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"AN ACTIVE MATRIX LIQUID CRYSTAL DISPLAY DEVICE"

This invention relates to active matrix liquid crystal display devices.

Recently thin film transistor technology has been studied more actively. There are many applications of thin film transistors, for example, in thin active matrix liquid crystal display devices employing relatively inexpensive insulating substrates, three-dimensional integrated circuits in which active elements, such as thin film transistors, are formed on semiconductor integrated circuits, relatively inexpensive image sensors with high performance, high-density memory devices etc.

Large scale active matrix liquid crystal display devices having a matrix of picture elements are attracting particular attention and are being applied to various apparatus such as small-size personal computers, hand-held television receivers etc. The use of thin film transistors as switching devices for the picture elements is now under serious consideration particularly for planar large scale active matrix liquid crystal display devices.

According to the present invention, there is provided an active matrix liquid crystal display device comprising a matrix of picture elements, each of the picture elements

being composed of a driving electrode, a capacitor for storing a data signal, a MOS transistor having a drain electrode, a source electrode and a gate electrode which is covered by a gate insulating layer, the MOS transistor being arranged selectively to apply the data signal to the capacitor, a gate line connected to the gate electrode, a source line orthogonal to the gate line and connected to the source electrode, and a further insulating layer between the gate line and the source line, the breakdown voltage of the further insulating layer being higher than the breakdown voltage of the gate insulating layer.

In the preferred embodiment, the thickness of the further insulating layer at least in the region of the section of each gate line with each source line is greater than in other regions.

In each picture element at least a portion of the gate line or the MOS transistor may be covered by the respective driving electrode, an insulating layer being disposed therebetween.

The picture elements are preferably formed on a glass substrate.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:-

Figure 1 consisting of Figures 1(a) and 1(b), illustrates the general construction of an active matrix liquid crystal display device;

Figure 2 consists of Figures 2(a) which is an enlarged plan view of a picture element of a conventional active matrix liquid crystal display device, and Figure 2(b) which is a section of the picture element of Figure 2(a) taken on the line A-B;

Figure 3 consists of Figure 3(a) which is a cross-section of a picture element of an active matrix liquid crystal display device according to the present invention and Figure 3(b) which is a plan view thereof; and

Figure 4 consists of Figure 4(a) which is a plan view of a picture element of another active matrix liquid crystal display device according to the present invention and Figure 4(b) which is a cross-section thereof taken on the line C-D.

Generally an active matrix liquid crystal display device consists of an upper transparent substrate, a lower transparent

substrate on which thin film transistors are formed, and a liquid crystal material which is sealed between the substrates. Liquid crystal driving elements associated with liquid crystal driving electrodes are arranged in a matrix on the thin film transistors. An external selecting circuit selects the liquid crystal driving elements, and the associated liquid crystal driving electrodes are excited to display desired letters, figures or pictures.

Figure 1 illustrates the general construction of an active matrix liquid crystal display device having a matrix of liquid crystal driving elements 2 on a lower substrate (not shown) within a display area 1. Data signals and timing signals are applied to the liquid crystal driving elements 2 through orthogonal input lines 3, 4, respectively. Figure 1(b) is a circuit diagram of one of the liquid crystal driving elements 2. A thin film transistor 5 is provided for switching the data signal on the line 3 in response to the timing signal on the line 4. A capacitor 6, which is not necessarily requred if the capacitance of the liquid crystal material is sufficiently large, is provided for storing data. A liquid crystal cell 7 includes a liquid crystal driving electrode 7-1 on the lower substrate and a transparent electrode 7-2 on an upper transparent substrate (not shown).

The active matrix liquid crystal display device shown in Figure 1(a) suffers from faults due to bad patterning of the liquid crystal driving elements, poor electrical insulation at the intersection of the input lines 3, 4 and poor electrical insulation of the liquid crystal picture elements 2. Bad patterning can be overcome

by improving the manufacturing techniques and making the manufacturing environment thoroughly clean so as to increase manufacturing yield. Improvement of quality and increase of thickness of an insulating layer of the thin film transistor of each picture element leads also to an increase in manufacturing yield by overcoming the problem of poor electrical insulation resulting at an early stage of manufacture. After the matrix of picture elements has been completely formed, however, poor electrical insulation between the input lines is apt to occur due to the effects of static electricity and other factors. When the input lines are subject to static electricity from outside the display area 1, breakdown of electrical insulation is caused at the intersections between the input lines. As a result a data signal from one of the input lines 3 may leak into one of the input lines 4 or a timing signal from one of the input lines 4 may leak into one of the input lines 3 at a region where the input lines 3, 4 intersect. This causes a so-called "line fault". As a result, the display of each picture element in the line where there is a breakdown of electrical insulation is reduced and the display produced by the active matrix liquid crystal display device as a whole deteriorates.

When there is a breakdown of electrical insulation, this is usually compensated for by disconnecting the input line around the breakdown. However, this inevitably generates a line fault because the picture elements connected to the disconnected input line cannot be energised. In the case where the matrix of picture elements is formed on a single crystalline silicon substrate, protection from damage caused by static

electricity can be achieved by providing a diode or resistor on the silicon substrate. On the other hand, in the case where the matrix of picture elements is formed on a glass substrate electrical insulation breakdown is likely to occur and it is very difficult to provide elements for protecting against damage due to static electricity. As a result, manufacturing yield is reduced.

Figure 2(a) is an enlarged plan view of a conventional active matrix liquid crystal display device and Figure 2(b) is a cross-section thereof. A polycrystalline silicon layer 508 is formed on a glass substrate 515 and a gate insulating layer 513 is formed by thermally oxidising the surface of the polycrystalline layer 508. A second layer of polycrystalline silicon is formed and is patterned by photo-etching thereby simultaneously forming a gate electrode and a gate line 509 of a thin film transistor, and one electrode 512 of a capacitor (such as the capacitor 6 of Figure 1(b)). Then, impurity is diffused into the second polycrystalline silicon layer and into the first polycrystalline silicon layer 508 except in the region masked by the gate electrode 509 in order to form a source region and a drain region. Subsequently an insulating layer 514 is formed all over the surface and contact holes are formed for the source region and the drain region. Lastly, a source line 510 and a picture element driving electrode 511 are formed.

The insulating layer 514 which insulates the source line 510 from the gate line 509 is disposed between the electrode 512 and an electrode 511 of the capacitor.As the capacitance of the capacitor

is in inverse proportion to the thickness of the insulating layer, the insulating layer 514 is required to be thin so that the capacitor has a relatively large capacitance. For example, in the case where each picture element is 1 mm square, the size of the capacitor is limited to 200 μm^2 so as not to effect the brightness of the display. If the insulating layer 514 is formed of silicon oxide and has a thickness of 5,000Å, the capacitance of the capacitor is only about 2.5 pF. On the other hand, the capacitance of the liquid crystal material of the picture element is about 9 pF when the thickness of the liquid crystal material is 10 microns. The capacitance of the capacitor should be at least equal to, but preferably twice or three times as great as that of the liquid crystal material. In order to satisfy this condition, the thickness of the insulating layer 514 should be reduced to one-fifth or one-tenth or the area of the capacitor should be increased by five to ten times. However, as the area of the capacitor must be limited in order not to affect the brightness of the display, the reduction of the thickness of the insulating layer is the only way to make the capacitance of a capacitor larger than the capacitance of the liquid crystal material. Consequently, the insulating layer should be 1000 Å in thickness. Even in the case of utilising silicon nitride for the insulating layer, silicon nitride having a relatively large dielectric constant, the thickness of the insulating layer should be 1000Å to 2000Å.

On the other hand, the gate insulating layer 513 of a thin film

transistor usually is at least 1000 to 2000Å in thickness. When the breakdown voltage of a transistor is to be relatively high, the gate insulating layer is required to have a thickness greater than 5000Å. The breakdown voltage of the gate insulating layer 513 is twice that of the insulating layer 514 when both layers are of the same thickness. Because the gate insulating layer 513 is of silicon oxide and is thermally formed and the insulating layer 514 is of silicon oxide and is deposited by a chemical vapour deposition technique, and the thickness of the gate insulating layer 513 and the insulating layer 514 is 1000 to 2000Å, the breakdown voltage of the insulating layer 514 is necessarily lower than that of the gate insulating layer 513. As a result, static electricity inevitably damages the gate line or the source line where they intersect. Increasing the thickness of the insulating layer 514 in order to protect against damage due to static electricity decreases the capacitance of the capacitor to less than the capacitance of the liquid crystal material.

Referring now to Figure 3(a), there is shown a cross-section of a picture element of an active matrix liquid crystal display device according to the present invention, the cross-section being taken on the same line as Figure 2(b). Figure 3(b) is a plan view of the picture element of Figure 3(a). Like parts in Figures 2 and 3 have been designated by the same reference numerals. In addition to the process steps followed for forming the insulating layer 514 of Figure 2 (indicated by reference numeral 514-1 in Figure 3) a second silicon oxide insulating layer 514-2 is formed all over the surface and

is removed by photo-etching except in the region where the gate line 509 and the source line 510 intersect. Subsequently, contact holes are provided in the source region and the drain region of the first insulating layer 514-1. Lastly the source line 510 is formed. The thickness of the first insulating layer 514-1 is 1000Å to give sufficient capacitance to the capacitor. On the other hand, the thickness of the second insulating layer 514-2 is 5000Å or more for raising the breakdown voltage at the intersection between the gate line and the source line. This construction has the advantage that the breakdown voltage at the intersection between the gate line and the source line is higher that that of the gate insulating film and the capacitance of the capacitor is sufficiently large. The second insulating layer 514-2 may be formed and photo-etched before the first insulating layer 514-1 is formed. In the case where the first and second insulating layers are formed of the same material, such as silicon oxide, the thicker insulating layer 514-2 insulating the gate line 509 from the source line 510 is much more easily photo-etched than the thinner insulating layer 514-1. Further, when the first insulating layer 514-1 is formed first and the second insulating layer 514-2 is then formed thereon, it is better to form the two insulating layers of different materials, for example, the first insulating layer may be silicon nitride and the second insulating layer may be silicon oxide. This is because either of these layers is alternatively photo-etched at the time of patterning.

Figure 4 (a) is a plan view of another embodiment of an active

matrix liquid crystal display device according to the present invention and Figure 4(b) is a cross-section thereof. Again like parts of Figures 2, 3 and 4 have been designated by the same reference numerals. As in Figure 3, the gate insulating layer 513 is formed on the surface of the polycrystalline silicon layer 508 by thermal oxidation and a second silicon oxide layer is formed and patterned to provide the gate line 509 and the electrode 512 of the capacitor. Impurity is diffused into the second silicon oxide layer as well as the first silicon layer 508, except in the region covered by the gate electrode 509. After forming the first insulating layer 514-1 and the second insulating layer 514-2, subsequently the second insulating layer 514-2 in the region of the electrode 512 is removed by photo-etching, thereby only the first insulating layer 514-1 is formed on the electrode 512.The contact holes are formed at the source region and the drain region.The source line 510 and the picture element driving electrode 511 are then formed. In this embodiment the thickness of the first insulating layer 514-1 is 1000Å and that of the second insulating layer 514-2 is 5000Å or more. Thus the breakdown voltage at the intersection between the source line and the gate line is higher than that of the gate insulating layer of the thin film transistor. Further, the capacitor has a sufficient capacitance. In addition the picture element is protected by the second insulating layer which is relatively thick and this permits improvement of reliability. As indicated by a broken line 516 in Figure 4(a), the second insulating layer 514-2 may

substantially agree with or partially cover the capacitor. The larger the area of the capacitor not covered by the second insulating layer 514-2, the greater its capacitance. The insulating layers 514-1, 514-2 are usually formed of silicon oxide, but can be made of silicon nitride and/or aluminium oxide. In addition, the order of forming the two insulating layers can be reversed similar to that described in relation to Figure 3.

Further, the display area of the driving electrode 511 can be increased because it covers the gate line 509 and a part of the first silicon layer 508. Therefore image brightness is much improved. To cover the gate line 509 and a part of the first silicon layer 508 with the driving electrode 511 can be done in the embodiment of Figure 4 because the second insulating layer 514-2 is relatively thick and this reduces or prevents short circuits.

As described above, the active matrix liquid crystal display devices of Figures 3 and 4 are such that breakdown voltage at the intersection of the source line and the gate line in each picture element is made higher than that of the gate insulating film of the thin film transistor by making the insulating layer thicker where the source line and gate line intersect than elsewhere. Damage to the active matrix liquid crystal display device due to static electricity can be reduced or prevented to only involve a single picture element and not produce a line fault. Accordingly, manufacturing yield is much improved and this aids mass production. In addition, the capacitance of the capacitor can be made relatively large so improving

writing characteristics of a data signal. As a result, display characteristics of the active matrix liquid crystal display device as a whole are much improved.

In the embodiments of the present invention described in relation to Figures 3 and 4, the electrodes of the capacitor are separate but it is clear that the invention is applicable to an active matrix liquid crystal display device where one electrode of the capacitor and the gate line of the adjacent picture element are common.

* C L M S *

C L A I M S

1. An active matrix liquid crystal display device comprising a matrix of picture elements, each of the picture elements is composed of a driving electrode, a capacitor for storing a data signal, a MOS trnasistor having a drain electrode, a source electrode and a gate electrode which is covered by a gate insulating layer, the MOS transistor being arranged selectively to apply the data signal to the capacitor, a gate line connected to the gate electrode, a source line orthogonal to the gate line and connected to the source electrode, and a further insulating layer between the gate line and the source line, the breakdown voltage of the further insulating layer being higher than the breakdown voltage of the gate insulating layer.

2. A device as claimed in claim 1, in which the thickness of the further insulating layer at least in the region of the section of each gate line with each source line is greater than in other regions.

3. A device as claimed in claim 1 or 2, in which in each picture element at least a portion of the gate line or the MOS transistor is covered by the respective driving electrode, an insulating layer being disposed therebetween.

* C L M S *

4. A device as claimed in any preceding claim in which the picture elements are formed on a glass substrate.

5. An active matrix liquid crystal display device substantially as herein described with reference to and as shown in Figure 3 or Figure 4 of the accompanying drawings.