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(54) **DEVICE INCLUDING OLED CONTROLLED BY N-TYPE TRANSISTOR**

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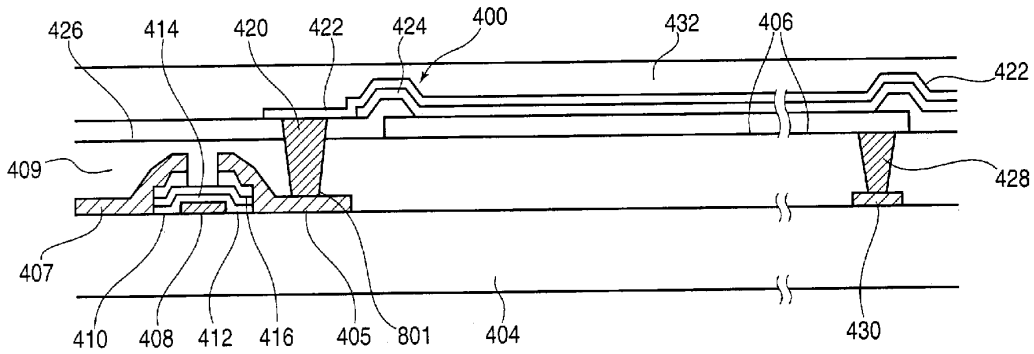
(57) **ABSTRACT**

A device and corresponding method are provided. The device includes an n-type transistor fabricated over a substrate, the n-type transistor having a gate and two current-carrying electrodes. The device also includes a non-inverted organic light emitting device fabricated over the substrate, the non-inverted organic light emitting device having an anode and a cathode. The cathode is connected to one of the current-carrying electrodes of the n-type transistor.



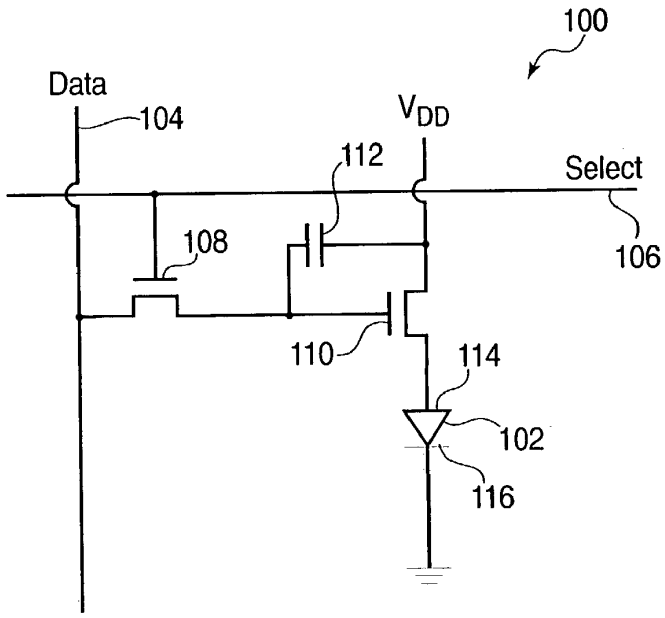

100
Data
104
V_{DD}
112
Select
106
108
110
114
102
116

Fig. 1

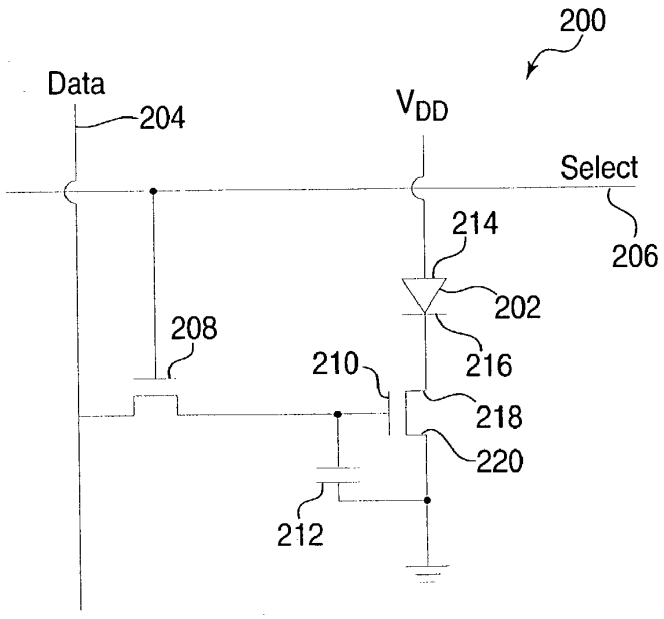

200
Data
204
V_{DD}
Select
206
214
202
208
210
216
218
220
212

Fig. 2

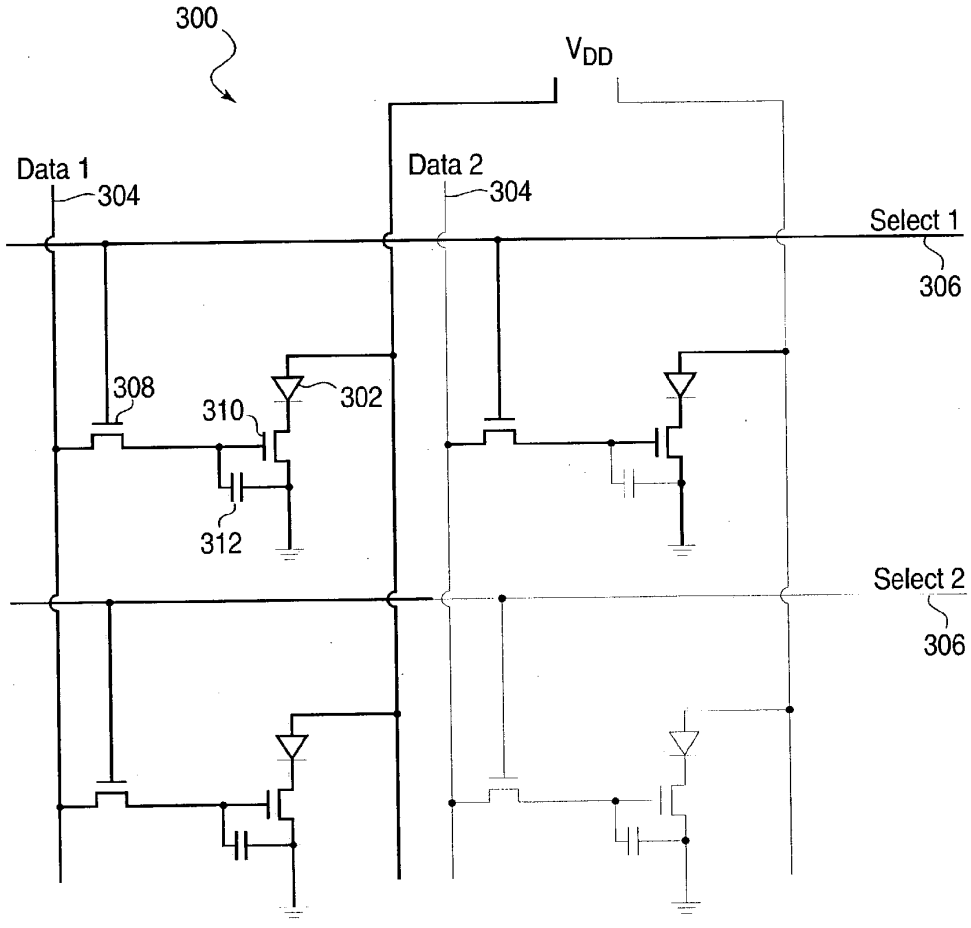

300
V_{DD}
Data 1
304
Data 2
304
Select 1
306
308
310
302
312
Select 2
306

Fig. 3

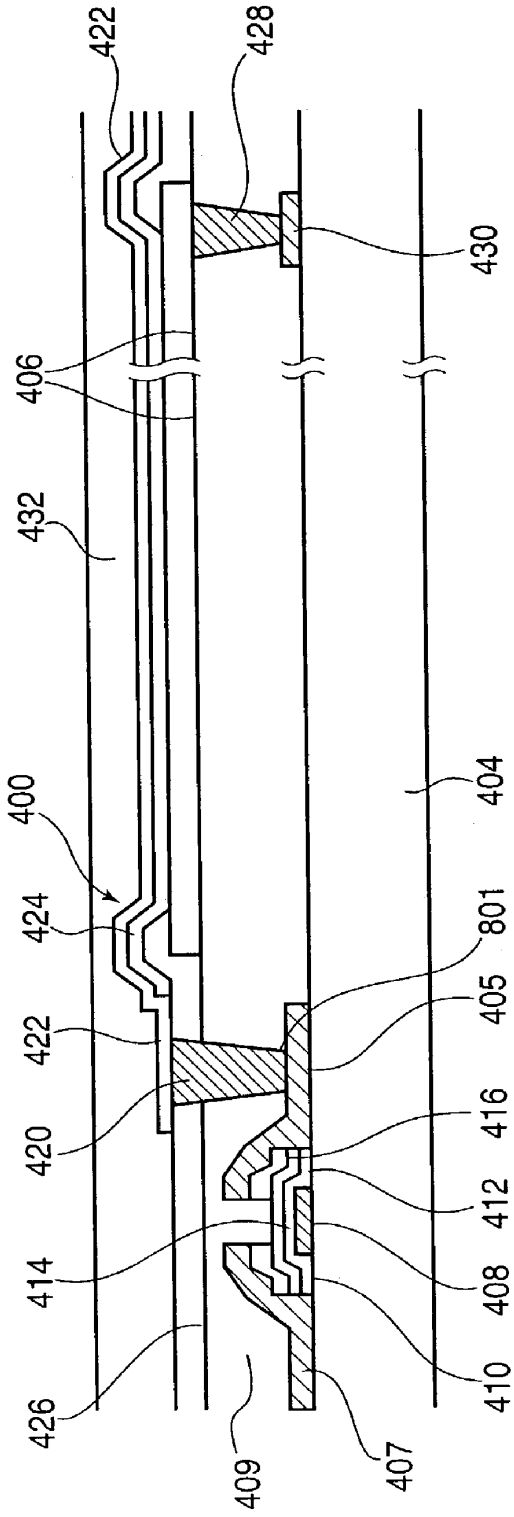

422
428
430
406
432
400
424
422
420
426
414
409
407
410
408
412
416
405
801
404

Fig. 4

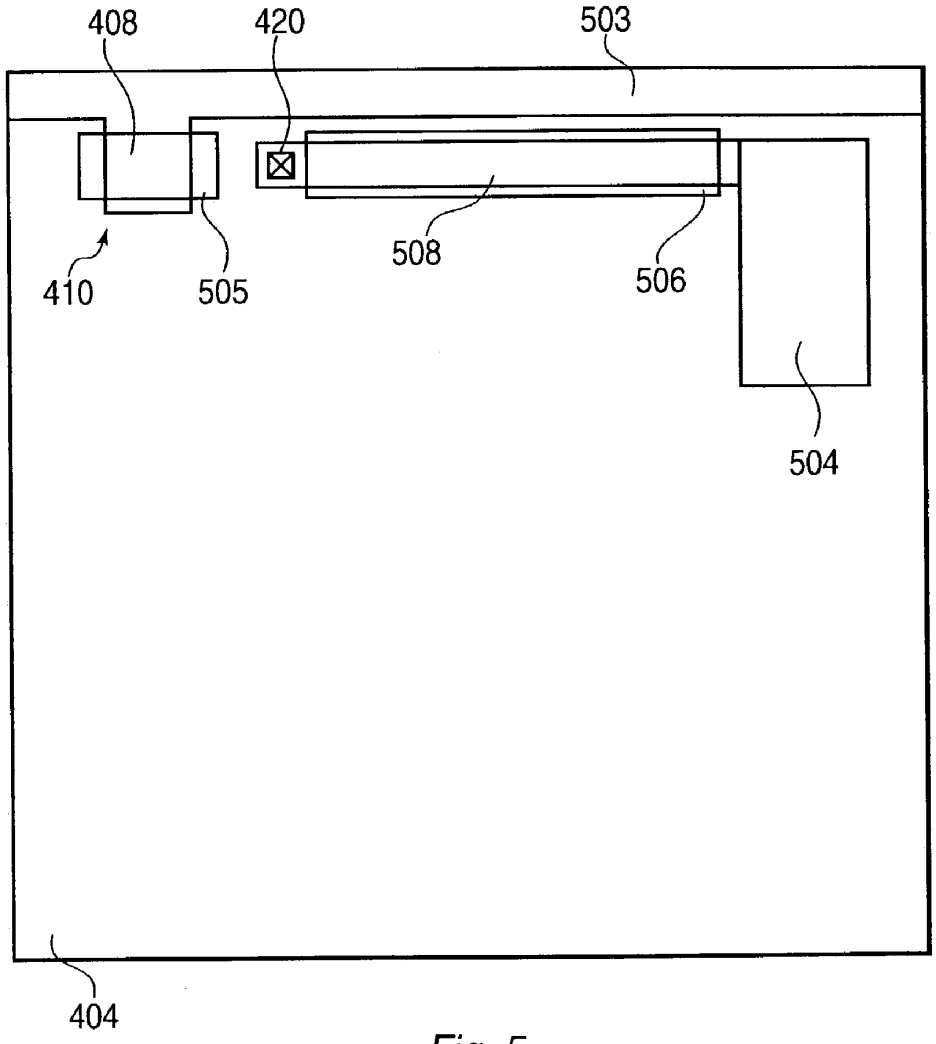


Fig. 5

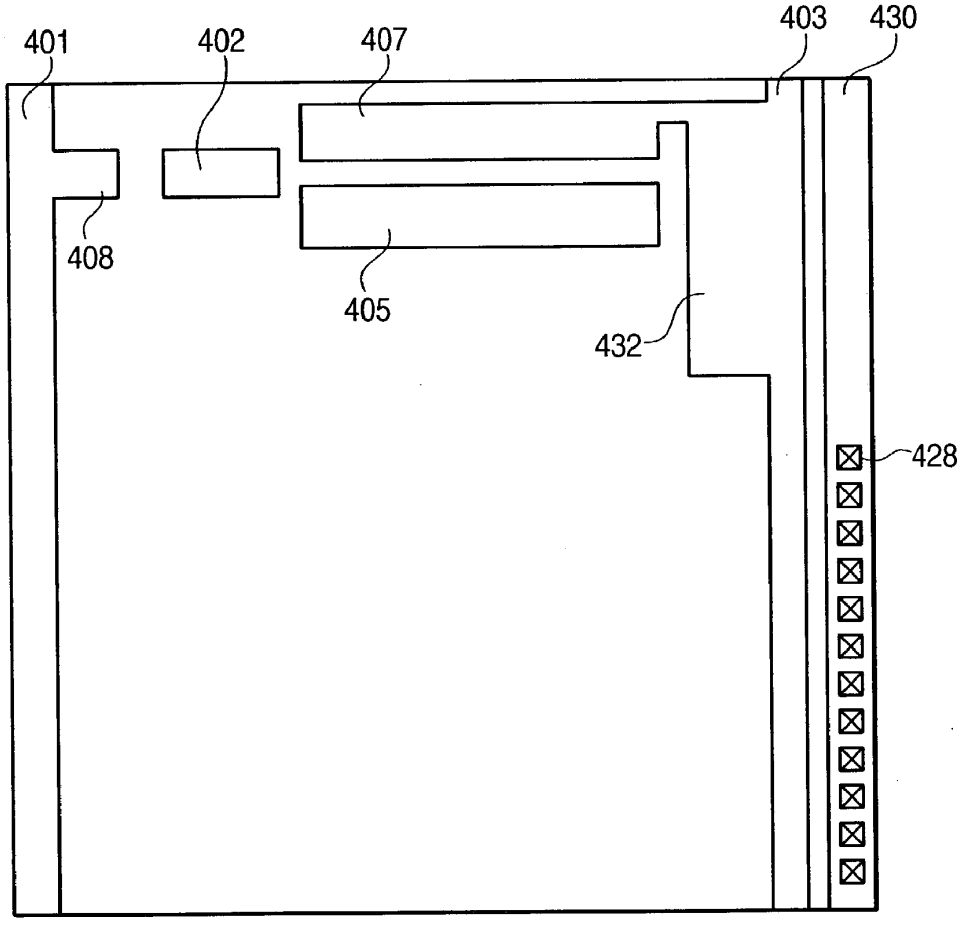


Fig. 6

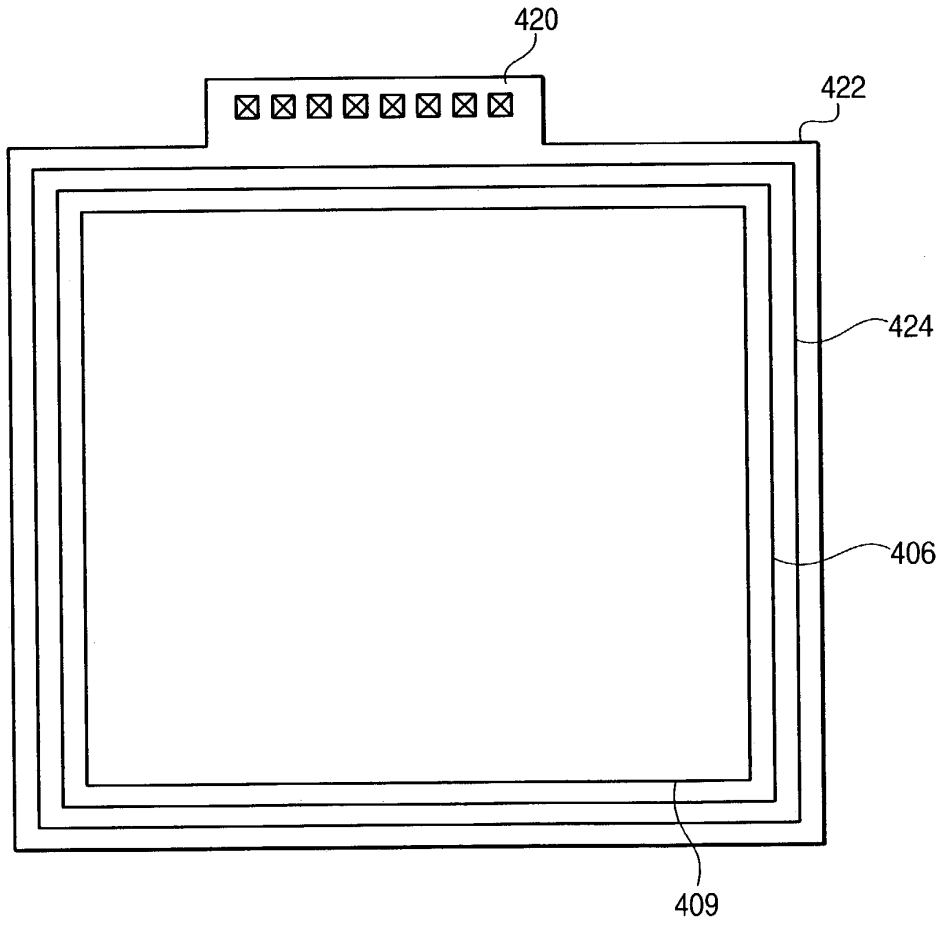


Fig. 7

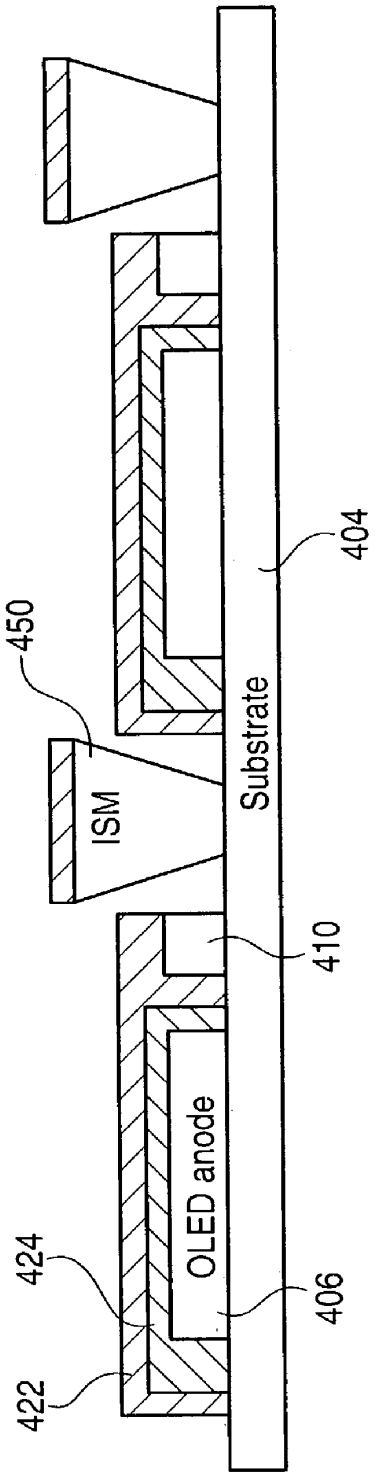


Fig. 8

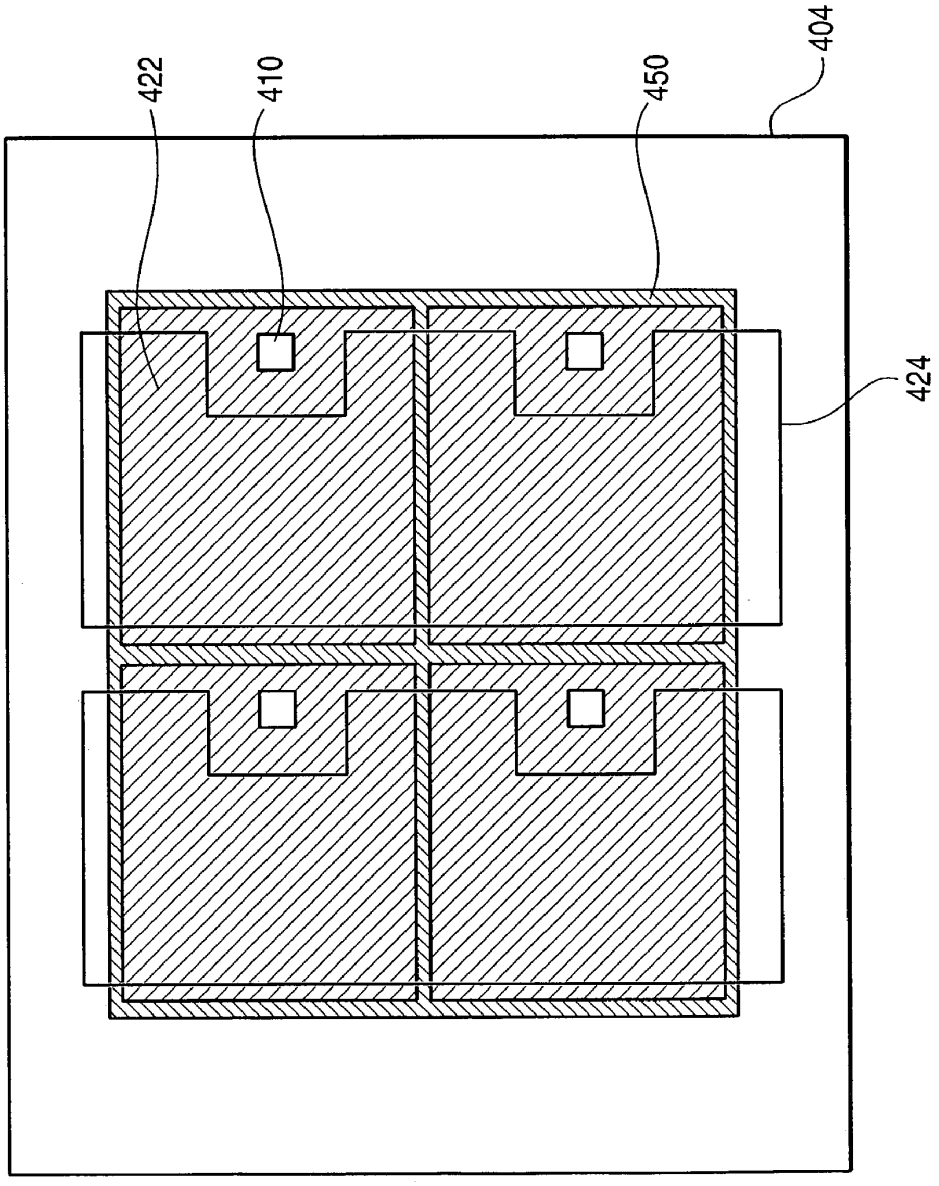


Fig. 9

DEVICE INCLUDING OLED CONTROLLED BY N-TYPE TRANSISTOR

FIELD OF THE INVENTION

[0001] The present invention relates to the field of devices including an organic light emitting device (OLED) device controlled by an n-type transistor.

BACKGROUND OF THE INVENTION

[0002] OLEDs are becoming increasingly desirable for a number of reasons. Many of the materials used to make such devices are relatively inexpensive, so organic light emitting devices have the potential for cost advantages over inorganic devices. In addition, the inherent properties of organic materials, such as their flexibility, may make them well suited for particular applications such as fabrication on a flexible substrate. In addition, the wavelength at which an organic emissive layer emits light may generally be readily tuned with appropriate dopants, while it may be more difficult to tune inorganic emissive materials.

[0003] OLEDs make use of thin organic films that emit light when voltage is applied across the device. OLEDs are becoming an increasingly popular technology for applications such as flat panel displays, illumination, and backlighting. OLED configurations include double heterostructure, single heterostructure, and single layer, and a wide variety of organic materials may be used to fabricate OLEDs. Representative OLED materials and configurations are described in U.S. Pat. Nos. 5,707,745, 5,703,436, 5,834,893, 5,844,363, 6,097,147 and 6,303,238, which are incorporated herein by reference in their entirety.

SUMMARY OF THE INVENTION

[0004] A device and corresponding method are provided. The device includes an n-type transistor fabricated over a substrate, the n-type transistor having a gate and two current-carrying electrodes. The device also includes a non-inverted organic light emitting device fabricated over the substrate, the non-inverted organic light emitting device having an anode and a cathode. The cathode is connected to one of the current-carrying electrodes of the n-type transistor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] **FIG. 1** shows a schematic diagram of a circuit for an OLED device;

[0006] **FIG. 2** shows a schematic diagram of a circuit for an OLED device;

[0007] **FIG. 3** shows an array configuration where a plurality of the devices embodiments of the present invention may be used together to form elements of an array;

[0008] **FIG. 4** shows an OLED and a thin film transistor in accordance with an embodiment of the present invention;

[0009] **FIG. 5** shows processing steps in forming the OLED device of an embodiment of the present invention,

[0010] **FIG. 6** shows processing steps in forming the OLED device of an embodiment of the present invention; and

[0011] **FIG. 7** shows processing steps in forming the OLED device of an embodiment of the present invention.

[0012] **FIG. 8** shows how an embodiment of the present invention may be fabricated through the use of an integrated shadow mask; and

[0013] **FIG. 9** shows how the an embodiment of the present invention may be fabricated through the use of an integrated shadow mask

DETAILED DESCRIPTION

[0014] An embodiment of the present invention includes an n-type transistor fabricated over a substrate, the n-type transistor having a gate and two current-carrying electrodes. The device also includes a non-inverted organic light emitting device (OLED) fabricated over the substrate, the non-inverted organic light emitting device having an anode and a cathode. The most common OLED configuration has a cathode disposed over the anode, and may be referred to as a "non-inverted" OLED. Because an OLED having an anode disposed over the cathode, it may be referred to as a "inverted OLED". The cathode is connected to one of the current-carrying electrodes of the n-type transistor. By connecting the cathode of the OLED to the transistor, the embodiments of the present invention make the use of n-type transistors practical. N-type thin film transistors may significantly lower the cost as compared to the use of low temperature polysilicon (LTP) p-type transistors. Embodiments of the invention allow for lower driving voltages, and results in the current through the OLED and driving transistor being independent of current-voltage characteristics of the OLED, as will be further explained below. In a preferred embodiment, the n-type transistor may be an n-type thin film transistor, although other n-type transistors may be used.

[0015] The cathode of the OLED is connected to one of the current-carrying electrodes of the n-type transistor. This connection may be a "direct connection", where the cathode is in physical contact with the current-carrying electrode. Alternatively, the connection may be an "indirect connection", with one or more elements between the cathode and the current-carrying electrode. For example, a resistor, transistor or other element could be placed between the cathode and the current carrying electrode, and such a connection would be an "indirect connection". Both a "direct connection" and an "indirect connection" are within the scope of the present invention.

[0016] The n-type transistor used in embodiments of the present invention may be manufactured by any process. One example of a suitable process is a "back channel etch process", but other processes may be used, including variations of what is described herein. Further, any n-type transistor structures may be used, including variations of what is described herein, although amorphous thin film transistors may be particularly desirable because of their low cost. The n-type transistor may be one of: a) a polycrystalline silicon thin film transistor; b) an amorphous thin film transistor; c) a cadmium selenide thin film transistor; or d) an organic thin film transistor.

[0017] A schematic diagram of a circuit **100** for an OLED device is shown in **FIG. 1**. Such a circuit could be used in a matrix display, for example. The circuit **100** includes an OLED **102**, a data line **104**, a select line **106**, a select

transistor **108**, a transistor **110** and a storage capacitor **112**. The OLED **102** has an anode **114** and a cathode **116**. The anode **114** is connected to the transistor **114**. The select transistor **108** is connected to select line **106**, so that an appropriate voltage applied to the select line will turn on the transistor **108**, allowing a voltage on data line **104** to be applied to the gate of driving transistor **110**, turning on transistor **110**. This configuration allows for the use of n-type transistors, but such a transistor would have it's source connected to the anode of the OLED. As a result, the voltage sufficient to turn on the transistor **110** so that current can flow between the drain and the source and through the OLED, which is referred to herein as Vdata, must be sufficiently high to account for the voltage between the gate and source, Vgs, and the voltage drop across the OLED **102**. A higher Vdata results in a higher power consumption. Also, because Vdata includes the voltage drop across the OLED, the current through the transistor and OLED is highly dependent on the I-V characteristics of the OLED. As a result, a display based on the circuit will be highly susceptible to problems due to non-uniformities in the OLEDs, as well as OLED degradation over time.

[**0018**] A schematic diagram of a circuit **200** that may be used with embodiments of the present invention is shown in **FIG. 2**. In this embodiment, n-type transistors are also used, which may be n-type thin film transistors. N-type transistors have several advantages as compared to conventional devices that use p-type transistors. First, n-type transistors have higher mobilities than p-type transistors, and therefore can be made smaller for any given drive current. Second, n-type transistors can be made from amorphous silicon, unlike p-type transistors, thus reducing the cost of the device. Third, amorphous silicon n-type transistors may be favorably fabricated with lower temperature processing.

[**0019**] The circuit **200** includes non-inverted OLED **202**, data line **204**, select line **206**, select transistor **208**, n-type thin film transistor **210** and storage capacitor **212**. The OLED **202** has an anode **214** and a cathode **216**. The transistor **210** has two current-carrying electrodes, drain **218** and source **220** The circuit **200** of **FIG. 2** differs from the circuit **100** of **FIG. 1** in that the OLED **202** is connected to the drain **218** of transistor **210**. In particular, the cathode **216** of OLED **202** is connected to the drain **218** of transistor **210**. This configuration is advantageous as compared to the circuit of **FIG. 1** in that Vdata, the voltage required to turn on and transistor **210**, is lowered to be Vgs, the voltage across the gate and source of transistor **210**, and does not include a voltage drop across the OLED **202**. This voltage may be less than about 10 volts. Further, this configuration results in the current through the transistor **210** and through OLED **202** being substantially independent of the current-voltage characteristics of the OLED. This is advantageous because the current-voltage characteristics of an OLED may change over time, and may be different between a plurality of OLEDs that may be used together in a single device, leading to non-uniformities. A circuit such as shown in **FIG. 2** could be realized with an inverted OLED having a bottom cathode, but such a configuration is usually less efficient than the inverted OLED of embodiments of the present invention.

[**0020**] The embodiments of the present invention may be used with any type of circuit, as long as it includes an OLED having a cathode connected to a current-carrying electrode of an n-type transistor. The particular form of the remaining circuit may vary. The circuit may include different or additional elements. For example, the circuit may additionally include correction circuitry to compensate for any non-uniformities in individual elements. The n-type transistor to which the cathode of the OLED is connected may be a "driving" transistor. A "driving" transistor as used herein is a transistor that determines the current that will flow through the OLED. While other transistors may affect or tweak the current flowing through the OLED, such as transistors used in correction circuits, these other transistors are not considered to be "driving" transistors. Other elements may replace the select transistor or storage capacitor, or they may be eliminated when not needed for a particular application.

[**0021**] The circuit **300** of **FIG. 3** illustrates an array configuration where a plurality of the devices of embodiments of the present invention may be used together to form elements of an array **300** that may be used in devices such as displays. In particular, this configuration may be used with active matrix displays. **FIG. 3** illustrates a plurality of circuits, each of which is a circuit such as that shown in **FIG. 2**. Each circuit is controlled by circuitry (not shown) to activate individual OLEDs **302** within the array as desired. The control circuitry is conventional and known to those of skill in the art, and therefore will not be further described. Each circuit is connected to a data line **304** and a select line **306**, and contains n-type transistors **308** and **310**, storage capacitor **312** and OLED **302**, which function in the same manner as the corresponding elements in **FIG. 2**. In addition to the array configuration shown in **FIG. 3**, embodiments of the present invention may be used with one or more of the OLED and n-type transistor circuits to form a lighting element.

[**0022**] **FIG. 4** shows an OLED **400** and transistor **410** in accordance with an embodiment of the present invention. The OLED **400** and transistor **410** may be elements of an array such as shown in **FIG. 3**, as further explained below.

[**0023**] Substrate **404** may be any suitable substrate known to the art. Ceramic, plastic, and glass are examples of suitable substrate materials. Substrate **404** may be flexible or inflexible. Where substrate **404** is flexible, preferred substrate materials include plastic and metal foils. Substrate **404** may be transparent or opaque. Substrate **404** and anode **406** may be any suitable material or combination of materials known to the art, such that anode **406** may be adapted to inject holes into a p-doped layer. Anode **406** and substrate **404** may be sufficiently transparent to create a bottom emitting device. A preferred substrate and anode combination, which is transparent, is commercially available ITO (anode) deposited on glass or plastic (substrate). Preferred anode materials include conductive metal oxides and metals. A hole-injection enhancement layer may be used to increase the injection of holes from anode **406** into a p-doped layer.

[**0024**] Transistor **410** is formed over substrate **404**. The transistor includes a gate **408**, source region **405** and drain region **407**. Between the gate **408** and the source and drain regions **405** and **407**, there may be three layers, a SiNx layer, an intrinsic a—Si layer **414** and a n+a—Si layer **416**.

[**0025**] The transistor **410** is connected to the OLED **400** through via **420**, which may be filled with a metal plug, for example. The via **420** connects the source region **405** of transistor **410** to the cathode **422** of OLED **400**.

[0026] The OLED **400** includes the cathode **422**, organic layer **424**, and anode **406**. Anode **406** may be any suitable anode material known to the art. Dielectric layer **426** may define boundries of the OLED. Via **428** connects the anode **406** of OLED **400** to bus line **430**. A passivation layer **409** is formed over transistor **410**, substrate **404** and bus line **430**.

[0027] Organic layer **424** may be any suitable organic material that emits light when sufficient current is passed between anode **406** and cathode **422**. Organic layer **424** may also comprise organic layers in addition to an organic emissive layer, such as those of a double heterostructure configuration, with a separate hole transport layer, an emissive layer, and an electron transport layer. Many organic hole transport, emissive, and electron transport materials are known to the art, and may be used with embodiments of the present invention. Organic layer **424** may comprise other configurations known to the art, such as single heterostructure or single layer. Organic layer **424** may include other layers not shown. For example, organic layer **424** may include blocking layers adapted to confine charge carriers in an emissive layer, which are described in more detail in U.S. patent application Ser. No. 10/173,682 to Forrest et al., filed Jun. 18, 2002, which is incorporated by reference in its entirety. Organic layer **424** may include a buffer layer disposed beneath cathode **422**, that protects underlying organic layers during the deposition of cathode **422**, as described in more detail in U.S. patent application Ser. No. 09/931,948 to Lu et al., attorney docket no. 10052/1601, filed Aug. 20, 2001, which is incorporated by reference in its entirety. Organic layer **424** may include other layers that provide an advantage to the OLED device. Preferably, the emissive layer is a phosphorescent material, due to the high efficiencies associated with such materials, but other types of materials, such as fluorescent materials, may also be used. Organic layer **424** may be deposited by any technique known to the art, including organic vapor phase deposition (OVPD), such as disclosed in U.S. Pat. No. 6,337,102, which is incorporated herein by reference in its entirety, and thermal vapor phase deposition. As used herein, the term "organic" includes polymeric materials as well as small molecule organic materials.

[0028] Organic layer **424** may include an emissive layer, which may be any suitable organic emissive material. Preferably, the emissive layer is a phosphorescent emissive material, although fluorescent emissive materials may also be used. Phosphorescent materials are preferred because of the higher luminescent efficiencies associated with such materials. Many emissive materials have resistivity that is significant, so it is also preferable to minimize the thickness of emissive layer, while still having a thickness sufficient to ensure a contiguous layer.

[0029] Cathode **422** may be any suitable material or combination of materials known to the art, such that cathode **422** is adapted to inject electrons into an n-doped layer (not shown). Cathode **422** may be sufficiently transparent to create a top emitting device. Both cathode **422** and anode **406** may be transparent, partially transparent, or substantially transparent to create a transparent OLED. Preferred transparent electrode materials include ITO, zinc-indium-tin oxide, and other materials, used in conjunction with a thin low-work function layer. Preferred opaque cathodes include LiF/Al and other materials known to the art. An electron-injection enhancement layer may be used to increase the injection of electrons from cathode **422** into the n-doped layer.

[0030] One or more transparent electrodes may be useful in an organic opto-electronic device. For example, OLED devices are generally intended to emit light through at least one of the electrodes. For OLEDs from which the light emission is only out of the bottom of the device, that is, only through the substrate side of the device, a transparent anode material, such as indium tin oxide (ITO), may be used as the bottom electrode. Since the top electrode of such a device does not need to be transparent, such a top electrode, which is typically a cathode, may be comprised of a thick and reflective metal layer having a high electrical conductivity. In contrast, for transparent or top-emitting OLEDs, a transparent cathode such as disclosed in U.S. Pat. Nos. 5,703,436 and 5,707,745 may be used. As distinct from a bottom-emitting OLED, a top-emitting OLED is one which may have an opaque and/or reflective substrate, such that light is produced only out of the top of the device and not through the substrate. In addition, a fully transparent OLED that may emit from both the top and the bottom.

[0031] Also show in **FIG. 4** is an encapsulation layer **432**. The encapsulation layer **432** may be formed over the entire structure to protect it from the environment. Other encapsulants, such as a metal lid or a glass lid secured by a perimeter or face seal may be used. An encapsulant is preferred but not necessary.

[0032] FIGS. **5-8** illustrate possible processing flow for forming a pixel, including the OLED **400**, transistor **410**, and a switching transistor **502**. These figures are further explained below.

[0033] **FIG. 5** illustrates initial processing steps. First, over the substrate **404** is formed a gate line **503**, which may be formed from a metal, such as Chromium, which is patterned to form a gate **408**, gate **508**, and the bottom electrode **504** of a storage capacitor. Then the active regions **505** and **506** are deposited, which may be formed from the three layer SiNx layer, an intrinsic a—Si layer, and a n+a—Si layer as described above. The via hole **420** is then formed in gate **102**.

[0034] The elements in **FIG. 6** are then formed over the elements in **FIG. 5**. A source/drain level metal (e.g. Mo) is deposited and patterned to form dataline **401**, source/drain **408**, contact **402**, drain **405** and source **407**, ground line **403**, a top electrode **432** of the storage capacitor and ITO bus line **430**. The T1-T2 contact **402** contacts gate **102** through vias **428**. The vias may be formed with one via hole as shown in **FIG. 4**, or may be formed from a plurality of via holes as shown in **FIG. 6**.

[0035] Then, n+amorphous silicon is etched using metal ground line **403**, drain **405** and source **407**, and source/drain **408** as a mask. Next, contact annealing is performed. A passivation layer is then deposited over the tfts and planarizing occurs to form a flat surface. The structure is contact annealed to improve contact between the metal and n+Sia layer. Via holes **428** are formed in the passivation layer to the bus line **430**, and metal plugs are formed therein.

[0036] The elements in **FIG. 7** are then formed over the elements in **FIG. 6**. An ITO layer is deposited and patterned to form anode **406**. Anode **406** is formed so as to cover vias

428 shown in **FIG. 6** to contact ITO bus line **430**. Dielectric layer **409** is then deposited. Vias **420** are then formed above drain **405**, and metal plugs may be formed therein. A shadowmask may then be used to deposit organic layer **424**. Cathode **422** is then deposited through a shadowmask, overlapping the vias **420** so that the cathode **422** connects to the drain **405** by the metal plug in vias **420**.

[**0037**] The above described process flow is only one possible process flow that could be used in connection with embodiments of the present invention. Any known variation of this process flow that results in the structure described herein can be used with embodiments of the present invention. For example, instead of depositing the organic layer through the shadow mask and depositing the cathode through a shadowmask, a two dimensional integrated shadowmask could be formed around the OLED opening, the organic layer could be deposited, and the cathode **422** could be deposited without a mask. In another embodiment, shadowmasks for the organic layer and the cathode could be adjusted to have a same shape, the organic layer could be first deposited, and then the shadowmask could be slid over the organic layer to deposit the cathode.

[**0038**] **FIGS. 8 and 9** shows how embodiments of the present invention may be fabricated through the use of an integrated shadow mask (ISM), which may be fabricated prior to OLED fabrication. First the OLED anode **406**, indium tin oxide for example, may be patterned around the n-type transistors **410**. This could be done with one large contact pad covering the device with islands (openings) within the contact pad where the transistor contact pads are. The organic layers **424** are then deposited through a shadow mask to overlap the idium tin oxide. The cathodes **422** are then deposited in a pattern overlapping the ITO/organic region and making contact to individual transistors, as shown in **FIG. 9**. This can be done using a conventional shadow mask or by constructing an integrated shadow mask on the substrate. While this method may be used to efficiently manufacture embodiments of the present invention, it should be noted that any method of forming an n-type transistor having a current-carrying electrode connected to the cathode of the OLED is within the scope of the present invention.

[**0039**] While the present invention is described with respect to particular examples and preferred embodiments, it is understood that the present invention is not limited to these examples and embodiments. The present invention as claimed therefore includes variations from the particular examples and preferred embodiments described herein, as will be apparent to one of skill in the art.

What is claimed is:

1. A device, comprising:

an n-type transistor fabricated over a substrate, the n-type transistor having a gate and two current-carrying electrodes; and

a non-inverted organic light emitting device fabricated over the substrate, the non-inverted organic light emitting device having an anode and a cathode, the cathode being connected to one of the current-carrying electrodes of the n-type transistor.

2. The device of claim 1, wherein the n-type thin film transistor is an n-type thin film transistor.

3. The device of claim 1, further comprising an integrated shadow mask over the substrate.

4. The device of claim 1, wherein the n-type transistor is a driving n-type transistor.

5. The device of claim 1, wherein the cathode of the organic light emitting device is connected directly to one of the current-carrying electrodes of the n-type transistor.

6. The device of claim 1, wherein the current-carrying electrode to which the cathode is connected functions as a drain.

7. The device of claim 1, wherein a current through the organic light emitting device and the n-type transistor is substantially independent of a current-voltage characteristic of the organic light emitting device.

8. The device of claim 1, wherein the n-type transistor is one of: a) a polycrystalline silicon thin film transistor; b) an amorphous thin film transistor; c) a cadmium selenide thin film transistor, or d) an organic thin film transistor.

9. The device of claim 1, wherein the organic light emitting device is phosphorescent.

10. The device of claim 1, wherein the device is flexible.

11. The device of claim 10, wherein the substrate includes a material selected from the group consisting of metal foil or plastic.

12. The device of claim 1, wherein the cathode is substantially transparent.

13. The device of claim 1, wherein the electronic device is top-emitting.

14. The device of claim 1, wherein a data voltage required to turn on the n-type transistor is less than about 10 volts.

15. The device of claim 1, further comprising an encapsulation layer formed over the organic light emitting device.

16. The device of claim 1, wherein a data voltage required to turn on the n-type transistor does not include a voltage across the organic light emitting diode.

17. A lighting device, comprising the device of claim 1.

18. A display device, comprising the device of claim 1.

19. A method of forming a device, comprising:

fabricating an n-type transistor over a substrate, the n-type transistor having a gate and two current-carrying electrodes; and

fabricating a non-inverted organic light emitting device over the substrate, the non-inverted organic light emitting device having an anode and a cathode, the cathode being connected to one of the current-carrying electrodes of the n-type transistor.

20. The method of claim 19, wherein the n-type transistor is an n-type thin film transistor

21. The method of claim 19, further comprising fabricating the non-inverted organic light emitting device with an integrated shadow mask.

22. The method of claim 19, wherein the n-type transistor is a driving n-type thin film transistor.

23. The method of claim 19, wherein the cathode of the organic light emitting device is connected directly to one of the current-carrying electrodes of the n-type transistor.

24. The method of claim 19, wherein a current through the organic light emitting device and the n-type transistor is substantially independent of a current-voltage characteristic of the organic light emitting device.

25. The method of claim 19, wherein the current-carrying electrodes to which the cathode is connected functions as a drain.

26. The method of claim 19, wherein the n-type transistor is one of: a) a polycrystalline silicon thin film transistor; b) an amorphous thin film transistor; c) a cadmium selenide thin film transistor, or d) an organic thin film transistor.

27. The method of claim 19, wherein the organic light emitting device is phosphorescent.

28. The method of claim 19, wherein the device is flexible.

29. The method of claim 28, wherein the substrate includes a material selected from the group consisting of a metal foil or plastic.

30. The method of claim 19, wherein the cathode is substantially transparent.

31. The method of claim 19, further comprising forming the device as a top-emitting device.

32. The method of claim 19, wherein a data voltage required to turn on the n-type transistor is less than about 10 volts.

33. The method of claim 19, further comprising forming an encapsulation layer over the organic light emitting device.

34. The method of claim 19, wherein a data voltage required to turn on the n-type transistor does not include a voltage across the organic light emitting diode.

35. A method of forming a lighting device, comprising forming the device of claim 19.

36. A method of forming a display device, comprising forming the device of claim 19.

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