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**Ota**(10) **Pub. No.: US 2018/0261155 A1**(43) **Pub. Date: Sep. 13, 2018**(54) **PIXEL CIRCUIT, ELECTRO-OPTICAL  
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**27/3276** (2013.01); **H01L 51/5221** (2013.01)(57) **ABSTRACT**

A transistor circuit outputs a drive current in accordance with a data signal. An OLED that is connected to the transistor circuit emits light with luminance corresponding to the drive current. A discharge transistor, when the OLED does not emit the light, is turned on to connect a discharge feeder line to a node at which the transistor circuit is connected to the OLED. An absolute value of a threshold voltage of the discharge transistor is lower than an absolute value of a threshold voltage of a drive transistor in the transistor circuit. When the data signal indicates zero, the discharge transistor can cause a flow of the drive current from the transistor circuit to bypass the OLED.

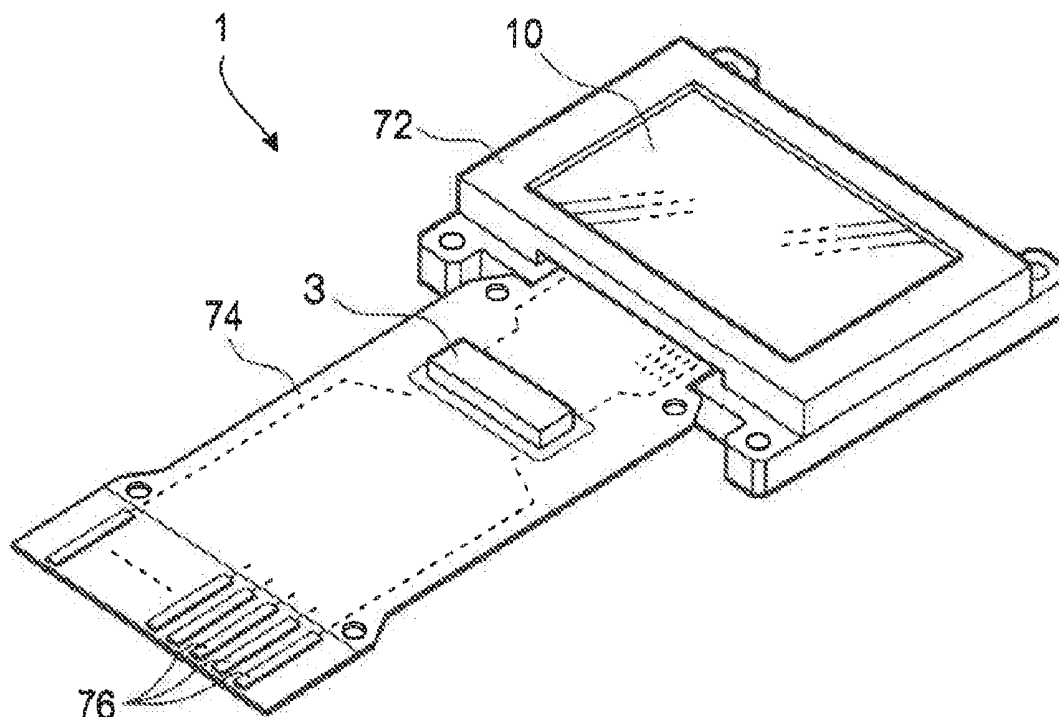


FIG. 1

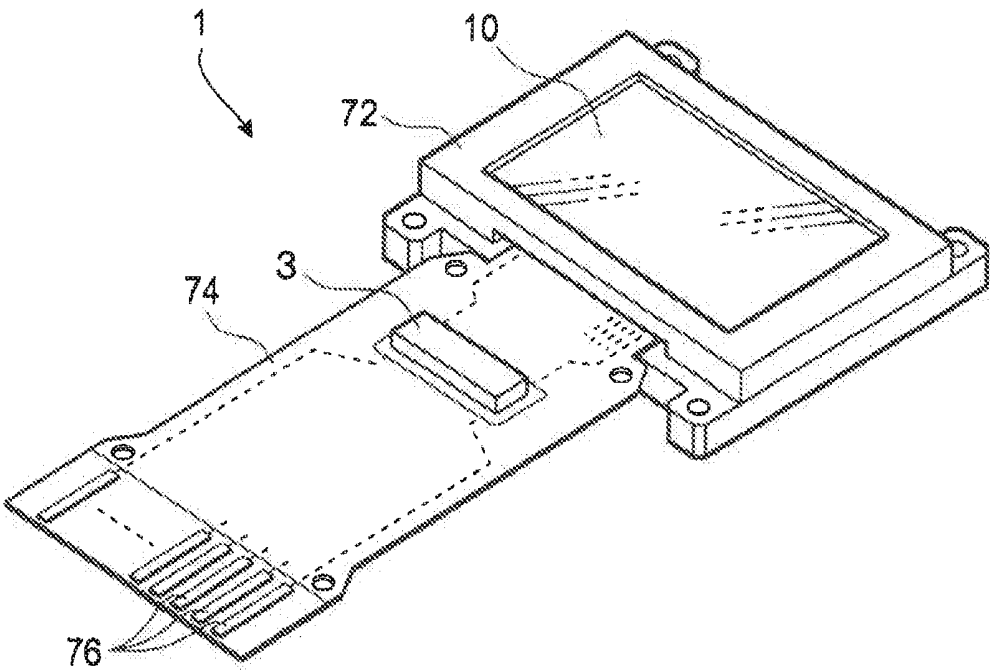


FIG. 2

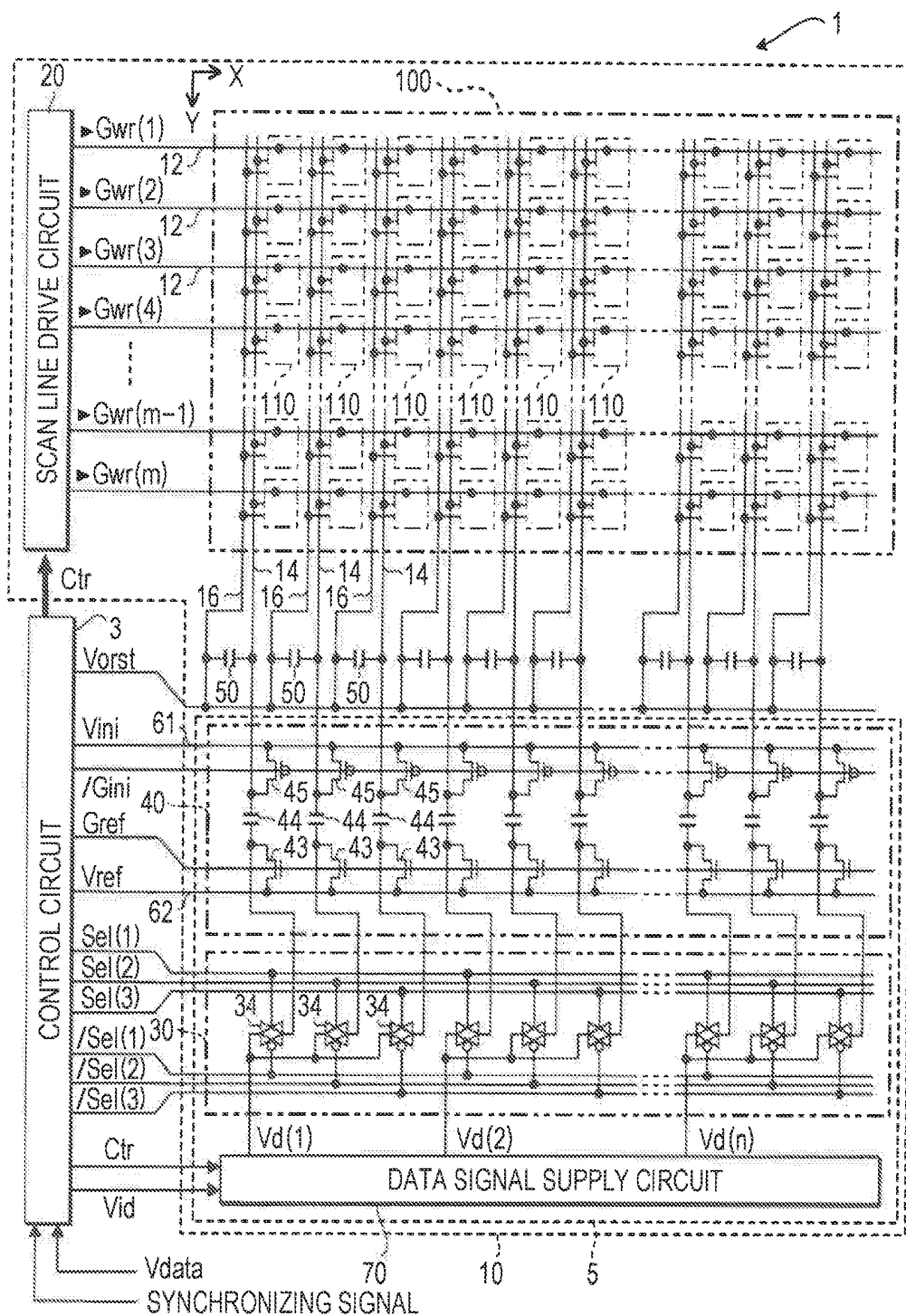




FIG. 5

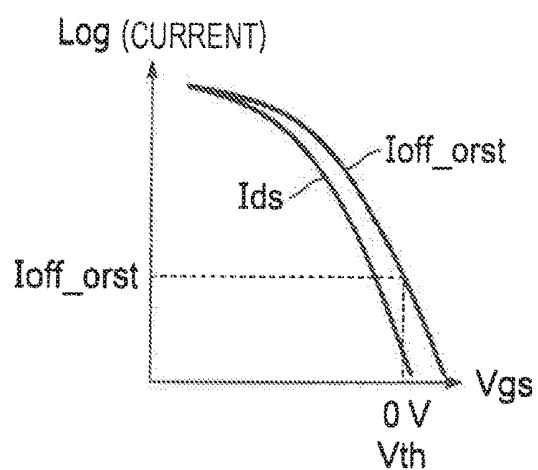


FIG. 6

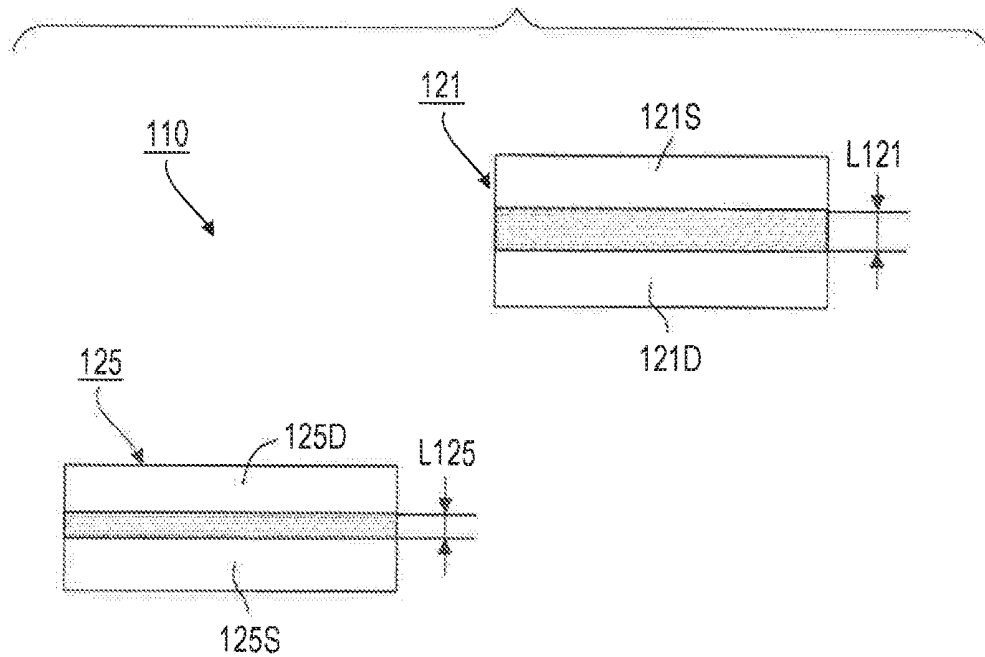


FIG. 7

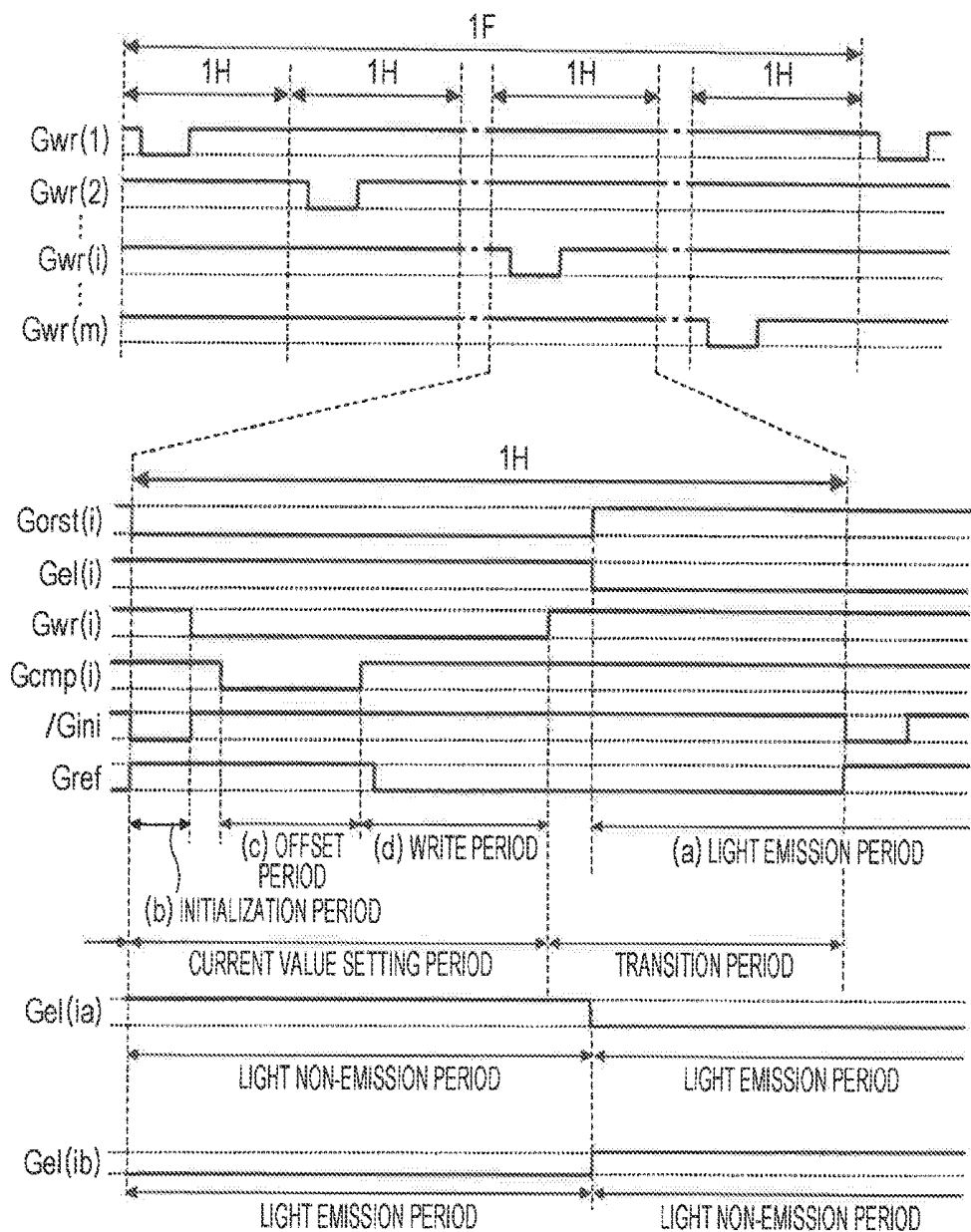


FIG. 8

&lt;(a) LIGHT EMISSION PERIOD&gt;

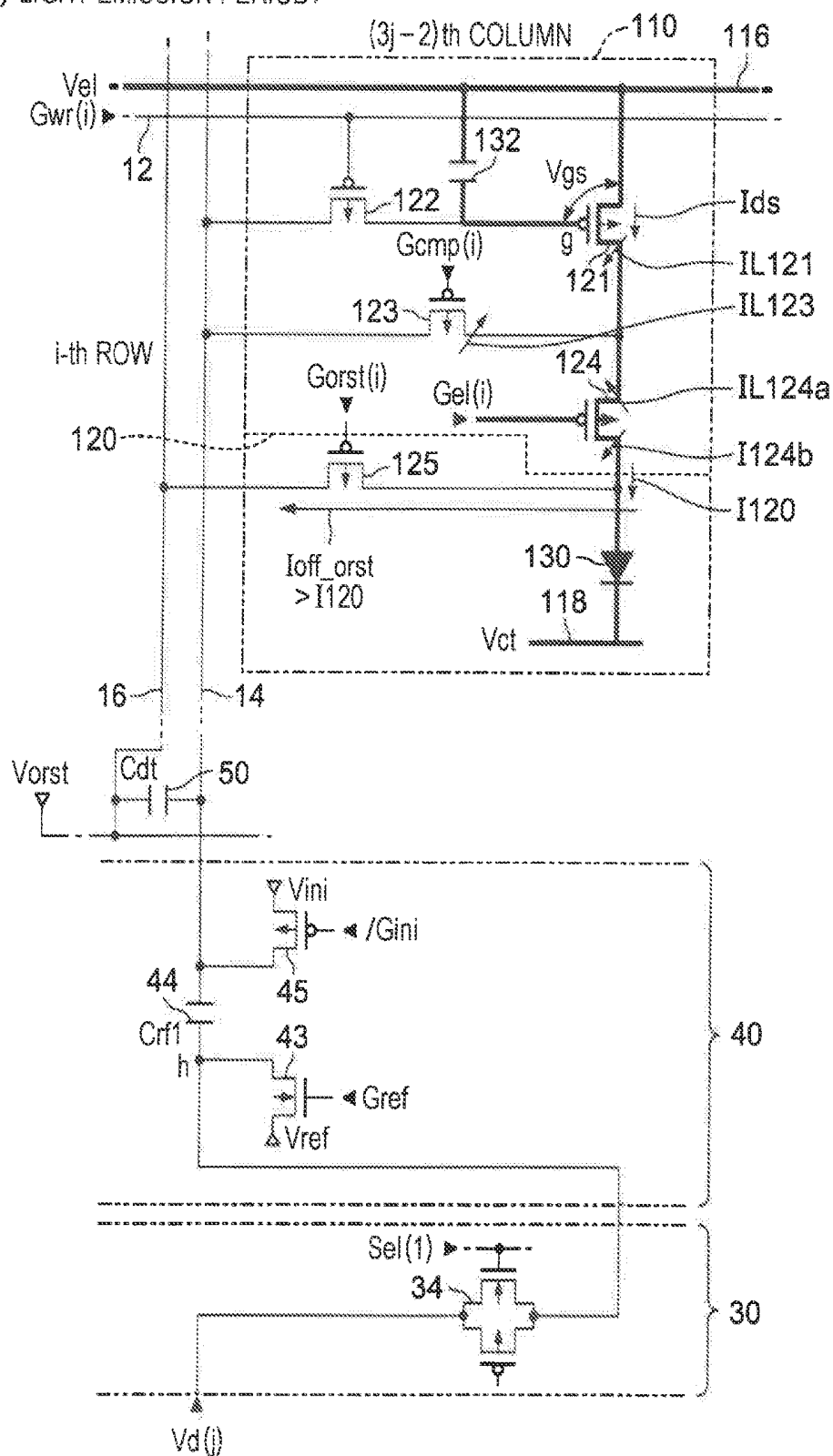


FIG. 9

<(b) INITIALIZATION PERIOD>

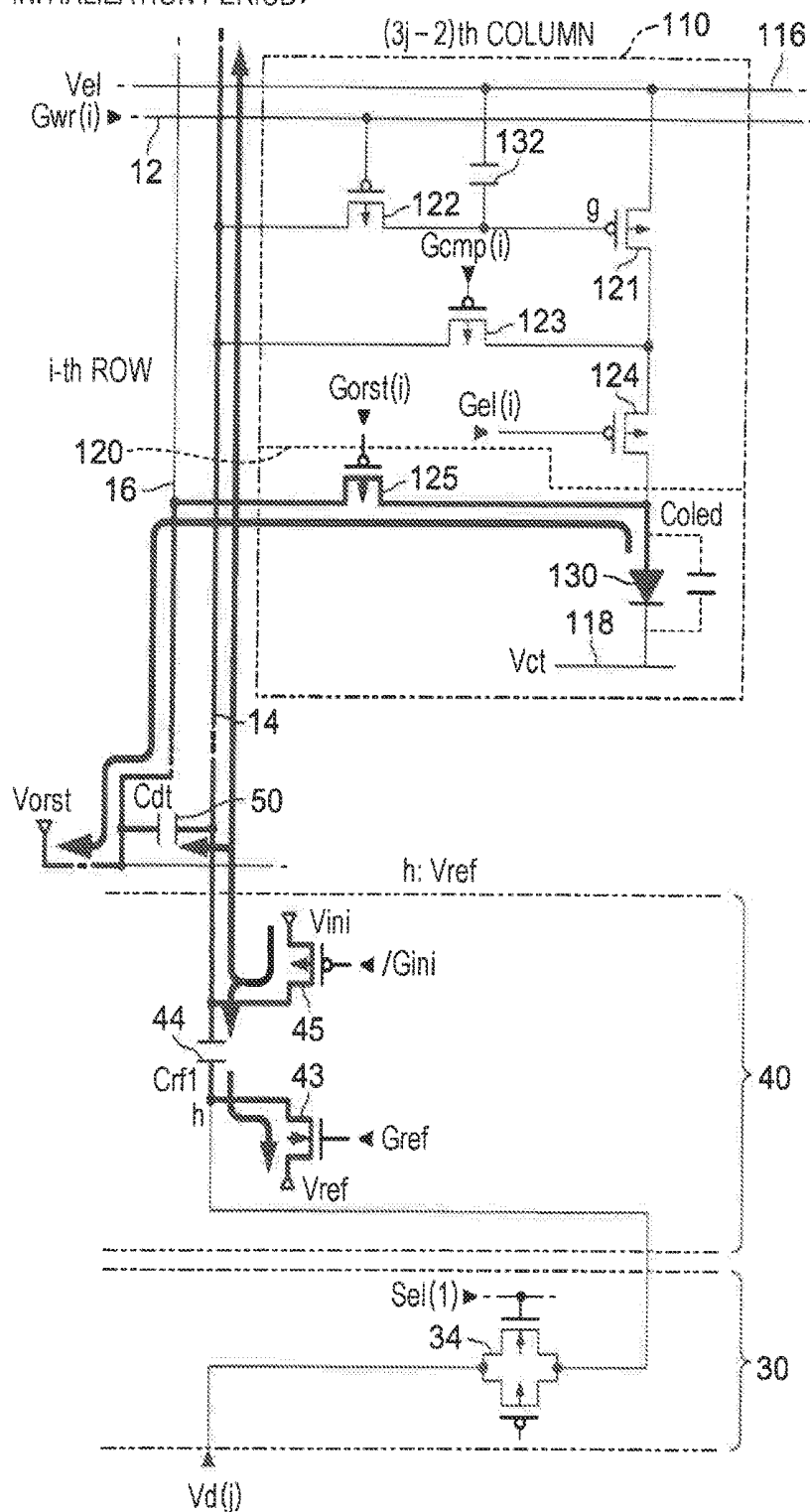


FIG. 10

<(c) OFFSET PERIOD>

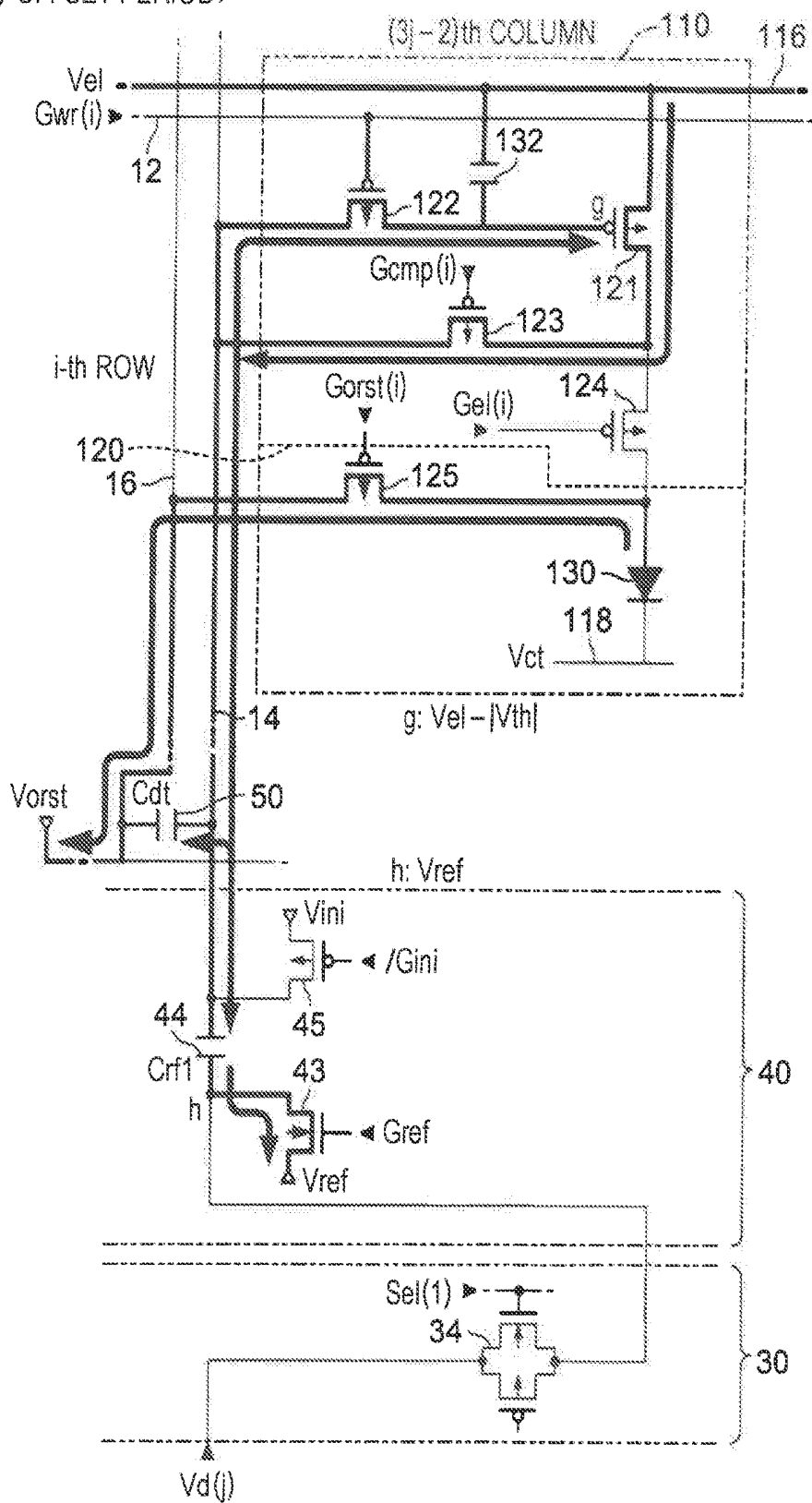


FIG. 11

<(d) WRITE PERIOD>

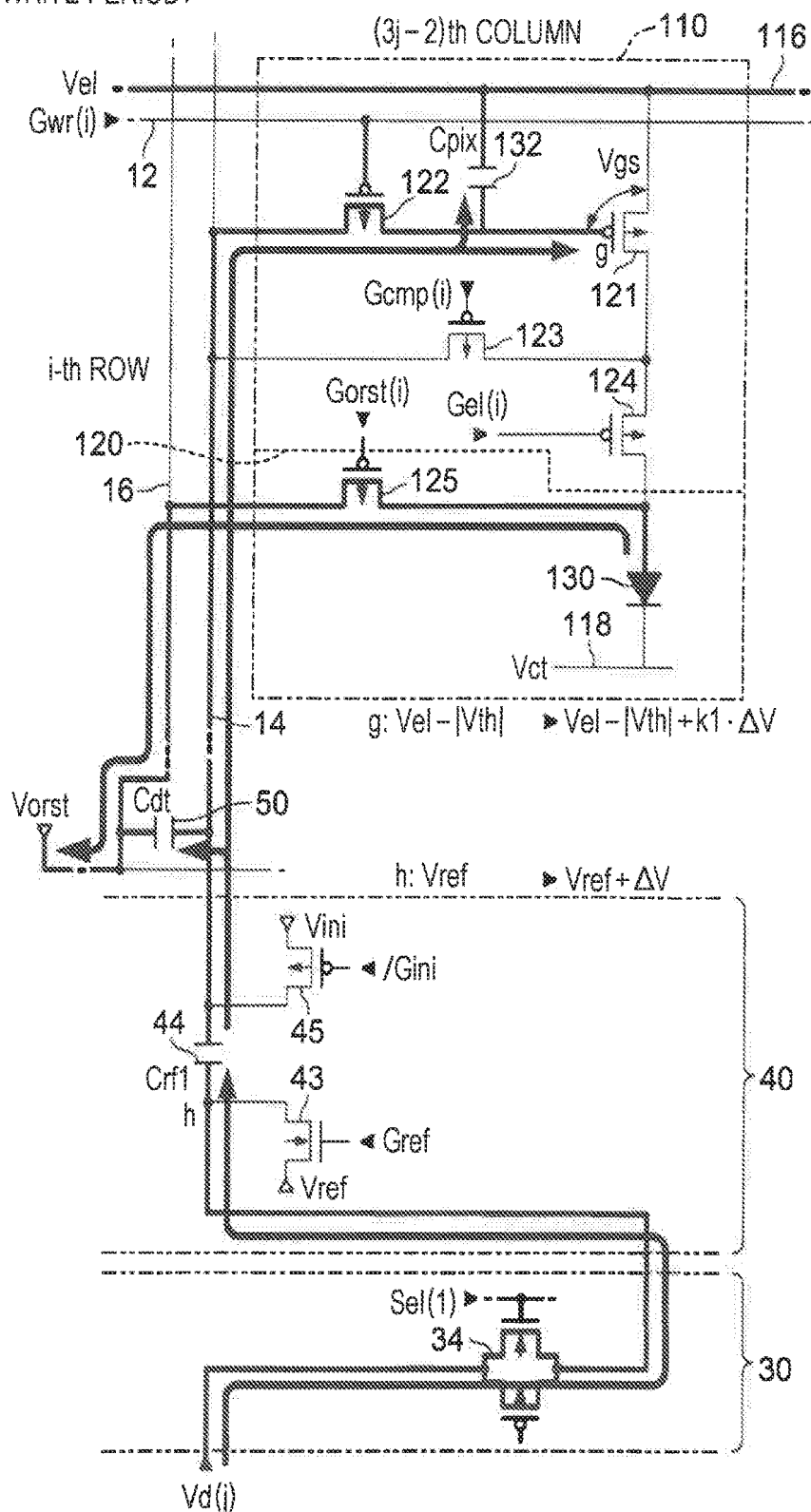


FIG. 12

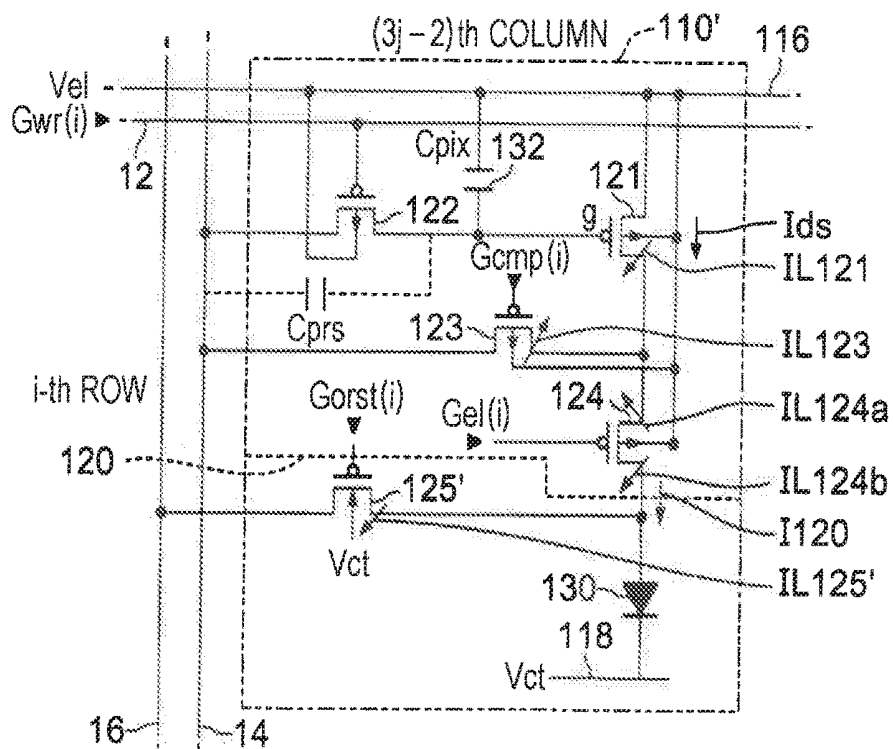


FIG. 13

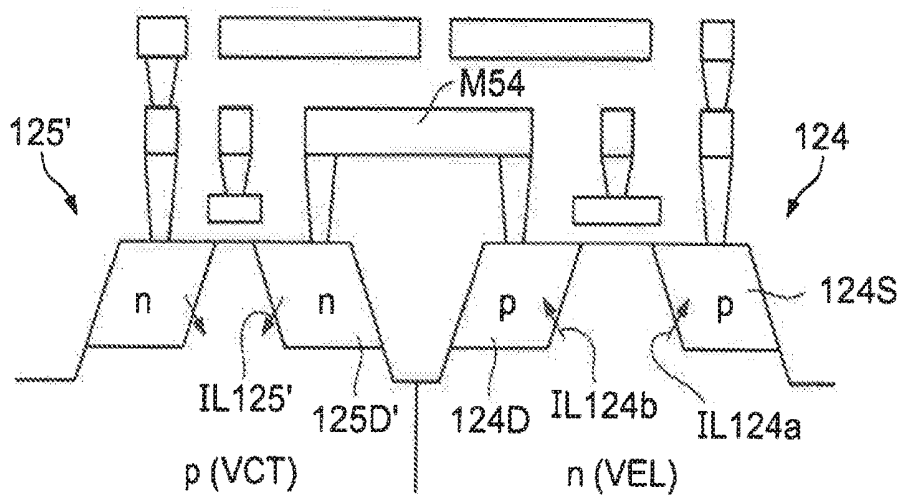


FIG. 14

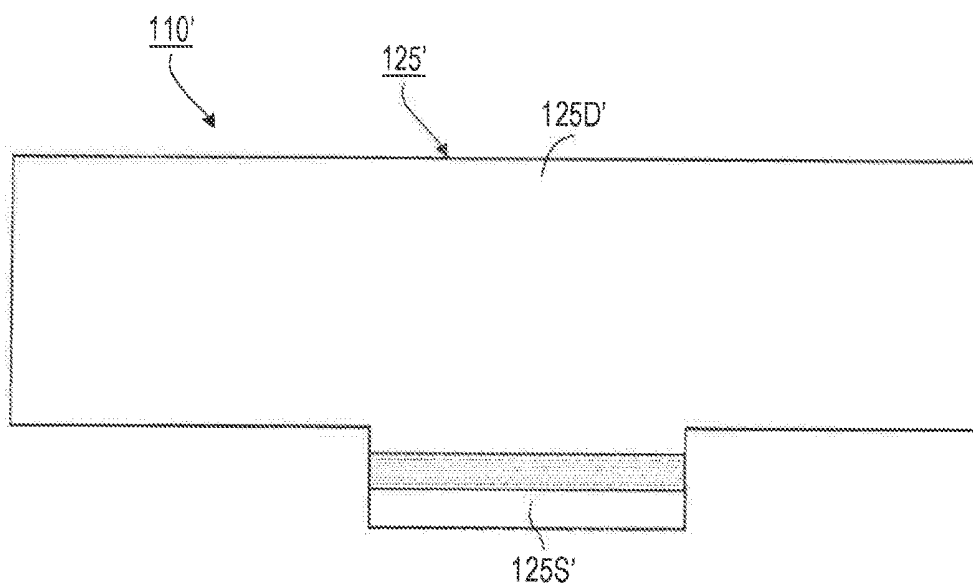


FIG. 15

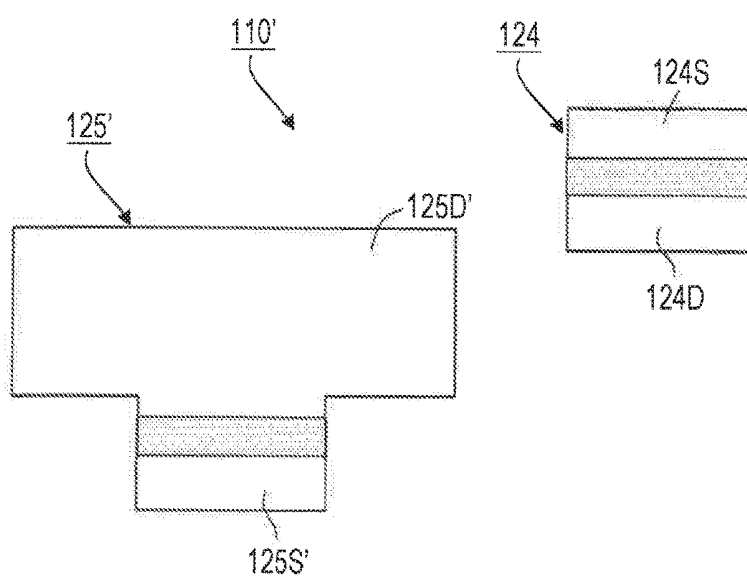


FIG. 16

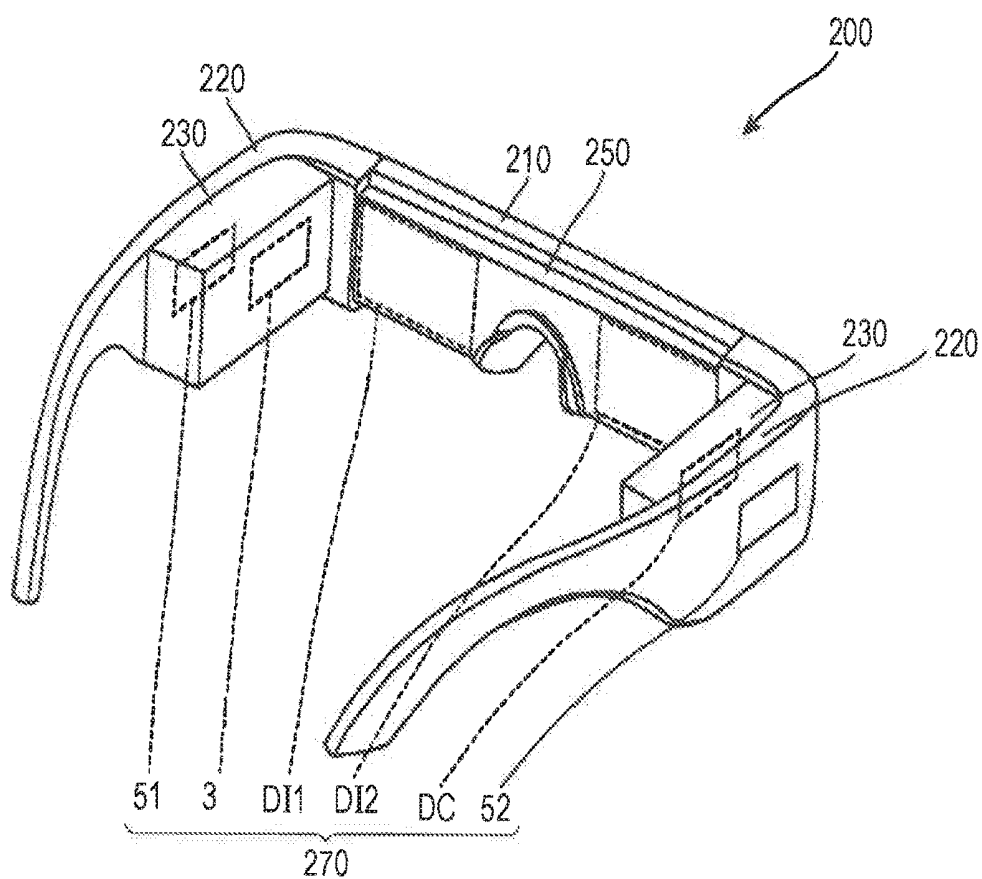
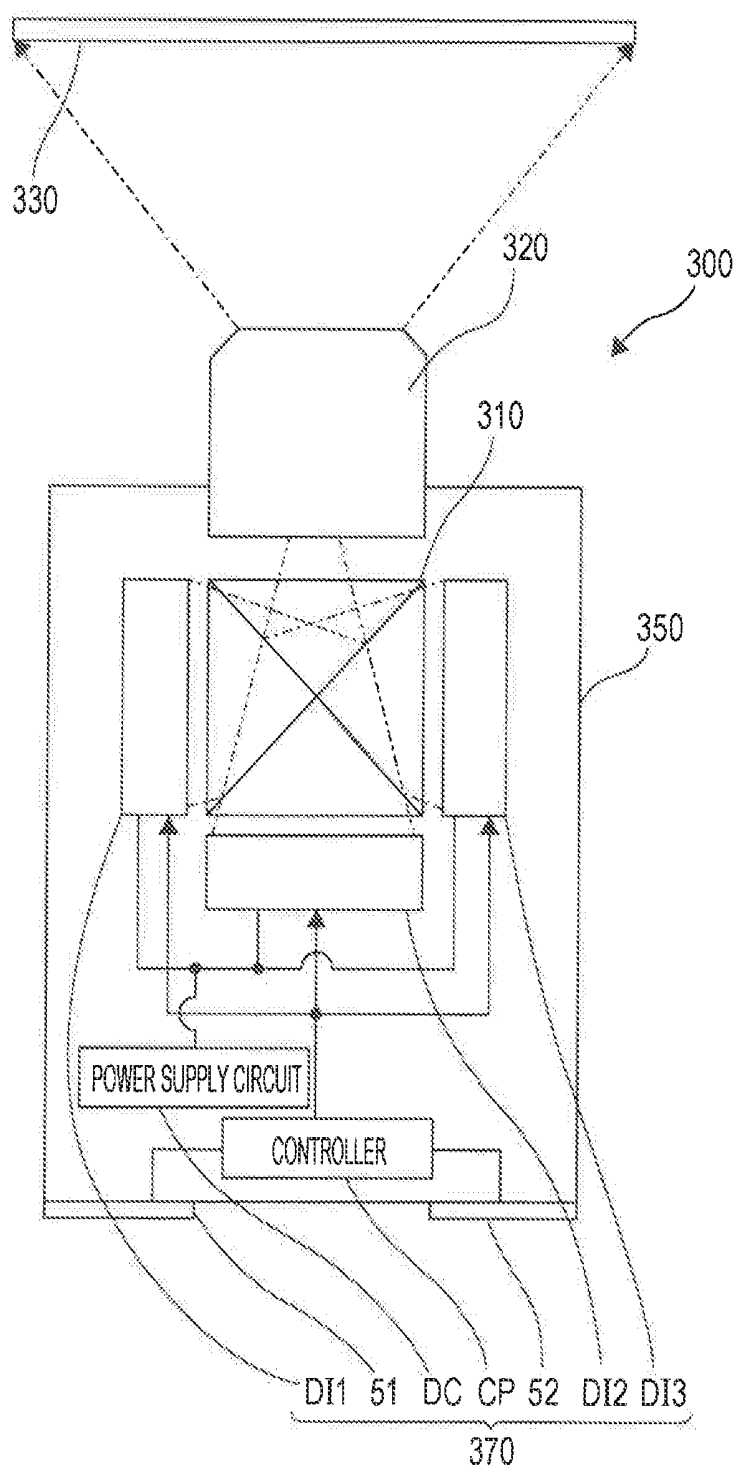


FIG. 17



# PIXEL CIRCUIT, ELECTRO-OPTICAL DEVICE, AND ELECTRONIC APPARATUS

## BACKGROUND

### 1. Technical Field

[0001] The present invention relates to a pixel circuit, an electro-optical device, and an electronic apparatus.

### 2. Related Art

[0002] To date, various electro-optical devices that include light emitting elements such as organic light emitting diodes (OLEDs) have been proposed. An electro-optical device of this type typically has pixel circuits in relation to pixels of an image to be displayed. These pixel circuits are disposed at the intersections of scan lines and data lines and each include a light emitting element and a transistor circuit. This transistor circuit supplies the light emitting element with a drive current whose magnitude is proportional to a data signal that indicates luminance of a corresponding light emitting element.

## SUMMARY

[0003] Pixel circuits, as described above, usually need to create clear black images. For that purpose, when the data signal indicates zero, the transistor circuit in a pixel circuit has to completely stop supplying the drive current to the light emitting element so that the light emitting element does not emit light.

[0004] When no drive current is supplied to the light emitting element, however, a leakage current may still flow from the transistor circuit to the light emitting element. As a result, the light emitting element might emit weak light, causing the so-called black floating, which is a phenomenon in which a black image is not created clearly.

[0005] JP-A-2010-243560 discloses a technique for discharging electric charge from the connection node between a transistor circuit and a light emitting element when the light emitting element does not emit light. JP-A-2013-088611 discloses a technique for suppressing an occurrence of the black floating, in which a bypass element is provided between a reference potential line and an end of a light emitting element which is closer to a transistor circuit. When the light emitting element does not emit light, a leakage current flows from the transistor circuit to this bypass element.

[0006] Unfortunately, the former technique may fail to address the problem associated with the black floating, because pixel circuits in micro displays and other related displays have small-capacitance light emitting elements. While such a light emitting element is not emitting light, electric charge may be excessively accumulated in the capacitance of the light emitting element, and as a result the leakage current might flow through the light emitting element, causing the black floating. Furthermore, both of the above techniques are intended to cause the flow of a leakage current from the transistor circuit to bypass the light emitting element when the light emitting element does not emit light. However, the techniques may fail to suppress an occurrence of the black floating effectively when the light emitting element emits light.

[0007] An advantage of some aspects of the invention is that a pixel circuit, an electro-optical device, and an electronic apparatus are all effective in suppressing an occurrence of the black floating.

[0008] A pixel circuit according to a first aspect of the invention includes: a transistor circuit that outputs a drive current in accordance with a data signal; a light emitting element that is connected to the transistor circuit and emits light with luminance corresponding to the drive current; and a discharge section that, when the data signal indicates zero, causes a flow of the drive current to bypass the light emitting element.

[0009] According to this aspect, when the data signal indicates zero, the discharge section stops the drive current output from the transistor circuit from flowing to the light emitting element. Thus, this configuration is effective in suppressing an occurrence of the black floating.

[0010] It is preferable that the transistor circuit include a drive transistor that generates the drive current in accordance with the data signal. It is preferable that the discharge section include a discharge transistor that, when the light emitting element does not emit the light, is turned on to connect a discharge feeder line to a node at which the transistor circuit is connected to the light emitting element. It is preferable that an absolute value of a threshold voltage of the discharge transistor be lower than an absolute value of a threshold voltage of the drive transistor.

[0011] According to this aspect, the absolute value of the threshold voltage of the discharge transistor is set to be lower than the absolute value of the threshold voltage of the drive transistor. In this case, when the data signal indicates zero, the discharge transistor in an off state can drive a current that is larger in amount than the drive current output from the transistor circuit. Thus, this configuration is more effective in suppressing an occurrence of the black floating.

[0012] It is preferable that the discharge transistor have a shorter channel length than that of the drive transistor.

[0013] According to this aspect, when the data signal indicates zero, the discharge transistor in an off state can drive a current that is larger in amount than the drive current output from the transistor circuit. Thus, this configuration is more effective in suppressing an occurrence of the black floating.

[0014] It is preferable that the drive transistor be a P-channel transistor and that the discharge transistor be an N-channel transistor.

[0015] According to this aspect, the current output from the transistor circuit flows into the p well of the N-channel discharge transistor through its drain. By the amount of this current, the amount of a current bypassing the light emitting element and flowing through the discharge section can be increased. Thus, this configuration is more effective in suppressing an occurrence of the black floating.

[0016] It is preferable that a drain of the discharge transistor which is connected to the light emitting element have a wider area than that of a source of the discharge transistor.

[0017] According to this aspect, a larger amount of current can flow from the drain into the p well of the discharge transistor. Thus, this configuration is more effective in suppressing an occurrence of the black floating.

[0018] It is preferable that the transistor circuit include a light emission control transistor connected between the drive transistor and the light emitting element. It is preferable that the light emission control transistor be a P-channel transis-

tor. It is preferable that a drain of the discharge transistor have a wider area than a total area of a drain and source of the light emission control transistor.

[0019] According to this aspect, the leakage current that flows from the n well to source of the P-channel light emission control transistor and the leakage current that flows from the n well to drain of the P-channel light emission control transistor through the pn junction are added to the current output from the transistor circuit. In addition, the area of the drain of the N-channel discharge transistor is set to be larger than the total area of the drain and source of the light emission control transistor. In this case, the current flowing from the drain into the p well of the discharge transistor is larger in amount than the leakage current flowing from the n well to the source and drain of the light emission control transistor through the pn junction. Thus, this configuration is more effective in suppressing an occurrence of the black floating.

[0020] It is preferable that the transistor circuit include a drive transistor that generates the drive current in accordance with the data signal. It is preferable that the discharge section include a discharge transistor that, when the light emitting element does not emit the light, is turned on to connect a discharge feeder line to a node at which the transistor circuit is connected to the light emitting element. It is preferable that the drive transistor be an enhancement type transistor and that the discharge transistor be a depletion type transistor.

[0021] According to this aspect, the drive transistor is an enhancement type transistor, and the discharge transistor is a depletion type transistor. When the data signal indicates zero, the discharge transistor in an off state can drive a current that is larger in amount than the drive current output from the transistor circuit. Thus, this configuration is more effective in suppressing an occurrence of the black floating.

[0022] An electro-optical device according to a second aspect includes the pixel circuit according to one of the above aspects.

[0023] According to this aspect, this configuration is effective in suppressing the black floating from occurring in the electro-optical device.

[0024] An electronic apparatus according to a third aspect includes the above electro-optical device. Examples of the electronic apparatus include a head mount display and a projector.

[0025] A pixel circuit according to a fourth aspect includes a transistor circuit that outputs a drive current in accordance with a data signal; a light emitting element that is connected to the transistor circuit and emits light with luminance corresponding to the drive current, the light emitting element; and in a light emission period, a discharge section that causes a flow of a part of the drive current.

[0026] A pixel circuit according to a fifth aspect includes: a transistor circuit that outputs a drive current in accordance with a data signal; a light emitting element that is connected to the transistor circuit and emits light with luminance corresponding to the drive current; and a discharge transistor that is turned off to cause a flow of a part of the drive current.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

[0028] FIG. 1 is a perspective view of a configuration of an electro-optical device according to a first embodiment of the invention.

[0029] FIG. 2 is a block diagram illustrating a configuration of the electro-optical device in FIG. 1.

[0030] FIG. 3 is a circuit diagram illustrating a configuration of a pixel circuit in the electro-optical device.

[0031] FIG. 4 is a cross-sectional view of a configuration of the light emission control transistor and the discharge transistor in the pixel circuit in FIG. 3.

[0032] FIG. 5 is a graph showing current characteristics of the drive transistor and the discharge transistor in the pixel circuit.

[0033] FIG. 6 is plan views of examples of the drive transistor and the discharge transistor in the pixel circuit.

[0034] FIG. 7 is a timing chart of an operation of the electro-optical device.

[0035] FIG. 8 is a circuit diagram for use in explaining an operation of the electro-optical device during a light emission period.

[0036] FIG. 9 is a circuit diagram for use in explaining an operation of the electro-optical device during an initialization period.

[0037] FIG. 10 is a circuit diagram for use in explaining an operation of the electro-optical device during an offset period.

[0038] FIG. 11 is a circuit diagram for use in explaining an operation of the electro-optical device during a write period.

[0039] FIG. 12 is a circuit diagram illustrating a configuration of a pixel circuit in an electro-optical device according to a second embodiment of the invention.

[0040] FIG. 13 is a cross-sectional view of a configuration of the light emission control transistor and the discharge transistor in the pixel circuit in FIG. 12.

[0041] FIG. 14 is a plan view of the discharge transistor in the pixel circuit.

[0042] FIG. 15 is plan views of examples of the light emission control transistor and the discharge transistor in the pixel circuit.

[0043] FIG. 16 is a view of an appearance of a head mount display (HMD) according to an application example of the invention.

[0044] FIG. 17 is a view of an optical configuration of a projector according to another application example of the invention.

#### DESCRIPTION OF EXEMPLARY EMBODIMENTS

##### First Embodiment

[0045] FIG. 1 is a perspective view of a configuration of an electro-optical device 1 according to a first embodiment of the invention. As an example, the electro-optical device 1 may be a micro display device in a head mount display (HMD) which displays images. As another example, the electro-optical device 1 may be an organic EL device in which a plurality of pixel circuits and drive circuits that drive the pixel circuits are mounted on a silicon substrate. Each pixel circuit has an organic light emitting diode (OLED), which is an example of a light emitting element.

[0046] The electro-optical device 1 includes a display panel 10 and a control circuit 3. The display panel 10 is mounted in a casing 72 having a frame and an opening in a display section. This display panel 10 is connected to an end

of a flexible printed circuit (FPC) substrate **74**. The control circuit **3** is mounted on the FPC substrate **74** by means of a chip on film (COF) technique. This control circuit **3** may be implemented using a semiconductor chip. The control circuit **3** is connected to an unillustrated upstream circuit through a plurality of terminals **76**.

[0047] FIG. 2 is a block diagram illustrating a configuration of the electro-optical device **1**. As described above, the display panel **10** and the control circuit **3** are mounted in the electro-optical device **1**.

[0048] The upstream circuit supplies digital image data *Vdata* and a synchronizing signal to the control circuit **3**; the image data *Vdata* and the synchronizing signal are synchronized together. The image data *Vdata* may be, for example 8-bit data that specifies gradation levels of the pixels in an image to be displayed on the display panel **10** by a display section **100** (described later). The synchronizing signal may contain a vertical synchronizing signal, a horizontal synchronizing signal, and a dot clock signal.

[0049] The control circuit **3** generates various control signals on the basis of the synchronizing signal and supplies these control signals to the display panel **10**. More specifically, the control circuit **3** supplies control signals *Ctrl*, a positive logic control signal *Gref*, and a negative logic control signal */Gini*, control signals *Sel(1)*, *Sel(2)*, and *Sel(3)*, */Sel(1)*, */Sel(2)*, and */Sel(3)*. The positive logic control signal *Gref* is equivalent to the logical inversion of the negative logic control signal */Gini*. The control signal *Sel(1)* is equivalent to the logical inversion of the control signal */Sel(1)*. The control signal *Sel(2)* is equivalent to the logical inversion of the control signal */Sel(2)*. The control signal *Sel(3)* is equivalent to the logical inversion of the control signal */Sel(3)*. Each control signal *Ctrl* contains a plurality of signals, including a pulse signal, a clock signal, and an enable signal. Hereinafter, the control signals *Sel(1)*, *Sel(2)*, and *Sel(3)* may be collectively referred to as the control signals *Sel*. Likewise, the control signals */Sel(1)*, */Sel(2)*, and */Sel(3)* may be collectively referred to as the control signals */Sel*.

[0050] The control circuit **3** includes a voltage generating circuit. This voltage generating circuit applies various electric potentials to the display panel **10**. More specifically, the control circuit **3** applies a potential *Vorst*, an initial potential *Vini*, and a potential *Vref* to the display panel **10**.

[0051] The control circuit **3** generates an analog image signal *Vid* on the basis of the image data *Vdata*. More specifically, the control circuit **3** has a lookup table in which a potential indicated by the image signal *Vid* is related to luminance of the light emitting elements in the display panel **10**; the light emitting elements may be OLEDs **130** that will be described later. The control circuit **3** refers to the lookup table and then generates the image signal *Vid* indicating a potential related to the luminance of the light emitting elements which is specified by the image data *Vdata*. Then, the control circuit **3** supplies the image signal *Vid* to the display panel **10**.

[0052] As illustrated in FIG. 2, the display panel **10** includes the display section **100**, a data transfer line drive circuit **5**, and a scan line drive circuit **20**.

[0053] In the display section **100**, a plurality of pixel circuits **110** are arranged in a matrix fashion and in relation to the pixels of an image to be displayed. More specifically, in the display section **100**, *m* rows of scan lines **12** extend along the short side of the page of FIG. 2, and *3n* columns

of data lines **14** extend along the long side of the page. Out of these data lines **14**, three data lines **14** make each group. The scan lines **12** and the data lines **14** are electrically isolated from each other. At the intersections between the scan lines **12** and the data lines **14** are the pixel circuits **110** provided. In this embodiment, thus, the pixel circuits **110** are arranged in the form of a matrix with *m* rows and *3n* columns.

[0054] Each of the numbers *m* and *n* may be any natural number. To differentiate the individual rows in the matrices of the scan lines **12** and the pixel circuits **110**, the rows may be referred to below as the first, second, third . . . (*m*-1)th, and *m*-th rows in the order from the upper side of the page of FIG. 2. Likewise, to differentiate the individual columns in the matrices of the data lines **14** and the pixel circuits **110**, the columns may be referred to below as the first, second, third . . . (*3n*-1)th, and (*3n*)th columns in the order from the left side of the page of FIG. 2. For example, if any one of the groups made by the data lines **14** is denoted by a *j*-th group (*j* is any integer ranging from 1 to *n*), this *j*-th group contains the data lines **14** of (*3j*-2)th, (*3j*-1)th, and *3j*-th columns.

[0055] Three pixel circuits **110** are provided at the intersections between a single scan line **12** and three data lines **14** in the same group. These pixel circuits **110** are related to three colors, namely, red, green, and blue and each form a dot of a color image to be displayed. In this embodiment, the OLEDs **130** emit red light, green light, and blue light, forming a single color dot in an additive color manner.

[0056] In this embodiment, along the data lines **14** are provided feeder lines **16**, which serve as discharge feeder lines for individual columns. The control circuit **3** applies the potential *Vorst* to all the feeder lines **16** as a discharge potential. In addition, each column is provided with a capacitor **50**. More specifically, first ends of the capacitors **50** are connected to the corresponding data lines **14**, whereas second ends of the capacitors **50** are connected to the corresponding feeder lines **16**. In short, each capacitor **50** functions as a second capacitor that retains a potential of a corresponding data line **14**.

[0057] Each capacitor **50** preferably has a structure in which an insulator or a dielectric is formed between wires of a data line **14** and a feeder line **16**.

[0058] Referring to FIG. 2, as an example, the capacitors **50** are provided outside the display section **100**. As an alternative example, the capacitors **50** may be provided either inside the display section **100** or from the inside to outside of the display section **100**. The capacitance of each capacitor **50** may be denoted by *Cdt*, which is not described in FIG. 2.

[0059] The data transfer line drive circuit **5** includes a demultiplexer **30**, a data transfer circuit **40**, and a data signal supply circuit **70**. The data signal supply circuit **70** outputs data signals *Vd(1)*, *Vd(2)* . . . *Vd(n)* to first, second . . . *n*-th blocks, respectively, in accordance with selection timings of the demultiplexer **30**. Each of the data signals *Vd(1)*, *Vd(2)* . . . *Vd(n)* indicates a potential ranging from a minimum potential *Vmin* to a maximum potential *Vmax*.

[0060] The scan line drive circuit **20** sequentially selects the plurality of pixel circuits **110** arranged in a matrix fashion and controls the operations of these pixel circuits **110**. The scan line drive circuit **20** repeatedly sequentially selects the pixel circuits **110** row by row. More specifically, the scan line drive circuit **20** generates scan signals used to

sequentially scan the scan lines **12** over a frame period **1F**, in accordance with a control signal **Ctr**. The frame period **1F** corresponds to a period over which the electro-optical device **1** displays a frame of an image. For example, if the vertical synchronizing signal contained in the synchronizing signal has a frequency of 120 Hz, the frame period **1F** is approximately 8.3 ms, which is equivalent to one period of the vertical synchronizing signal. Hereinafter, scan signals supplied to the scan lines **12** on the first, second, third . . . (m-1)th, and m-th rows may be denoted by **Gwr(1)**, **Gwr(2)**, **Gwr(3)** . . . **Gwr(m-1)**, and **Gwr(m)**, respectively. In addition, the scan line drive circuit **20** causes each pixel circuit **110** to perform a current value setting operation and a light emitting operation. In the current value setting operation, each pixel circuit **110** sets a value of a drive current to be supplied to the OLED **130** within the frame period **1F** between when a pixel circuit **110** is selected and this pixel circuit **110** is selected again. In the light emitting operation, each pixel circuit **110** supplies a current to the OLED **130** with an emission of light.

**[0061]** To control the operations of the pixel circuits **110** described above, the scan line drive circuit **20** generates, in addition to the scan signals **Gwr(1)** to **Gwr(m)**, various control signals for respective rows in synchronization with the scan signals. Then, the scan line drive circuit **20** supplies the generated control signals to the display section **100**. It should be noted that these control signals are not illustrated in FIG. 2.

**[0062]** The demultiplexer **30** includes a plurality of groups of transmission gates **34** provided on the respective columns. The demultiplexer **30** sequentially supplies data signals to the three rows in each group.

**[0063]** The transmission gates **34** on the (3j-2)th, (3j-1)th, and (3j)th columns which belong to the j-th group have a common input terminal to which the data signal **Vd(j)** is to be supplied.

**[0064]** When the control signal **Sel(1)** is at the H level, in other words, when the control signal /**Sel(1)** is at the L level, the transmission gate **34** on the leftmost column, or on the (3j-2)th column, in the j-th group is turned on to conduct electricity. Likewise, when the control signal **Sel(2)** is at the H level, in other words, when the control signal /**Sel(2)** is at the L level, the transmission gate **34** on the central column, or the (3j-1)th column, in the j-th group is turned on to conduct electricity. When the control signal **Sel(3)** is at the H level, in other words, when the control signal /**Sel(3)** is at the L level, the transmission gate **34** on the rightmost row, or the 3j-th row, in the j-th group is turned on to conduct electricity.

**[0065]** The data transfer circuit **40** includes a capacitor **44**, a P-channel metal oxide semiconductor (MOS) transistor **45**, and an N-channel MOS transistor **43** on each column. The data transfer circuit **40** shifts the potentials of the data signals output from the output terminals of the transmission gates **34** on the respective columns. A first end of each capacitor **44** is connected to both the data line **14** and the drain node of the P-channel MOS transistor **45** on a corresponding column, whereas a second end of each capacitor **44** is connected to both the output terminal of the transmission gate **34** and the drain node of the N-channel MOS transistor **43** on the corresponding column. In short, each capacitor **44** functions as a first capacitor having an end connected to the corresponding data line **14**. The capacitance of each capacitor **44** is denoted by **Crfl**, which is not described in FIG. 2.

**[0066]** The source nodes of the P-channel MOS transistors **45** on the respective columns are connected to the feeder line **61** through which the potential **Vini** is applied as the initial potential, whereas the gate nodes of the P-channel MOS transistors **45** on the respective rows are supplied with the control signal /**Gini**. Thus, the P-channel MOS transistors **45** electrically connect the data lines **14** to the feeder line **61** when the control signal /**Gini** is at the L level and electrically disconnect the data lines **14** from the feeder line **61** when the control signal /**Gini** is at the H level.

**[0067]** The source nodes of the N-channel MOS transistors **43** on the respective columns are connected to a feeder line **62** through which the potential **Vref** is applied as a predetermined potential, whereas the gate nodes of the N-channel MOS transistors **43** on the respective rows are supplied with the control signal **Gref**. In short, the N-channel MOS transistors **43** electrically connect the second ends, or nodes **h**, of the capacitors **44** to a feeder line **62** when the control signal **Gref** is at the H level and electrically disconnect the nodes **h** of the capacitors **44** from the feeder line **62** when the control signal **Gref** is at the L level.

**[0068]** For the sake of convenience, in this embodiment, the scan line drive circuit **20**, the demultiplexer **30**, and the data transfer circuit **40** are separated from one another; however, the scan line drive circuit **20**, the demultiplexer **30**, and the data transfer circuit **40** may be integrated to constitute a single drive circuit that drives the pixel circuits **110**.

**[0069]** Next, the pixel circuits **110** will be described below with reference to FIG. 3. All the pixel circuits **110** have substantially the same electrical configuration. Therefore, the pixel circuit **110** on the i-th row and the (3j-2)th column which is positioned on the leftmost column in the J-th group is taken as an example and will be described below. The number **i** is used to designate a row on which any array of pixel circuits **110** are arranged. The number **i** may be any integer ranging from 1 to **m**.

**[0070]** As illustrated in FIG. 3, the pixel circuit **110** includes P-channel MOS transistors **121** to **125**, the OLED **130**, and a capacitor **132**. The pixel circuit **110** is supplied with the scan signal **Gwr(i)** and control signals **Gel(i)**, **Gcmp(i)**, and **Gorst(i)**. The scan signal **Gwr(i)** and the control signals **Gel(i)**, **Gcmp(i)**, and **Gorst(i)** are supplied from the scan line drive circuit **20** to the pixel circuits **110** on the i-th row. Thus, the scan signal **Gwr(i)** and the control signals **Gel(i)**, **Gcmp(i)**, and **Gorst(i)** are supplied not only to the pixel circuit **110** on the i-th row and the (3j-2)th column but also to the other pixel circuits **110** on the i-th row.

**[0071]** In the pixel circuit **110** on the i-th row and the (3j-2)th column, the gate node of the P-channel MOS transistor **122** is connected to the scan line **12** on the i-th row. In addition, one of the drain and source nodes of the P-channel MOS transistor **122** is connected to the data line **14** on the (3j-2)th column, whereas the other of the drain and source nodes of the P-channel MOS transistor **122** is connected to a gate node **g** of the P-channel MOS transistor **121**, a first end of the capacitor **132**, and the drain node of the P-channel MOS transistor **123**. This P-channel MOS transistor **122** serves as a current value setting transistor that sets a value of a current to be driven by the P-channel MOS transistor **121** by supplying the data signal received through the data line **14** to the gate node of the P-channel MOS transistor **121**. The gate node of the P-channel MOS transistor **121** is denoted by **g** so as to be differentiable from other nodes.

[0072] The P-channel MOS transistor 121 serves as a drive transistor that generates a drive current to be supplied to the OLED 130. The source node of the P-channel MOS transistor 121 is connected to the feeder line 116, whereas the drain node of the P-channel MOS transistor 121 is connected to both the source nodes of the P-channel MOS transistor 123 and the P-channel MOS transistor 124. Through the feeder line 116, a potential Vel is applied to the pixel circuit 110; the potential Vel corresponds to the high potential of the supply voltage.

[0073] The P-channel MOS transistor 123 serves as an offset transistor that offsets the threshold voltage of the P-channel MOS transistor 121. The drain node of the P-channel MOS transistor 123 is connected to the data line 14. The gate node of the P-channel MOS transistor 123 is supplied with the control signal Gcmp(i).

[0074] The gate node of the P-channel MOS transistor 124 is supplied with the control signal Gel(i), whereas the drain node of the P-channel MOS transistor 124 is connected to both the source node of the P-channel MOS transistor 125 and the anode of the OLED 130. The P-channel MOS transistor 124 is provided on a path along which the drive current is to be supplied to the OLED 130. This P-channel MOS transistor 124 serves as a light emission control transistor that controls a light emission period of the OLED 130. More specifically, the P-channel MOS transistor 124 is turned on to cause the OLED 130 to emit light and turned off to stop the OLED 130 from emitting the light.

[0075] The P-channel MOS transistors 121 to 124 described above constitute a transistor circuit 120 that supplies the drive current to the OLED 130.

[0076] The gate node of the P-channel MOS transistor 125 is supplied with the control signal Gorst(i) for the i-th row, whereas the drain node of the P-channel MOS transistor 125 is connected to the feeder line 16 on the (3j-2)th column and kept at the potential Vorst. This P-channel MOS transistor 125 serves as a discharge transistor that is turned on to connect the anode of the OLED 130 to the feeder line 16 when the OLED 130 does not emit light. The P-channel MOS transistor 125, which serves as the discharge transistor in this embodiment, functions as a “discharge section” herein, which causes the flow of the drive current output from the transistor circuit 120 to bypass the OLED 130 when the data signal indicates zero during the light emission period.

[0077] A second end of the capacitor 132 is connected to the feeder line 116. Thus, the capacitor 132 maintains a voltage between the source and drain of the P-channel MOS transistor 121. When the capacitance of the capacitor 132 is denoted by Cpix, a capacitance Cdt of each capacitor 50, a capacitance Crf1 of each capacitor 44, and the capacitance Cpix of the capacitor 132 are set so as to satisfy the relationship:

$$Cdt > Crf1 >> Cpix \quad (1).$$

In short, the capacitance Cdt is set to be larger than the capacitance Crf1, and the capacitance Cpix is set to be much smaller than the capacitances Cdt and Crf1.

[0078] The capacitor 132 may be implemented using a parasitic capacitance at the gate node g of the P-channel MOS transistor 121. Alternatively, the capacitor 132 may be implemented using a capacitance between different conducting layers formed on a silicon substrate with an insulating layer therebetween.

[0079] In this embodiment, the electro-optical device 1 is formed on the silicon substrate. Therefore, a substrate potential of the P-channel MOS transistors 121 to 125 is the potential Vel.

[0080] The anode of the OLED 130 corresponds to a pixel electrode provided uniquely in each pixel circuit 110. The cathode of the OLED 130 corresponds to a common electrode 118 shared by all the pixel circuits 110. This cathode is kept at a potential Vct, which corresponds to the low potential of the supply voltage.

[0081] The OLED 130 is an element having a structure in which a white organic EL layer is formed between an anode and a light transmissive cathode on the silicon substrate. In addition, the surface of the OLED 130 on the cathode side from which light is to be output is covered with a red, green, or blue color filter.

[0082] When a current flows from the anode to cathode of the OLED 130 described above, holes injected from the anode are recoupled to electrons injected from the cathode in the organic EL layer, thereby generating exciton. As a result, the OLED 130 emits white light. This white light passes through the cathode positioned opposite the silicon substrate or the anode, and then is changed into red light, green light, or blue light by the color filter. After that, the resultant light is observed by a viewer.

[0083] The configuration in this embodiment, when the P-channel MOS transistor 125 is turned off during the light emission period, allows a large amount of off-state current Ioff\_orst to flow through the P-channel MOS transistor 125 that serves as the discharge transistor. This configuration is effective in suppressing the black floating from occurring when the electro-optical device 1 displays a black image. Details of the configuration will be described below.

[0084] When the OLED 130 emits light, the data signal indicating zero, which is an instruction of displaying a black image, is supplied to the pixel circuit 110. In response, a gate-source voltage Vgs corresponding to the threshold voltage of the P-channel MOS transistor 121 is applied to the P-channel MOS transistor 121, as will be described later. As a result, the P-channel MOS transistor 121 operates in the subthreshold region. Thus, a current I120 output from the transistor circuit 120 contains a drain current Ids of the P-channel MOS transistor 121 operating in the subthreshold region.

[0085] The current I120 output from the transistor circuit 120 may also contain other currents. FIG. 4 is a cross-sectional view of a configuration of the P-channel MOS transistors 124 and 125 in this embodiment. As illustrated in FIG. 4, each transistor in the pixel circuit 110 has a shallow trench isolation (STI) structure. A source 124S and drain 124D of the P-channel MOS transistor 124 are formed in an n well to which the highest potential VEL is to be applied. In this structure, the P-channel MOS transistor 124 generates leakage currents IL124a and IL124b. The leakage current IL124a flows from the n well at the potential VEL to the source 124S through the pn junction therebetween; the leakage current IL124b flows from the n well at the potential VEL to the drain 124D through the pn junction. Likewise, the P-channel MOS transistor 121 generates a leakage current IL121; the P-channel MOS transistor 123 generates a leakage current IL123. In short, when the data signal indicates zero, the current I120 output from the transistor circuit 120 contains the drain current Ids of the P-channel MOS transistor 121 operating in the subthreshold region, as

well as the leakage current  $IL_{121}$  generated in the P-channel MOS transistor **121**, the leakage current  $IL_{123}$  generated in the P-channel MOS transistor **123**, and the leakage currents  $IL_{124a}$  and  $IL_{124b}$  generated in the transistor **124**.

[0086] As illustrated in FIG. 4, the P-channel MOS transistor **125** also generates a leakage current  $IL_{125}$  flowing from the n well at the potential VEL to the drain **125D**. In this structure, the drain **125D** of the P-channel MOS transistor **125** is connected to the drain **124D** of the P-channel MOS transistor **124** by a metal wire **M54**, which is connected to the anode of the OLED **130** (see FIG. 3). In some instances, in addition to the current output from the transistor circuit **120**, the leakage current  $IL_{125}$  of the P-channel MOS transistor **125** may flow to the OLED **130** unless any measures are taken.

[0087] In this embodiment, however, when the data signal indicates zero, the off-state current  $I_{off\_orst}$  generated in the P-channel MOS transistor **125** in the off state is set to be larger in amount than the sum ( $I_{120}+IL_{125}$ ) of the current  $I_{120}$  output from the transistor circuit **120** and the leakage current  $IL_{125}$  of the P-channel MOS transistor **125** itself.

[0088] By setting the off-state current  $I_{off\_orst}$  in this manner, all the current  $I_{120}$  output from the transistor circuit **120** can be caused to flow to the feeder line **16** through the P-channel MOS transistor **125** when the data signal indicates zero while the OLED **130** is emitting light. In this way, an occurrence of the black floating is suppressed.

[0089] To set the off-state current  $I_{off\_orst}$  to be larger in amount than the sum of the leakage currents  $I_{120}$  and  $IL_{125}$ , this embodiment takes the following measures.

[0090] In this embodiment, the absolute value of the threshold voltage of the P-channel MOS transistor **125** serving as the discharge transistor is set to be smaller than that of the P-channel MOS transistor **121** serving as the drive transistor. By setting both threshold voltages in this manner, the off-state current  $I_{off\_orst}$  can be increased.

[0091] FIG. 5 is a graph showing current characteristics of the P-channel MOS transistor **121** serving as the drive transistor and the P-channel MOS transistor **125** serving as the discharge transistor. In this example, the P-channel MOS transistor **125** has a lower threshold voltage than that of the P-channel MOS transistor **121**. In the graph of FIG. 5, the horizontal axis represents gate-source voltages  $V_{gs}$  of the P-channel MOS transistors **121** and **125**; the vertical axis represents the logarithmic values of the drain currents of the P-channel MOS transistors **121** and **125**. The gate-source voltage of the P-channel MOS transistor **125** is set to 0 V over the light emission period. When the data signal indicates zero during the light emission period, the gate-source voltage  $V_{gs}$  equivalent to the threshold voltage  $V_{th}$  is applied to the P-channel MOS transistor **121**. Therefore, as can be found from FIG. 5, the horizontal axes related to the gate-source voltages  $V_{gs}$  of the P-channel MOS transistors **121** and **125** are shifted from each other at the point where the gate-source voltage  $V_{gs}$  of the P-channel MOS transistor **125** becomes 0 V, so that the gate-source voltage  $V_{gs}$  of the P-channel MOS transistor **121** equals the threshold voltage  $V_{th}$ .

[0092] The graph of FIG. 5 demonstrates that, when the threshold voltage of the P-channel MOS transistor **125** is lowered, the off-state current  $I_{off\_orst}$  generated in the P-channel MOS transistor **125** in the off state ( $V_{gs}=0$  V)

during the light emission period is larger than the current  $I_{ds}$  ( $V_{th}$ ) driven by the P-channel MOS transistor **121** in the subthreshold region.

[0093] As needed, the P-channel MOS transistor **121** may be an enhancement type transistor having a negative threshold voltage, and the P-channel MOS transistor **125** may be a depletion type transistor having a positive threshold voltage. In this case, the P-channel MOS transistor **125** can drive a larger amount of current when its gate-source voltage  $V_{gs}$  is 0 V. Thus, this configuration is more effective in suppressing an occurrence of the black floating.

[0094] In this embodiment, as illustrated in FIG. 6, a channel length  $L_{125}$  between a source **125S** and the drain **125D** of the P-channel MOS transistor **125** is set to be shorter than a channel length  $L_{121}$  between a source **121S** and the drain **121D** of the P-channel MOS transistor **121**. By setting the channel lengths  $L_{125}$  and  $L_{121}$  in this manner, the threshold voltage of the P-channel MOS transistor **125** can be lowered due to the short channel effect. As a result, the off-state current  $I_{off\_orst}$  generated in the P-channel MOS transistor **125** in the off state ( $V_{gs}$  is 0 V) can be increased. The above-described configurations are those employed by this embodiment.

[0095] Next, an operation of the electro-optical device **1** in this embodiment will be described below. FIG. 7 is a timing chart of the operation of the electro-optical device **1**. As indicated by this timing chart, the scan signals  $Gwr(1)$  to  $Gwr(m)$  are sequentially switched to the L level during the frame period **1F**. The scan lines **12** on the first to m-th rows are thereby sequentially scanned. The time interval between the selections of one and the next one of the plurality of scan lines **12** corresponds to a horizontal scanning period **1H**. In this example, the frame period **1F** contains an m number of horizontal scanning periods **1H**.

[0096] Over every horizontal scanning period **1H**, the pixel circuits **110** on each row perform the same operation. For this reason, a description will be given below regarding only the case where the pixel circuit **110** on the i-th row and the (3j-2)th column operates over the horizontal scanning period **1H** in which the scan line **12** on the i-th row is horizontally scanned.

[0097] In this embodiment, a cycle of an initialization period, an offset period, a write period, and a light emission period is generated within the frame period **1F**. In FIG. 7 illustrates a first cycle of (b) the initialization period, (c) the offset period, (d) the write period, and (a) the light emission period within the frame period **1F**.

[0098] The time interval between the start of the initialization period and the end of the write period corresponds to a current value setting period, in which each pixel circuit **110** on the selected scan line **12** sets a value of its drive current. In this example, the current value setting period contains the initialization period, the offset period, and the write period; however, the current value setting period may have any other configuration. Within the horizontal scanning period (**1H**), the periods other than the current value setting period corresponds to transition periods. In this embodiment, the scan line drive circuit **20** causes the OLEDs **130** to transit between the light emission state and the light non-emission state over the transition periods, in order to adjust luminance of the entire screen.

[0099] FIG. 8 illustrates an operating state of the pixel circuit **110** on the i-th row and the (3j-2)th column over the (a) light emission period. FIG. 9 illustrates an operating state

over the (b) initialization period. FIG. 10 illustrates an operating state over the (c) offset period. FIG. 11 illustrates an operating state over the (d) write period. In each of FIGS. 8 to 11, the current routes in the pixel circuit 110 which are regarded as being important for the explanation of its operation are indicated by thick lines.

#### Light Emission Period

[0100] As described above, the initialization period, the offset period, and the write period constitute the current value setting period. In this current value setting period, each pixel circuit 110 operates in such a way that the OLED 130 emits light of an appropriate luminance according to the data signal over the light emission period. To understand the operations of the pixel circuit 110 in the initialization, offset, and write periods, it is necessary to understand an operation of the pixel circuit 110 in the light emission period. For this reason, the operation of the pixel circuit 110 in the light emission period will be described first.

[0101] As illustrated in FIG. 7, the scan signal  $Gwr(i)$  is at the H level over the light emission period in which the pixels on the  $i$ -th row emit light. In addition, the control signal  $Gel(i)$  is at the L level, and the control signals  $Gorst(i)$  and  $Gcmp(i)$  are at the H level.

[0102] In the pixel circuit 110 on the  $i$ -th row and the  $(3j-2)$  column, as illustrated in FIG. 8, the P-channel MOS transistor 124 is turned on, and the P-channel MOS transistors 122, 123, and 125 are turned off. As a result, the P-channel MOS transistor 121 supplies the OLED 130 with the current  $I_{ds}$  according to the gate-source voltage  $V_{gs}$ .

[0103] Over the light emission period, in this embodiment, the gate-source voltage  $V_{gs}$  of the P-channel MOS transistor 121 is shifted from its threshold voltage in accordance with the potential of the data signal, as a result of the operations in the initialization, offset, and write periods, details of which will be described later. Thus, with its threshold voltage offset, the P-channel MOS transistor 121 supplies the OLED 130 with a current according to a gradation level over the light emission period.

[0104] When the data signal indicates zero, which instructs a black display, during the light emission period, the gate-source voltage  $V_{gs}$  of the P-channel MOS transistor 121 becomes equal to its threshold voltage. As a result, the transistor circuit 120 outputs the current  $I_{120}$  containing the drain current of the P-channel MOS transistor 121 operating in the subthreshold region and the leakage currents of the P-channel MOS transistors 121 and 123. Simultaneously, the P-channel MOS transistor 125 also generates a leakage current. In this embodiment, however, the off-state current  $I_{off\_orst}$  that exceeds the total of the current  $I_{120}$  output from the transistor circuit 120 and the leakage current of the P-channel MOS transistor 125 flows through the P-channel MOS transistor 125. Thus, no current flows through the OLED 130 upon the display of the black display. Consequently, this embodiment is effective in suppressing an occurrence of the black floating.

#### Initialization Period

[0105] When the scan line 12 on the  $i$ -th row is horizontally scanned, the initialization period (b) comes first. Over this initialization period, the scan signal  $Gwr(i)$  is at the H level. In addition, the control signal  $Gel(i)$  and  $Gcmp(i)$  are at the H level, and the control signal  $Gorst(i)$  is at the L level.

[0106] In the pixel circuit 110 on the  $i$ -th row and the  $(3j-2)$  column, as illustrated in FIG. 9, the P-channel MOS transistor 124 is turned off, and the P-channel MOS transistors 122, 123, and 125 are turned on. As a result, no current flows along the route from the P-channel MOS transistor 121 to the OLED 130, and the anode of the OLED 130 is reset to the potential  $V_{orst}$ .

[0107] As described above, the OLED 130 has the configuration in which the organic EL layer is formed between the anode and the cathode. Therefore, between the anode and the cathode is a parasitic capacitance  $C_{oled}$  present, as indicated by the broken line in FIG. 9. While the current is flowing through the OLED 130 during the light emission period, the voltage between the anode and cathode of the OLED 130 is maintained by the parasitic capacitance  $C_{oled}$ . In this embodiment, however, this voltage is reset in response to the turn-on of the P-channel MOS transistor 125 over the initialization period. This scheme reduces the influence of the voltage maintained by the parasitic capacitance  $C_{oled}$  on the OLED 130 when the current next flows through the OLED 130 during the following light emission period.

[0108] For example, if the voltage between the anode and cathode of the OLED 130 is not reset, when the display panel 10 changes from a high-luminance state into a low-luminance state, a high voltage may be maintained between the anode and cathode of the OLED 130. Thus, even when the P-channel MOS transistor 121 attempts to supply a small amount of current to the OLED 130, an overcurrent may flow through the OLED 130, hindering the display panel 10 from entering the low-luminance state. In this embodiment, however, the potential at the anode of the OLED 130 is reset in response to the turn-on of the P-channel MOS transistor 125; therefore, a color production of the electro-optical device 1 can be enhanced when the display panel 10 is in the low-luminance state.

[0109] In this embodiment, the difference between the potential  $V_{orst}$  and the potential  $V_{ct}$  at the common electrode 118 is set to be lower than the threshold voltage of the OLED 130. Therefore, the OLED 130 is maintained in an off state, or in a light non-emission state, over the initialization period as well as over the following offset and write periods.

[0110] Over the initialization period, the control signal  $/Gini$  is at the L level, and the control signal  $Gref$  is at the H level. In response, the P-channel MOS transistors 43 and 45 in the data transfer circuit 40 are turned on, as illustrated in FIG. 9. As a result, the data line 14 connected to a first end of the capacitor 44 is reset to the potential  $V_{ini}$ , and a node  $h$  at a second end of the capacitor 44 is reset to the potential  $V_{ref}$ .

[0111] In this embodiment, the potential  $V_{ini}$  is set such that the difference  $(V_{el}-V_{ini})$  between the potential  $V_{el}$  and the potential  $V_{ini}$  exceeds the absolute value  $|V_{thl}|$  of the threshold voltage  $V_{th}$  of the P-channel MOS transistor 121. In this case, the threshold voltage  $V_{th}$  of the P-channel MOS transistor 121 has a negative value relative to the potential at the source node. Thus, for the purpose of helping an understanding of the magnitude relationship, the threshold voltage is represented by an absolute value  $|V_{thl}|$ .

[0112] In this embodiment, the potential  $V_{ref}$  is set such that the potential at the node  $h$  increases during the following the write period, relative to the potentials that the data

signals  $V_d(1)$  to  $V_d(n)$  may have. As an example, the potential  $V_{ref}$  may be set to be lower than the minimum voltage  $V_{min}$ .

#### Offset Period

[0113] While the scan line 12 on the  $i$ -th row is being horizontally scanned, the offset period (c) comes after the initialization period (b). Over this offset period, the scan signal  $G_{wr}(i)$  and the control signal  $G_{cmp}(i)$  are switched to the L level. The control signal  $G_{ref}$  is kept at the H level. The control signal  $/G_{ini}$  is switched to the H level.

[0114] As a result, as illustrated in FIG. 10, in the data transfer circuit 40, the N-channel MOS transistor 43 is turned on, and the P-channel MOS transistor 45 is turned off. The node h is thereby fixed at the potential  $V_{ref}$ . In the pixel circuit 110 on the  $i$ -th row and the  $(3j-2)$  column, the P-channel MOS transistor 122 is turned on. In response, the gate node g gets electrically connected to the data line 14. The gate node g is set to the potential  $V_{ini}$  at the initial stage of the offset period.

[0115] During the offset period, the P-channel MOS transistor 123 is turned on. The gate node g of the P-channel MOS transistor 121 thereby gets connected to the drain node of the P-channel MOS transistor 121 through the P-channel MOS transistors 122 and 123, making a diode connection. As a result, the drain current flows through the P-channel MOS transistor 121, charging the gate node g and the data line 14. More specifically, the current flows along the route on which the feeder line 16, the P-channel MOS transistors 121 and 123, the data line 14 on the  $(3j-2)$  column, the P-channel MOS transistor 122, and the gate node g are disposed in this order. In this case, the potential on the data line 14 and at the gate node g that have gotten interconnected in response to the turn-on of the P-channel MOS transistor 121 increases from the potential  $V_{ini}$ .

[0116] However, the current is less likely to flow along the above route as the potential at the gate node g becomes closer to the potential  $(V_{el}-|V_{th}|)$ . Before the offset period ends, the potential on the data line 14 and at the gate node g is saturated to the potential  $(V_{el}-|V_{th}|)$ . In this case, the capacitor 132 maintains the threshold voltage  $|V_{th}|$  of the P-channel MOS transistor 121 at the final stage of the offset period.

#### Write Period

[0117] After the initialization period has ended, the write period (d) comes. Over this write period, the control signal  $G_{cmp}(i)$  is at the H level, and the diode connection made by the P-channel MOS transistor 121 is thereby broken off. In addition, the control signal  $G_{ref}$  is at the L level, and the N-channel MOS transistor 43 is thereby turned off. As a result, the route from the data line 14 on the  $(3j-2)$  column to the gate node g of the pixel circuit 110 on the  $i$ -th row and the  $(3j-2)$  column electrically floats. However, this route is kept at the potential  $(V_{el}-|V_{th}|)$  by the capacitors 50 and 132.

[0118] Over the write period, the control circuit 3 sequentially changes the potentials of the data signals  $V_d(j)$  into potentials according to gradation levels of the pixels on the  $i$ -th row and the  $(3j-2)$  column, the  $i$ -th row and the  $(3j-1)$  column, and the  $i$ -th row and the  $3j$ -th column. In response to the change in the potentials of the data signals, the control circuit 3 sequentially switches the control signals  $Sel(1)$ ,

$Sel(2)$ , and  $Sel(3)$  to the H level in an exclusive manner. In this case, the control circuit 3 also outputs the control signals  $/Sel(1)$ ,  $/Sel(2)$ , and  $/Sel(3)$ , which are equivalent to the logical inversions of the control signals  $Sel(1)$ ,  $Sel(2)$ , and  $Sel(3)$ , respectively that are not illustrated in FIG. 7. As a result, in the demultiplexers 30, the transmission gates 34 on the leftmost, central, and the rightmost columns in each group are turned on in this order.

[0119] When the transmission gate 34 on the leftmost column in a certain group is turned on in response to the control signals  $Sel(1)$  and  $/Sel(1)$ , the potential  $V_{ref}$  at the node h connected to the second end of the capacitor 44 which has been fixed over the initialization and offset periods is changed into the potential of the data signal  $V_d(j)$ , namely, a potential according to the gradation level of the pixel on the  $i$ -th row and the  $(3j-2)$  column, as illustrated in FIG. 11. In this case, the variation in the potential at the node h is denoted by  $\Delta V$ , and the changed potential is denoted by  $(V_{ref}+\Delta V)$ .

[0120] The gate node g connected to the first end of the capacitor 44 through the data line 14 increases to a potential  $(V_{el}-|V_{th}|+k1\cdot\Delta V)$ , which is the sum of the potential  $(V_{el}-|V_{th}|)$  that has been set during the offset period and the product of a capacitance ratio  $k1$  and the variation in the potential at the node h. In this case, if the voltage  $V_{gs}$  of the P-channel MOS transistor 121 is expressed by an absolute value, the voltage  $V_{gs}$  can be  $(|V_{th}|-k11\cdot\Delta V)$ , which is the difference between the threshold voltage  $|V_{th}|$  and the increased amount of the potential at the gate node g.

[0121] The capacitance ratio  $k1$  can be expressed by  $Cr_{f1}/(C_{dt}+Cr_{f1})$ . Strictly speaking, it is necessary to consider the capacitance  $C_{pix}$  of the capacitor 132. However, this capacitance  $C_{pix}$  may be ignored, because the capacitance  $C_{pix}$  is set to be sufficiently smaller than each of the capacitances  $Cr_{f1}$  and  $C_{dt}$ .

[0122] After the write period for the  $i$ -th row has ended and the scan line 12 on the  $i$ -th row has been horizontally scanned, the light emission period comes. Over the light emission period, as described above, the control signal  $G_{el}(i)$  is set to the L level. In the pixel circuit 110, the P-channel MOS transistor 124 on the  $i$ -th row and the  $(3j-2)$  column is thereby turned on. In this case, the gate-source voltage  $V_{gs}$  of the P-channel MOS transistor 121 is expressed by  $(|V_{th}|-k1\cdot\Delta V)$ . Therefore, as explained with reference to FIG. 5, the current according to the gradation level is supplied to the OLED 130 with the threshold voltage of the P-channel MOS transistor 121 offset.

[0123] The above operation is being performed concurrently by not only the pixel circuit 110 on the  $i$ -th row and the  $(3j-2)$  column but also the pixel circuits 110 on the  $i$ -th row and other columns while the scan line 12 is being horizontally scanned. In fact, this operation is sequentially performed on the scan lines 12 on the  $i$ -th row ( $i=1, 2, 3, \dots, (m-1)$ , and  $m$ ) over one frame period. Furthermore, the operation is repeated in units of frame periods.

[0124] According to this embodiment, a potential range  $\Delta V_{gate}$  of a gate node g is narrower than a potential range  $\Delta V_{data}$  of a data signal; the potential range  $\Delta V_{gate}$  is a range in which the potential at the gate node g varies, and the potential range  $\Delta V_{data}$  is a range in which the potential of the data signal varies. This configuration makes it possible to apply a voltage considering a gradation level between the gate and source of a P-channel MOS transistor 121 without the need to finely adjust the data signal. Consequently, it is

possible to control currents supplied to OLEDs 130 with great precision even when the OLEDs 130 are mounted in tiny pixel circuits 110 each in which the supplied current is sensitive to a variation in a gate-source voltage  $V_{gs}$  of the P-channel MOS transistor 121.

[0125] As indicated by the broken line in FIG. 3, in fact, a parasitic capacitance  $C_{prs}$  is present between a data line 14 and a gate node  $g$  of the P-channel MOS transistor 121 in each pixel circuit 110. When the potential on the data line 14 largely fluctuates, this fluctuation may be transferred to the gate node  $g$  through the capacitance  $C_{prs}$ , thereby causing a lowered display quality such as crosstalk or uneven luminance. This parasitic capacitance  $C_{prs}$  influences a pixel circuit 110 more significantly as the pixel circuit 110 is smaller in size.

[0126] This embodiment, however, can reduce the influence of the parasitic capacitance  $C_{prs}$  by setting the potential variation range of the data line 14 to be narrower than the potential range  $\Delta V_{data}$  of the data signal.

[0127] The write period ends in response to the timing at which the scan signal  $Gwr(i)$  is switched to the H level. The time interval between the end of the write period for the scan line 12 on the  $i$ -th row and the start of the initialization period for the scan line 12 on the  $(i+1)$ th row corresponds to a transition period. In this embodiment, the scan line drive circuit 20 switches the control signals  $Gorst(i)$  and  $Gel(i)$  for the pixel circuits 110 on any scan line 12 to the H and L levels, respectively, within the transition period. In response, the pixel circuits 110 connected to this scan line starts the light emission period. Likewise, the scan line drive circuit 20 switches the control signals  $Gorst(i)$  and  $Gel(i)$  for the pixel circuits 110 on any scan line 12 to the L and H levels, respectively, within the transition period. In response, the pixel circuits 110 connected to this scan line ends the light emission period.

[0128] FIG. 7 illustrates the example in which the pixel circuits 110 on the  $i$ -th row start the light emission period within the transition period following the write period. In this example, the scan line drive circuit 20 switches the control signals  $Gorst(i)$  and  $Gel(i)$  for the pixel circuits 110 along the scan line 12 on the  $i$ -th row to the H and L levels, respectively. Furthermore, FIG. 7 also illustrates the examples in which the pixel circuits 110 along the scan line 12 on an  $ia$ -th row, which differs from the  $i$ -th row, start the light emission period and in which the pixel circuits 110 along the scan line 12 on an  $ib$ -th row, which differs from the  $i$ -th and  $ia$ -th rows, ends the light emission period. Each pixel circuit 110 operates over the light emission period in the above-described manner.

[0129] According to this embodiment, when a pixel circuit 110 creates a black image during a light emission period, a transistor circuit 120 outputs a current that equals the sum of a drain current  $I_{ds}$  driven by a P-channel MOS transistor 121 in accordance with the gate-source voltage equivalent to the threshold voltage, a leakage current  $IL_{121}$  of the P-channel MOS transistor 121, a leakage current  $IL_{123}$  of a P-channel MOS transistor 123, and leakage currents  $IL_{124a}$  and  $IL_{124b}$  of the P-channel MOS transistor 124. In addition, a P-channel MOS transistor 125 outputs a leakage current  $IL_{125}$  from its n well through a connection node between the P-channel MOS transistor 125 and an OLED 130. However, during the light emission period for the pixel circuit 110, these output currents bypass the OLED 130 and flows to a feeder line 16 as an off-state current  $I_{off\_orst}$  of the P-channel MOS transistor 125. Consequently, this embodiment is effective in suppressing the black floating from occurring when each pixel circuit 110 creates a black image.

## Second Embodiment

[0130] FIG. 12 is a circuit diagram illustrating a configuration of a pixel circuit 110' in an electro-optical device according to a second embodiment of the invention. In this embodiment, instead of the P-channel MOS transistor 125 in the foregoing first embodiment, an N-channel MOS transistor 125' is used. The gate of this N-channel MOS transistor 125' is supplied with a signal equivalent to the logical inversion of the signal supplied to the gate of the P-channel MOS transistor 125. Other configurations of the pixel circuit 110' are substantially the same as those of each pixel circuit 110.

[0131] FIG. 13 is a cross-sectional view of a configuration of a P-channel MOS transistor 124 and the N-channel MOS transistor 125' in the pixel circuit 110'. As illustrated in FIG. 13, a drain 125D', formed of an N-type diffusion layer, of the N-channel MOS transistor 125' which is connected to the anode of an OLED 130 is formed in a p well to which a lowest potential  $V_{CT}$  is to be applied. In this configuration, no leakage current flows from the drain 125D' of the N-channel MOS transistor 125' to the outside. Conversely, a leakage current  $IL_{125'}$  flows from the drain 125D' to the p well. In this embodiment, when the OLED 130 does not emit light, an off-state current  $I_{off\_orst}$  flows through the N-channel MOS transistor 125'. The off-state current  $I_{off\_orst}$  equals the sum of a channel current flowing from the drain to source of the N-channel MOS transistor 125' in the off state and the leakage current  $IL_{125'}$  flowing from the drain 125D' to the p well. This off-state current  $I_{off\_orst}$  is set to be larger than a current  $I_{120}$  that is output from a transistor circuit 120 upon the display of a black image.

[0132] Similar to the foregoing first embodiment, this embodiment is effective in suppressing the black floating from occurring when each pixel circuit 110 creates a black image. In this embodiment, the leakage current flowing from the drain 125D' to the p well is added to the off-state current  $I_{off\_orst}$ . Therefore, the leakage current flowing from the source to drain of the N-channel MOS transistor 125' in the off state is decreased by an amount corresponding to the leakage current flowing from the drain 125D' to the p well. Consequently, for example, it is possible to easily control the threshold of the N-channel MOS transistor 125'.

[0133] To enhance the effect of this embodiment, as an example of FIG. 14, the drain 125D' of the discharge transistor 125' which is connected to the OLED 130 preferably has a smaller area than that of a source 125S' of the discharge transistor 125'. By widening the area of the drain 125D', the leakage current  $IL_{125'}$  can be increased.

[0134] As an example of FIG. 15, the area of the drain 125D' of the N-channel MOS transistor 125' is preferably larger than the total area of a drain 124D and source 124S of the P-channel MOS transistor 124. The P-channel MOS transistor 124 switches and controls the flow of the drive current that the P-channel MOS transistor 121 supplies to the OLED 130. Therefore, the P-channel MOS transistor 124 is usually designed to have a large channel width so as not to affect the current flow. However, a larger channel width may result in a larger total area of the drain 124D and the source 124S, thereby generating larger amounts of leakage currents  $IL_{124a}$  and  $IL_{124b}$ . To decrease these leakage currents, the area of the drain 125D' of the N-channel MOS transistor 125' is preferably designed to be larger than the total area of the drain 124D and source 124S of the P-channel MOS transistor 124. By designing the area of the drain 125D' in this manner, the leakage current  $IL_{125'}$  that exceeds the sum of the leakage currents  $IL_{124a}$  and  $IL_{124b}$  generated in the P-channel MOS transistor 124 is caused to

flow from the drain 125D' to the p well in the P-channel MOS transistor 125. This configuration can help suppress an occurrence of the black floating.

#### Modification

[0135] The invention is not limited to the foregoing first and second embodiments, and thus various modifications are possible. Some examples of such modifications will be described below. It should be noted that some of these examples may be combined as appropriate.

#### First Modification

[0136] Although both of the pixel circuit 110 in the foregoing first embodiment and the pixel circuit 110' in the foregoing second embodiment include an OLED as an electro-optic element, the electro-optic element may be any light emitting element that emits light of luminance proportional to a driven current. As an alternative example, the light emitting element may be an inorganic light emitting diode or other light emitting diode (LED).

#### Second Modification

[0137] in the foregoing first and second embodiments and the first modification, the data transfer circuit 40 transfers electric charge to the pixel circuits 110, thereby writing data into the pixel circuits 110. However, there is no limitation on a method of writing data into the pixel circuits 110. Although each pixel circuit 110 is provided with the five transistors in the foregoing first and second embodiments and the first modification, each pixel circuit 110 does not necessarily have to be provided with the P-channel MOS transistor 123. In short, each pixel circuit 110 only has to be provided with the P-channel MOS transistors 121, 122, and 124 that serve as drive, write, and light emission control transistors, respectively.

#### Application Example

[0138] Next, a description will be given below of an electronic apparatus according to an application example which employs the electro-optical device 1 according to any one of the first and second embodiments and the first and second modifications. The electro-optical device 1 is intended to display a high-resolution image with small-sized pixels. A head mount display (HMD) is employed as an example of the electronic apparatus and will be described below.

[0139] FIG. 16 is a schematic view of an HMD 200 that employs the electro-optical device according to one of the first and second embodiments and the first and second modifications. As illustrated in FIG. 16, the HMD 200 includes a front frame 210, a pair of side frames 220, an optical panel 250, circuit covers 230, and an electro-optical device 270. The front frame 210 is to be positioned in front of a user's head. The pair of side frames 220 is connected to both ends of the front frame 210 and to be positioned on both sides of the user's head. The optical panel 250 is fixed to the front frame 210 and aims to cover the user's eyes. The circuit covers 230 are fixed to the respective side frames 220. The electro-optical device 270 adjusts the luminance of the screen by using the function described in the first and second embodiments and the first and second modifications.

[0140] The electro-optical device 270 in this application example includes a pair of display panels DI1 and DI2. Furthermore, the electro-optical device 270 includes a pair of adjusters 51 and 52 to adjust a light emission period in the manner described in the first embodiment.

[0141] The pair of display panels DI1 and DI2 is mounted on the optical panel 250 so as to be positioned in front of the user's left eye and right eye, respectively. The pair of display panels DI1 and DI2 emits light through the optical panel 250. The user is expected to view the light from the display panel DI1 with the left eye and the light from the display panel DI2 with the right eye.

[0142] In the HMD 200, the adjuster 51 is operably disposed on one of the pair of side frames 220, whereas the adjuster 52 is operably disposed on the other of the pair of side frames 220. In addition, a control circuit 3 is mounted in one of the circuit covers 230 which is fixed to a corresponding one of the pair of side frames 220, whereas a power supply circuit DC is mounted in the other of the circuit covers 230. It should be noted that these arrangements may be modified as appropriate.

[0143] FIG. 17 is a schematic view of a projector that employs the electro-optical device according to one of the first and second embodiments and the first and second modifications. As illustrated in FIG. 17, the projector 300 includes a housing 350, an electro-optical device 370, a dichroic prism 310, and a projection lens 320.

[0144] The electro-optical device 370 includes three display panels DI1, DI2, and DI3. Furthermore, the electro-optical device 370 includes adjusters 51 and 52, a power supply circuit DC, and a controller CP.

[0145] The display panels DI1, DI2, and DI3 are disposed inside the housing 350. Each of the display panels DI1, DI2, and DI3 has arrays of color pixels. In this example application, the display panel DI1 displays a red image; the display panel DI2 displays a green image; and the display panel DI3 displays a blue image. Each of the display panels DI1, DI2, and DI3 has a display section. These display sections are disposed adjacent to one another with their emission light beams forming approximately 90 degrees with one another. In this example application, the display panel DI1 is disposed adjacent to the display panel DI2; the display panel DI2 is disposed adjacent to the display panel DI3; and the display panel DI1 is disposed opposite the display panel DI3.

[0146] The dichroic prism 310 is disposed surrounded by the display panels DI1, DI2, and DI3. The dichroic prism 310 has side surfaces that the light beams are to enter. These side surfaces are disposed opposite the display panels DI1, DI2, and DI3. In addition, the dichroic prism 310 has a side surface from which a light beam is to be output. This side surface is disposed opposite the projection lens 320. The light beam is output from the inside to outside of the housing 350 through the projection lens 320. The projection lens 320 may be composed of either a single lens or a plurality of lenses.

[0147] The adjusters 51 and 52 are operably disposed on the exterior of the housing 350 to adjust the light emission period in the manner described in the first embodiment. Upon operation, the projector 300 mixes the red light beam from the display panel DI1, the green light beam from the display panel DI2, and the blue light beam from the display panel DI3 to make a mixed color light beam. Then, the projector 300 projects this mixed color light beam onto a screen 330. It should be noted that the screen 330 may be either of a light transmissive or light reflective type.

[0148] In this example application, the display panels DI1, DI2, and DI3 emit specific color light beams, namely, red, green, and blue light beams, respectively. Alternatively, the display panels DI1, DI2, and DI3 may emit any other color light beams.

[0149] In this example application, the display panel DI1 displays a red image; the display panel DI12 displays a green image; and the display panel DI13 displays a blue image. However, the display panels DI1, DI12, and DI13 do not necessarily have to display images. Alternatively, the display panel DI1 may be a red light source; the display panel DI12 may be a green light source; and the display panel DI13 may be a blue light source. In this case, liquid crystal panels or other optical panels are disposed in front of the display panels DI1, DI2, and DI3. The display panels DI1, DI2, and DI13 emit light beams to such optical panels, which then display images on the basis of the light beams.

[0150] The electro-optical device 1 described above is applicable to not only the HMD 200 but also an electronic viewfinder for video cameras or digital cameras with interchangeable lenses, as well as an information display section for portable information processing devices such as tablets, wristwatches, and projectors.

[0151] The entire disclosure of Japanese Patent Application No. 2017-047109, filed Mar. 13, 2017 is expressly incorporated by reference herein.

What is claimed is:

1. A pixel circuit comprising:

a transistor circuit that outputs a drive current in accordance with a data signal;

a light emitting element that emits light with luminance corresponding to the drive current, the light emitting element being connected to the transistor circuit; and

a discharge section that, when the data signal indicates zero, causes a flow of the drive current to bypass the light emitting element.

2. The pixel circuit according to claim 1, wherein

the transistor circuit includes a drive transistor that generates the drive current in accordance with the data signal,

the discharge section includes a discharge transistor that, when the light emitting element does not emit the light, is turned on to connect a discharge feeder line to a node at which the transistor circuit is connected to the light emitting element, and

an absolute value of a threshold voltage of the discharge transistor is lower than an absolute value of a threshold voltage of the drive transistor.

3. The pixel circuit according to claim 2, wherein

the discharge transistor has a shorter channel length than that of the drive transistor.

4. The pixel circuit according to claim 2, wherein

the drive transistor is a P-channel transistor, and the discharge transistor is an N-channel transistor.

5. The pixel circuit according to claim 4, wherein

a drain of the discharge transistor which is connected to the light emitting element has a wider area than that of a source of the discharge transistor.

6. The pixel circuit according to claim 4, wherein

the transistor circuit includes a light emission control transistor connected between the drive transistor and the light emitting element,

the light emission control transistor is a P-channel transistor, and

a drain of the discharge transistor has a wider area than a total area of a drain and source of the light emission control transistor.

7. The pixel circuit according to claim 1, wherein

the transistor circuit includes a drive transistor that generates the drive current in accordance with the data signal,

the discharge section includes a discharge transistor that, when the light emitting element does not emit the light, is turned on to connect a discharge feeder line to a node at which the transistor circuit is connected to the light emitting element, and

the drive transistor is an enhancement type transistor, and the discharge transistor is a depletion type transistor.

8. An electro-optical device comprising the pixel circuit according to claim 1.

9. An electro-optical device comprising the pixel circuit according to claim 2.

10. An electro-optical device comprising the pixel circuit according to claim 3.

11. An electro-optical device comprising the pixel circuit according to claim 4.

12. An electro-optical device comprising the pixel circuit according to claim 5.

13. An electro-optical device comprising the pixel circuit according to claim 6.

14. An electro-optical device comprising the pixel circuit according to claim 7.

15. An electronic apparatus comprising the electro-optical device according to claim 8.

16. An electronic apparatus comprising the electro-optical device according to claim 9.

17. An electronic apparatus comprising the electro-optical device according to claim 10.

18. An electronic apparatus comprising the electro-optical device according to claim 11.

19. A pixel circuit comprising:

a transistor circuit that outputs a drive current in accordance with a data signal;

a light emitting element that emits light with luminance corresponding to the drive current, the light emitting element being connected to the transistor circuit; and

in a light emission period, a discharge section that causes a flow of a part of the drive current.

20. A pixel circuit comprising:

a transistor circuit that outputs a drive current in accordance with a data signal;

a light emitting element that emits light with the luminance corresponding to drive current, the light emitting element being connected to the transistor circuit; and

a discharge transistor that is turned off to cause a flow of the drive current.

\* \* \* \* \*

|                |                                                                                                        |         |            |
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#### 摘要(译)

晶体管电路根据数据信号输出驱动电流。连接到晶体管电路的OLED发出具有与驱动电流对应的亮度的光。当OLED不发光时，放电晶体管导通以将放电馈线连接到晶体管电路连接到OLED的节点。放电晶体管的阈值电压的绝对值低于晶体管电路中的驱动晶体管的阈值电压的绝对值。当数据信号指示零时，放电晶体管可以使来自晶体管电路的驱动电流流动绕过OLED。

