



US 20010000440A1

(19) **United States**

(12) **Patent Application Publication**
Hirakata et al.

(10) **Pub. No.: US 2001/0000440 A1**

(43) **Pub. Date: Apr. 26, 2001**

(54) **CONTACT STRUCTURE**

Publication Classification

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(51) **Int. Cl.⁷** **G02F 1/1343; G02F 1/1339**

(52) **U.S. Cl.** **349/155; 349/138; 349/139**

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(57) **ABSTRACT**

(21) Appl. No.: **09/734,177**

(22) Filed: **Dec. 12, 2000**

Related U.S. Application Data

(62) Division of application No. 09/361,218, filed on Jul. 27, 1999, now Pat. No. 6,177,974, which is a division of application No. 09/046,685, filed on Mar. 24, 1998, now Pat. No. 5,982,471.

(30) **Foreign Application Priority Data**

Mar. 27, 1997 (JP) 9-094606

There is disclosed a contact structure for electrically connecting conducting lines formed on a first substrate of an electrooptical device such as a liquid crystal display with conducting lines formed on a second substrate via conducting spacers while assuring a uniform cell gap among different cells if the interlayer dielectric film thickness is nonuniform across the cell or among different cells. A first conducting film and a dielectric film are deposited on the first substrate. Openings are formed in the dielectric film. A second conducting film covers the dielectric film left and the openings. The conducting spacers electrically connect the second conducting film over the first substrate with a third conducting film on the second substrate. The cell gap depends only on the size of the spacers, which maintain the cell gap.

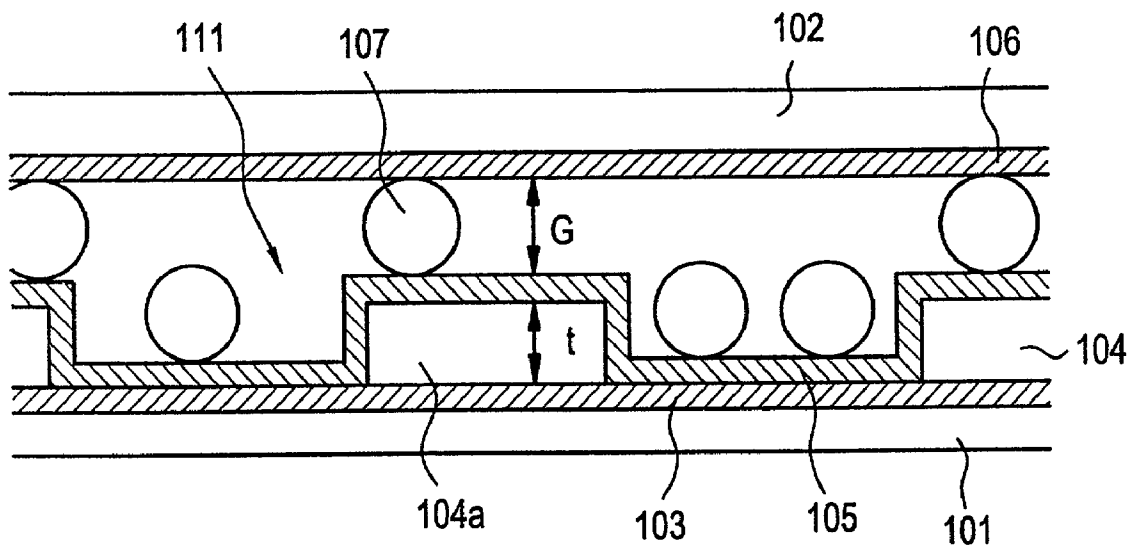


FIG.1

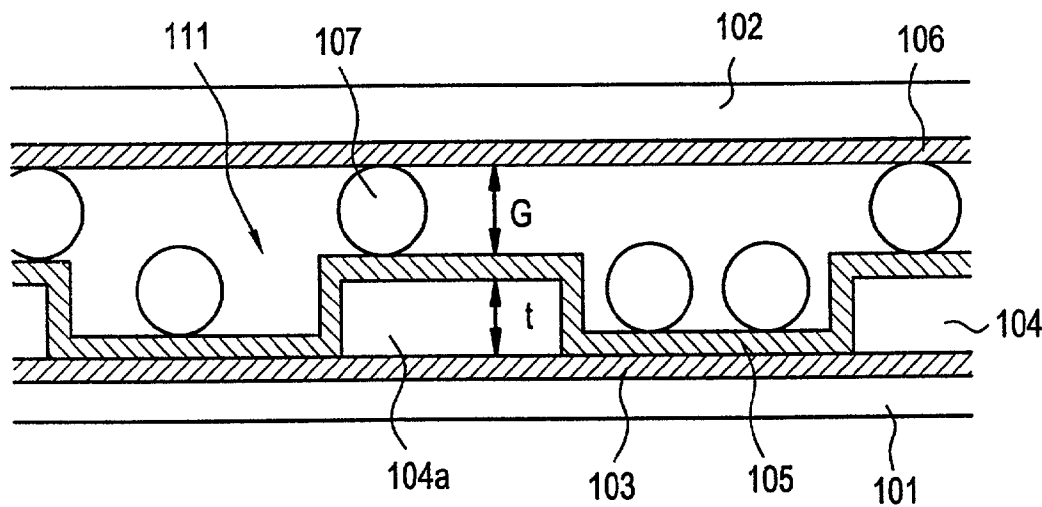


FIG.2A

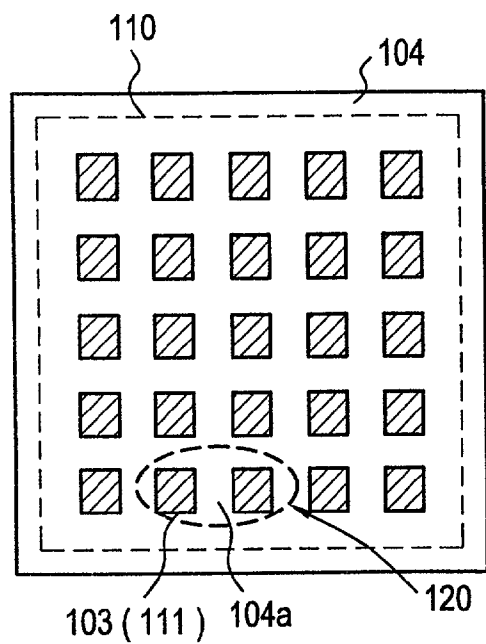


FIG.2B

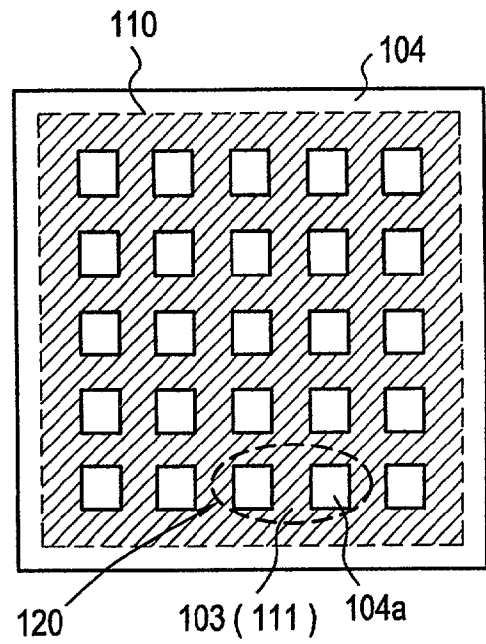


FIG.3

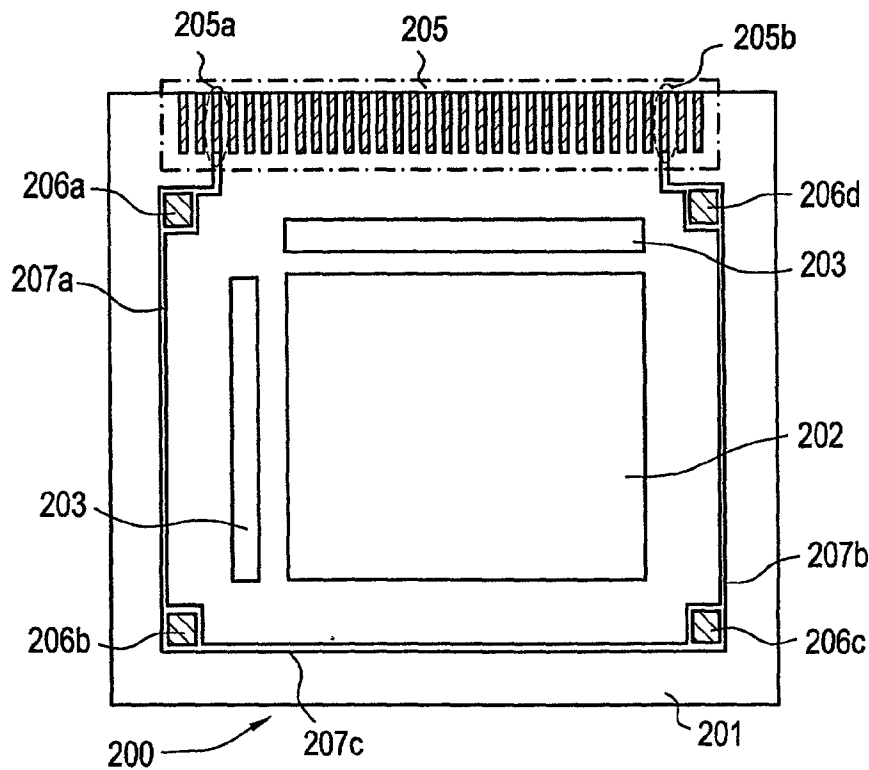


FIG.4

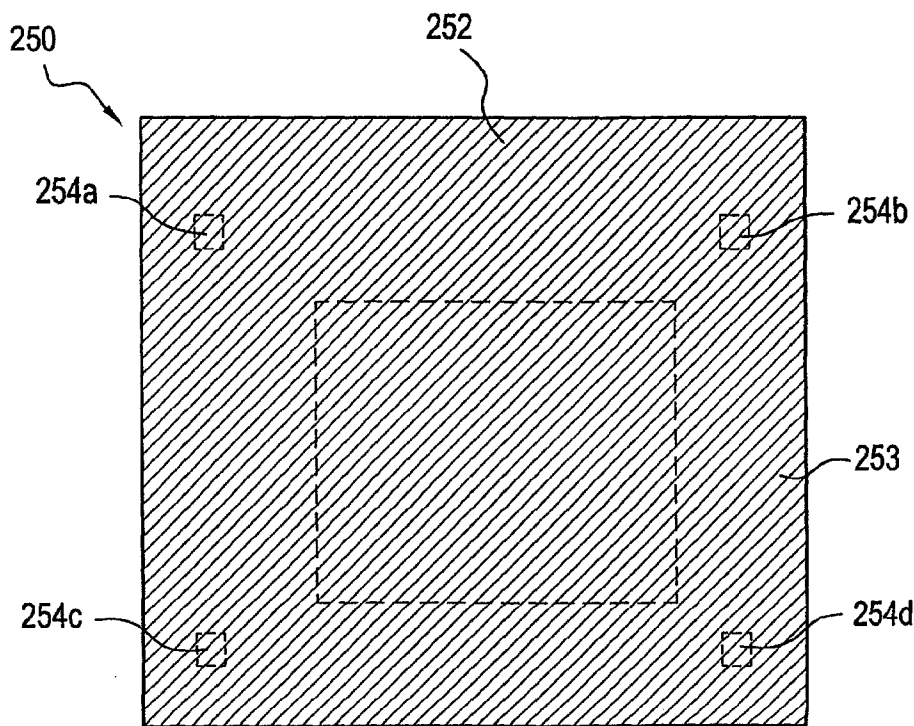


FIG.5A

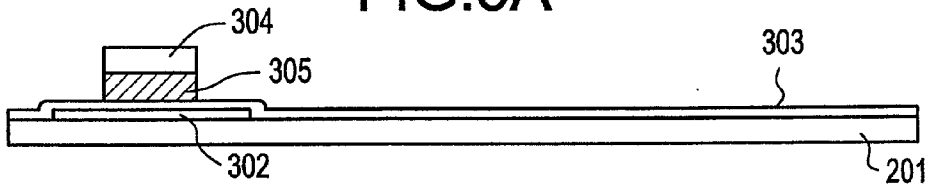


FIG.5B



FIG.5C

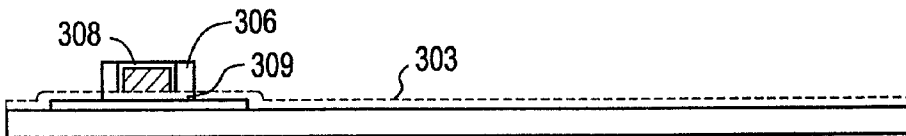


FIG.5D

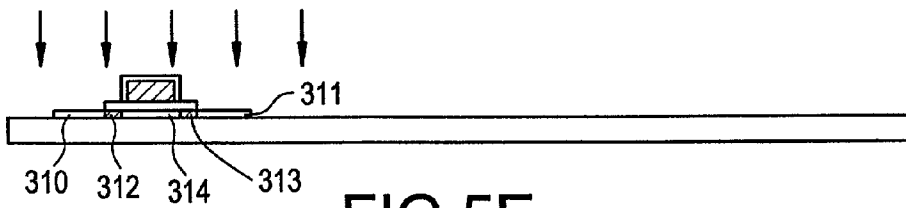


FIG.5E

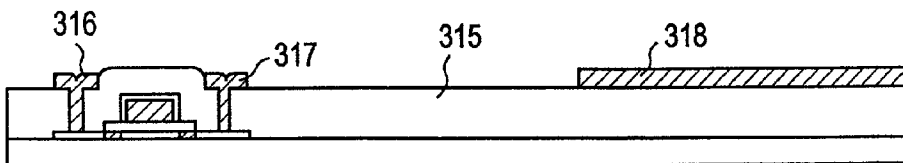


FIG.5F

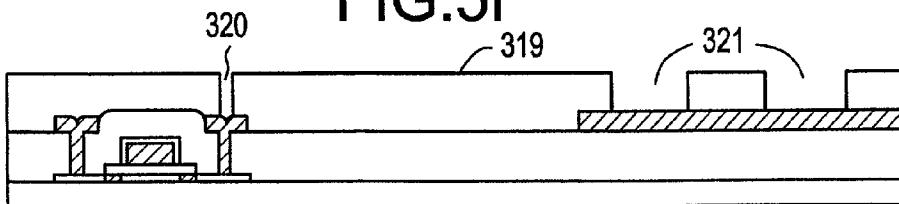
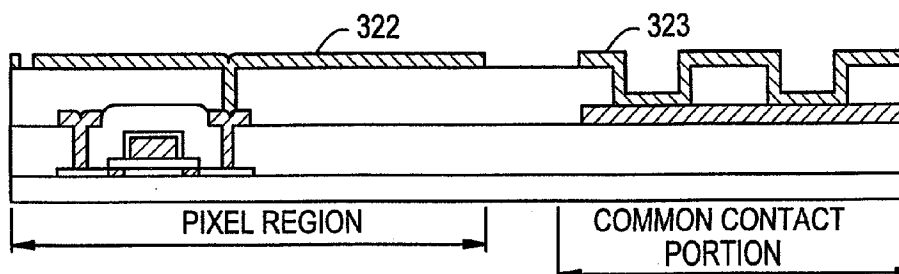
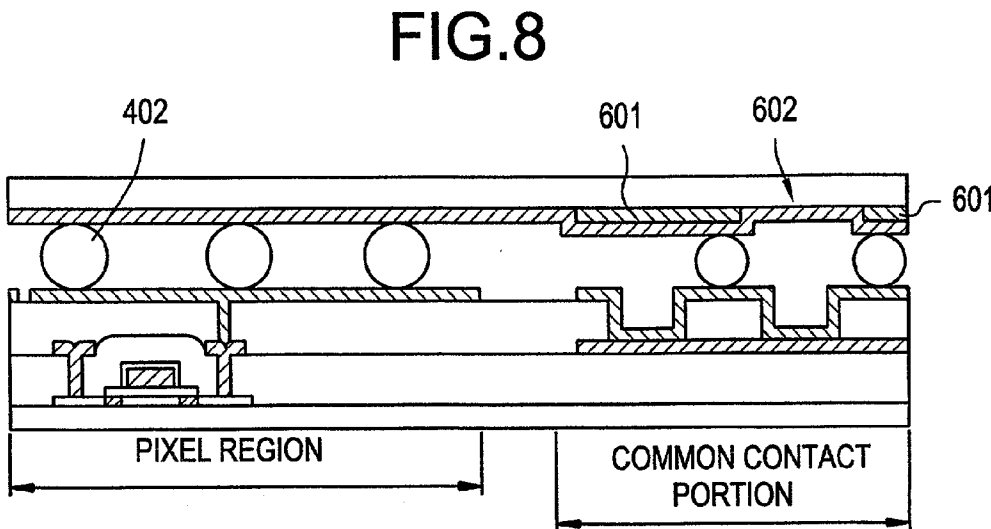
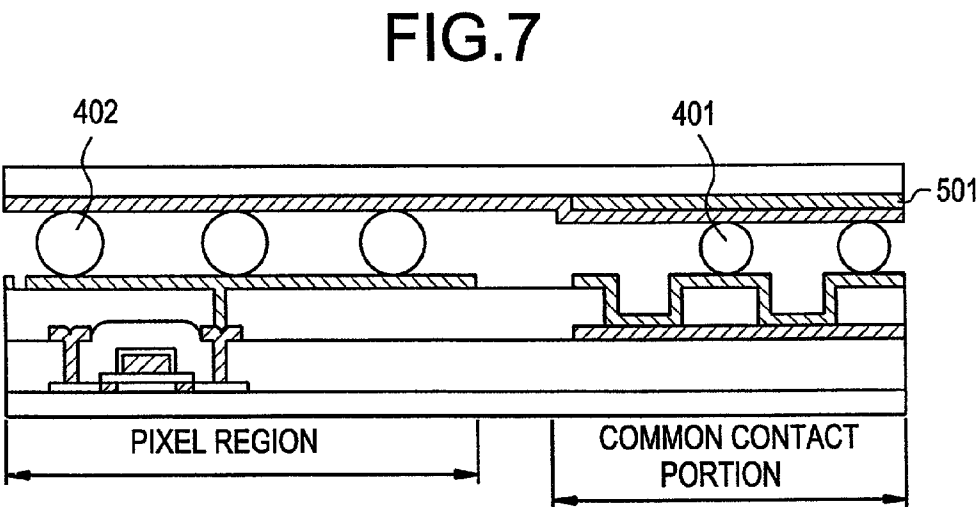
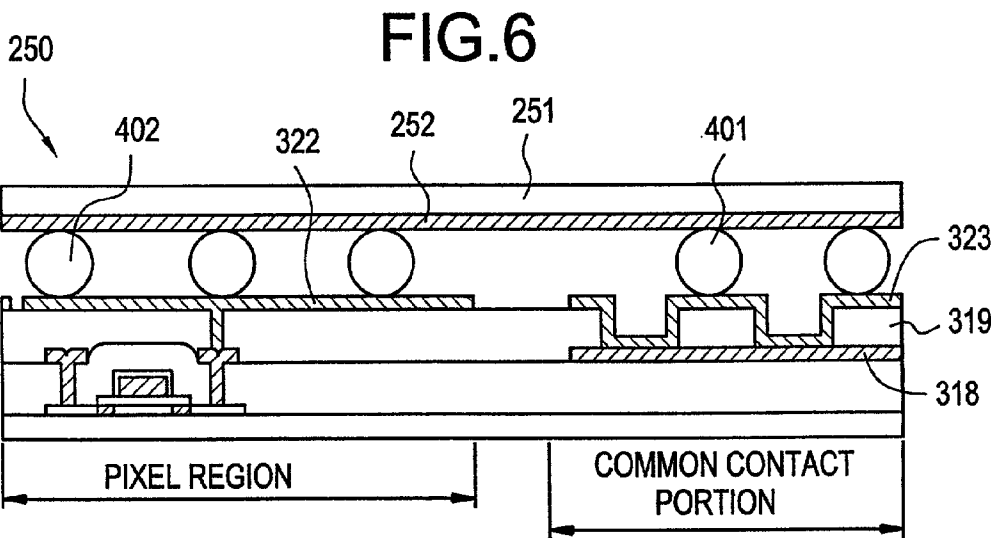


FIG.5G





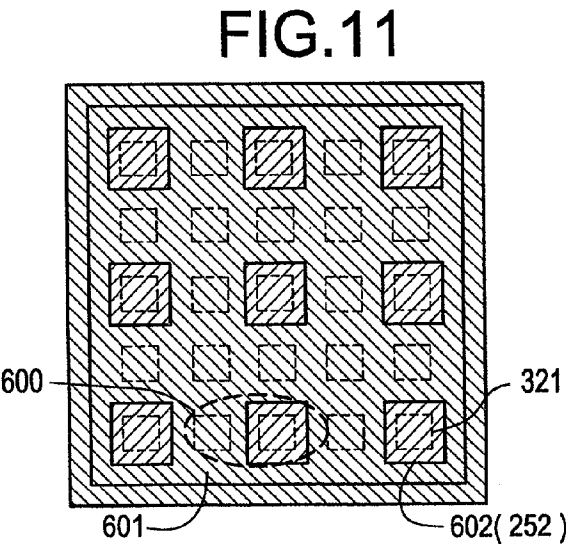
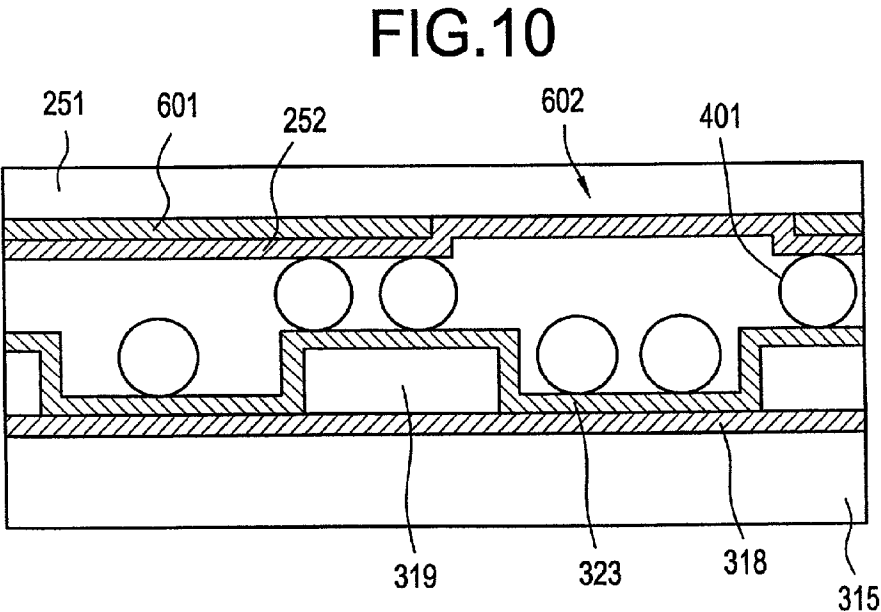
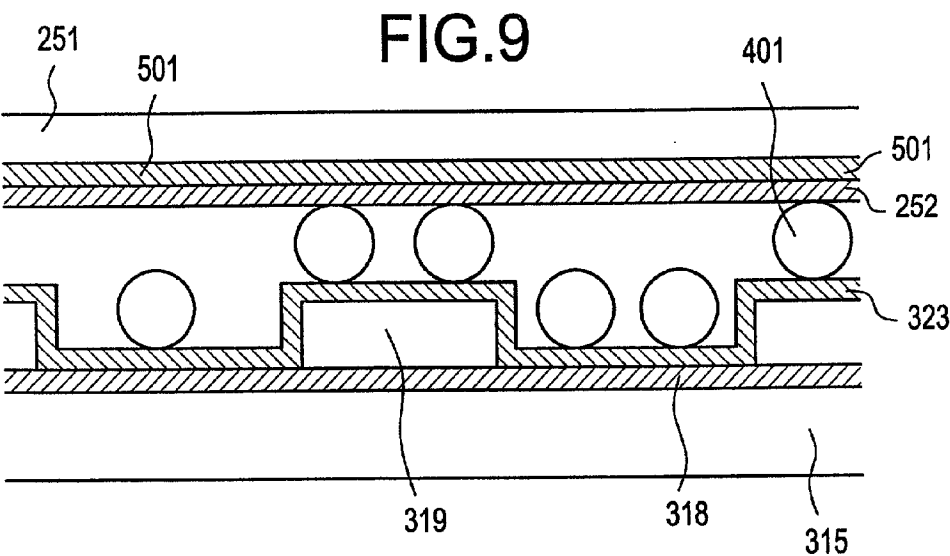


FIG.12
PRIOR ART

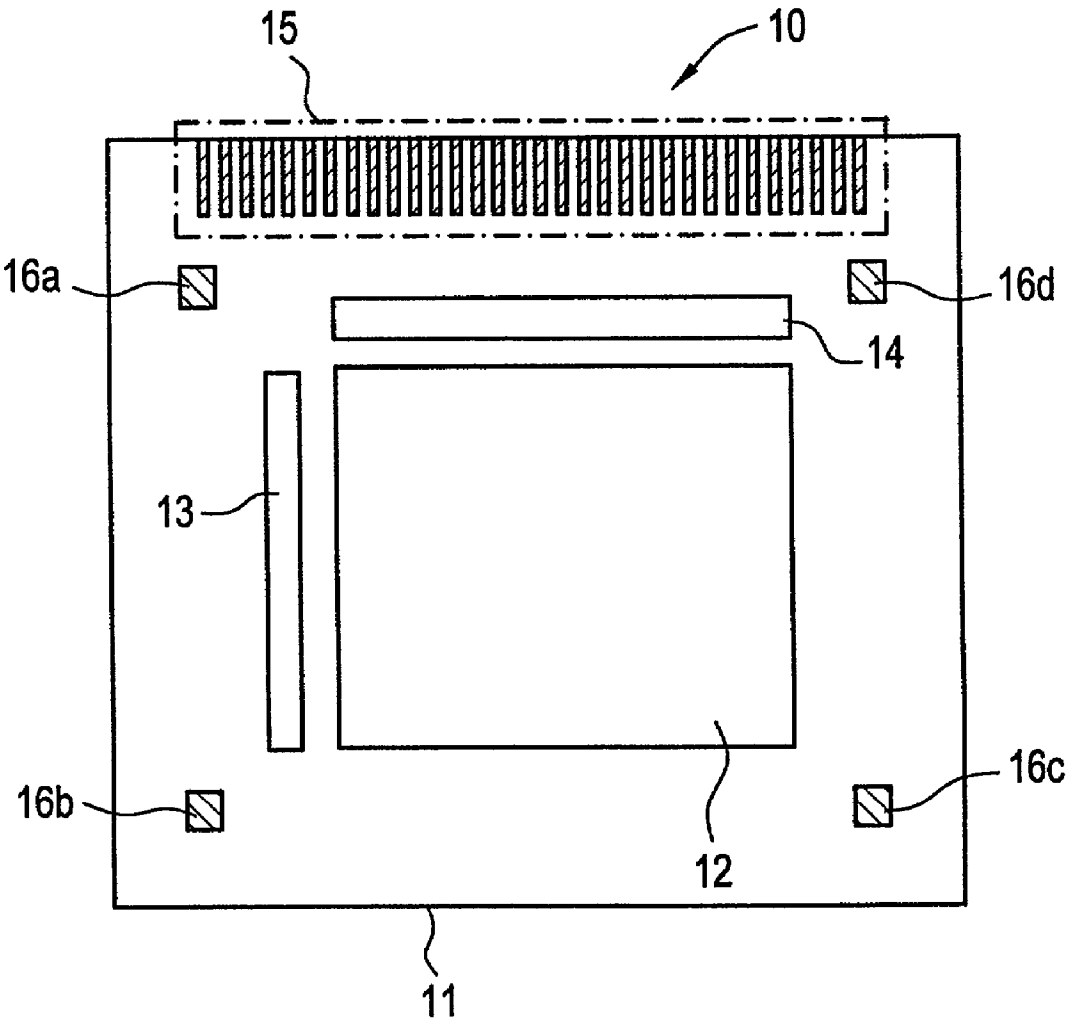


FIG.13
PRIOR ART

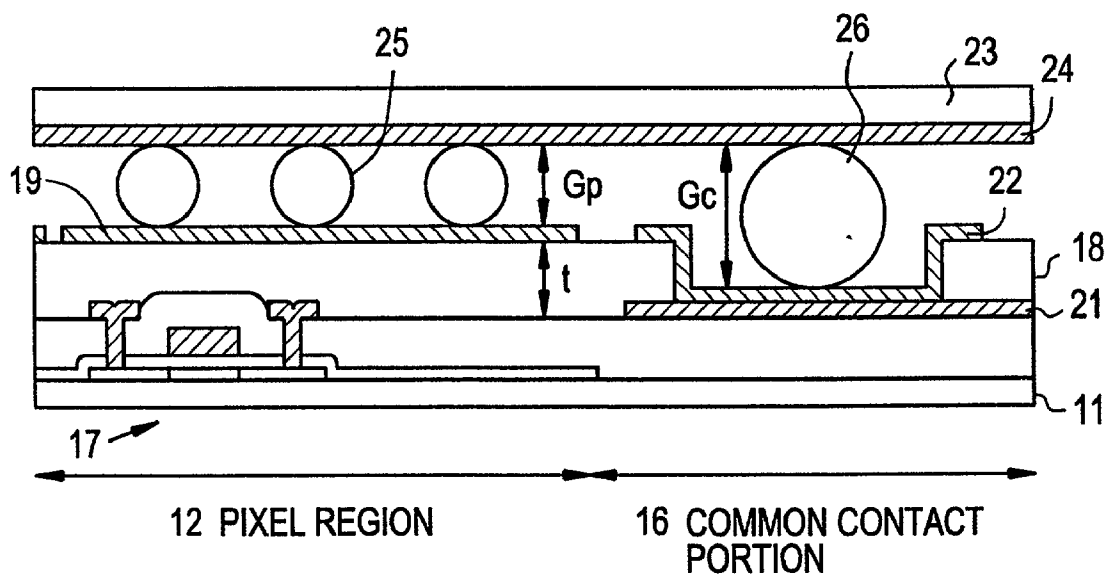
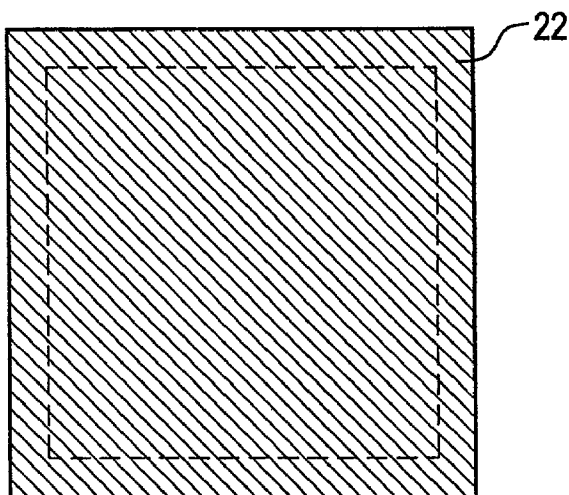


FIG.14
PRIOR ART



CONTACT STRUCTURE

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a contact structure for electrically connecting together conducting lines formed on two opposite substrates, respectively, via conducting spacers and, more particularly, to a contact structure used in common contacts of an electrooptical device such as a liquid crystal display.

[0003] 2. Description of the Related Art

[0004] In recent years, liquid crystal displays have been extensively used in the display portions of mobile intelligent terminals such as mobile computers and portable telephones including PHS (personal handyphone system). Also, active-matrix liquid crystal displays using TFTs as switching elements are well known.

[0005] A liquid crystal display comprises two substrates and a liquid crystal material sealed between them. Electrodes are formed on these two substrates to set up electric fields. A desired image or pattern is displayed by controlling the magnitudes of these electric fields. In the active-matrix liquid crystal display, TFTs (thin-film transistors) are formed on one substrate to control the supply of voltage to each pixel electrode. Therefore, this substrate is referred to as the TFT substrate. A counter electrode placed opposite to the pixel electrodes is formed on the other substrate and so it is referred to as the counter substrate.

[0006] In the active matrix display, an electric field is produced between each pixel electrode on the TFT substrate and the counter electrode on the counter substrate, thus providing a display. The potential at each pixel electrode on the TFT substrate is controlled by the TFT and thus is varied. On the other hand, the counter electrode on the counter substrate is clamped at a common potential. For this purpose, the counter electrode is connected with an extractor terminal via a common contact formed on the TFT substrate. This extractor terminal is connected with an external power supply. This connection structure clamps the counter electrode at the common potential.

[0007] The structure of the common contact of the prior art active-matrix liquid crystal display is next described briefly by referring to FIGS. 12-14.

[0008] FIG. 12 is a top plan view of a TFT substrate 10. This TFT substrate comprises a substrate 11 having a pixel region 12, a scanning line driver circuit 13, and a signal line driver circuit 14. In the pixel region 12, pixel electrodes and TFTs connected with the pixel electrodes are arranged in rows and columns. The scanning line driver circuit 13 controls the timing at which each TFT is turned on and off. The signal line driver circuit 14 supplies image data to the pixel electrodes. Furthermore, there are extractor terminals 15 to supply electric power and control signals from the outside. The substrate 11 makes connection with the counter electrode at common contact portions 16a-16d.

[0009] FIG. 13 is a cross-sectional view of the pixel region 12 and a common contact portion 16 representing the common contact portions 16a-16d. A TFT 17 and many other TFTs (not shown) are fabricated in the pixel region 12 on the substrate 11. An interlayer dielectric film 18 is

deposited on the TFT 17. A pixel electrode 19 connected with the drain electrode of the TFT 17 is formed on the interlayer dielectric film 18.

[0010] A precursor for the source and drain electrodes of the TFT 17 is patterned into internal conducting lines 21 at the common contact portion 16. The interlayer dielectric film 18 is provided with a rectangular opening. A conducting pad 22 is formed in this opening and connected with the internal conducting lines 21. The pixel electrode 19 and the conducting pad 22 are patterned from the same starting film.

[0011] FIG. 14 is a top plan view of the known common contact portion 16. A region located inside the conducting pad 22 and indicated by the broken line corresponds to the opening formed in the interlayer dielectric film 18.

[0012] As shown in FIG. 13, a counter electrode 24 consisting of a transparent conducting film is formed on the surface of a counter substrate 23. This counter electrode 24 is opposite to the pixel electrodes 19 in the pixel region 12 and to the conducting pad 22 at the common contact portion 16.

[0013] Spherical insulating spacers 25 are located in the pixel region 12 to maintain the spacing between the substrates 11 and 23. A spherical conducting spacer 26 is positioned at the common contact portion 16 and electrically connects the counter electrode 24 with the conducting pad 22. The pad 22 is electrically connected with the internal conducting lines 21, which in turn are electrically connected with an extractor terminal 15. This connection structure connects the counter electrode 24 on the counter substrate 23 with the extractor terminal 15 on the substrate 11.

[0014] In the prior art liquid crystal display, the interlayer dielectric film 18 is provided with the opening at the common contact portion 16, as shown in FIG. 13. Therefore, the cell gap G_c in the common contact portion is almost equal to the sum of the cell gap G_p in the pixel region + the film thickness t of the interlayer dielectric film 18.

[0015] The cell gap G_p (also known as the cell spacing) in the pixel region 12 is determined by the insulating spacers 25. It is common practice to use standardized spacers as the insulating spacers 25 and so if the spacers 25 have a uniform diameter, the cell gap G_p in the pixel region 12 is substantially uniform among liquid-crystal cells. However, it is difficult to avoid nonuniformity of the cell gap G_c in the common contact portion among liquid-crystal cells.

[0016] The cell gap G_p in the common contact portion is constant since the cell gap G_p is constant because of the relation described above. Therefore, the cell gap G_c in the common contact portion depends only on the film thickness t of the interlayer dielectric film 18. Consequently, to make the cell gap G_c uniform among liquid-crystal cells, it is necessary that the film thickness t of this interlayer dielectric film 18 be uniform among cells. However, this is impossible to circumvent.

[0017] Normally, the common contact portions of the liquid crystal display are 2 to 4 in number. The film thickness t of the interlayer dielectric film 18 may differ from location to location on the same substrate. In this case, the film thickness t may differ among different common contacts even on the same substrate.

[0018] Because of the aforementioned nonuniformity of the thickness t of the interlayer dielectric film 18, the cell gap G_c in the common contact portion differs among different cells or different common contacts. Furthermore, the non-uniformity of the cell gap G_c results in the cell gap G_p in the pixel region to be nonuniform.

[0019] The cell gap G_p in the pixel region is affected more by the nonuniformity of the cell gap G_c in the common contact portion as the area of the pixel region 12 becomes narrower than the area of the common contact portion. Especially, in the case of a projection display as used in a projector, the problem of above-described nonuniformity of the cell gap G_p in the pixel region becomes conspicuous, because it is a quite accurate small-sized display of about 1 to 2 inches.

[0020] A standardized spacer is also used as the conducting spacer 26. The diameter of this conducting spacer 26 is determined by the diameter of the insulating spacers 25 in the pixel region 12 and by the design thickness of the interlayer dielectric film 18. Where the thickness of the interlayer dielectric film 18 is much larger than the designed value, the cell gap G_c in the common contact portion becomes very large. This makes it impossible to connect the counter electrode with the conducting pad well by the conducting spacer 26. In consequence, the counter electrode cannot be clamped at the common potential. As a result, a display cannot be provided.

SUMMARY OF THE INVENTION

[0021] It is an object of the present invention to provide a contact structure which is free of the foregoing problems, provides less nonuniform cell gap among different cells if the thickness of the interlayer dielectric film is nonuniform across the cell or among different cells, and reduces poor electrical contacts which would normally be caused by conducting spacers.

[0022] This object is achieved in accordance with the teachings of the invention by a contact structure for connecting a conducting film formed on a first substrate with a conducting film formed on a second substrate opposite to the first substrate, the contact structure comprising: a cell gap defined between the first and second substrates; a first conducting film formed on the first substrate; a dielectric film covering the first conducting film; openings formed in the dielectric film to expose parts of the first conducting film by selectively leaving the dielectric film; a second conducting film covering the dielectric film left and the openings; a third conducting film formed on the second substrate; and conducting spacers held between the first and second substrates and connecting the second and third conducting films. The second conducting film is connected with the first conducting film through the openings. The second conducting film, the conducting spacers, and the third conducting film are connected in turn on the dielectric film left. The conducting spacers maintain the cell gap between the first and second substrates.

[0023] One embodiment of the invention resides in a contact structure for connecting a conducting film formed on a first substrate with a conducting film formed on a second substrate opposite to the first substrate, the contact structure comprising: a cell gap defined between the first and second substrates; a first conducting film formed on the first sub-

strate; a dielectric film covering the first conducting film; openings formed in the dielectric film to expose parts of the first conducting film; an insulator deposited on only portions of the first conducting film exposed through the openings; a second conducting film covering the openings; a third conducting film formed on the second substrate; and conducting spacers held between the first and second substrates and connecting the second and third conducting films. The second conducting film is connected with the first conducting film through the openings extending through the insulator. The second conducting film, the conducting spacers, and the third conducting film are connected in turn through the openings extending through the insulator. The conducting spacers maintain the cell gap between the first and second substrates.

[0024] Another embodiment of the invention resides in a contact structure for connecting a conducting film formed on a first substrate of an electrooptical device with a counter electrode formed on a second substrate opposite to the first substrate, which has pixel electrodes formed thereover, the contact structure comprising: a cell gap defined between the first and second substrates; a first conducting film formed on the first substrate and under the pixel electrodes; an interlayer dielectric film covering the first conducting film; openings formed in the interlayer dielectric film to expose parts of the first conducting film by selectively leaving the interlayer dielectric film; a second conducting film defining the counter electrode formed on the second substrate; a third conducting film covering the interlayer dielectric film left and the openings; and conducting spacers held between the first and second substrates and connecting the second and third conducting films. The second conducting film is connected with the first conducting film through the openings. The third conducting film and the pixel electrodes are formed from a common starting film. The second conducting film, the conducting spacers, and the third conducting film are connected in turn on the dielectric film left. The conducting spacers maintain the spacing between the first and second substrates.

[0025] A further embodiment of the invention resides in a contact structure for connecting a first conducting film formed over a first substrate of an electrooptical device with a counter electrode formed on a second substrate opposite to the first substrate, which has pixel electrodes formed thereon, the contact structure comprising: a cell gap defined between the first and second substrates; a first conducting film formed on the first substrate and under the pixel electrodes; an interlayer dielectric film covering the first conducting film; openings formed in the interlayer dielectric film to expose parts of the first conducting film; an insulator formed on selected portions of the surface of the first conducting film extending through the openings; a second conducting film covering the openings; a third conducting film defining the counter electrode formed on the second substrate; conducting spacers held between the first and second substrates and connecting the second and third conducting films. The pixel electrodes and the second conducting film are formed from a common starting film. The second conducting film is connected with the first conducting film through the openings extending through the insulator. The second conducting film, the conducting spacers, and the third conducting film are connected in turn on the insulator formed in the openings. The conducting spacers maintain the cell gap between the first and second substrates.

[0026] A still other embodiment of the invention resides in a contact structure for connecting a conducting film formed on a first substrate with a conducting film formed on a second substrate opposite to the first substrate, the contact structure comprising: a cell gap defined between the first and second substrates; a first conducting film formed on the first substrate; a dielectric film covering the first conducting film; openings formed in the dielectric film and exposing parts of the first conducting film; a second conducting film covering the openings; a third conducting film formed over the second substrate; a fourth conducting film formed between the second substrate and the third conducting film and in contact with the third conducting film; and conducting spacers held between the first and second substrates. The first conducting film, the second conducting film, the conducting spacers, the third conducting film, and the fourth conducting films are connected in turn through the openings. The spacers maintain the cell gap between the first and second substrates.

[0027] Other objects and features of the invention will appear in the course of the description thereof, which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] FIG. 1 is a fragmentary cross-sectional view of a common contact portion in accordance with the present invention;

[0029] FIGS. 2A and 2B are top plan views of the common contact portion shown in FIG. 1;

[0030] FIG. 3 is a top plan view of the TFT substrate of a liquid crystal display in accordance with Example 1 of the invention;

[0031] FIG. 4 is a top plan view of the counter substrate of the liquid crystal display in accordance with Example 1;

[0032] FIGS. 5A-5G are cross-sectional views illustrating a process sequence for fabricating the TFT substrate shown in FIG. 3;

[0033] FIG. 6 is a fragmentary cross-sectional view of a pixel region and a common contact portion of the liquid crystal display in accordance with Example 1;

[0034] FIG. 7 is a cross-sectional view similar to FIG. 6, but illustrating Example 2 of the invention;

[0035] FIG. 8 is a cross-sectional view similar to FIG. 6, but illustrating Example 3 of the invention;

[0036] FIG. 9 is an enlarged cross-sectional view of the common contact portion shown in FIG. 7;

[0037] FIG. 10 is an enlarged cross-sectional view of the common contact portion shown in FIG. 8;

[0038] FIG. 11 is a top plan view of the common contact portion shown in FIG. 8;

[0039] FIG. 12 is a top plan view of the TFT substrate of the prior art liquid crystal display;

[0040] FIG. 13 is a cross-sectional view of a pixel region and a common contact portion on the TFT substrate shown in FIG. 12; and

[0041] FIG. 14 is a top plan view of the common contact portion shown in FIG. 13.

DETAILED DESCRIPTION OF THE INVENTION

EMBODIMENT 1

[0042] The present embodiment of this invention is described by referring to FIGS. 1, 2A and 2B. FIG. 1 is a fragmentary cross-sectional view of a common contact portion of a liquid crystal display in accordance with the present embodiment. FIGS. 2A and 2B are top plan views of the TFT substrate of the liquid crystal display. The structure of a region 120 shown in FIG. 2A is depicted in the enlarged cross section of FIG. 1.

[0043] As shown in FIG. 13, in the prior art structure, the spacers in the pixel region 12 are located over the interlayer insulating film 18 via the pixel electrode 19. However, the interlayer dielectric film 18 does not exist under the conducting pad 22 at the common contact portion 16. Hence, the cell gap G_c in the common contact portion depends on the thickness of the interlayer dielectric film 18.

[0044] Accordingly, in the present embodiment, an insulator, or a dielectric, is inserted under the conducting pad in the common contact portion. Conducting spacers are placed on top of the dielectric, so that the cell gap G_c in the contact portion does not depend on the thickness of the interlayer dielectric film 18. In the present embodiment, openings are formed, selectively leaving the interlayer dielectric film 18.

[0045] In the present embodiment, as shown in FIG. 1, a first conducting film 103 is formed on a first substrate 101. A dielectric film 104 is deposited on the first conducting film 103. The dielectric film 104 is selectively left to form openings 111 that expose parts of the first conducting film 103. A second conducting film 105 is formed so as to cover the left parts of the dielectric film, 104a, and the openings 111.

[0046] A third conducting film 106 is formed on the second substrate 102. Conducting spacers 107 are sandwiched between the first substrate 101 and the second substrate 102.

[0047] In the prior art opening 110 shown in FIG. 2A, the dielectric film 104 has been fully removed. In the present embodiment, the dielectric film 104 is selectively left to form the dielectric film portions 104a and the openings 111. The openings 111 expose parts of the first conducting film 103. The first conducting film 103 is connected with the second conducting film 105 at these openings 111.

[0048] On the first substrate 101, the left dielectric film 104a is closest to the second substrate 102; therefore, on the left dielectric film 104a, the second conducting film 105 formed on the first substrate electrically connects with the third conducting film 106 formed on the second conducting film 102 through the conducting spacer 107, as shown in FIG. 1.

[0049] In region 110, the left dielectric film 104a is closest to the second substrate; therefore, the conducting spacers 107 electrically connecting the second conducting film 105 with the third conducting film 106 maintain the gap G between the substrates. Consequently, this gap G is dependent only on the size of the conducting spacers 107. Therefore, where the conducting spacers 107 are uniform among

liquid-crystal cells, the gap G can be made uniform among cells, even if the thickness t of the dielectric film **104** differs among cells.

[0050] In the present embodiment, it is desired that the area of each opening **111** be sufficiently larger than the area occupied by each conducting spacer and offer space so that the conducting spacers can move freely, because the spacers **107** existing in the openings **111** do not contribute toward maintaining the gap. Otherwise, plural conducting spacers **107** would be stacked on top of each other, making it impossible to maintain the cell gap G uniform across the cell.

[0051] Also in the present embodiment, it is desirable that the area of the surface of each left dielectric film portion **104a** be sufficiently larger than the area occupied by each conducting spacer **107**, assuring arrangement of the conducting spacers **107**. If the spacers **107** are not positioned over the dielectric film **104a** with certainty, it will not be possible to make electrical connections between the first and second substrates. Furthermore, the gap will not be maintained.

[0052] The openings **111** are formed as shown in **FIG. 2A** in the present embodiment. The relation between the left dielectric film **104a** and each opening **111** may be reversed as shown in **FIG. 2B**. It is that noted **FIG. 1** is an enlarged view of the region **120** indicated by the broken line in **FIG. 2B**.

EMBODIMENT 2

[0053] The present embodiment is described by referring to **FIGS. 1** and **2A**. **FIG. 1** is a cross-sectional view of a common contact portion of the liquid crystal display in accordance with the present embodiment. **FIG. 2A** is a top plan view of the TFT substrate of the liquid crystal display. **FIG. 1** is an enlarged cross-sectional view of the region **120** indicated by the broken line in **FIG. 2A**.

[0054] A dielectric is inserted under a conducting pad in the common contact portion, in the same manner as in Embodiment 1. Conducting spacers are positioned on the dielectric. Thus, the cell gap G_c in the common contact portion does not depend on the thickness of the interlayer dielectric film **18**. The present embodiment is characterized in that the dielectric film **18** is selectively left to form openings.

[0055] In particular, in the present embodiment, the dielectric layer is formed underneath the conducting pad **22**. The conducting spacers are positioned on the dielectric. Consequently, the cell gap G_c in the common contact portion is not dependent on the thickness of the interlayer dielectric film **18**.

[0056] Referring to **FIG. 1**, a first conducting film **103** is formed on top of a first substrate **101**. A dielectric film **104** covers the first conducting film **103**. The dielectric film **104** is provided with openings **111** to selectively expose the surface of the first conducting film **103**. The exposed portions of the dielectric **104** are indicated by **104a**. A second conducting film **105** is formed to cover the openings **111**.

[0057] A third conducting film **106** is formed on the second substrate **102**. Conducting spacers **107** are located between the first substrate **101** and the second substrate **102**.

[0058] **FIG. 2A** is a top plan view of the TFT substrate, and in which the second conducting film **105** is not yet deposited. In **FIG. 2A**, the region **110** indicated by the broken line corresponds to the opening for the common contact formed in the interlayer dielectric film **18** of the prior art structure. A dielectric **104a** is selectively deposited to leave portions of the first conducting film **103** to be exposed.

[0059] The first conducting film **103** is exposed at locations where the dielectric **104a** is not deposited. The exposed portions of the first conducting film **103** are connected with the overlying second conducting film **105**.

[0060] On the first substrate **101**, the dielectric **104a** is closest to the second substrate. As shown in **FIG. 1**, on the dielectric **104a**, conducting spacers **107** electrically connect the second conducting film **105** on the first substrate **101** with the third conducting film **106** on the second substrate **102**.

[0061] The dielectric **104a** is closest to the second substrate **102**. Therefore, the conducting spacers **107** electrically connecting the second conducting film **105** with the third conducting film **106** hold the cell gap G . In consequence, the gap G is dependent only on the size of the conducting spacers **107**. Where the spacers **107** are uniform in size, the cell gap G can be rendered uniform among liquid-crystal cells even if the thickness t of the dielectric film **104** differs among cells.

[0062] In the present embodiment, the area of each portion not covered with the dielectric **104a** is preferably sufficiently wider than the area occupied by one conducting spacer **107** and permits the conducting spacers **107** to move freely, because the spacers **107** existing in the regions where the dielectric **104a** is not present do not contribute toward maintaining the gap. Otherwise, plural conducting spacers **107** would be stacked on top of each other, making it impossible to maintain the cell gap G uniform across the cell.

[0063] Also in the present embodiment, it is desirable that the area of each portion of the dielectric film **104a** be sufficiently larger than the area occupied by one conducting spacer **107** and that the conducting spacers **107** be arranged with certainty. If the spacers **107** are not positioned on the dielectric film **104a** with certainty, it will not be possible to make electrical connections between the first and second substrates. Furthermore, the cell spacing will not be maintained.

[0064] In this embodiment, the dielectric **104a** is deposited as shown in **FIG. 2A**. The relation between the regions where the dielectric **104a** is deposited and each region where the first conducting film **103** is exposed may be reversed as shown in **FIG. 2B**.

EXAMPLE 1

[0065] In this example, the present invention is applied to a common contact portion of a reflection-type liquid crystal display. **FIG. 3** is a top plan view of the TFT substrate of this liquid crystal display. **FIG. 4** is a top plan view of the counter substrate of the liquid crystal display.

[0066] Referring to **FIG. 3**, the TFT substrate **200** comprises a substrate **201** having a pixel region **202**, a scanning line driver circuit **203**, and a signal line driver circuit **204**.

Pixel electrodes and TFTs connected with the pixel electrodes are arranged in rows and columns in the pixel region **202**. The scanning line driver circuit **203** controls the timing at which each TFT is turned on and off. The signal line driver circuit **204** supplies image data to the pixel electrodes. Extractor terminals **205** are also provided to supply electric power and control signals from the outside. Common contact portions **206a-206d** form junctions with the counter electrode.

[**0067**] As shown in **FIG. 4**, the counter substrate **250** comprises a substrate on which a counter electrode **252** consisting of a transparent conducting film is deposited. A central rectangular region **253** is opposite to the pixel region **202** of the TFT substrate **200**. Four corner regions **254a-254d** are electrically connected with the contact portions **206a-206d**, respectively, of the TFT substrate **200**.

[**0068**] As shown in **FIG. 3**, conducting pads are formed in the common contact portions **206a-206d**, respectively, of the TFT substrate **200**. These conducting pads are electrically connected together by internal conducting lines **207a-207c**. The internal lines **207a** and **207b** extend to the extractor terminals **205** and are electrically connected with common terminals **205a** and **205b**, respectively.

[**0069**] A process sequence for manufacturing the pixel region **202** and the common contact portion **206a-206d** on the TFT substrate is next described by referring to **FIGS. 5A-5G**.

[**0070**] First, the substrate **201** having an insulating surface was prepared. In the present example, a silicon oxide film was formed as a buffer film on the glass substrate. An active layer **302** consisting of a crystalline silicon film was formed over the substrate **201**. Although only one TFT is shown, millions of TFTs are built in the pixel region **202** in practice.

[**0071**] In the present example, an amorphous silicon film was thermally crystallized to obtain the crystalline silicon film. This crystalline silicon film was patterned by an ordinary photolithographic step to obtain the active layer **302**. In this example, a catalytic element such as nickel for promoting the crystallization was added during the crystallization. This technology is described in detail in Japanese Unexamined Patent Publication No.7-130652.

[**0072**] Then, a silicon oxide film **303** having a thickness of 150 nm was formed. An aluminum film (not shown) containing 0.2% by weight of scandium was deposited on the silicon oxide film **303**. The aluminum film was patterned, using a resist mask **304**, into an island pattern **305** from which gate electrodes will be formed (**FIG. 5A**).

[**0073**] The present example made use of the anodization technique described in Japanese Unexamined Patent Publication No. 7-135318. For further information, refer to this publication.

[**0074**] First, the island pattern **305** was anodized within a 3% aqueous solution of oxalic acid while leaving the resist mask **304** on the island pattern **305**, the mask **304** having been used for the patterning step. At this time, an electrical current of 2 to 3 mV was passed, using a platinum electrode as a cathode. The voltage was increased up to 8 V. Since the resist mask **304** was left on the top surface, porous anodic oxide film **306** was formed on the side surfaces of the island pattern **305** (**FIG. 5B**).

[**0075**] After removing the resist mask **304**, anodization was carried out within a solution prepared by neutralizing a 3% aqueous solution of tartaric acid with aqueous ammonia. At this time, the electrical current was set to 5-6 mV. The voltage was increased up to 100 V. In this way, a dense anodic oxide film **307** was formed.

[**0076**] The above-described anodic oxidation step defined the unoxidized island pattern **305** into gate electrodes **308**. Internal connecting lines **207c** interconnecting the common contact portions **206c** and **206d** were created from the aluminum film described above simultaneously with the gate electrodes **308**.

[**0077**] Then, using the gate electrodes **308** and surrounding anodic oxide film **306, 307** as a mask, the silicon oxide film **303** was etched into a gate insulating film **309**. This etching step relied on dry etching using CF_4 gas (**FIG. 5C**).

[**0078**] After the formation of the gate insulating film **309**, the porous anodic oxide film **307** was removed by wet etching using Al mixed acid.

[**0079**] Thereafter, impurity ions for imparting one conductivity type were implanted by ion implantation or plasma doping. Where N-type TFTs are placed in the pixel region, P (phosphorus) ions may be implanted. Where P-type TFTs are placed, B (boron) ions may be implanted.

[**0080**] In the present example, the above-described process for implanting the impurity ions was carried out twice by ion implantation. The first step was performed under a high accelerating voltage of 80 keV. The system was so adjusted that the peak of the impurity ions was brought under the ends (protruding portions) of the gate insulating film **309**. The second step was effected under a low accelerating voltage of 5 keV. The accelerating voltage was adjusted so that the impurity ions were not implanted under the ends (protruding portions) of the gate insulating film **309**.

[**0081**] In this way, a source region **310**, a drain region **311**, lightly doped regions **312, 313**, and a channel region **314** for the TFT were formed. The lightly doped region **313** on the side of the drain region **311** is also referred to as the LDD region (**FIG. 5D**).

[**0082**] At this time, it is preferable to implant the impurity ions to such a dosage that the source and drain regions **310** and **311**, respectively, exhibit a sheet resistance of 300 to 500 Ω/\square . In addition, it is necessary to optimize the lightly doped regions **312** and **313** according to the performance of the TFT. After the impurity ion implantation step, a thermal treatment was carried out to activate the impurity ions.

[**0083**] Then, a 1 μm -thick-silicon oxide film was formed as a first interlayer dielectric film **315**. The thickness of the interlayer dielectric film **315** was set to 1 μm to flatten the surface of the first interlayer dielectric film **315** as much as possible. This could mitigate the protrusions due to the gate electrodes **308**.

[**0084**] The first interlayer dielectric film **315** may be made of silicon nitride or silicon oxynitride, as well as silicon oxide. Alternatively, the first interlayer dielectric film **315** may be a multilayer film of these materials.

[**0085**] Contact holes for gaining access to the source and drain regions **310** and **311**, respectively, were created in the

first interlayer dielectric film **315**. Contact holes for allowing access to the internal conducting lines **207c** were formed in the common contact portions **206c** and **206d**. Then, a conducting film forming a precursor for source and drain electrodes **316** and **317**, respectively, and for internal conducting lines **318** was deposited.

[0086] In this example, the conducting film was created from a multilayer film of titanium (Ti), aluminum (Al), and titanium (Ti) by sputtering. Each of the titanium layers was 100 nm thick, while the aluminum layer was 300 nm thick. This multilayer film was patterned to form a source electrode **316**, a drain electrode **317**, and internal conducting lines **318** (FIG. 5E).

[0087] The internal conducting lines **318** shown FIG. 5E correspond to the internal conducting lines **207a** and **207b** shown in FIG. 3. These conducting lines **207a** and **207b** were connected with internal conducting lines **207c** at the common contact portions **206c** and **206d**. The internal conducting lines **207c** and the gate electrode **308** were created by the same processing steps.

[0088] Subsequently, an organic resinous film was formed as a second interlayer dielectric film **319** to a thickness of 1 to 2 μm . Polyimide, polyamide, polyimideamide, acrylic resin, or other material may be used as the material of the organic resinous film. The organic resinous material acts to planarize the surface of the second interlayer dielectric film **319**. This is important to make the cell gap uniform. In the present example, polyimide was deposited as the second interlayer dielectric film **319** to a thickness of 1 μm .

[0089] Then, contact holes **320** and **321** were formed in the second interlayer dielectric film **319** to have access to the drain electrode **317** and to the internal conducting lines **318**, respectively. The contact holes **321** for the internal conducting lines **318** were formed in the openings **111** shown in FIG. 2A. That is, rectangular holes measuring 100 μm ×100 μm were arranged in 5 rows and 5 columns within the rectangular region **110** measuring 1.1 mm×1.1 mm. These holes were spaced 100 μm from each other. Moreover, contact holes for connecting the internal conducting lines **318** (**207a** and **207b**) with the common terminals **205a** and **205b** at the extractor terminals **205** were formed.

[0090] As described later, the size of each hole was set to 100 μm ×100 μm to set the diameter of the conducting spacers to 3.5 μm in this example. This provides sufficient space so that the conductive spacer located at this position can move. Hence, the conducting spacers are prevented from being stacked on top of each other.

[0091] The area of the left portions of the interlayer dielectric film **319** in the common contact portions is large enough to permit the conducting spacers to move. This assures that the conducting spacers are arranged in these regions. Consequently, the conducting spacers positioned in these regions can maintain the cell gap and make electrical connections reliably.

[0092] A thin metal film which would later be made into pixel electrodes **322** and a conducting pad **323** were formed to a thickness of 100 to 400 nm. In the present example, the thin metal film was made of an aluminum film containing 1 wt % titanium and deposited to a thickness of 300 nm by sputtering. Then, the thin metal film was patterned to form the pixel electrodes **322** and the conducting pad **323**. This

pad **323** measured 1.1 mm×1.1 mm, was rectangular, and covered the contact holes **321**. The extractor terminals **205** were also patterned. Thus, the TFT substrate was completed (FIG. 5G).

[0093] Referring to FIG. 6, the counter substrate **250** comprised a transparent plate **251** on which the counter electrode **252** was formed from an ITO film. A glass or quartz substrate can be used as the substrate **251**.

[0094] Then, the TFT substrate **200** and the counter substrate **250** were bonded together. This bonding step may be a well-known cell assembly method.

[0095] First, a sealing material was applied to one of the TFT substrate **200** and the counter substrate **250**. In this example, the sealing material was applied to the counter substrate **250**. A UV-curable and thermosetting resin was used as the sealing material. This sealing material was applied around the substrate along straight lines except for the liquid crystal injection port by a sealant dispenser. A sealing material to which 3.0 wt % spherical conducting spacers **401** were added was applied to regions **254a-254d** shown in FIG. 4. The sealing material to which the conducting spacers were added functioned as an anisotropic conducting film.

[0096] Generally, the conducting spacers **401** consist of resinous spheres coated with a conducting film. In the present example, the conducting spacers **401** were coated with gold (Au). The diameter of the conducting spacers **401** may be larger than the cell gap by about 0.2 to 1 μm . In this example, the conducting spacers **401** had a diameter of 3.5 μm to set the cell gap to 3 μm . After applying the sealing material, it was temporarily baked.

[0097] Thereafter, spacers **402** were dispersed onto one of the TFT substrate **200** and the counter substrate **250** to maintain the cell gap. In this example, the spacers **402** were applied to the counter substrate **250**. To set the cell gap to 3 μm , spherical spacers of a polymeric material were used as the spacers **402**.

[0098] Then, the TFT substrate **200** and the counter substrate **250** were held opposite to each other, and they were pressed against each other until the cell gap in the pixel region was decreased to the diameter of the spacers **402**. Under the pressed state, UV light was directed at this assembly for more than 10 seconds to cure the sealing material. The cell gap was fixed. Then, the assembly was heated under pressure, thus enhancing the adhesive strength.

[0099] Subsequently, a liquid crystal material was injected, and the entrance hole was sealed off, thus completing the cell assembly process. As shown in FIG. 6, the counter electrode **252** on the counter substrate **250** was electrically connected with the conducting pad **323** on the TFT substrate **200** by the conducting spacer **401**. On the TFT substrate, the conducting pad **323** connected the internal conducting lines **318** with the common terminals. This connection structure permitted the counter electrode **252** on the counter substrate **250** to be connected with an external power supply via the conducting lines on the TFT substrate. FIG. 1 is an enlarged view of the common contact portion of FIG. 6.

[0100] In the present example, to set the cell gap to 3 μm , the spacers **402** applied to the pixel region had a diameter of

3 μm . The diameter of the conducting spacers **401** was 3.5 μm . Setting the diameter of the conducting spacers greater than the diameter of the spacers **402** (i.e., the cell gap) made reliable the connection between the counter electrode **252** and the conducting pad **318**. When the two plates were being clamped together to bond them together, the conducting spacers **401** were crushed because they were larger in diameter than the cell gap. This increased the areas of the portions in contact with the counter electrode **252** and with the conducting pad **318**, respectively. Hence, the electrical connection was rendered more reliable. Furthermore, the cell gap could be maintained at the same dimension as in the pixel region.

[0101] In this example, the internal conducting lines **318** were made of the precursor for the source and drain electrodes **316** and **317**, respectively. It is only necessary for the internal conducting lines **318** to be under the pixel electrodes **322**. For instance, where a black matrix consisting of a conducting film of titanium or the like is formed inside the second interlayer dielectric film **315**, the internal conducting lines **318** can be formed from this conducting film.

[0102] In the present example, it is important to flatten the surface of the second interlayer dielectric film **319** on which the pixel electrodes **322** are formed in order to make uniform the cell gap. Also, the flatness of the surface of the first interlayer dielectric film **315** where the internal conducting lines **318** are formed is important.

[0103] Methods of obtaining an interlayer dielectric film having a flat surface include a method of increasing the thickness of the interlayer dielectric film, a leveling method using an organic resinous film, a mechanical polishing method, and etch-back techniques. The present example made use of the method of increasing the film thickness to planarize the first interlayer dielectric film **315**. Also, the method of relying on leveling using an organic resinous film was used to flatten the first interlayer dielectric film **315**. Other methods may also be employed for the same purpose.

[0104] In a liquid crystal display in accordance with the present example, a dichroic dye may be dispersed in the liquid crystal layer. Orientation films may be deposited on the TFT substrate and on the counter substrate. Color filters may be formed on the counter substrate. The practitioner may appropriately determine the kind of the liquid crystal layer, the presence or absence of the orientation films and the color filters according to the driving method, the kind of the liquid crystal, and other factors.

[0105] For instance, where the color filters are mounted on the counter substrate **250**, the color filters are not formed at the common contact portions and so steps are formed between the pixel region and the common contact portions on the counter substrate. To compensate for these steps, it is necessary to make the diameter of the conducting spacers larger by an amount almost equal to the thickness of the color filter.

[0106] In the present example, the liquid crystal display is of the reflection type. A transmissive liquid crystal display may also be fabricated. In this case, the precursor for the pixel electrode and for the conducting pad may be made of a transparent ITO film or the like.

[0107] In the example described above, the transistor is a coplanar TFT that is a typical top-gate TFT. It may also be

a bottom-gate TFT. In addition, thin-film diodes, metal-insulator-metal (MIM) devices, metal-oxide varistors, and other devices can be used, as well as the TFTs.

EXAMPLE 2

[0108] The present example is a modification of the common contact portions of Example 1. FIG. 7 is a fragmentary cross-sectional view of an active-matrix display in accordance with the present example. The configuration of a TFT substrate shown in FIG. 7 is the same as the configuration shown in FIG. 6, and some reference numerals are omitted. Like components are indicated by like reference numerals in both FIGS. 6 and 7. FIG. 9 is an enlarged view of the common contact portion shown in FIG. 7.

[0109] In Example 1 shown in FIG. 6, the counter electrode **252** consists of an ITO film that is a transparent conducting film. Therefore, the counter electrode **252** and the conducting spacers **401** are larger in electrical resistance than metal films. The present example is intended to reduce this electrical resistance.

[0110] Accordingly, the resistance value between the counter electrode **252** and the conducting spacers **401** can be lowered by forming a metallization layer on the counter substrate **250** and patterning the metallization layer into conducting pads, or conducting film, **501** at the common contact portions **254a-254d**. Importantly, the conducting film forming the conducting pads **501** is lower in electrical resistance than the conducting film forming the counter electrode **252**.

[0111] Where the black matrix on the counter substrate is formed from a conducting film as consisting of chromium, the connecting pads **501** can be formed from this conducting film. When the conducting film is patterned to form the black matrix, the connecting pad **501** may be created.

EXAMPLE 3

[0112] The present example is a modification of Example 2. FIG. 8 is a fragmentary cross-sectional view of an active-matrix display in accordance with the present example. The TFT substrate shown in FIG. 8 is identical in structure with that shown in FIG. 6, and some reference numerals are omitted in FIG. 8. It is noted like components are denoted by like reference numerals in both FIGS. 6 and 8. FIG. 10 is an enlarged view of the common contact portion of FIG. 8.

[0113] In Example 1, both counter substrate **251** and counter electrode **252** are transparent to light and so the distribution of the conducting spacers **401** on the common contact portions can be visually observed from the side of the counter substrate **250** after both substrates have been bonded together. In Example 2, however, the connecting pad **501** consisting of metallization layer is formed and, therefore, the distribution of the conducting spacers **401** cannot be visually checked.

[0114] The present example is intended to permit one to visually observe the distribution of the conducting spacers **401** while a connecting pad is provided to lower the resistance value. For this purpose, the connecting pad, **601**, is provided with openings formed at selected locations. One can observe the conducting spacers **401** through these openings.

[0115] FIG. 11 is a top plan view of the contact portions according to the present example, taken from the side of the counter substrate. FIG. 10 is a cross-sectional view of the common contact portion in a region 600 surrounded by the broken line. As shown in FIG. 11, the conducting pad 601 is formed with openings 602. In each opening 602, there exist only the counter substrate 251 and the counter electrode 252, both of which have transparency. Hence, the distribution of the conducting spacers 401 can be observed through the openings 602.

[0116] To maintain the cell gap, the openings 602 should be formed opposite to the contact holes 321 formed in the second interlayer dielectric film of the TFT substrate. At these locations, the conducting spacers 401 are not in contact with the counter electrode. The area of each opening 602 should be slightly larger than the area of each contact holes 321 formed in the second interlayer dielectric film, i.e., about several to thirty percent greater. The number of the openings 602, their arrangement, and their shape are not limited to the example of FIG. 11. Rather, one can arbitrarily set these geometrical factors.

[0117] Setting each opening 602 in the connecting pad 601 slightly larger than each contact holes 321 makes it possible to visually check the conducting pad 602 on the second interlayer dielectric film 319, which contributes to electrical connection.

[0118] In Examples 2 and 3, the cell gap in the common contact portions is made uniform. At the same time, the contact resistances of the conducting spacers 401 and of the counter electrode 252 are decreased. If the main purpose is to lower these resistance values, the common contact portions on the TFT substrate may have the prior art structure as shown in FIG. 13. In this case, any of the connecting pads 501 and 601 described in Examples 2 and 3, respectively, maybe formed between the substrate 23 and the counter electrode 24 at the common contact portions 16 shown in FIG. 13.

[0119] In Examples 1-3 described above, the present invention is applied to active-matrix liquid crystal displays. The contact structure in accordance with the present invention is applicable to any apparatus having a contact structure for electrically connecting conductors formed on one substrate with conducting conductors formed on the other opposite substrate via conducting spacers. For example, the novel contact structure can connect ICs built on different silicon wafers.

[0120] The common contact structure in accordance with the present invention can eliminate variations of the cell gap among liquid-crystal cells even if the film thickness varies among interlayer dielectric films. Also, poor contacts due to conducting spacers can be reduced.

[0121] In particular, in accordance with the present invention, the cell gap depends only on the size of conducting spacers. Therefore, where the conducting spacers are uniform in size, the cell gap between opposite substrates or plates can be made uniform among different liquid-crystal cells, if the thickness of a dielectric film electrically insulating the first and second conducting films is different among different liquid-crystal cells.

In the claims:

1. An active matrix display device comprising:

a first substrate;

a first interlayer insulating film provided over said first substrate;

a first conductive film provided on said first interlayer insulating film;

a second interlayer insulating film provided on said first conductive film, said second interlayer insulating film having at least two openings;

a second conductive film provide on said second interlayer insulating film and in said openings;

a second substrate opposed to said first substrate;

a third conductive film provided on said second substrate; and

a plurality of conductive spacers held between said first substrate and said second substrate;

wherein said first conductive film is connected with said second conductive film ins aid openings;

wherein at least one of said conductive spacers is held over said second interlayer insulating film and in contact with both said second conductive film and said third conductive film.

2. An active matrix display device according to claim 1, wherein each of said conductive spacers is a sphere coated with gold.

3. An active matrix display device according to claim 1, wherein said second interlayer insulating film comprises an organic resin selected from the group consisting of polyimide, polyamide, polyimideamide and acrylic resin.

4. An active matrix display device according to claim 1, wherein siad active matrix display device further comprises a fourth conductive film between said third conductive film and second conductive film.

5. An active matrix display device according to claim 1, wherein said active matrix display device is a liquid crystal display device.

6. An active matrix display device comprising:

a first substrate;

a first interlayer insulating film provided over said first substrate;

a first conductive film provided on said first interlayer insulating film;

a second interlayer insulating film provided on said first conductive film, said second interlayer insulating film having at least two openings;

a second conductive film provided on said second interlayer insulating film and in said openings;

a second substrate opposed to said first substrate;

a third conductive film provided on said second substrate; and

a plurality of conductive spacers held between said first substrate and said second substrate;

wherein said first conductive film is connected with said second conductive film in said openings,

wherein said conductive spacers are dispersed into a sealing material,

wherein at least one of said conductive spacers is held over said second interlayer insulating film and in contact with both said second conductive film and said third conductive film.

7. An active matrix display device according to claim 6, wherein each of said conductive spacers is a sphere coated with gold.

8. An active matrix display device according to claim 6, wherein said second interlayer insulating film comprises an organic resin selected from the group consisting of polyimide, polyamide, polyimideamide and acrylic resin.

9. An active matrix display device according to claim 6, wherein said active matrix display device further comprises a fourth conductive film between said third conductive film and said second conductive film.

10. An active matrix display device according to claim 6, wherein said active matrix display device is a liquid crystal display device.

11. An active matrix display device comprising:

a first substrate;

a first interlayer insulating film provided over said first substrate;

a first conductive film provided on said first interlayer insulating film;

a second interlayer insulating film provided on said first conductive film, said second interlayer insulating film having at least two openings;

a second conductive film provided on said second interlayer insulating film and in said openings;

a second substrate opposed to said first substrate;

a third conductive film provided on said second substrate; and

a plurality of conductive spacers held between said first substrate and said second substrate;

wherein said first conductive film is connected with said second conductive film in said openings;

wherein at least one of said conductive spacers is held over said second interlayer insulating film and in contact with both said second conductive film and said third conductive film,

wherein each of said openings occupies an area larger than an area occupied by each of said conductive spacers.

12. An active matrix display device according to claim 11, wherein each of said conductive spacers is a sphere coated with gold.

13. An active matrix display device according to claim 11, wherein said second interlayer insulating film comprises an organic resin selected from the group consisting of polyimide, polyamide, polyimideamide and acrylic resin.

14. An active matrix display device according to claim 11, wherein said active matrix display device further comprises a fourth conductive film between said third conductive film and said second conductive film.

15. An active matrix display device according to claim 11, wherein said active matrix display device is a liquid crystal display device.

16. An active matrix display device comprising:

a first substrate;

a first interlayer insulating film provided over said first substrate;

a first conductive film provided on said first interlayer insulating film;

a second interlayer insulating film provided on said first conductive film, said second interlayer insulating film having an opening with a part of said second interlayer insulating film remaining in said opening;

a second conductive film provided on said second interlayer insulating film and in said opening;

a second substrate opposed to said first substrate;

a third conductive film provided on said second substrate; and

a plurality of conductive spacers held between said first substrate and said second substrate;

wherein said first conductive film is connected with said second conductive film in said opening,

wherein at least one of said conductive spacers is held over said part of said second interlayer insulating film and in contact with both said second conductive film and conductive film.

17. An active matrix display device according to claim 16, wherein each of said conductive spacers is a sphere coated with gold.

18. An active matrix display device according to claim 16, wherein said second interlayer insulating film comprises an organic resin selected from the group consisting of polyimide, polyamide, polyimideamide and acrylic resin.

19. An active matrix display device according to claim 16, wherein said active matrix display device further comprises a fourth conductive film between said third conductive film and said second conductive film.

20. An active matrix display device according to claim 16, wherein said active matrix display device is a liquid crystal display device.

21. An active matrix display device comprising:

a first substrate;

a first interlayer insulating film provided over said first substrate;

a first conductive film provided on said first interlayer insulating film;

a second interlayer insulating film provided on said conductive film, said second interlayer insulating film having an opening with a part of said second interlayer insulating film remaining in said opening;

a second conductive film provided on said second interlayer insulating film and in said opening;

a second substrate opposed to said first substrate;

a third conductive film provided on said second substrate; and

a plurality of conductive spacers held between said first substrate and said second substrate;

wherein said first conductive film is connected with said second conductive film in said opening,

wherein said conductive spacers are dispersed into a sealing material,

wherein at least one of said conductive spacers is held over said part of said second interlayer insulating film and in contact with both said second conductive film and said third conductive film.

22. An active matrix display device according to claim 21, wherein each of said conductive spaces is a sphere coated with gold.

23. An active matrix display device according to claim 21, wherein said second interlayer insulating film comprises an organic resin selected from the group consisting of polyimide, polyamide, polyimideamide and acrylic resin.

24. An active matrix display device according to claim 21, wherein said active matrix display device further comprises a fourth conductive film between said third conductive film and said second conductive film.

25. An active matrix display device according to claim 21, wherein said active matrix display is a liquid crystal display device.

26. An active matrix display device comprising:

a first substrate;

a first interlayer insulating film provided over said first substrate;

a first conductive film provided on said first interlayer insulating film;

a second interlayer insulating film provided on said first conductive film, said second interlayer insulating film

having an opening with a part of said second interlayer insulating film remaining in said opening;

a second conductive film provided on said second interlayer insulating film and in said opening;

a second substrate opposed to said first substrate;

a third conductive film provided on said second substrate; and

a plurality of conductive spacers held between said first substrate and said second substrate;

wherein said first conductive film is connected with said second conductive film in said opening,

wherein at least one of said conductive spacers is held over said part of said second interlayer insulating film and in contact with both said second conductive film and said third conductive film,

wherein said opening occupies an area larger than an area occupied by each of said conductive spacers.

27. An active matrix display device according to claim 26, wherein each of said conductive spacers is a sphere coated with gold.

28. An active matrix display device according to claim 26, wherein said second interlayer insulating film comprises an organic resin selected from the group consisting of polyimide, polyamide, polyimideamide and acrylic resin.

29. An active matrix display device according to claim 26, wherein said active matrix display device further comprises a fourth conductive film between said third conductive film and said second conductive film.

30. An active matrix display device according to claim 26, wherein said active matrix display device is a liquid crystal display device.

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