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(54) IMPROVEMENTS IN OR RELATING TO LIQUID CRYSTAL DISPLAY ARRANGEMENTS

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a corporation of Japan, domiciled in 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 arrangements.

It is well known to display the output from an electronic calculating machine by means of a display device adapted to display indicia, usually numerals or letters, under the control of the output from the machine, said device having one or more sets of elements in such mutual relationship that, by selectively energising different combinations of the elements of any set, that set may be caused (under the control of the machine) to display a different one of a number of predetermined indicia. Thus, to take as an example the case where the display device is adapted to give a numeric display, said device may comprise a plurality of sets of elements each set consisting of elements so positioned with respect to one another that, by selectively energising (under the control of the calculating machine) different combinations of elements in any set, that set may be caused recognisably to display any number between 0 and 9.

The invention provides impoved liquid crystal display arrangements that is to say, arrangements comprising display devices in which use is made, for display purposes, of the light scattering properties of a liquid crystal when subjected to the influence of an electric field. As is well known, if a liquid crystal, notably a nematic type of liquid crystal or a cholestric type of liquid crystal, or a mixture of these types of crystal is positioned between opposed electrodes, the liquid crystal will scatter light. A liquid crystal display device is one in which use is made of this light scattering property. Liquid crystal display devices have very useful advantages over other forms of light display devices such as cathode ray tubes. Among the more important of these advantages is that of very low power consumption (about 1mW/cm² of displayed area); small size; (a liquid crystal thickness between electrodes of only about 20μ is usually sufficient); the inherent ability to present a planar display; low cost, and the inherent ability to present a clearly distinguishable display under conditions of strong ambient light. On the other hand known liquid crystal display devices have certain defects which make them unsatisfactory and the present invention seeks to provide improved liquid crystal display devices in which these defects are greatly reduced or eliminated. The aforesaid defects will be explained with reference to Figures 1, 2 and 3 of the accompanying drawings, in which:—

Figure 1 is a diagrammatic cross-section of a known single element liquid crystal device, and

Figures 2 and 3 show diagrammatically two known arrangements of multi-element liquid crystal display device and driving circuit therefor.

Referring to Figure 1 which shows in schematic cross-section a single element of a liquid crystal display device comprising flat glass plates 1 which are spaced apart by insulating spacers 3, and film electrodes 2 made of the material known under the Registered Trade Mark "Nesa" on the opposed faces of the plates. The cell volume constituted by the space bounded by the electrodes 2 and the spacers 3 is filled with a liquid crystal 5. By means of leads 6 a suitable potential may be applied between the electrodes and thus, by subjecting the liquid crystal to an electric field, cause it to scatter light.

The power consumption of a device as illustrated by Figure 1 is very small, only about 1mw/cm², it is compact because as little as 20μ is enough for the thickness of the liquid crystal, it gives a planar display, the cost per unit area of the device is relatively low, and the lighter the environment the more distinguishable is the display.

[Price 25p]

Price 75p

A display device as so far described with reference to Figure 1 would tend to have a short useful working life because of the effects on the electrodes of Hydrogen and Oxygen gas bubbles which are released by electrolysis of water in the liquid crystal when potential is applied between the electrodes. A known expedient for avoiding this defect is so to construct at least one of the electrodes 2 that the surfaces thereof in contact with the liquid crystal is of a material which acts as a catalyst with respect to the combination of Hydrogen and Oxygen into water. This expedient is preferably adopted in carrying out the present invention.

A known device as illustrated in Figure 1, when forming part of a multi-element display device comprising selectively energisable elements, each as illustrated by Figure 1, and associated with a known energising or driving circuit, has operating defects which it is the object of the present invention to overcome. One of these defects is that leakage through stray capacity may cause faint illumination of one or more elements at a time when they are required to be de-energised and not produce any display. Another defect is that if, as is often the case, a drive of a pulsed wave form nature is employed, the range of pulse periodicities and the range of pulse duration/space ratios which can be satisfactorily employed, are undesirably limited. In addition, in arrangements in which the display device is a passive one in the sense that it receives (and scatters) only external light, the display capacity by light scattering is undesirably limited.

These defects will be better understood from a consideration of Figure 2 which shows diagrammatically a known arrangement including a liquid crystal display device comprising three sets A, B, C each of four elements. In Figure 2 the liquid crystal is represented diagrammatically as though it were arranged in columns K, of which twelve are shown, four in each set. Each column is between upper and lower electrodes, there being four upper electrodes (i.e. upper in Figure 2) co-operating with a common lower counter electrode in each set. Of course in practice the liquid crystal is not in divided columns but is in a continuous layer between all the individual upper electrodes, on the one hand, and the common lower counter electrode on the other, each element including the portion of the liquid layer which is directly between one of the individual upper electrodes and the directly opposite portion of the appropriate common lower counter electrode. It is, however convenient, for purposes of diagrammatic illustration, to show the liquid as if it were in separate columns and also to show all the upper electrodes as side by side in a sort of developed sectional view. In practice, of course, each set of elements could consist of any convenient number of elements and be in any known mutual arrangement— for example as shown in Figure 8 (to be described later)—so that, by selecting different elements in a set for energisation (by means of the transistors 7 and 9) any of a number of different indicia (for example numerals) could be displayed by any set.

The known selective energising circuit shown in Figure 2 comprises a group of four transistors 7 and a group of three transistors 9. Each of the four transistors 7 enables a pulse to be applied to a different group of three individual upper electrodes, one in each set, when a negative going pulse is applied to the base to be cut off the transistor. Each of the three transistors 9 enables an earth connection to be applied to a selected common lower counter electrode when a positive-going pulse applied to the base to render the transistor conductive. Although, theoretically, the combination of switching transistors 7 and 9 can be used to select any desired combination of elements, in practice leakage, partly transverse currents through the resistance of the liquid and general "cross-talk" effects between adjacent elements may cause weak but nevertheless undesirable illumination of elements which are not intended (at the time) to be illuminated. Thus, for example, although only certain elements in a set may be, at some particular time, selected for energisation by the transistors, all the elements in that set may become weakly illuminated. Moreover, the illumination of the elements actually switched in at any given instant, i.e. the light scattering effected by those elements, will not be sufficient if the repetition period of the applied is to much longer than the pulse width, i.e. if the pulse duration/space ratio is too low. This defect—insufficient illumination of selected eltments—will be manifested if the duration/space ratio is too low even when the peak voltage applied, i.e. the pulse amplitude, is quite high. The same defects apply to the other known arrangement illustrated by Figure 3, which differs from Figure 2 only by the insertion of the diodes D in the leads to the individual upper electrodes for these diodes are inserted in their respective leads in such polarity sense as to pass capacity-discharging current from the capacitances of the elements of which the upper individual electrodes form part.

According to this invention there is provided a liquid crystal display arrangement comprising a display device having at least one indicia-displaying set of elements said set having a plurality of individual electrodes each individual to a different element in the set and a counter electrode which is common to all said individual electrodes, the liquid crystal material being between said individual electrodes, on the one hand, and said counter electrode on the other hand: and an operating circuit arrangement for selectively causing said

elements to effect display, said operating circuit arrangement comprising a plurality of transistors each of which has its output electrode connected to a different one of said individual electrodes through a diode which is inserted in the connection between said output electrode and said individual electrode in such polarity sense as to prevent capacitance-discharging current from the capacitance of the element of which said individual electrode forms part flowing from said individual electrode through said diode; a further transistor connected to and in series with said counter electrode; and means for simultaneously applying a negative-going pulse to the control electrode or electrodes of a selected transistor or transistors in said plurality of transistors to control the conductivities thereof and applying a positive-going pulse to the control electrode of said further transistor to render it conductive.

There may be a plurality of sets of elements, corresponding elements in each set being connected, each through the diode connected thereto, to the output electrode of the same transistor in said plurality of transistors, there being a plurality of said further transistors, each connected to the counter electrode in a different set, and means being provided for applying positive pulses simultaneously to a selected counter electrode or electrodes.

The aforesaid diodes are preferably incorporated in the structure of the display device.

In carrying out the present invention the known expedient of making at least one of the electrodes in each element so as to have a surface made of a substance which acts as a catalyst with respect to the combination of hydrogen and oxygen into water—preferably a transition metal or an alloy of such metals or an oxide or oxides of such metal or alloy—is adopted in order to avoid shortening of the useful life as a result of the release of Hydrogen and Oxygen by hydrolysis.

The present invention will now be described with reference to Figures 4 to 9 of the accompanying drawings in which Figure 4 is a circuit diagram representation of one embodiment of this invention; Figure 5 is a diagrammatic representation of another embodiment comprising a multi-element liquid crystal display device connected in an operating circuit providing co-ordinate (X and Y) operation; Figure 6 is a schematic representation of a preferred form of display device for use in carrying out the invention; Figures 7 and 8 illustrate a modification; and Figure 9 shows, so far as is necessary to an understanding thereof, a numeric display panel utilising the invention.

Referring to Figure 4 which is a circuit diagram representation of the invention, it will be observed that this figure differs from Figure 3 by the fact that the diodes D of Figure 4 are poled oppositely to the diodes D of Figure 3. In the arrangement of Figure 3 the electric charge stored in an element which is switched in can discharge through the liquid crystal to another element which is not switched in and said other element can accordingly be weakly illuminated. In Figure 4, on the other hand, when the liquid crystal is to be caused to produce a light display at some element, a negative-going pulse is applied to the base of a transistor 7 and a positive-going one to the base of a transistor 9. A potential of +V is thus applied to the electrodes at both ends of the appropriate column of the liquid crystal. In the absence of such applied pulses on the bases of the said transistors 7 and 9, the former is conductive but the latter is cut off. However, owing to the way in which the diodes D are poled, the electric charge stored in the element is not discharged through a diode D. In this way the charge storing capacity is increased as compared with what happens in Figure 3 in which the diodes D are so poled as to allow discharge through them. Accordingly the above-mentioned defect of Figure 3 is avoided for each element is electrically separated, and faint illumination of an undesired segment by leakage through stray capacity is eliminated, so that the illuminated and non-illuminated conditions can be completely distinguished. As explained above, electric charges are stored in the elements switched in. Even when narrow pulses are used, an element is charged during a pulse, the charge leaking away due to the resistance of the liquid crystal in that element until the next pulse re-charges that same element. Therefore electric current always flows through the liquid crystal of a selected element and the previously mentioned defect of poor light scattering response of the liquid crystal in the element if the pulsing is of low duration/space ratio is overcome.

Referring to Figure 5 a Y co-ordinate pulse input is applied from a pulse generator PY via the transistors shown connected thereto and an X co-ordinate pulse input is applied from a pulse generator PX via the AND gates G and the transistors shown connected thereto, the second inputs to the AND gates being provided from the source (the calculating machine) the output from which is to be displayed. In Figure 5 this source is represented merely by the block SS. The diodes D, in series with resistances, between the X connections and the Y connections will be noted.

Figure 6 shows a preferred way of carrying out the invention. Here diodes D (see Figure 4) are integrally incorporated in the structure, in manner somewhat akin to integrated circuit construction, in the display device itself, Figure 6 being a schematic cross-section of part of the said device. In Figure 6 a transparent glass plate 14 carries a transparent thin film coating 15 constituting a common counter electrode. 16 is a liquid crystal substance, and

17 an opposed electrode arrangement constructed to incorporate the diodes. The electrode arrangement 17 includes an N type silicon base plate 20 with P and N type diffused layers 18 and 19 respectively. 21 is a protecting film for surface insulation such as SiO_2, SiN_4, Al_2O_3 and which is windowed as shown to expose areas of P type material. In use 20 is connected to the point of maximum potential in the operating circuit and, as will be seen, individually insulated P-N diodes are thus formed.

If in any particular case, the effective area of each element is very small the illumination of a selected switched-in element may be less than is required. If this difficulty is encountered it can be overcome by connecting a capacity in parallel with each element. This is illustrated diagrammatically in Figure 7 in which C are the added parallel condensers. Figure 8 is a schematic representation showing a practical way of providing the added condensers. In Figure 8 electrodes 24 are connected to the element electrodes 23 of a numeric display set of elements of which 22 is the common counter electrode. The liquid crystal is between the element electrodes and the common counter electrode and is represented by the dotted line 25, being retained by a suitable highly conductive peripheral spacer (not indicated). An electric charge stored between 24 and 22 is discharged between 23 and 22 so the capacity between 23 and 22 is substantially increased. The condenser electrode spacing material (not shown) should be a material of high dielectric constant. Figure 8 does not show the diodes which are provided in carrying out the invention but it is to be understood that there are provided in the manner already described with reference to Figure 6.

As already explained unless steps are taken to prevent it, the life of a liquid crystal in a known liquid crystal display device is reduced by gas bubbles produced by electrolysis of water present in the liquid crystal by direct current voltage, deterioration of the liquid crystal being caused by influence of the gas. For this reason in carrying out the present invention, at least the surface of an electrode in contact with the liquid crystal is preferably made up of a transition metal such as palladium, platinum, nickel, rhodium, iridium, cobalt, or their alloys, or oxides of their metals and alloys. If this is done the electrode acts as a catalyst to cause hydrogen and oxygen released by electroloysis to re-combine into water.

A liquid crystal in a display device when subjected to applied voltage, scatters light to which it is exposed and will therefore operate as a passive device in the sense that it will work with no other light source but ambient light. For such operation, however, it must receive enough light from outside otherwise it cannot function as a display cell. If, however, this difficulty is met by providing a light source to supplement ambient light, the electric power required for that source constitutes a practical disadvantage, especially if the liquid crystal display device is to form part of a portable electric calculated equipment, for then the requirement of very small overall electric power cannot be satisfied. However, considerable improvement in the utilisation of ambient light can be obtained by providing a mirror or a half mirror at the back of the liquid crystal. If this is done it is desirable to eliminate as far as possible unnecessary reflection from the mirror reaching the eyes of an observer. This can be achieved, in manner known *per se*, by absorbing with a black substance, light rays which could be otherwise reflected into the eyes of an observer.

In a conventional type of numeric electronic calculator, the number of columns of numerals is generally 8 to 16, and a whole column is so arranged that 8 to 16 display tubes are arranged in one column. This, however, is costly and the wiring is complex and apt to give trouble.

The above defects can be reduced, the advantages of the liquid crystal display fully utilized, and the response of the liquid crystal improved, by limiting the thickness of the liquid crystal film within a certain range of values.

Figure 9 shows a display unit which can be used in carrying out this invention with considerable advantage as compared with a conventional display tube type display wherein the number of tubes is equal to that of the columns. In Figure 9, 26 is a transparent glass plate which is nearest the viewer and 27 a glass plate opposite to it (behind it in Figure 9). A mirror type of thin film providing good reflection is evaporated onto the back of the glass plate 27. 28 are individual element electrodes of transparent film on the side of the glass plate 26 there being seven such element electrodes in each set (of which eight are shown) the elements of each set being in such mutual arrangement that, by selective energisation of the elements of any set, it will display a desired numeral. 29 is a common counter electrode for all the individual element electrodes and is on the front of the back plate 27. 30 are connections, preferably in conductive deposit form, leading to the individual element electrodes from terminals 31; 32 is a lead to the common counter electrode 29 and is also of deposited form, being deposited on the glass plate 27. 33 are connecting terminals for applying signals from the driving circuit (not shown in Figure 9) to the common counter electrode and in Figure 9, there are eight of these as the number of sets (columns) is eight. The hatched area 34 represents an insulating spacer, preferably of plastic film from 1μ to 12μ thick. It deter-

mines the thickness of the thin film of the liquid crystal cell (1μ to 12μ thick) and insulates the lead wires 30 of the elements and of the common electrode as clear from Figure 9. Only the portions of the liquid crystal immediately between individual element electrodes on the one hand and a common counter electrode on the other hand, between which potential is applied will scatter light and therefore contribute to the display. Figure 9 shows eight numeric indicating sets in one display unit and is suitable for an electronic calculator of the eight column type. For a calculator adapted to provide 16 columns 16 numeric indicator sets could easily be incorporated in one unit which would be easy to manufacture, very convenient for wiring and assembly in the calculating machine of high reliability and low cost.

By suitably choosing the liquid crystal, its thickness (i.e. making it thin), and the operating and applied signal voltages, very fast response times and decrement times can be achieved. With a really thin liquid crystal film a very fast delay time of light scatter—less than 30 milli-seconds—is achievable. Such a display device is thus very well adapted to display the output from a computer or other electronic calculating device, being capable of high speed display.

WHAT WE CLAIM IS:—

1. A liquid crystal display arrangement comprising a display device having at least one indicia-displaying set of elements said set having a plurality of individual electrodes each individual to a different element in the set and a counter electrode which is common to all said individual electrodes, the liquid crystal material being between said individual electrodes, on the one hand, and said counter electrode on the other hand: and an operating circuit arrangement for selectively causing said elements to effect display, said operating circuit arrangement comprising a plurality of transistors each of which has its output electrode connected to a different one of said individual electrodes through a diode which is inserted in the connection between said output electrode and said individual electrode in such polarity sense as to prevent capacitance-discharging current from the capacitance of the element of which said individual electrode forms part flowing from said individual electrode through said diode; a further transistor connected to and in series with said counter electrode; and means for simultaneously applying a negative-going pulse to the control electrode or electrodes of a selected transistor or transistors in said plurality of transistors to control the conductivities thereof and applying a positive-going pulse to the control electrode of said further transistor to render it conductive.

2. A display arrangement as claimed in claim 1 wherein there is a plurality of sets of elements, corresponding elements in each set being connected, each through the diode connected thereto to the output electrode of the same transistor in said plurality of transistors, there being a plurality of said further transistors, each connected to the counter electrode in a different set, and means being provided for applying positive pulses simultaneously to a selected counter electrode or electrodes.

3. A dsplay arrangement as claimed in claim 1 or 2 wherein the aforesaid diodes are incorporated in the structure of the display device.

4. A display arrangement as claimed in any of the preceding claims wherein each set comprises a plurality of individual electrodes of such shapes and in such mutual arrangement that, by selection of different combinations of said individual electrodes, different numerals can be displayed by the set.

5. A display arrangement as claimed in any of the preceding claims wherein a plurality of additional parallel condensers is provided, each connected between the counter electrode of a set and a different one of the individual electrodes thereof.

6. A display arrangement as claimed in claim 3 wherein the diodes are incorporated as junctions of semi-conductor material of opposite conductivity types in a semi-conductor individual electrode structure of semi-conductor material.

7. A display arrangement as claimed in claim 6 wherein the display device comprises a transparent insulating plate carrying a common counter electrode and constituting one wall of a cell containing liquid crystal with said liquid crystal in contact with said electrode, and a semi-conductor plate structure forming another opposite wall of said cell, said structure including a member of semi-conductor material having diffused areas of one conductivity type therein, said areas being recessed below that surface of said member which is towards the liquid crystal, diffused areas of opposite conductivity type in the recesses in the first mentioned areas, and a protective insulating covering over the diffused areas said covering being windowed to expose portions of the areas of said opposite conductivity type to the liquid crystal.

8. A display arrangement as claimed in any of the preceding claims and comprising a display device wherein the liquid crystal is of small thickness of between 1μ and 12μ.

9. A display arrangement as claimed in any of the preceding claims and comprising a display device wherein there is a liquid crystal cell one wall of which is formed as a mirror.

mines the thickness of the thin film of the liquid crystal cell (1μ to 12μ thick) and insulates the lead wires 30 of the elements and of the common electrode as clear from Figure 9. Only the portions of the liquid crystal immediately between individual element electrodes on the one hand and a common counter electrode on the other hand, between which potential is applied will scatter light and therefore contribute to the display. Figure 9 shows eight numeric indicating sets in one display unit and is suitable for an electronic calculator of the eight column type. For a calculator adapted to provide 16 columns 16 numeric indicator sets could easily be incorporated in one unit which would be easy to manufacture, very convenient for wiring and assembly in the calculating machine of high reliability and low cost.

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2. A display arrangement as claimed in claim 1 wherein there is a plurality of sets of elements, corresponding elements in each set being connected, each through the diode connected thereto to the output electrode of the same transistor in said plurality of transistors, there being a plurality of said further transistors, each connected to the counter electrode in a different set, and means being provided for applying positive pulses simultaneously to a selected counter electrode or electrodes.

3. A dsplay arrangement as claimed in claim 1 or 2 wherein the aforesaid diodes are incorporated in the structure of the display device.

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5. A display arrangement as claimed in any of the preceding claims wherein a plurality of additional parallel condensers is provided, each connected between the counter electrode of a set and a different one of the individual electrodes thereof.

6. A display arrangement as claimed in claim 3 wherein the diodes are incorporated as junctions of semi-conductor material of opposite conductivity types in a semi-conductor individual electrode structure of semi-conductor material.

7. A display arrangement as claimed in claim 6 wherein the display device comprises a transparent insulating plate carrying a common counter electrode and constituting one wall of a cell containing liquid crystal with said liquid crystal in contact with said electrode, and a semi-conductor plate structure forming another opposite wall of said cell, said structure including a member of semi-conductor material having diffused areas of one conductivity type therein, said areas being recessed below that surface of said member which is towards the liquid crystal, diffused areas of opposite conductivity type in the recesses in the first mentioned areas, and a protective insulating covering over the diffused areas said covering being windowed to expose portions of the areas of said opposite conductivity type to the liquid crystal.

8. A display arrangement as claimed in any of the preceding claims and comprising a display device wherein the liquid crystal is of small thickness of between 1μ and 12μ.

9. A display arrangement as claimed in any of the preceding claims and comprising a display device wherein there is a liquid crystal cell one wall of which is formed as a mirror.

10. Liquid crystal display device arrangements substantially as herein described with reference to Figures 4 to 9 inclusive of the accompanying drawings.

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