosure cover modifications and variations of this disclosure provided they fall within the scope of the following claims.

What is claimed is:

1. A micro light-emitting diode display device, comprising:
- a driving transistor comprising:
  - a substrate;
  - a gate on the substrate;
- a gate insulator having a thickness less than or equal to about 500 angstroms and on the gate and the substrate;
  - a semiconductor layer on the gate insulator;
- a drain electrode on the semiconductor layer; and
- a source electrode on the semiconductor layer and spaced apart from the drain electrode; and
- a micro light-emitting diode having a lateral length less than or equal to about 50 μm and electrically connected to one of the source electrode and the drain electrode, the micro light-emitting diode comprising:
  - a first type semiconductor layer;
- an active layer on and joined with the first type semiconductor layer; and
- a second type semiconductor layer on and joined with the active layer, wherein a current injection channel is extended within one of the first type semiconductor layer and the second type semiconductor layer and spaced apart from a side surface of the micro light-emitting diode, and the active layer has a portion in contact with the current injection channel and having a lateral length less than or equal to about 10 μm.

2. The micro light-emitting diode display device of claim **1**, further comprising an etch stopper on the semiconductor layer of the driving transistor and in contact with the drain electrode and the source electrode, wherein at least a portion of the etch stopper between the drain electrode and the source electrode is exposed.

3. The micro light-emitting diode display device of claim **1**, further comprising a connecting electrode on the substrate and in contact with one of the source electrode and the drain electrode.

4. The micro light-emitting diode display device of claim **3**, further comprising a bottom electrode on the substrate and in contact with the connecting electrode, and the micro light-emitting diode being in contact with the bottom electrode.

5. The micro light-emitting diode display device of claim **1**, further comprising:
- a top gate insulator on the semiconductor layer; and
- a top gate on the top gate insulator.

6. The micro light-emitting diode display device of claim **5**, wherein a vertical projection of the top gate on the substrate is overlapped with a vertical projection of at least a portion of the gate on the substrate.

7. A micro light-emitting diode display device, comprising:
- a driving transistor comprising:
  - a substrate;
- a semiconductor layer on the substrate;
- a drain electrode on the semiconductor layer;
- a source electrode on the semiconductor layer and spaced apart from the drain electrode;
- a gate insulator having a thickness less than or equal to about 500 angstroms and on the semiconductor layer; and
- a gate on the gate insulator;
- a micro light-emitting diode having a lateral length less than or equal to about 50 μm and electrically connected

to one of the source electrode and the drain electrode, comprising:

a first type semiconductor layer;

an active layer on and joined with the first type semiconductor layer; and

a second type semiconductor layer on and joined with the active layer, wherein a current injection channel is extended within one of the first type semiconductor layer and the second type semiconductor layer and spaced apart from a side surface of the micro light-emitting diode, and the active layer has a portion in contact with the current injection channel and having a lateral length less than or equal to about 10 μm.

8. The micro light-emitting diode display device of claim **7**, further comprising a connecting electrode on the substrate and in contact with one of the source electrode and the drain electrode.

9. The micro light-emitting diode display device of claim **8**, further comprising a bottom electrode on the substrate and in contact with the connecting electrode, and the micro light-emitting diode being in contact with the bottom electrode.

10. A micro light-emitting diode driving circuit, comprising:

a storage capacitor having two ends;

a switching transistor having a gate terminal connected to a scan line, a drain terminal connected to a data line, and a source terminal connected to one end of the storage capacitor;

a micro light-emitting diode having a lateral length less than or equal to about 50 μm and comprising:

a first type semiconductor layer;

an active layer on and joined with the first type semiconductor layer; and

a second type semiconductor layer on and joined with the active layer, wherein a current injection channel is extended within one of the first type semiconductor layer and the second type semiconductor layer and spaced apart from a side surface of the micro light-emitting diode, and the active layer has a portion in contact with the current injection channel and having a lateral length less than or equal to about 10 μm, the micro light-emitting diode having an anode and a cathode respectively connected to the first type semiconductor layer and the second type semiconductor layer, and the micro light-emitting diode receives a first driving voltage from a driving voltage source and is electrically connected to a low voltage source; and

a driving transistor having a gate terminal, a drain terminal, and a source terminal, the gate terminal being connected to the source terminal of the switching transistor, the micro light-emitting diode being electrically connected to one of the source terminal and the drain terminal of the driving transistor, the driving transistor receiving a second driving voltage from the driving voltage source and being electrically connected to the low voltage source, the driving transistor being one of a first structure, a second structure and a third structure, wherein

the first structure comprises:

a first substrate;

a first gate on the first substrate;

a first gate insulator having a thickness less than or equal to about 500 angstroms on the first gate;

a first semiconductor layer on the first gate insulator;

a first drain electrode on the first semiconductor layer; and

a first source electrode on the first semiconductor layer and spaced apart from the first drain electrode;

the second structure comprises:

a second substrate;

a second gate on the second substrate;

a second gate insulator having a thickness less than or equal to about 500 angstroms on the second gate;

a second semiconductor layer on the second gate insulator;

a second drain electrode on the second semiconductor layer;

a second source electrode on the second semiconductor layer and spaced apart from the second drain electrode;

a top gate insulator on the second semiconductor layer; and

a top gate on the top gate insulator;

the third structure comprises:

a third substrate;

a third semiconductor layer on the third substrate;

a third drain electrode on the third semiconductor layer;

a third source electrode on the third semiconductor layer and spaced apart from the third drain electrode;

a third gate insulator having a thickness less than or equal to about 500 angstroms on the third semiconductor layer; and

a third gate on the third gate insulator.

11. The micro light-emitting diode driving circuit of claim **10**, further comprising an emission control transistor having a gate terminal connected to an emission signal, the emission control transistor being electrically connected to the driving transistor and the micro light-emitting diode in series.

12. The micro light-emitting diode display device of claim **7**, wherein the semiconductor layer is sandwiched between the gate and the substrate.

* * * * *

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摘要(译)

提供了一种包括驱动晶体管和微发光二极管的微发光二极管显示装置。驱动晶体管包括基板，栅极，栅极绝缘体，半导体层，漏极和源极。 栅极绝缘体的厚度小于或等于约500埃。 微型发光二极管的横向长度小于或等于约50μm，并且电连接到源电极和漏电极之一。 电流注入通道在微发光二极管的第一类型半导体层和第二类型半导体层之一中延伸，并且与微发光二极管的侧面间隔开。 微型发光二极管的有源层的发光部分的横向长度小于或等于大约10μm。