

LIQUID CRYSTAL DISPLAY UNIT

The present invention relates to a liquid crystal display unit having a liquid crystal layer between a pair of substrates, pixel electrodes and elements for driving the pixel electrodes arranged in a matrix on one of the pair of substrates, and inter-pixel connections for applying signals to the driving elements.

Conventionally, the elements for driving the pixels of a display unit are non-linear elements with two terminals, typically being non-linear elements employing inorganic film and comprising a metal-insulator-metal (MIM), metal-semi-insulator (MSI), ring diode, back to back diode, varistor and the like structure, or non-linear elements employing organic film such as polyimide and the like.

A first conventional liquid crystal display unit using metal-insulator-metal layers (hereinafter referred to as MIM elements) as elements for driving pixels of the display unit is shown in Figures 3 and 4.

The following explanation is based on using tantalum (Ta) / tantalum oxide (TaOx) / chromium (Cr) layers as a typical layer structure for each MIM element. Generally after preparing a tantalum layer, a layer of tantalum oxide is formed all over the tantalum layer by anodic oxidation or thermal oxidation. It should be noted, however, that it is also known to use aluminium (Al), gold (Au), indium tin oxide (ITO), NiCr + Au, ITO + Cr and the like for the metal layers instead of Ta and Cr, and that it is known to use SiOx, SiNx, SiOxNy, TaNx and ZnOx for the insulator layer instead of TaOx.

In Figures 3 and 4, an overlapping part of a

tantalum layer 1, a tantalum oxide layer 3 formed on the tantalum layer 1, and a chromium element 4, forms an MIM element 9 for driving a pixel by way of a pixel electrode 5. Signals input from a terminal area 6 provided by the tantalum layer 1 are applied to the pixel electrode 5 through an inter-pixel connection 7, which is provided by the tantalum layer 1 and to the tantalum oxide layer 3, and the MIM element 9. All the layers are formed on a substrate 12.

In the above structure, the number of photo-etching steps necessary in the preparation of an element substrate is: one for the formation of the tantalum layer 1, one for the formation of the chromium element 4, and one for the formation of the pixel electrode 5, that is three steps in total. Actually, as shown in Figure 3, it is necessary to remove the tantalum oxide layer 3 from the terminal area 6 and, therefore, a very simple additional photo-etching step, that does not require precise accuracy, must also be executed.

An equivalent circuit diagram is shown in Figure 7. In Figure 7, the distribution resistance of the inter-pixel connection 7 having a value  $R$  is represented by a resistance  $11$  and is provided substantially by the distribution resistance of the tantalum layer 1 because the tantalum oxide layer 3 is an insulator. The MIM element 9 has a structure represented by a capacitor  $C_m$  and a resistance  $R_m$  connected in parallel. As shown, the resistance  $11$  and MIM element 9 are connected in series with a liquid crystal layer 8.

Since the resistance of the inter-pixel connection 7 reduces the signal voltage applied from the terminal area 6, a voltage difference arises between signals applied to those pixel electrodes 5 near the terminal area 6 and signals applied to those pixel electrodes 5

remote from the terminal area 6. The display condition of the liquid crystal display unit near the terminal area 6 thus differs from the display condition remote from the terminal area 6, presented as unevenness in contrast. In order to improve the picture quality of the liquid crystal display unit, it is, therefore, desirable to reduce the resistance of the inter-pixel connection 7.

In the case of the structure of Figure 3, the resistance of the inter-pixel connection 7 can be reduced by enlarging the pattern width of a part of the tantalum layer 1 corresponding to the inter-pixel connection 7, or by increasing the thickness of the tantalum layer 1. However, the former method is contrary to a picture quality improvement obtained by densification of the pixels. The latter method has an adverse effect both on pattern accuracy during pattern formation of the tantalum layer 1 and on step coverage of the chromium element 4 at the edge of the tantalum layer 1.

Therefore, it is extremely difficult to reduce distribution resistance of the inter-pixel connection in a satisfactory manner by these two methods.

An alternative structure for the inter-pixel connection 7 as shown in Figures 5 and 6 has also been proposed.

Using the same chromium layer forming the chromium element 4, a chromium connection element 2 is arranged on the tantalum layer 1 between portions of the tantalum oxide layer 3 such that the inter-pixel connection 7 has a two layer structure provided by the tantalum layer 1 and the chromium connection element 2.

Although the resistivity of the tantalum layer 1 is approximately 220 micro-ohm-cm, that of the chromium

connection element 2 is approximately 30 micro-ohm-cm. Therefore, the above two layer structure is very effective in reducing the resistance of the inter-pixel connection 7.

By increasing the thickness of the chromium layer as the need arises, a sufficiently low resistance can basically be obtained for the inter-pixel connection 7.

However, in this structure, the number of photo-etching steps necessary to prepare an element substrate is: one for the formation of the tantalum layer 1, one for the removal of the tantalum oxide layer 3 at the terminal area 6 and along the inter-pixel connection 7, one for the formation of the chromium element 4 and the chromium connection element 2, and one for the formation of the pixel electrode 5, that is four steps in total.

Consequently, by reducing the distribution resistance of the inter-pixel connection in this way, the cost of producing the liquid crystal display unit is drastically increased and, moreover, the production yield is reduced.

As in the manufacture of semi-conductor products, such as ICs, the cost of producing a liquid crystal display unit depends on the number of photo-etching steps in the process. Therefore, the production costs for the structure in Figure 5 are approximately  $4/3$  times the costs for the structure in Figure 4.

The production process for the structure in Figure 5 is described below with reference to Figures 9 (a) to 9 (e).

First, a thin film of tantalum is formed on the substrate 12, and patterned into a desired configuration to provide the tantalum layer 1 as shown in Figure 9 (a).

Second, the surface of the patterned tantalum layer 1 is oxidized to generate the tantalum oxide layer 3 (see Figure 9 (b)).

The tantalum oxide layer 3 of the inter-pixel connection 7 is removed in a desired portion by boring as shown in Figure 9 (c).

Then, chromium is formed and patterned in a desired configuration to produce the chromium connection element 2 of the inter-pixel connection 7 and the chromium element 4 constituting an upper electrode of the MIM element 9 as shown in Figure 9 (d).

Finally, a transparent conductive film is formed and patterned in a desired configuration to provide the pixel electrode 5 as shown in Figure 9 (e), which corresponds with a section along the line d - d' in Figure 5.

In Figure 9 (c) in the above process, the surface of the tantalum oxide layer 3 in the region where the tantalum layer 1 and the chromium element 4 overlap, that is the region forming the MIM element, is to be exposed to the photo-etching process. Therefore, by comparison with the process for manufacturing the structure shown in Figure 3, defects are increased at the tantalum oxide inter-face of the MIM element, and this results in a reduction in the production yield for the liquid crystal display unit.

As stated above, the conventional structures for liquid crystal display units either have the problem that it is difficult to reduce the distribution resistance of an inter-pixel connection, or the problem that reducing distribution resistance causes a drastic increase in production cost and a reduction in yield.

The present invention seeks to provide an element substrate for a liquid crystal display unit, in which

an inter-pixel connection may have a low resistance without increasing cost.

According to the present invention, there is provided a liquid crystal display unit having a liquid crystal layer between a pair of substrates, pixel electrodes and non-linear elements for driving the pixel electrodes arranged in a matrix on one of the pair of substrates, and inter-pixel connections for applying signals to the non-linear elements, characterised in that each of the inter-pixel connections comprises a connection element capacitively connected in series with each of the associated non-linear elements.

The present invention will be described further, by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is a plan view of an element substrate of a liquid crystal display unit according to the present invention;

Figure 2 is a sectional view taken on the line a - a' in Figure 1;

Figure 3 is a plan view of an element substrate of a conventional liquid crystal display unit;

Figure 4 is a sectional view taken on the line b - b' in Figure 3;

Figure 5 is a plan view of an element substrate of a conventional liquid crystal display unit;

Figure 6 is a sectional view taken on the line c - c' in Figure 5;

Figure 7 is an equivalent circuit diagram of a pixel of a conventional liquid crystal display unit;

Figure 8 is an equivalent circuit diagram of a pixel of a liquid crystal display unit of the present invention; and

Figures 9 (a) to 9 (e) are sectional views showing



stages in the production process for the element substrate of the conventional liquid crystal display unit of Figures 5 and 6.

Referring to Figures 1 and 2, an element substrate of a liquid crystal display unit according to the invention is illustrated. Like parts are indicated by the same reference numerals as in Figures 3 to 6.

In this instance, a chromium connection element 2 is formed along an inter-pixel connection 7 and over a terminal area 6 without removing a tantalum oxide layer 3 from the inter-pixel connection 7 or the terminal area 6.

Signals input from the terminal area 6, and thus input to the chromium connection element 2, are applied to a pixel electrode 5 through the tantalum oxide layer 3 of the inter-pixel connection 7 and an MIM element 9.

The tantalum oxide layer 3 is naturally an insulator film. Signals supplied to the chromium connection element 2 are transmitted through this insulator film to a tantalum layer 1 of the inter-pixel connection 7 and thence to the MIM element 9. Now, the insulator film generally has a large insulation resistance. Therefore, the signals cannot be supplied to the MIM element 9 unless they pass through this high resistance portion even when the resistance of the chromium connection element 2 is at a low level.

The inter-pixel connection 7 composed of the chromium connection element 2, the tantalum oxide layer 3 and the tantalum layer 1 has the same structure as the MIM element 9. Moreover, it effectively comprises an MIM portion having a larger area than the MIM element 9, being composed of layers of tantalum, tantalum oxide and chromium. Namely, the signals supplied to the chromium connection element 2 are transmitted through

the larger area MIM portion into the MIM element 9.

An equivalent circuit diagram is shown in Figure 8.

In Figure 8, a distribution resistance 11, having a resistance value  $R$ , represents the distribution resistance of the inter-pixel connection 7 in Figure 1, and is substantially provided by the distribution resistance of the chromium connection element 2. A connection area MIM portion 10 represents the large area MIM portion, which is composed of the tantalum layer 1, the tantalum oxide layer 3 and the chromium connection element 2 of the inter-pixel connection 7. The qualitative electrical properties of the liquid crystal display unit can be explained on the basis that these parts, namely the MIM portion 10, the MIM element 9, and a liquid crystal layer 8 are connected in series.

In this state,  $C_m \ll C_L$  and  $r_m \gg r_L$ . Since the MIM element 9 and the connection area MIM portion 10 are connected in series:

$$\begin{aligned} C_o &= 1/(1/C_m + 1/C_L) \\ &= C_m / (1 + C_m/C_L) \\ &= C_m \\ R_o &= r_m + r_L \\ &= r_m (1 + r_L/r_m) \\ &= r_m \end{aligned}$$

where  $C_o$  is the composite capacitance of the two MIM portions, and  $R_o$  is the composite resistance. As can be seen, from the point of view of the electrical properties, the connection area MIM portion 10 can be ignored as against the MIM element 9.

Therefore, in accordance with the present invention, a liquid crystal display unit having an

inter-pixel connection with a low resistance using the chromium connection element 2 is obtained.

In the structure of the present invention, the number of photo-etching steps necessary to prepare an element substrate is: one for the formation of the tantalum layer 1, one for the formation of the chromium element 4 and the chromium connection element 2, and one for the formation of the pixel electrode 5, that is only three steps in total.

In other words, a fewer number of photo-etching steps is necessary than to prepare the conventional element substrate shown in Figure 3 having the high distribution resistance for the inter-pixel connection.

Compared with the number of photo-etching steps necessary to prepare the conventional element substrate shown in Figure 5, having the low distribution resistance as a result of the modified inter-pixel connection 7, which is four steps in total, the production costs for an element substrate can be reduced to 3/4.

Moreover, defects at the tantalum oxide interface of the MIM element can also be reduced drastically, because the surface of the tantalum oxide layer 3 is not exposed to the photo-etching process.

A liquid crystal display unit having element substrates as described above in accordance with the present invention provides an improved picture quality as a result of low distribution resistance of the inter-pixel connections, and, moreover, permits reduced production costs.

Further, the double structure of the inter-pixel connections enables a drastic reduction in defects resulting from dis-connections in the inter-pixel connections.

C L A I M S

1. A liquid crystal display unit having a liquid crystal layer between a pair of substrates, pixel electrodes and non-linear elements for driving the pixel electrodes arranged in a matrix on one of the pair of substrates, and inter-pixel connections for applying signals to the non-linear elements, characterised in that each of the inter-pixel connections (7) comprises a connection element (2) capacitively connected in series with each of the associated non-linear elements (9).
2. A liquid crystal display unit as claimed in claim 1 characterised in that each of the inter-pixel connections comprises a multi-layer structure providing the connection element and the capacitive connection.
3. A liquid crystal display unit as claimed in claim 2 characterised in that the multi-layer structure comprises the connection element, which has a relatively low resistance, an insulating layer (3), and a conductive layer (1) which has a relatively high resistance.
4. A liquid crystal display unit as claimed in claim 2 or 3 characterised in that the multi-layer structure comprises an MIM structure.
5. A liquid crystal display unit comprising liquid crystals held between a pair of substrates, pixel electrodes and non-linear elements for driving said pixel electrodes arranged in a matrix on one of said pair of substrates, and inter-pixel connections for

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applying signals to said non-linear elements, characterised in that a capacitor ( $C_L$ ) is arranged between said inter-pixel connections (7) and said non-linear elements (9), and said inter-pixel connections, said capacitor and said non-linear elements are connected in series.



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