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"LIQUID CRYSTAL DISPLAY DEVICE"

This invention relates to liquid crystal display devices and in particular twisted nematic liquid crystal display devices.

Twisted nematic liquid crystal display devices are commonly
5 used in electronic watches, pocket calculators etc. Twisted nematic liquid crystal display devices are described in detail, for example, in U.S. Patent Specification No. 3 731 986 and U.S. Patent Specification No. 3 995 949. A twisted nematic liquid crystal display device occupies a relatively large percentage of the space
10 in an electronic watch or an electronic calculator and it is, therefore, desirable to make it lightweight and thin.

Usually, a twisted nematic liquid crystal display device produces a dark or black display on a clear or white background. If a twisted nematic liquid crystal display device produces a
15 clear or white display on a dark background undesirable shadow images appear with the result that the display is indistinct and not easy to read.

According to the present invention there is provided a twisted nematic liquid crystal display device comprising a first
20 substrate having electrode means on one surface and a first polariser on the opposite surface, the electrode means being in contact with a twisted nematic liquid crystal layer, a second polariser having electrode means on one surface thereof in contact with the liquid crystal layer, and a reflective second substrate
25 in contact with the opposite surface of the second polariser,

the surface of said second substrate being roughened to diffuse light but having substantially no sharp points.

Preferably the planes of polarisation of said first and second polarisers are parallel to each other to produce a white or clear display on a black or dark background.

The twist angle of said liquid crystal layer may be substantially 90° . Alternatively the twist angle of said liquid crystal layer may be between 65° and 89° or between 91° and 115° .

In one embodiment said second polariser comprises a stretched polyvinyl alcohol film impregnated with iodine and a transparent protective film.

In another embodiment said second polariser comprises a polarising plate.

Preferably the distance between the opposed surfaces of the said liquid crystal layer and the second substrate is sufficiently small so as to reduce substantially the formation of shadow images. Said distance may be less than $250\text{ }\mu\text{m}$.

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

Figure 1 is a cross-sectional view of a conventional twisted nematic liquid crystal display device;

Figure 2 is provided to explain the formation of the shadow images in the conventional twisted nematic liquid crystal display device of Figure 1; and

Figure 3 is a cross-sectional view of an embodiment of a twisted nematic liquid crystal display according to the present invention.

A conventional twisted nematic liquid crystal display device shown in Figure 1 has a twisted nematic liquid crystal layer 1, an upper substrate 2, a lower substrate 3, an upper polariser 4, a lower polariser 5, and a reflector 6. The planes of polarisation of the upper and lower polarisers are perpendicular to each other, corresponding to the molecular direction of the adjacent surface of the liquid crystal layer 1. The interior or opposed surfaces of the substrates 2, 3 are each unidirectionally rubbed with a material such as cotton, the directions of rubbing being at about 90° to each other. The liquid crystal display device shown in Figure 1 produces a dark display on a clear background. If the planes of polarisation of the upper and lower polariser are parallel to each other, then a clear or white display on a dark background will be produced. In the latter case, the liquid crystal display device has the disadvantage that the display is unclear and brightness and contrast are poor.

Figure 2 is a cross-sectional view showing the liquid crystal display device of Figure 1 to explain these disadvantages. If the liquid crystal layer 1 has a display region 7 and the planes of polarisation of the upper and lower polarisers 4, 5 are parallel to each other, a clear or white display of the display region 7 on a dark background will be produced. The rays of light from

directions A, B, C of incidence may pass through only the display region 7 and they form images between points a_1 and a_2 , between points b_1 and b_2 and between points c_1 and c_2 of the display region 7, respectively, on the light reflecting surface of the reflector 6. A relatively large amount of the incident light falls upon the area between points a_1 and c_2 and, therefore, this area is relatively bright. However, only a relatively small amount of the incident light falls upon the area between points c_1 and b_1 and between points b_2 and a_2 and so these areas are not very bright. Because the polarised light reflected by the reflector 6 from the area between points c_1 and b_1 and the area between points b_2 and a_2 enters the liquid crystal layer 1 away from the display region 7, and the plane of polarisation is rotated by 90° by the liquid crystal layer 1, this light cannot pass through the upper polariser 4. Thus the central part of the image produced from the display region 7 is brightest and as one moves away from this central part, the brightness reduces. That is, the image of the display region 7 has a non-uniform brightness. In the case of a black display on a clear background, the same phenomenon is present but non-uniformity of the black display is inconspicuous. However, in the case of a clear or white display on a dark background, the display is indistinct because of the various angles of incidence of light passing through the display region 7 and so such a liquid crystal display device has not, up until now, been practical. The non-uniformity of the brightness depends upon the distance between the

lower surface of the liquid crystal layer 1 and the reflecting surface of the reflector 6. The greater this distance the more the brightness of the image is non-uniform. Conventionally, as this distance is usually greater than 500 μm , the image has a
5 distinct non-uniformity of brightness.

Figure 3 is a cross-sectional view of an embodiment of a twisted nematic liquid crystal display device according to the present invention. Upper electrodes 12 having a desired pattern and made of a transparent electrically conductive material such as
10 indium oxide or indium tin oxide are formed on an inner surface of an upper transparent substrate 14. The upper electrodes 12 are in contact with a twisted nematic liquid crystal layer 11. A lower substrate 17 is made of glass, plastics material, ceramic material, metal or some other suitable material, and the inner surface thereof
15 is roughened by, for example, grinding, sand-blasting or moulding to provide a light diffusing surface 18. In the case where the lower substrate is transparent, a coating of a reflecting material, for example, aluminium, silver, gold or copper is deposited on the roughened surface. Preferably, the inner surface of the lower
20 substrate 17 is roughened by aluminium balls or the like having diameters of 1 to 100 μm , preferably about 50 μm , and is buffed or heat-treated so that the roughness of the surface has no sharp points. This has been found to improve contrast of the display because sharp points cause light to be reflected in a undesired
25 directions. Light reflected in undesired directions, i.e. directions

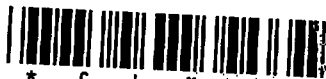
which are at a large angle to the normal to the lower surface of the liquid crystal layer 11, is reflected by the latter and is not used in the formation of an image. A lower polarising layer 15 is disposed on the lower substrate 17. The polarising layer 15 may be formed by adhering a stretched polyvinyl alcohol (PVA) film impregnated with iodine and a transparent protective film such as silicon dioxide, (SiO_2), aluminium oxide (Al_2O_3) or plastics material thereon, or by adhering a conventional polarising plate thereto. In the former case the polarising layer may be 20 μm to 50 μm thick, and in the latter case it may be a 100 μm to 250 μm thick. On the polarising layer 15, lower electrodes 13 having a desired pattern of transparent conductive material such as indium oxide or indium tin oxide is formed by, for example, cold sputtering. The lower electrodes 13 are in contact with the liquid crystal layer 11.

It is preferably to form the lower electrode 13 at a relatively low temperature if the polarising layer 15 is a stretched PVA film impregnated with iodine, because the latter loses its polarising characteristics at above about 100°C. The inner surfaces of the upper transparent substrate 14 with the upper electrodes 12 and the polarising layer 15 with the protective film and the lower electrodes 13 are each unidirectionally rubbed with, for example, cotton and nematic liquid crystal material is sandwiched therebetween to form the twisted nematic liquid crystal layer 11. The upper and lower substrates 14, 17 are mounted so that the directions of rubbing of the opposed surfaces are at about 90° to each other, and the

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molecules of the liquid crystal layer 11 form a helix with a 90° twist. The angle between the rubbing directions, that is the twist angle of the liquid crystal layer 11, may be between 65° and 89° or 91° and 115° so that the molecules are arrayed in helices having the same twist. This is described in greater detail in U.S. Patent Specification No. 3 947 185. An upper polarising layer 16 is disposed on the outer surface of the upper substrate 14 so that the plane of polarisation of the upper polarising layer 16 is parallel to that of the lower polarising layer 15. Such a liquid crystal display device produces a white or clear display on a black or dark background.

The twisted nematic liquid crystal display device described above in relation to Figure 3 may be made very thin and only a very small space exists between the lower surface of the liquid crystal layer 11 and the reflecting surface of the lower substrate, so that it is possible to reduce the formation of undesired shadow images to produce a clear or white display on a black background. Thus the display can have a high degree of contrast and a relatively wide visual angle.



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CLAIMS

1. A twisted nematic liquid crystal display device comprising a first substrate having electrode means on one surface and a first polariser on the opposite surface, the electrode means being in contact with a twisted nematic liquid crystal layer, a second
5 polariser having electrode means on one surface thereof in contact with the liquid crystal layer, and a reflective second substrate in contact with the opposite surface of the second polariser, the surface of said second substrate being roughened to diffuse light but having substantially no sharp points.
- 10 2. A liquid crystal display device as claimed in claim 1 in which the planes of polarisation of said first and second polarisers are parallel to each other to produce a white or clear display on a black or dark background.
3. A liquid crystal display device as claimed in claim 1 or 2
15 in which the twist angle of said liquid crystal layer is substantially 90° .
4. A liquid crystal display device as claimed in claim 1 or 2 in which the twist angle of said liquid crystal layer is between 65° and 89° or between 91° and 115° .
- 20 5. A liquid crystal display device as claimed in any preceding claim in which said second polariser comprises a stretched polyvinyl alcohol film impregnated with iodine and a transparent protective film.



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6. A liquid crystal display device as claimed in any of claims 1 to 5 in which said second polariser comprises a polarising plate.
7. A liquid crystal display device as claimed in any preceding claim in which the distance between the opposed surfaces of the said liquid crystal layer and the second substrate is sufficiently small so as to reduce substantially the formation of shadow images.
8. A liquid crystal display device as claimed in claim 7 in which said distance is less than 250 μm .
9. A twisted nematic liquid crystal display device substantially as herein described with reference to and as shown in Figure 3 of the accompanying drawings.

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