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(54) LIQUID CRYSTAL DISPLAY DEVICE

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a Japanese company, of 3-4, 4-chome, Ginza, Chuo-ku, Tokyo, Japan, do hereby declare the invention for which we pray that a patent may be granted to us and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to liquid crystal display devices.

Liquid crystal display devices utilising nematic liquid crystal material may be classified roughly into those of the dynamic scattering type and those of the field-effect type. Liquid crystal display devices of the field-effect type may be classified into those of the DAP type and those of the twisted nematic type, according to the orientation of the molecules of the nematic liquid crystal material. Liquid crystal display devices of the DAP type are such that the nematic liquid crystal material has negative dielectric anisotropy and the molecules thereof are homeotropically aligned, that is to say the molecular axes are aligned perpendicular to the plane of plates between which the nematic liquid crystal material is sandwiched. Liquid crystal display devices of the twisted nematic type are such that the nematic liquid crystal material has positive dielectric anisotropy and the molecules thereof are homogeneously aligned, that is to say, the molecular axes are aligned parallel to the plane of plates between which the nematic liquid crystal material is sandwiched and, furthermore, the molecules of the nematic liquid crystal material in contact with the surface of each plate are orientated in a given direction depending upon the nature of the surface, so that the nematic liquid crystal material has a helical structure in a direction perpendicular to the plane of the plates when the given directions are at an angle to one another.

In the case of a liquid crystal display

device of the twisted nematic type, the surface of each plate may be rubbed, for example, with cotton in a given direction so that the molecules of the nematic liquid crystal material in contact with that surface become aligned with the given direction. It is believed that the rubbing of the surface of the plates, causes minute grooves to be formed, the molecules of the nematic liquid crystal material being trapped in these grooves with their molecular axes parallel thereto.

If each of the plates is rubbed in a given direction, and if the given directions are at an angle to one another, the nematic liquid crystal material has a helical structure with the axis of the helix perpendicular to the plane of the plates, so that the nematic liquid crystal material is optically active and rotates the phase of polarisation of incident light passing through the nematic liquid crystal material through an angle equal to the angle between the given directions of rubbing. If an electric field is applied to the nematic liquid crystal material, this optical activity is destroyed. Thus, if the liquid crystal display device is sandwiched between polarizing plates the liquid crystal display device will appear light or dark depending upon whether or not an electric field is applied to the nematic liquid crystal material.

It will be appreciated that the molecules of the nematic liquid crystal material may be aligned with the given directions of rubbing of each plate in one of two opposite directions. Since there are two such directions of alignment for each plate, there are four possible directions of alignment for the liquid crystal display device as a whole. In the conventional liquid crystal display device of the twisted nematic type, although all four directions of alignment are not always present, a plurality of directions of alignment are present. The presence of different directions of alignment cause domains to

be observed, the direction of alignment of the molecules of nematic liquid crystal material in adjacent domains being different. The presence of these domains causes a contrast of the display produced by the liquid crystal display device to vary with the direction of observation. To avoid this undesirable change in contrast, it is necessary to ensure that that molecules of the nematic liquid crystal material are aligned in a single direction and that there is only one domain on the surface of each plate, i.e. the nematic liquid crystal material is in a monocrystalline condition.

According to one aspect of the present invention there is provided a liquid crystal display device comprising two spaced-apart transparent plates having transparent electrode means on the opposed surfaces thereof, and nematic liquid crystal material having positive dielectric anisotropy disposed between the plates, the arrangement being such that the nematic liquid crystal material in the absence of an electric field has a single domain helical structure with the axis of the helix perpendicular to the plane of the plates, and the twist angle of the helical structure being either between 65° and 89° or between 91° and 115° .

The nematic liquid crystal material may be of a type in which the potential energy stored therein increases with increase of twist angle. Thus the twist angle may be substantially 75° .

Alternatively the nematic liquid crystal material may be of a type in which the potential energy stored therein reduces with increase of twist angle. Thus the twist angle may be substantially 105° .

The liquid crystal display device may include at least two apertures being formed in the plates for insertion of nematic liquid crystal material therebetween and exhaust of air and/or excess nematic liquid crystal material therefrom, the line joining the apertures being parallel to the long molecular axis of the nematic liquid crystal material in a plane intermediate the two plates.

According to a further aspect of the present invention there is provided a timepiece or an electronic calculator having a liquid crystal display device as recited above.

According to another aspect of the present invention there is provided a method of making a liquid crystal display device comprising the steps of disposing a nematic liquid crystal material having positive dielectric anisotropy between two spaced-apart transparent plates having transparent electrode means on the opposed surfaces thereof, and arranging for the nematic liquid crystal material to have a single domain helical structure with the axis of the helix perpendicular to the plane of the plates in the absence of an electric field, the twist

angle of the helical structure being either between 65° and 89° or between 91° and 115° .

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), shows graphically the relationship between potential energy E and twist angle ϕ for liquid crystal display devices of type A and type B respectively.

Figure 2 is a plan view of a known type of liquid crystal display device given for the purpose of explaining the present invention;

Figure 3 is a plan view of one embodiment of a liquid crystal display device according to the present invention;

Figure 4 is a plan view of a second embodiment of a liquid crystal display device according to the present invention;

Figure 5 is a sectional view of a further embodiment of a liquid crystal display device according to the present invention; and

Figure 6 is a plan view of the liquid crystal display device of Figure 5.

Liquid crystal display devices of the twisted nematic type may be classified according to the potential energy needed to produce the helical structure of the nematic liquid crystal material. Figure 1(a) illustrates graphically the relationship between twist angle ϕ of the helical structure of the nematic liquid crystal material of type A and potential energy E. It will be seen that the larger the twist angle ϕ , the larger the potential energy E.

Figure 1(b) illustrates graphically, the relationship between twist angle ϕ of the helical structure of the nematic liquid crystal material of type B and potential energy E. It will be seen, in this case, that the larger the twist angle ϕ the smaller the potential energy E.

Whether the nematic liquid crystal material is of type A or type B appears to be determined by the molecular structure and the intermolecular forces thereof.

Referring to Figure 2, there is shown a known type of liquid crystal display device given for the purpose of explaining the present invention. The liquid crystal display device has a front plate 11, a rear plate 12 between which is sandwiched the nematic liquid crystal material 13. The plates 11, 12 are transparent having transparent electrode means (not shown) on the opposed surfaces thereof. The direction of orientation of the inner surface of the front plate 11 in contact with the nematic liquid crystal material is shown by a solid arrow and the direction of orientation of the inner surface of the rear plate 12 in contact with the nematic liquid crystal material is shown by a dotted arrow. The angle ϕ between these directions of orientation is 90° and the directions of

orientation are generated by rubbing the opposed surfaces of the plates in the direction of the arrows with, for example, cotton.

The orientation of the molecules of the nematic liquid crystal material in contact with either the front plate 11 or the rear plate 12 in a first respective direction will be referred to herein as "normal surface orientation". The orientation of the molecules of the nematic liquid crystal material in contact with either the front plate or the rear plate in a second respective direction, opposite to the first direction, will be referred to as "reverse surface orientation". The nematic liquid crystal material is relatively free to select normal or reverse surface orientation. Minute grooves formed in the front plate and the rear plate by rubbing e.g. with cotton, are thought to trap the molecules of the nematic liquid crystal material so that they tend to have normal surface orientation. However, if the molecules of the nematic liquid crystal material have reverse surface orientation, this cannot easily be reversed. As will be discussed whether the molecules of the nematic liquid crystal material in contact with the surface of either the front plate or the rear plate have uniform orientation or not, depends upon the twist angle and the potential energy of the associated helical structure.

When there is a domain on the surface of the front plate having normal surface orientation and a domain on the surface of the rear plate having reverse surface orientation there is little possibility of the orientation of either domain being reversed. The reason for this is because that the twist angle between a domain on the front plate 11 and a domain on the rear plate 12 both having normal surface orientations (a situation called herein "normal-normal surface orientations") is 90° and this is the same as the twist angle between a domain on the front surface having a reverse surface orientation and a domain on the rear surface having a normal surface orientation (a situation called herein "normal-reverse surface orientations"). Thus the potential energy for normal-normal surface orientations and normal-reverse surface orientations is substantially the same and consequently both are equally stable, all that, in effect, differs between these two conditions is whether the twist of the helical structure is left-handed or right-handed. Consequently, once a domain has a normal or reverse surface orientation it is almost impossible to change it.

Figure 3 show a liquid crystal display device according to the present invention similar to that of Figure 2, but where the twist angle of the helical structure of the nematic liquid crystal material is 75° . The twist angle between domains having normal-

normal surface orientations is 75° and the twist angle between domains having normal-reverse surface orientations is 105° ($180^\circ - 75^\circ = 105^\circ$). In the case where the nematic liquid crystal material is of type A, the twist angle is 75° for normal-normal surface orientations and this is more stable than for normal-reverse surface orientations where the twist angle is 105° . Thus for nematic liquid crystal material of type A, domains having normal-normal surface orientations are more stable than those having normal-reverse surface orientations because the former has a lower potential energy than the latter. Thus there is a tendency for domains with normal-reverse surface orientations to revert to normal-normal surface orientations, so that alignment of the molecules in nematic liquid crystal material in contact with the surfaces of the plates 11, 12 tends to become uniform.

In the case of a liquid crystal display device of Figure 3 having nematic liquid crystal material of type B, neither domains with normal-normal surface orientation nor normal-reverse surface orientation are particularly stable because there is a significant energy difference between the normal and reverse orientations at each plate so it is difficult to achieve uniform alignment of the molecules of nematic liquid crystal material in contact with the surfaces of the plates 11, 12.

In Figure 4 there is shown a liquid crystal display device, similar to that of Figure 3, where the twist angle of the helical structure of the nematic liquid crystal material is 105° . In the case where the nematic liquid crystal material is of type B, the twist angle is 75° for normal-reverse surface orientations and this is less stable than for normal-normal surface orientations where the twist angle is 105° . Thus, there is a tendency for domains with normal-reverse surface orientation to revert to normal-normal surface orientation and so the alignment of molecules in nematic liquid crystal material in contact with the surfaces of the plates 11, 12 tends to become uniform.

In the case where the nematic liquid crystal material is of type A, neither the domains with normal-normal surface orientations nor normal-reverse surface orientation are particularly stable so it is difficult to achieve uniform alignment of the molecules of nematic liquid crystal material in contact with the surface of the plates 11, 12.

From the above discussion, it will be appreciated that the greater the difference between the twist angle ϕ and 90° the more uniform surface orientation can be achieved. However, when this difference is extremely large, a clearly visible display is difficult to obtain. Therefore, the twist angle must be between 65° and 89° or between 91° and 130° .

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115°.

In the conventional liquid crystal display device of the twisted nematic type, the influence upon the formation of domains by pouring or otherwise inserting the nematic liquid crystal material between the plates has not yet been considered.

Figure 5 is a sectional view of a further embodiment of a liquid crystal display device according to the present invention and comprising a front plate 21, a rear plate 22 both of which are transparent and both of which have transparent electrodes (not shown) on the opposed surfaces thereof, a thin layer of nematic liquid crystal material 23 sandwiched between the plates, a spacer 24 for sealing the liquid crystal display device against leakage of nematic liquid crystal material therefrom, an aperture 25 for inserting a nematic liquid crystal material into the space between the plates, and an aperture 26 for exhausting air and excess nematic liquid crystal material from between the plates.

Referring to Figure 6, the orientation of the molecules of the nematic liquid crystal material in contact with the front plate 21 is indicated by a solid arrow and the orientation of the molecules of the nematic liquid crystal material in contact with the rear plate 22 is indicated by a dotted arrow, the two directions being at an angle ϕ and passing through the centre of the layer of nematic liquid crystal material. The orientation of the molecules of the nematic liquid crystal material in contact with the surfaces of the plates is generated by rubbing the surfaces, for example, with cotton. The aperture 25 is disposed in a first quadrant and the aperture 26 is disposed in the diametrically opposite quadrant.

The nematic liquid crystal material is injected into the space between the plates 21, 22 through the aperture 25, air and excess nematic liquid crystal material in the space exiting therefrom via the aperture 26. Since the molecules of the nematic liquid crystal material have a non-symmetric molecular structure and anisotropic viscosity, they show a tendency to be aligned in a fixed direction when the nematic liquid crystal material flows. Therefore, the apertures 25, 26 are located so that the fixed direction of alignment of the molecules of nematic liquid crystal material as it flows corresponds to the directions desired for the alignment of the molecules of the nematic liquid crystal material in contact with the surface of the plates. Thus the line drawn between the apertures 25, 26 is disposed at a predetermined angle to the direction of alignment of the molecules of nematic liquid crystal material in contact with the plates.

Depending upon the nature of the nematic liquid crystal material, the functions of the

apertures 25, 26 may be reversed. In this manner uniform alignment of the molecules and nematic liquid crystal material in contact with the surface of the plates may be achieved, and the formation of domains is reduced or prevented.

The two methods of preventing or reducing formation of domains discussed above, whilst they can be used independently to advantage, produce a more improved liquid crystal display device if employed together.

The present invention may be applied to all liquid crystal display devices of the twisted nematic type and enables a clear display to be achieved.

Liquid crystal display devices according to the present invention may be applied, for example, to timepieces and electronic desk calculators.

WHAT WE CLAIM IS:—

1. A liquid crystal display device comprising: two spaced-apart transparent plates having transparent electrode means on the opposed surfaces thereof, and nematic liquid crystal material having positive dielectric anisotropy disposed between the plates, the arrangement being such that the nematic liquid crystal material in the absence of an electric field has a single domain helical structure with the axis of the helix perpendicular to the plane of the plates, and the twist angle of the helical structure being either between 65° and 89° or between 91° and 115°.

2. A liquid crystal display device as claimed in claim 1 in which the nematic liquid crystal material is of a type in which the potential energy stored therein increases with increase of twist angle.

3. A liquid crystal display device as claimed in claim 2 in which the twist angle is substantially 75°.

4. A liquid crystal display device as claimed in claim 1 in which the nematic liquid crystal material is of a type in which the potential energy stored therein reduces with increase of twist angle.

5. A liquid crystal display device as claimed in claim 4 in which the twist angle is substantially 105°.

6. A liquid crystal display device as claimed in any preceding claim including at least two apertures formed in the plates for insertion of nematic liquid crystal material therebetween and exhaust of air and/or excess nematic liquid crystal material therefrom, the line joining apertures being parallel to the long molecular axis of the nematic liquid crystal material in a plane intermediate the two plates.

7. A liquid crystal display device substantially as herein described with reference to and as shown in Figures 3 to 6 of the accompanying drawings.

115°.

In the conventional liquid crystal display device of the twisted nematic type, the influence upon the formation of domains by pouring or otherwise inserting the nematic liquid crystal material between the plates has not yet been considered.

Figure 5 is a sectional view of a further embodiment of a liquid crystal display device according to the present invention and comprising a front plate 21, a rear plate 22 both of which are transparent and both of which have transparent electrodes (not shown) on the opposed surfaces thereof, a thin layer of nematic liquid crystal material 23 sandwiched between the plates, a spacer 24 for sealing the liquid crystal display device against leakage of nematic liquid crystal material therefrom, an aperture 25 for inserting a nematic liquid crystal material into the space between the plates, and an aperture 26 for exhausting air and excess nematic liquid crystal material from between the plates.

Referring to Figure 6, the orientation of the molecules of the nematic liquid crystal material in contact with the front plate 21 is indicated by a solid arrow and the orientation of the molecules of the nematic liquid crystal material in contact with the rear plate 22 is indicated by a dotted arrow, the two directions being at an angle ϕ and passing through the centre of the layer of nematic liquid crystal material. The orientation of the molecules of the nematic liquid crystal material in contact with the surfaces of the plates is generated by rubbing the surfaces, for example, with cotton. The aperture 25 is disposed in a first quadrant and the aperture 26 is disposed in the diametrically opposite quadrant.

The nematic liquid crystal material is injected into the space between the plates 21, 22 through the aperture 25, air and excess nematic liquid crystal material in the space exiting therefrom via the aperture 26. Since the molecules of the nematic liquid crystal material have a non-symmetric molecular structure and anisotropic viscosity, they show a tendency to be aligned in a fixed direction when the nematic liquid crystal material flows. Therefore, the apertures 25, 26 are located so that the fixed direction of alignment of the molecules of nematic liquid crystal material as it flows corresponds to the directions desired for the alignment of the molecules of the nematic liquid crystal material in contact with the surface of the plates. Thus the line drawn between the apertures 25, 26 is disposed at a predetermined angle to the direction of alignment of the molecules of nematic liquid crystal material in contact with the plates.

Depending upon the nature of the nematic liquid crystal material, the functions of the

apertures 25, 26 may be reversed. In this manner uniform alignment of the molecules and nematic liquid crystal material in contact with the surface of the plates may be achieved, and the formation of domains is reduced or prevented.

The two methods of preventing or reducing formation of domains discussed above, whilst they can be used independently to advantage, produce a more improved liquid crystal display device if employed together.

The present invention may be applied to all liquid crystal display devices of the twisted nematic type and enables a clear display to be achieved.

Liquid crystal display devices according to the present invention may be applied, for example, to timepieces and electronic desk calculators.

WHAT WE CLAIM IS:—

1. A liquid crystal display device comprising: two spaced-apart transparent plates having transparent electrode means on the opposed surfaces thereof, and nematic liquid crystal material having positive dielectric anisotropy disposed between the plates, the arrangement being such that the nematic liquid crystal material in the absence of an electric field has a single domain helical structure with the axis of the helix perpendicular to the plane of the plates, and the twist angle of the helical structure being either between 65° and 89° or between 91° and 115°.
2. A liquid crystal display device as claimed in claim 1 in which the nematic liquid crystal material is of a type in which the potential energy stored therein increases with increase of twist angle.
3. A liquid crystal display device as claimed in claim 2 in which the twist angle is substantially 75°.
4. A liquid crystal display device as claimed in claim 1 in which the nematic liquid crystal material is of a type in which the potential energy stored therein reduces with increase of twist angle.
5. A liquid crystal display device as claimed in claim 4 in which the twist angle is substantially 105°.
6. A liquid crystal display device as claimed in any preceding claim including at least two apertures formed in the plates for insertion of nematic liquid crystal material therebetween and exhaust of air and/or excess nematic liquid crystal material therefrom, the line joining apertures being parallel to the long molecular axis of the nematic liquid crystal material in a plane intermediate the two plates.
7. A liquid crystal display device substantially as herein described with reference to and as shown in Figures 3 to 6 of the accompanying drawings.





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8. A timepiece or an electronic calculator having a liquid crystal display device as claimed in any preceding claim.

9. A method of making a liquid crystal display device comprising the steps of disposing a nematic liquid crystal material having positive dielectric anisotropy between two spaced-apart transparent plates having transparent electrode means on the opposed surfaces thereof, and arranging for the nematic liquid crystal material to have a single domain helical structure with the axis of the helix perpendicular to the plane of the plates in the absence of an electric field, the twist angle of the helical structure being

either between 65° and 89° or between 91° and 115° .

10. A method of making a liquid crystal display device substantially as herein described with reference to Figures 3 to 6 of 20 the accompanying drawings.

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