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(54) **ACTIVE MATRIX DISPLAY COMPENSATING METHOD**

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(51) **Int. Cl.**
G09G 3/30 (2006.01)

(52) **U.S. Cl.** **345/77**; 345/76; 345/690; 315/169.3

(58) **Field of Classification Search** 345/76–82, 345/211, 690, 204
See application file for complete search history.

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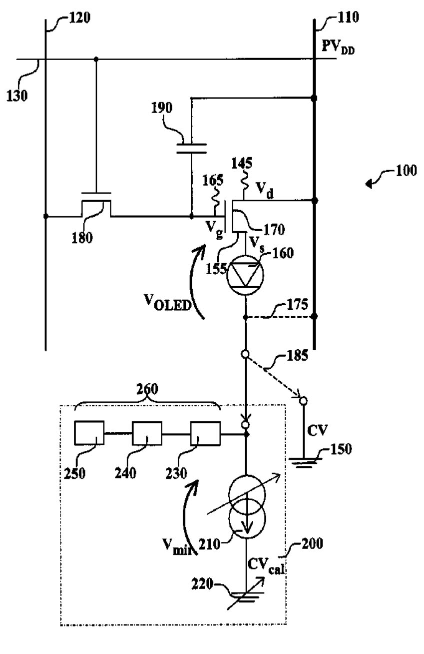
(57) **ABSTRACT**

Compensating for changes in the threshold voltage of the drive transistor of an OLED drive circuit, the drive transistor includes a first electrode, second electrode, and gate electrode; connecting a first voltage source to the first electrode, and an OLED device to the second electrode and to a second voltage source; providing a test voltage to the gate electrode and connecting to the OLED drive circuit, a test circuit, that includes an adjustable current mirror causing voltage applied to the current mirror, to be at a first test level; providing a test voltage to the gate electrode of the drive transistor and connecting the test circuit to the OLED device producing a second test level after the drive transistor and the OLED device age; and using the first and second test levels to calculate changes in the voltage applied to the gate electrode of the drive transistor to compensate for drive transistor aging.

21 Claims, 5 Drawing Sheets



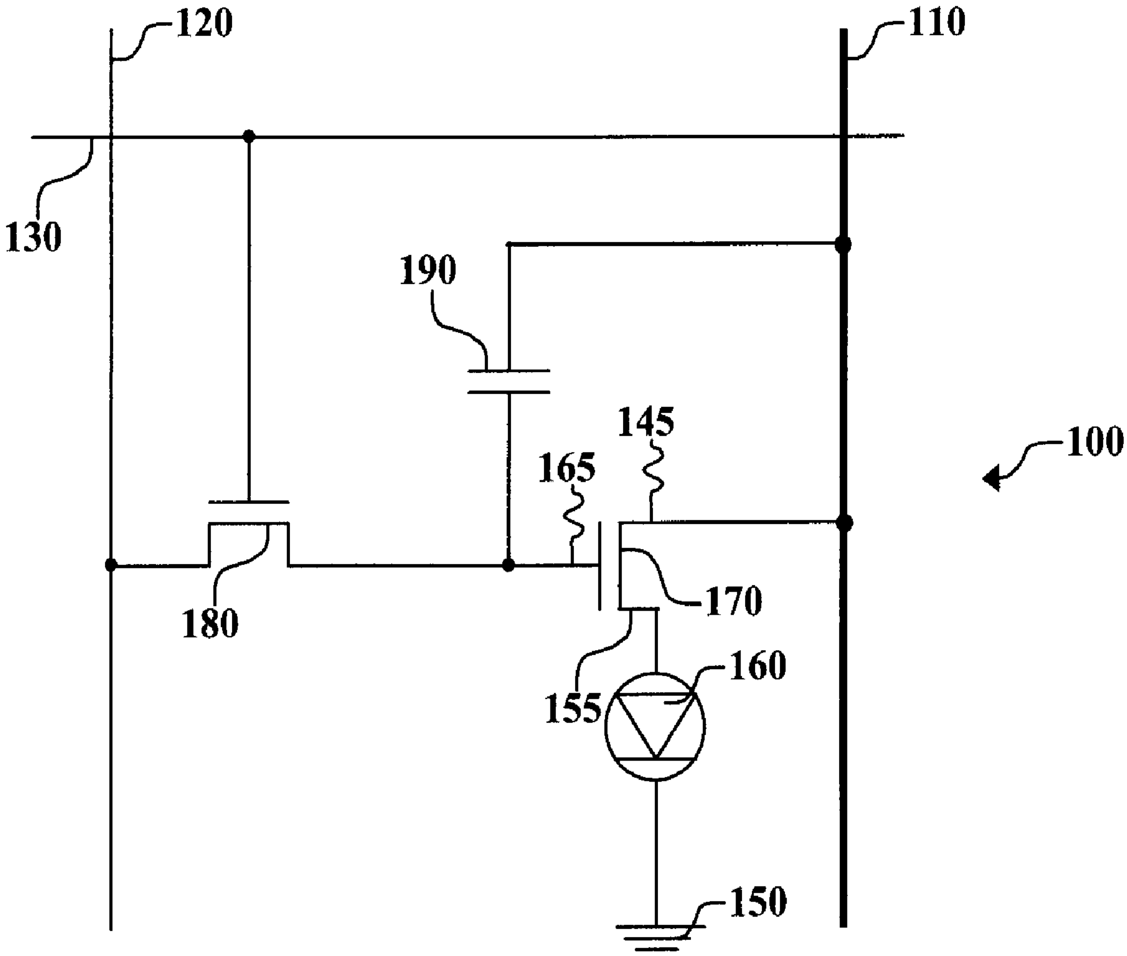
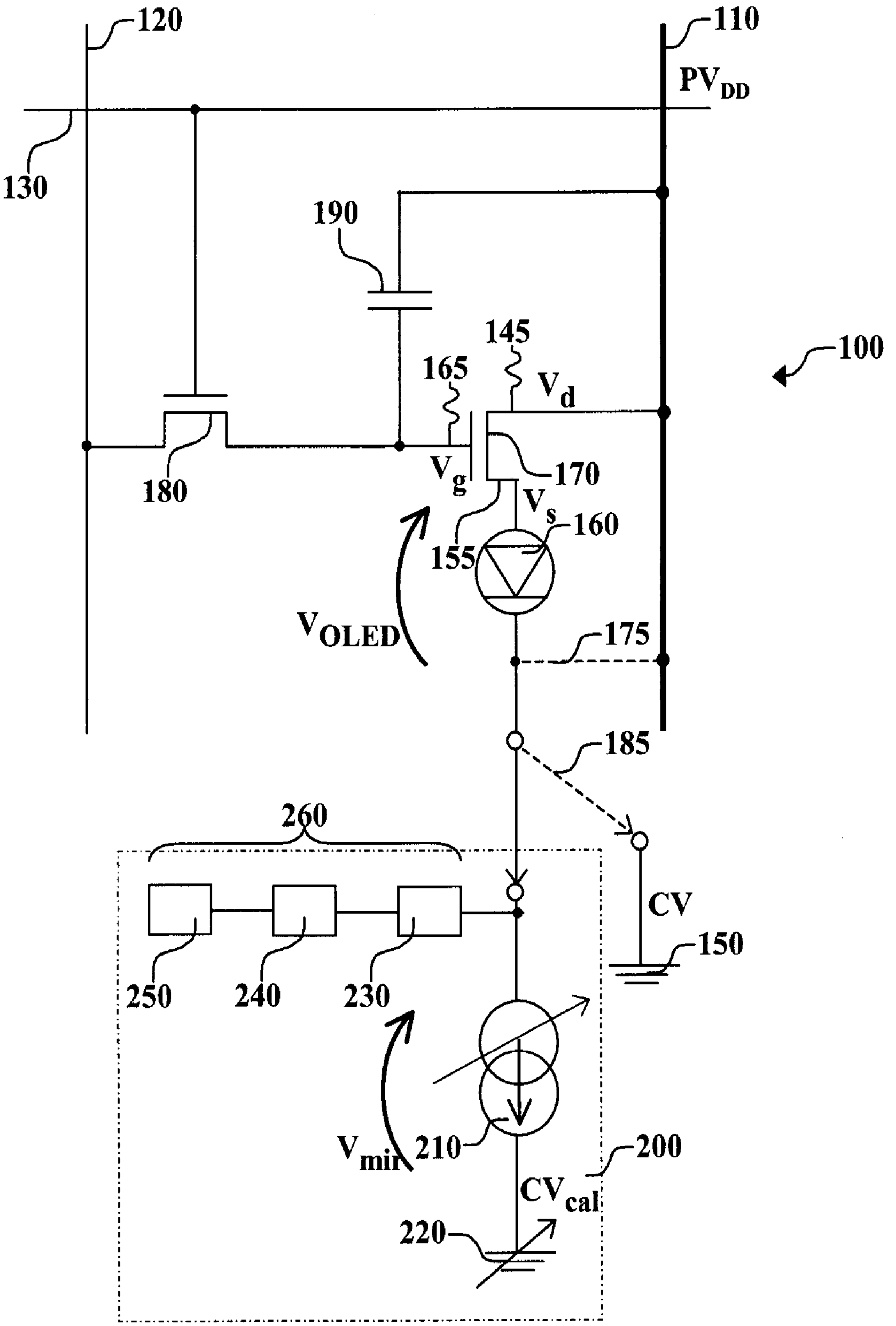


FIG. 1



120
110
PV_DD
130
190
145
100
165
V_d
170
V_g
V_s
160
155
V_OLED
175
185
260
CV
150
250
240
230
V_mir
210
200
CV_cal
220

FIG. 2

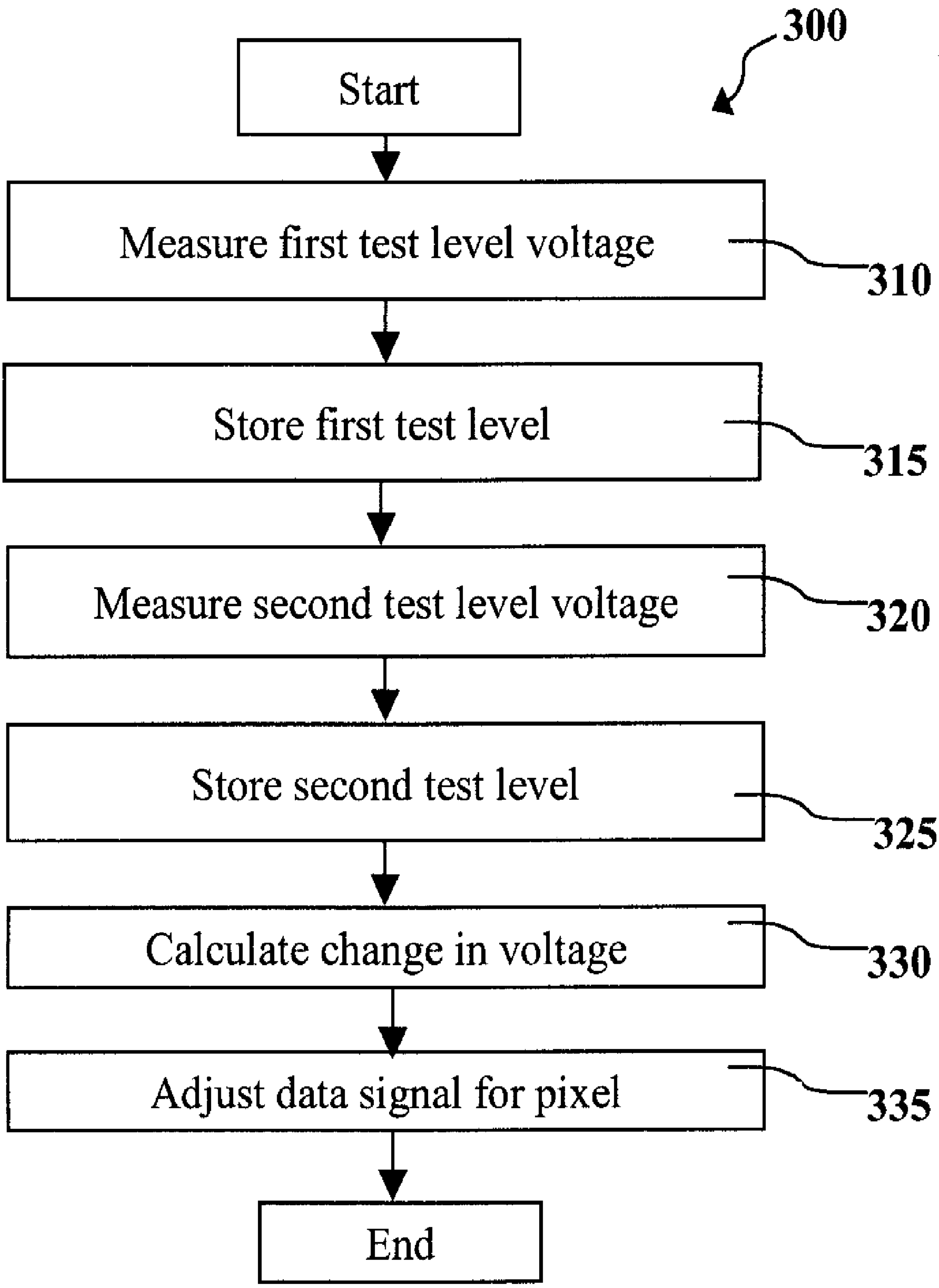

300
Start
Measure first test level voltage
310
Store first test level
315
Measure second test level voltage
320
Store second test level
325
Calculate change in voltage
330
Adjust data signal for pixel
335
End

FIG. 3

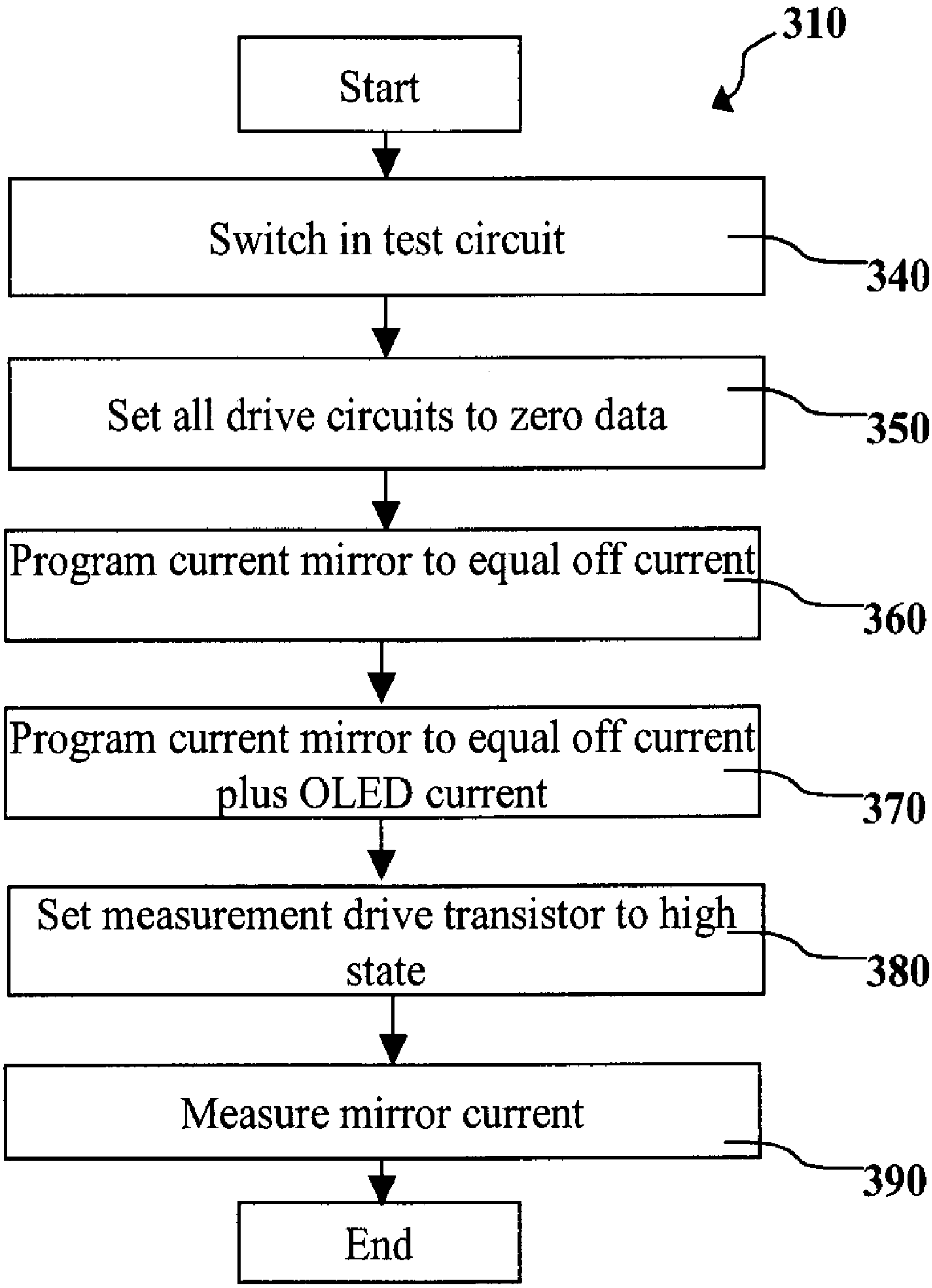

310
Start
Switch in test circuit
340
Set all drive circuits to zero data
350
Program current mirror to equal off current
360
Program current mirror to equal off current plus OLED current
370
Set measurement drive transistor to high state
380
Measure mirror current
390
End

FIG. 4

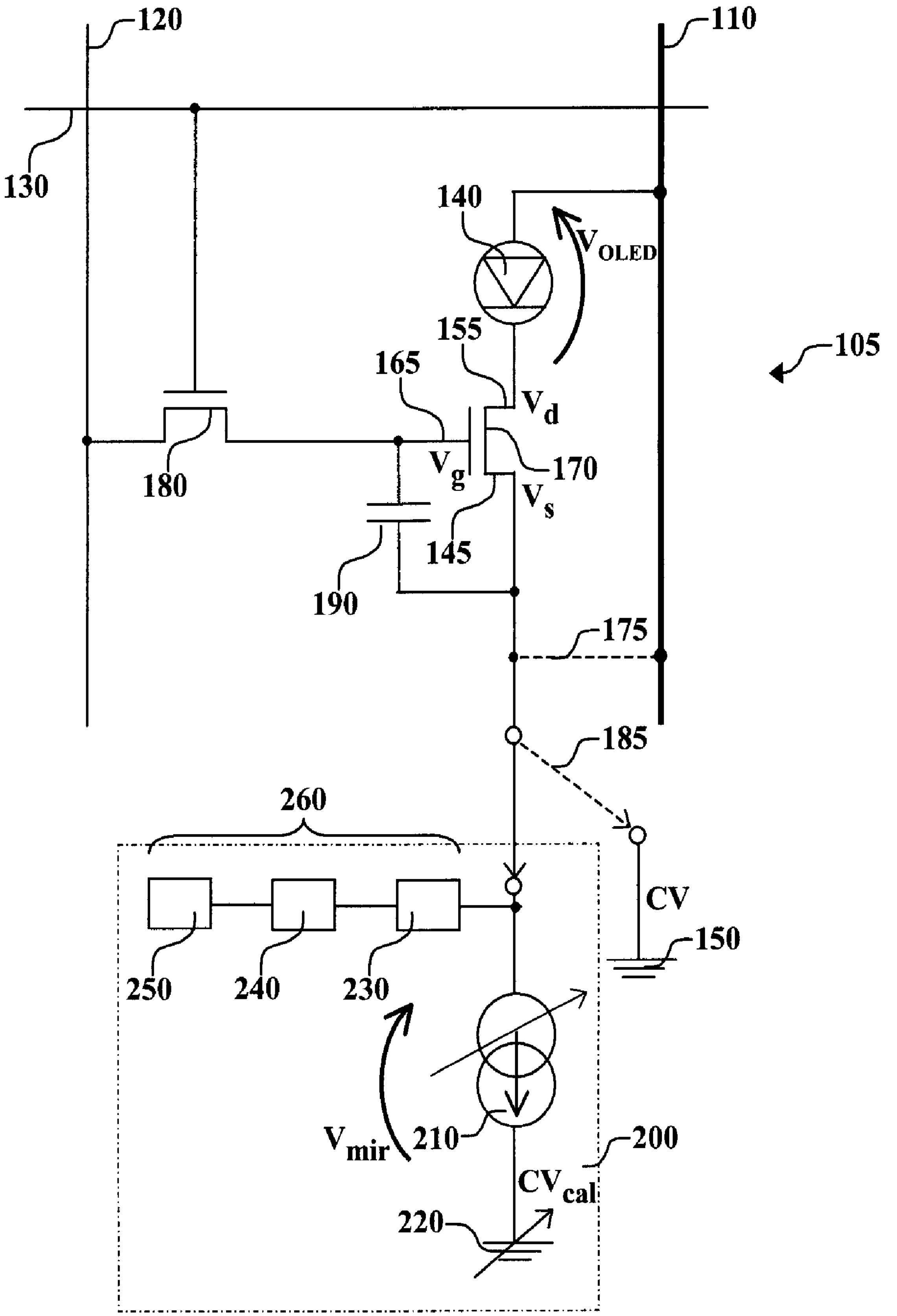

120
110
130
140
V_{OLED}
155
105
165
V_d
V_g
170
180
V_s
145
190
175
185
260
CV
150
250
240
230
V_{mir}
210
200
CV_{cal}
220

FIG. 5

ACTIVE MATRIX DISPLAY COMPENSATING METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation-in-part of commonly-assigned U.S. patent application Ser. No. 11/563,864, filed Nov. 28, 2006, now abandoned entitled "Active Matrix Display Compensation Method" by Charles I. Levey.

FIELD OF THE INVENTION

The present invention relates to an active matrix-type display device for driving display elements.

BACKGROUND OF THE INVENTION

In recent years, it has become necessary that image display devices have high-resolution and high picture quality, and it is desirable for such image display devices to have low power consumption and be thin, lightweight, and visible from wide angles. With such requirements, display devices (displays) have been developed where thin-film active elements (thin-film transistors, also referred to as TFTs) are formed on a glass substrate, with display elements then being formed on top.

In general, a substrate forming active elements is such that patterning and interconnects formed using metal are provided after forming a semiconductor film of silicon, e.g. amorphous silicon or polysilicon. Due to differences in the electrical characteristics of the active elements, the former requires Integrated Circuits (ICs) for drive use, and the latter is capable of forming circuits for drive use on the substrate. In liquid crystal displays (LCDs) currently widely used, the amorphous silicon type is widespread for larger screens, while the polysilicon type is more common in medium and small screens.

Typically, electroluminescent elements, for example organic light-emitting diodes (OLEDs), are used in combination with TFTs and utilize a voltage/current control operation so that current is controlled. The current/voltage control operation refers to the operation of applying a signal voltage to a TFT gate terminal so as to control current between two electrodes, one of which is connected to the OLED. As a result, it is possible to adjust the intensity of light emitted from the organic EL element and to control the display to the desired gradation.

However, in this configuration, the intensity of light emitted by the organic EL element is extremely sensitive to the TFT characteristics. In particular, for amorphous silicon TFTs (referred to as a-Si), it is known that comparatively large differences in electrical characteristics occur with time between neighboring pixels due to changes in transistor threshold voltage. This is a major cause of deterioration of the display quality of organic EL displays, in particular, screen uniformity. Uncompensated, this effect can lead to "burned-in" images on the screen. Additionally, changes in the EL element itself, such as forward voltage rise and efficiency loss, can cause image bum-in.

Goh et al. (IEEE Electron Device Letters, Vol. 24, No. 9, pp. 583-585) have proposed a pixel circuit with a precharge cycle before data loading to compensate for this effect. Compared to the standard OLED pixel circuit with a capacitor, a select transistor, a power transistor, and power, data, and select lines, Goh's circuit uses an additional control line and two additional switching transistors. Jung et al. (IMID '05

Digest, pp. 793-796) have proposed a similar circuit with an additional control line, an additional capacitor, and three additional transistors. While such circuits can be used to compensate for changes in the threshold voltage of the driving transistor, they add to the complexity of the display, thereby increasing the cost and the likelihood of defects in the manufactured product. Further, such circuitry generally comprises thin-film transistors (TFTs) and necessarily uses up a portion of the substrate area of the display. For bottom-emitting devices, where the aperture ratio is important, such additional circuitry reduces the aperture ratio, and can even make such bottom-emitting displays unusable. Thus, there exists a need to compensate for changes in the OLED emitter and in the electrical characteristics of the pixel circuitry in an OLED display without reducing the aperture ratio of such a display.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a method of compensating for changes in the electrical characteristics of the pixel circuitry in an OLED display.

This object is achieved by a method of compensating for changes in the threshold voltage of the drive transistor of an OLED drive circuit, comprising:

a) providing the drive transistor with a first electrode, a second electrode, and a gate electrode;

b) connecting a first voltage source to the first electrode of the drive transistor, and an OLED device to the second electrode of the drive transistor and to a second voltage source;

c) providing a test voltage to the gate electrode of the drive transistor and connecting to the OLED drive circuit a test circuit that includes an adjustable current mirror that is set to provide a predetermined drive current through the drive transistor and the OLED device and causes the voltage applied to the current mirror to be at a first test level when the drive transistor and the OLED device are not degraded by aging conditions, and storing the first test level;

d) providing a test voltage to the gate electrode of the drive transistor and connecting the test circuit to the OLED device to produce a second test level after the drive transistor and the OLED device have aged, and storing the second test level; and

e) using the first and second test levels to calculate a change in the voltage applied to the gate electrode of the drive transistor to compensate for aging of the drive transistor.

ADVANTAGES

It is an advantage of the present invention that it can compensate for changes in the electrical characteristics of the thin-film transistors of an OLED display. It is a further advantage of this invention that it can so compensate without reducing the aperture ratio of a bottom-emitting OLED display and without increasing the complexity of the within-pixel circuits.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a schematic diagram of one embodiment of an OLED drive circuit that can be used in the practice of this invention;

FIG. **2** shows a schematic diagram of the OLED drive circuit of FIG. **1** connected to a test circuit that can be used in the practice of this invention;

FIG. **3** shows a block diagram of one embodiment of the method of this invention;

FIG. **4** shows a block diagram of a portion of the method of FIG. **3** in greater detail; and

FIG. **5** shows a schematic diagram of another embodiment of a OLED drive circuit connected to a test circuit that can be used in the practice of this invention.

DETAILED DESCRIPTION OF THE INVENTION

Turning now to FIG. **1**, there is shown a schematic diagram of one embodiment of an OLED drive circuit that can be used in the practice of this invention. Such OLED drive circuits are well known in the art in active matrix OLED displays. OLED pixel drive circuit **100** has a data line **120**, a power supply line or first voltage source **110**, a select line **130**, a drive transistor **170**, a switch transistor **180**, an OLED device **160** that can be a single pixel of an OLED display, and a capacitor **190**. Drive transistor **170** is an amorphous-silicon (a-Si) transistor and has first electrode **145**, second electrode **155**, and gate electrode **165**. First electrode **145** of drive transistor **170** is electrically connected to first voltage source **110**, while second electrode **155** is electrically connected to OLED device **160**. In this embodiment of pixel drive circuit **100**, first electrode **145** of drive transistor **170** is a drain electrode and second electrode **155** is a source electrode. By electrically connected, it is meant that the elements are directly connected or connected via another component, e.g. a switch, a diode, another transistor, etc. OLED device **160** is a non-inverted OLED device, which is electrically connected to drive transistor **170** and to a second voltage source, which is negative relative to the first voltage source. In this embodiment, the second voltage source is ground **150**. Those skilled in the art will recognize that other embodiments can utilize other sources as the second voltage source. Switch transistor **180** has a gate electrode electrically connected to select line **130**, as well as source and drain electrodes, one of which is electrically connected to the gate electrode **165** of drive transistor **170**, while the other is electrically connected to data line **120**. OLED device **160** is powered by flow of current between power supply line **110** and ground **150**. In this embodiment, the first voltage source (power supply line **110**) has a positive potential, relative to the second voltage source (ground **150**), to cause current to flow through drive transistor **170** and OLED device **160**, so that OLED device **160** produces light. The magnitude of the current—and therefore the intensity of the emitted light—is controlled by drive transistor **170**, and more exactly by the magnitude of the signal voltage on gate electrode **165** of drive transistor **170**. During a write cycle, select line **130** activates switch transistor **180** for writing and the signal voltage data on data line **120** is written to drive transistor **170** and stored on capacitor **190**, which is connected between gate electrode **165** and power supply line **110**.

Transistors such as drive transistor **170** of OLED drive circuit **100** have a characteristic threshold voltage (V_{th}). V_{gs}, the voltage on gate electrode **165** minus the voltage on source electrode **155**, must be greater than the threshold voltage to enable current flow between first and second electrodes **145** and **155**, respectively. For amorphous silicon transistors, the threshold voltage is known to change under aging conditions, which include placing drive transistor **170** under actual usage conditions, thereby leading to an increase in the threshold voltage. Therefore, a constant signal on gate electrode **165** will cause a gradually decreasing light intensity emitted by OLED device **160**. The amount of such decrease will depend upon the use of drive transistor **170**; thus, the decrease can be different for different drive transistors in a display. It is desirable to compensate for such changes in the threshold voltage to maintain consistent brightness and color balance of the display, and to prevent image "burn-in" wherein an often-displayed image (e.g. a network logo) can cause a ghost of itself to always show on the active display. Also, there can be age-related changes to OLED device **160**, e.g. efficiency loss.

Turning now to FIG. **2**, there is shown a schematic diagram of the OLED drive circuit **100** of FIG. **1** connected to a test circuit that can be used in the practice of this invention. Test circuit **200** includes an adjustable current mirror **210**, a calibrated second voltage source **220**, a low-pass filter **230**, and an analog-to-digital converter **240**. The signal from analog-to-digital converter **240** is sent to processor **250**. Low-pass filter **230**, analog-to-digital converter **240**, and processor **250** comprise measurement apparatus **260**. Adjustable current mirror **210** can be set to provide a predetermined drive current through drive transistor **170** and OLED device **160**. In this embodiment, adjustable current mirror **210** is an adjustable current sink as known in the art. It will be understood that other embodiments are possible that instead incorporate an adjustable current source. OLED drive circuit **100** can be switched between ground **150** and test circuit **200** by switch **185**. When OLED drive circuit **100** is connected to test circuit **200**, OLED device **160** is electrically connected to adjustable second voltage source **220**.

In the most basic case, test circuit **200** measures a single drive transistor **170** of OLED drive circuit **100**. To use test circuit **200**, one first sets switch **185** to connect test circuit **200** to OLED drive circuit **100**. Next, adjustable current mirror **210** is set to provide the predetermined drive current I_{mir}, which is a characteristic current for OLED device **160**. I_{mir} is selected to be less than the maximum current possible through drive transistor **170** and OLED device **160**; a typical value for I_{mir} will be in the range of 1 to 5 microamps and will generally be constant for all measurements during the lifetime of the OLED device. A test voltage data value V_{test} is provided to gate electrode **165** of drive transistor **170** sufficient to provide a current through drive transistor **170** greater than the selected value for I_{mir}. Thus, the limiting value of current through drive transistor **170** and OLED device **160** will be controlled entirely by adjustable current mirror **210**, and the current through adjustable current mirror **210** (I_{mir}) will be the same as through drive transistor **170** (I_{ds}) and OLED device **160** (I_{OLED}) ($I_{mir}=I_{ds}=I_{OLED}$, neglecting leakage). The selected value of V_{test} is generally constant for all measurements during the lifetime of the display, and therefore must be sufficient to provide a drive-transistor current greater than I_{mir} even after aging expected during the lifetime of the display. The value of V_{test} can be selected based upon known or determined current-voltage and aging characteristics of drive transistor **170**. CV_{cal} is set to allow sufficient voltage adjustment of the current mirror voltage, V_{mir}, to maintain I_{mir} when the threshold voltage (V_{th}) of drive transistor **170** changes. This value of CV_{cal} will be used for all measurements during the lifetime of the display. The voltages of the components in the circuit can be related by:

$$V_{test}=CV_{cal}+V_{mir}+V_{OLED}+V_{gs} \quad \text{(Eq. 1)}$$

which can be rewritten as:

$$V_{mir}=V_{test}-(CV_{cal}+V_{OLED}+V_{gs}) \quad \text{(Eq. 2)}$$

Under the conditions described above, V_{test} and CV_{cal} are set values. V_{gs} will be controlled by the value of I_{mir} and the current-voltage characteristics of drive transistor **170**, and will change with age-related changes in the threshold voltage of drive transistor **170**. V_{OLED} will be controlled by the value of I_{mir} and the current-voltage characteristics of OLED device **160**. V_{OLED} can change with age-related changes in OLED device **160**.

The values of these voltages will cause the voltage applied to current mirror **210** (V_{mir}) to adjust to fulfill Eq. 2. This can be measured by measurement apparatus **260** and will be called the test level. To determine the change in the threshold voltage of drive transistor **170** (and the change in V_{OLED}, if any), two tests are performed. The first test is performed when drive transistor **170** and OLED device **160** are not degraded by aging, e.g. before OLED drive circuit **100** is used for display purposes, to cause the voltage V_{mir} applied current mirror **210** to be at a first test level. The first test level is measured and stored. After drive transistor **170** and OLED device **160** have aged, e.g. by displaying images for a predetermined time, the measurement is repeated with the same V_{test} and CV_{cal}. Changes to the threshold voltage of drive transistor **170** will cause a change to V_{gs} to maintain I_{mir}, while changes in OLED device **160** can cause changes to V_{OLED}. These changes will be reflected in changes to V_{mir} in Eq. 2, so as to produce voltage V_{mir} at a second test level. The second test level can be measured and stored. The first and second test levels can be used to calculate a change in the voltage applied to current mirror **210**, which is related to the changes in the drive transistor and the OLED device as follows:

$$\Delta V_{mir} = -(\Delta V_{OLED} + \Delta V_{gs}) \quad \text{(Eq. 3)}$$

Thus, to compensate for changes due to aging of drive transistor **170** and OLED device **160**, a change (ΔV_g) in the voltage V_g to be applied to gate electrode **165** of drive transistor **170** can be calculated as:

$$\Delta V_g = -\Delta V_{mir} = \Delta V_{OLED} + \Delta V_{gs} \quad \text{(Eq. 4)}$$

In more realistic cases, OLED drive circuit **100** is one pixel of a much larger OLED display comprising an array of pixels with a plurality of OLED drive circuits. Each OLED drive circuit includes a drive transistor and an OLED device as described above. Test circuit **200** can measure a single drive transistor **170**. This can be accomplished by putting a test voltage (V_{test}) on gate electrode **165** of a single drive transistor **170**, and setting the gate voltages (V_g) for all other drive transistors in a display to zero, thus putting them in the off state. Ideally, current would then flow only through drive transistor **170** and corresponding OLED device **160**, and thus the current through adjustable current mirror **210** (I_{mir}) would be the same as through drive transistor **170** (I_{ds}) and OLED device **160** (I_{OLED}), as above. In reality, the drive circuits that are in the off state have a slight current leakage, which can be significant due to the large number of drive circuits in the off state. The leakage current is shown as off-pixel current **175** (I_{off}, also known as dark current) in FIG. **2**, and is part of the total current through adjustable current mirror **210**, that is,

$$I_{mir} = I_{OLED} + I_{off} \quad \text{(Eq. 5)}$$

To use test circuit **200** with a plurality of OLED drive circuits, one first sets switch **185** to connect test circuit **200** to the display, including OLED drive circuit **100**. CV_{cal} is set such that a negative V_{gs} will be applied to all the drive circuits that are off to reduce the amount of off-pixel current **175**. Thus, if V_g for the drive circuits in the off condition is zero volts, CV_{cal} is set to be greater than or equal to zero volts. This value for CV_{cal} will be used for all measurements during the lifetime of the display. Before any individual OLED drive circuit measurements are done, all drive circuits are programmed to the off condition, e.g. V_g is set to zero for all drive circuits, to provide the off-pixel current off for the display. Adjustable current mirror **210** is programmed to the off-pixel current at a selected mirror voltage V_{mir}. V_{mir} for the off-pixel current is selected to allow sufficient adjustment in the voltage over the life of OLED drive circuit **100**. Typically, V_{mir} for the off-pixel current will be selected in the range of 1 to 6 volts, and this value will be used for all measurements during the lifetime of the display. Next, adjustable current mirror **210** is incremented to allow passage of an additional characteristic current I_{OLED} for a single pixel, e.g. OLED device **160**. I_{OLED} is selected as described above; a typical value for I_{OLED} will be in the range of 1 to 5 microamps and will generally be constant for all measurements during the lifetime of the display. A data value V_{test} is written to gate electrode **165** sufficient to provide a current through drive transistor **170** greater than the selected value for I_{OLED}. Thus, the limiting value of current through drive transistor **170** and corresponding OLED device **160** will be controlled entirely by adjustable current mirror **210**. The value of V_{test} is selected as described above and is generally constant for all measurements during the lifetime of the display. The gate electrodes of all other OLED drive circuits in the display remain at the off value (e.g. zero volts). Eq. 2 can relate the voltages of the components in OLED drive circuit **100**.

Under these conditions, V_{test} and CV_{cal} are set values. V_{gs} will be controlled by the value of I_{OLED} and the current-voltage characteristics of drive transistor **170**, and will change with age-related changes in the threshold voltage of drive transistor **170**. V_{OLED} will be controlled by the value of I_{OLED} and the current-voltage characteristics of OLED device **160**. V_{OLED} can change with age-related changes in OLED device **160**. The voltage through current mirror **210**, V_{mir}, will self-adjust to fulfill Eq. 2, above, to be at the test level, which can be measured by measurement apparatus **260**. To determine the change in the threshold voltage of drive transistor **170** (and the change in V_{OLED}, if any), two tests are performed as described above: a first test when drive transistor **170** and OLED device **160** are not degraded by aging to produce a first test level, and a second after drive transistor **170** and OLED device **160** have aged to produce a second test level. The first and second test levels can be used to calculate a change in the voltage applied to current mirror **210**, which is related to the changes in the drive transistor and the corresponding OLED device as shown above in Eq. 3. Thus, to compensate for changes due to aging of drive transistor **170** and corresponding OLED device **160**, a change (ΔV_g) in the voltage V_g to be applied to gate electrode **165** of drive transistor **170** can be calculated as shown above in Eq. 4. This can be repeated individually for each drive circuit in the display.

In another embodiment of this method, the test levels can be obtained for a group of drive circuits, e.g. a complete row or column of drive circuits. This would provide an average test level and an average ΔV_g for each group of drive circuits, but would have the advantage of requiring less time and storage memory for the method.

Turning now to FIG. **3**, and referring to FIG. **2** as well, there is shown a block diagram of one embodiment of the method of this invention. In method **300**, the voltage at current mirror **210** for an OLED drive circuit **100**, is measured by measurement apparatus **260** (Step **310**). This measurement, which is done when drive transistor **170** and OLED device **160** are not degraded by aging conditions, e.g., just after manufacturing the OLED display, or at a time after manufacturing before the OLED display has had significant use, is at a first test level. The first test level is stored by processor **250** (Step **315**). After drive transistor **170** and OLED device **160** have aged, the measurement is repeated, to provide a voltage at current mirror **210** at a second test level (Step **320**). The second test level is stored by processor **250** (Step **325**). Then, processor **250** uses the first and second test levels to calculate a change in the voltage applied to gate electrode **165** of drive transistor **170** to compensate for aging of the drive transistor, as in Eq. 4 above (Step **330**). This change in voltage is applied to the voltage at gate electrode **165** to compensate for aging of OLED device **160** and drive transistor **170** (Step **335**).

Turning now to FIG. **4**, and referring to FIG. **2**, as well, there is shown a block diagram of a portion of the method of FIG. **3** in greater detail. FIG. **4** represents individual steps in Step **310** of FIG. **3**, as well as Step **320**. Initially, switch **185**, which is connected to the common cathode of the display, connects OLED drive circuit **100** to test circuit **200** instead of second voltage source **150** (Step **340**). Then all drive circuits in the display are programmed as off by setting the data on gate electrode **165** to zero for every OLED drive circuit in the display (Step **350**). If the drive transistors **170** were ideal transistors, no current would flow; however, as non-ideal transistors, they do indeed pass some current under these conditions, indicated as off-pixel current **175**. Adjustable current mirror **210** is programmed to equal off-pixel current **175** (Step **360**); that is, adjustable current mirror **210** is set to pass off-pixel current **175** as its maximum passable current at the selected V_{mir}. Then adjustable current mirror **210** is programmed to equal off-pixel current **175** plus the desired current through the individual drive transistor **170** when in the on condition (Step **370**). Then drive transistor **170** is set to a high state by placing a data value on gate electrode **165** (Step **380**). The data value placed on gate electrode **165** is sufficient to provide a current passing through drive transistor **170** that is greater than the current that will be allowed by adjustable current mirror **210**, even when drive transistor **170** has been aged for the expected lifetime of the display. Thus, adjustable current mirror **210** will be the current-limiting apparatus under these conditions. Then the voltage is measured by measurement apparatus **260** (Step **390**) to provide the test level. For displays of multiple drive circuits, Steps **380** and **390** can be repeated for each individual drive circuit.

Turning now to FIG. **5**, there is shown a schematic diagram of another embodiment of an OLED drive circuit connected to a test circuit that can be used in the practice of this invention. OLED drive circuit **105** is constructed much as OLED drive circuit **100** described above. However, OLED device **140** is an inverted OLED device, wherein the anode of the pixel is electrically connected to power line **110** and the cathode of the pixel is electrically connected to second electrode **155** of drive transistor **170**. In this embodiment, first electrode **145** is the source and second electrode **155** is the drain. In the method described above, the voltages between gate electrode **165** and calibrated second voltage source **220** have an effect on the measurement of the test level. Therefore, aging of OLED device **140** will have no effect on the test level measured, and a change in the voltage applied to gate electrode **165** will compensate for aging of drive transistor **170** only. With the method of this invention applied to this embodiment, the voltages of the components in the circuit can be related by:

$$V_{test}=CV_{cal}+V_{mir}+V_{gs} \quad \text{(Eq. 6)}$$

which can be rewritten as:

$$V_{mir}=V_{test}-(CV_{cal}+V_{gs}) \quad \text{(Eq. 7)}$$

The change in voltage at current mirror **210** will then be related as follows:

$$\Delta V_{mir}=-\Delta V_{gs} \quad \text{(Eq. 8)}$$

and the change in the voltage to be applied to gate electrode **165** will be:

$$\Delta V_g=-\Delta V_{mir}=\Delta V_{gs} \quad \text{(Eq. 9)}$$

Turning back to FIG. **2**, another embodiment of an OLED drive circuit connected to a test circuit, wherein the OLED drive circuit has a p-channel drive transistor, can be used in the practice of this invention. Note that in general, the test circuit may be connected at any point of the OLED drive circuit on the current path through the drive transistor and OLED device, in order to allow for compensating for aging of a drive transistor of an OLED drive circuit and of an OLED device.

In this embodiment, first electrode **145** can be the source and second electrode **155** can be the drain of a p-channel drive transistor **170**, which can be an amorphous silicon transistor. The test circuit is employed as described above.

V_{test} can be selected to bias the drive transistor such that it is operated in the linear regime. In this regime, V_{ds}, the difference between the voltage V_d at second electrode **155** and the voltage V_s at first electrode **145**, can be independent of V_{gs} and depend only on I_{ds}, which is controlled by current mirror **210**.

The selected value of V_{test} is generally constant for all measurements during the lifetime of the display, and therefore must be sufficient to provide a drive-transistor current greater than I_{mir} even after aging expected during the lifetime of the display. The value of V_{test} can be selected based upon known or determined current-voltage and aging characteristics of drive transistor **170**. CV_{cal} is set as described above.

The voltages of the components in the circuit can be related:

$$PV_{DD}-CV_{cal}=V_{mir}+V_{OLED}+V_{ds} \quad \text{(Eq. 10)}$$

which can be rewritten as:

$$V_{mir}=PV_{DD}-(CV_{cal}+V_{OLED}+V_{ds}) \quad \text{(Eq. 1)}$$

Note that V_{test} does not appear in the equation. Any value of V_{test} which biases the drive transistor to operate in the linear regime can be used. Under the conditions described above, PV_{DD} and CV_{cal} are set values. V_{ds} will be controlled by the value of I_{mir} and the current-voltage characteristics of drive transistor **170**, and may change as drive transistor **170** ages. V_{OLED} will be controlled by the value of I_{mir} and the current-voltage characteristics of OLED device **160**. V_{OLED} can change with age-related changes in OLED device **160**.

The values of these voltages will cause the voltage applied to current mirror **210** (V_{mir}) to adjust to fulfill Eq. 11. This can be measured by measurement apparatus **260** and will be called the test level. To determine the change in V_{OLED} and V_{ds}, two tests are performed as described above. Thus, to compensate for changes due to aging of the OLED device **160** and drive transistor **170**, a change (ΔV_g) in the voltage V_g to be applied to gate electrode **165** of drive transistor **170** can be calculated as described above.

Referring to FIG. **5**, in another embodiment, first electrode **145** can be the source and second electrode **155** can be the drain of a p-channel drive transistor **170**, which can be an amorphous silicon transistor or LTPS transistor. The OLED test circuit can be attached to the OLED drive circuit at the source **145** of the drive transistor. This is the p-channel dual of the embodiment of FIG. **5**. Calibrated second voltage source **220** and second voltage source **150** can have more positive values than first voltage supply **110**, current mirror **210** can drive current from source **220** to drive transistor **170**, and OLED **140** can have its anode connected to second electrode **155** and its cathode connected to first voltage source **110**. In this case, V_{test} can be selected to bias the drive transistor **170** such that is operated in the linear regime. Thus the characteristic equation of the transistor is:

$$I_{ds}=k_p[(V_{gs}-V_{th})V_{ds}-V_{ds}^2/2] \quad \text{(Eq. 12)}$$

(Kano, Kanaan. *Semiconductor Devices*. Upper Saddle River, N.J.: Prentice-Hall, 1998, p. 397, Eq. 13.18). Further, the voltage loop equation for this configuration is:

$$PV_{DD,cal}-CV=V_{mir}+V_{OLED}+V_{ds} \quad \text{(Eq. 13)}$$

wherein $PV_{DD,cal}$ is the voltage supplied to the programmable current mirror and CV is a constant rather than an adjustable voltage. When V_{gs} is sufficiently large to make the $V_{ds}^2/2$ term negligible, and when V_{th} is constant, as it would be for a drive transistor fabricated e.g. in LTPS, equations 12 and 13 can be combined to yield

$$V_{oled} = (I_{ds}/(k_p(PV_{DD,cal} - V_{test} - V_{th} - V_{mir}))) + V_{mir} - (PV_{DD,cal} - CV) \quad \text{(Eq. 14)}$$

Where k_p is a constant given in Kano, op cit., Eq. 13.17. In this configuration, $PV_{DD,cal}$, CV, I_{ds} and V_{test} are selected values, V_{th} is constant, and V_{mir} is the measured value. Consequently, this configuration can be used to calculate change in the OLED device voltage V_{oled} by measuring V_{mir} and applying Eq. 14.

A useful simplification of Eq. 12 can be

$$I_{ds}=k_pV_{ds} \quad \text{(Eq. 15)}$$

when the effect of gate voltage is fairly small, and when the effect of the squared term is fairly small, as described above. In this case, with the conditions given above for deriving Eq. 14, V_{oled} can be expressed as

$$V_{oled}=PV_{DD,cal}-CV-V_{mir}-I_{ds}/k_p \quad \text{(Eq. 16)}$$

This simplification is easy to calculate and can be widely applicable.

This approach can be particularly useful on an OLED display comprising a plurality of OLED drive circuits. In this case, the display can comprise multiple groups of drive circuits. A test circuit can be provided for each group. For example, in the case of FIG. **2**, the cathode **150** can be quartered, each quarter supplying one-quarter of the OLED drive circuits on the display, and each quarter can have its own test circuit **200**. In another example, for the embodiment described above of the p-channel dual of FIG. **5**, the more positive bus lines **150**, which take the role of PV_{DD} in this case, could be divided into groups, each with its own test circuit. This can be less costly than dividing a sheet cathode. Providing a display comprising multiple groups can advantageously improve readout time and increase S/N ratio by reducing plane capacitance, which resists voltage changes, and crosstalk, which couples noise from one subpixel on to another.

In one embodiment, changes in an OLED drive circuit in an OLED display having two or more groups of drive circuits can be compensated. Changes in either the drive transistor or the OLED device of each drive circuit can be compensated. Each drive circuit is as described above, e.g. as shown in FIG. **2**. The OLED drive circuits can be divided into groups and each group can be provided with a corresponding test circuit. For example, as described above, one of the power planes can be split and each side of the split provided with its own test circuit.

In this embodiment, each test circuit can be connected to the OLED drive circuits in the corresponding group. The test procedure can be as for the single-pixel case, e.g. as described above in reference to FIG. **2**. The first and second test levels are measured as described above, and those levels used to calculate a change in the voltage applied to the gate electrode of each drive transistor in the group to compensate for aging of each drive circuit. The groups can be measured simultaneously to advantageously decrease readout time. Any individual test circuit can also be multiplexed between the groups; this reduces cost of the test circuit(s) at the expense of longer readout time.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention. For example, the above embodiments are constructed wherein the drive transistors and switch transistors are n-type transistors. It will be understood by those skilled in the art, that embodiments wherein the drive transistors and switch transistors are p-type transistors, with appropriate well-known modifications to the circuits, can also be useful in this invention. It will also be understood by those skilled in the art, that this invention can also be employed in embodiments using other well-known 2T1C pixel circuits, such as embodiments in which the capacitor **190** is connected between V_g and a voltage supply other than that shown on the drawings.

100	OLED drive circuit
105	OLED drive circuit
110	first voltage source
120	data line
130	select line
140	OLED device
145	first electrode
150	ground
155	second electrode
160	OLED device
165	gate electrode
170	drive transistor
175	off-pixel current
180	switch transistor
185	switch
190	capacitor
200	test circuit
210	adjustable current mirror
220	calibrated second voltage source
230	low-pass filter
240	analog-to-digital converter
250	processor
260	measurement apparatus
300	method
310	block
315	block
320	block
325	block
330	block
335	block
340	block
350	block
360	block
370	block
380	block
390	block

The invention claimed is:

1. A method of compensating for changes in the threshold voltage of the drive transistor of an OLED drive circuit, comprising:

a) providing the drive transistor with a first electrode, a second electrode, and a gate electrode;

b) connecting a first voltage source to the first electrode of the drive transistor, and an OLED device to the second electrode of the drive transistor and to a second voltage source;

c) providing a test voltage to the gate electrode of the drive transistor and connecting to the OLED drive circuit a test circuit that includes an adjustable current mirror that is set to provide a predetermined drive current through the drive transistor and the OLED device and causes the voltage applied to the current mirror to be at a first test level when the drive transistor and the OLED device are not degraded by aging conditions, and storing the first test level;

d) providing a test voltage to the gate electrode of the drive transistor and connecting the test circuit to the OLED device to produce a second test level after the drive transistor and the OLED device have aged, and storing the second test level; and

e) using the first and second test levels to calculate a change in the voltage applied to the gate electrode of the drive transistor to compensate for aging of the drive transistor.

2. The method of claim **1** wherein the first electrode is the drain, the second electrode is the source, and the OLED device is a non-inverted OLED device.

3. The method of claim **2** wherein the change in voltage applied to the gate electrode also compensates for aging of the OLED device.

4. The method of claim **1** wherein the first electrode is the source, the second electrode is the drain, and the OLED device is an inverted OLED device.

5. The method of claim **1** wherein the drive transistor is an amorphous silicon transistor.

6. The method of claim **5** wherein the drive transistor is an n-type transistor.

7. The apparatus of claim **5** wherein the drive transistor is a p-type transistor.

8. The method of claim **1** wherein the test circuit includes a low-pass filter and an analog-to-digital converter.

9. A method of compensating for changes in the threshold voltage of the drive transistor for an OLED device in a plurality of OLED drive circuits, comprising:

a) including in each drive circuit a drive transistor with a first electrode, a second electrode, and a gate electrode, and connecting a first voltage source to the first electrode of the drive transistor, and an OLED device to the second electrode of the drive transistor and to a second voltage source;

b) connecting a test circuit to the OLED drive circuits, and simultaneously providing individually a test voltage to the gate electrode of each of the drive transistors, and providing the test circuit with an adjustable current mirror that is set to provide a predetermined drive current through the drive transistors and the OLED devices and causes the voltage applied to the current mirror to be at a first test level when the drive transistors and OLED devices are not degraded by aging conditions, and storing the first test level;

c) again connecting the test circuit to the OLED drive circuits and simultaneously providing individually a test voltage to the gate electrode of each of the drive transistors to produce a second test level after the drive transistors and the OLED devices have aged, and storing the second test level; and

d) using the first and second test levels to calculate a change in the voltage applied to the gate electrode of each drive transistor to compensate for aging of each drive transistor.

10. The method of claim **9** wherein the first electrode is the drain, the second electrode is the source, and the OLED device is a non-inverted OLED device.

11. The method of claim **10** wherein the change in the voltage applied to the gate electrode of each drive transistor also compensates for the aging of the corresponding OLED device.

12. The method of claim **9** wherein the first electrode is the source, the second electrode is the drain, and the OLED device is an inverted OLED device.

13. The method of claim **9** wherein the drive transistor is an amorphous silicon transistor.

14. The method of claim **13** wherein the drive transistor is an n-type transistor.

15. The apparatus of claim **13** wherein the drive transistor is a p-type transistor.

16. The method of claim **9** wherein the test circuit includes a low-pass filter and an analog-to-digital converter.

17. A method of compensating for aging of a drive transistor of an OLED drive circuit and of an OLED device, comprising:

a) providing the drive transistor with a first electrode, a second electrode, and a gate electrode;

b) connecting a first voltage source to the first electrode of the drive transistor, and an OLED device to the second electrode of the drive transistor and to a second voltage source;

c) providing a test voltage to the gate electrode of the drive transistor and connecting to the OLED drive circuit a test circuit that includes an adjustable current mirror that is set to provide a predetermined drive current through the drive transistor and the OLED device and causes the voltage applied to the current mirror to be at a first test level when the drive transistor and the OLED device are not degraded by aging conditions, and storing the first test level;

d) providing a test voltage to the gate electrode of the drive transistor and connecting the test circuit to the OLED drive circuit to produce a second test level after the drive transistor and the OLED device have aged, and storing the second test level; and

e) using the first and second test levels to calculate a change in the voltage applied to the gate electrode of the drive transistor to compensate for aging of the drive transistor and of the OLED device.

18. The method of claim **17**, wherein the drive transistor is a p-type transistor, the first electrode is the source, the second electrode is the drain, and the OLED device is a non-inverted OLED device.

19. The method of claim **17** wherein the drive transistor is an amorphous silicon transistor.

20. The method of claim **17**, wherein the drive transistor is operated in the linear regime while the test circuit is connected to the OLED drive circuit.

21. A method of compensating for changes in an OLED drive circuit in an OLED display having two or more groups of drive circuits, comprising:

a) providing in each drive circuit a drive transistor with a first electrode, a second electrode, and a gate electrode, and connecting a first voltage source to the first electrode of the drive transistor, and an OLED device to the second electrode of the drive transistor and to a second voltage source;

b) providing for each group of OLED drive circuits a corresponding test circuit;

c) connecting a test circuit to the OLED drive circuits in the corresponding group, and simultaneously providing individually a test voltage to the gate electrode of each of the drive transistors in that group, and providing the test circuit with an adjustable current mirror that is set to provide a predetermined drive current through the drive transistors and the OLED devices and causes the voltage applied to the current mirror to be at a first test level when the drive transistors and OLED devices are not degraded by aging conditions, and storing the first test level;

d) again connecting the test circuit to the OLED drive circuits in the corresponding group and simultaneously providing individually a test voltage to the gate electrode of each of the drive transistors in that group to produce a second test level after the drive transistors and the OLED devices have aged, and storing the second test level; and

e) using the first and second test levels to calculate a change in the voltage applied to the gate electrode of each drive transistor in the group to compensate for aging of each drive circuit.

* * * * *

专利名称(译)	有源矩阵显示补偿方法		
公开(公告)号	US7928936	公开(公告)日	2011-04-19
申请号	US11/869834	申请日	2007-10-10
[标]申请(专利权)人(译)	利维查理一世 HAMER JOHNW一		
申请(专利权)人(译)	利维查理一世 HAMER JOHNW一		
当前申请(专利权)人(译)	全球OLED科技有限责任公司		
[标]发明人	LEVEY CHARLES I HAMER JOHN W		
发明人	LEVEY, CHARLES I. HAMER, JOHN W.		
IPC分类号	G09G3/30		
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其他公开文献	US20080122760A1		
外部链接	Espacenet USPTO		

摘要(译)

补偿OLED驱动电路的驱动晶体管的阈值电压的变化，驱动晶体管包括第一电极，第二电极和栅电极;将第一电压源连接到第一电极，将OLED器件连接到第二电极和第二电压源;向栅电极提供测试电压并连接到OLED驱动电路，测试电路包括可调电流镜，该电流镜使施加到电流镜的电压处于第一测试电平;在驱动晶体管和OLED器件老化之后，向驱动晶体管的栅极提供测试电压并将测试电路连接到OLED器件，产生第二测试电平;并使用第一和第二测试电平来计算施加到驱动晶体管的栅电极的电压的变化，以补偿驱动晶体管的老化。