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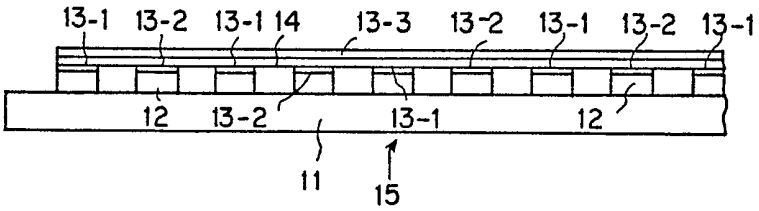
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(54) A multi-colour liquid crystal display device

(57) A multi-colour liquid crystal display device is described comprising two base plates 11 (11'), each having a plurality of electrodes 12 provided thereon in the form of a plurality of parallel rows, the rows of electrodes on one base plate being not parallel to, and preferably perpendicular to, the rows of electrodes on the other base plate. A plurality of colour filters 13—1, 13—2 13—3, (and 13—4) are provided between the base plates. At least one colour filter is provided in the form of rows parallel to the plurality of electrodes on each of the base plates (11 and 11') so that at least two colour filters overlap. A light path from an electrode on one plate to the corresponding electrode on the other plate passes through one or more of the filters so that a colour display of many different hues is obtained. Subtractive or additive mixing of the colours may occur which may include a combination of primary and secondary colours. A protective film 14 may separate the two sets of filters.

FIG. 7



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FIG. 1

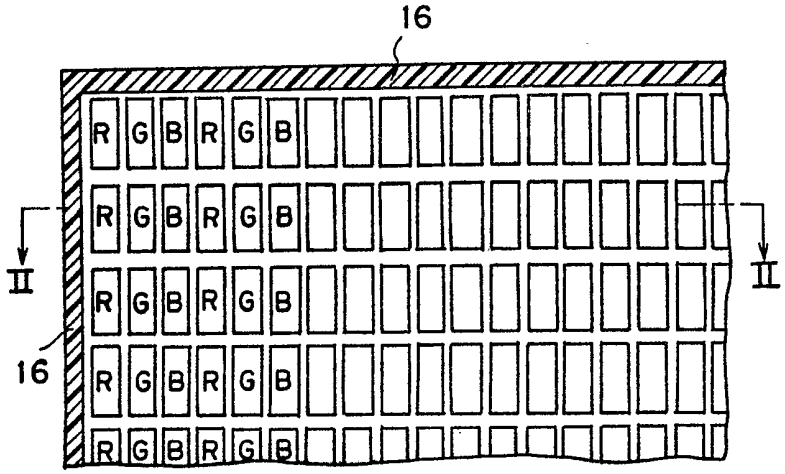


FIG. 2

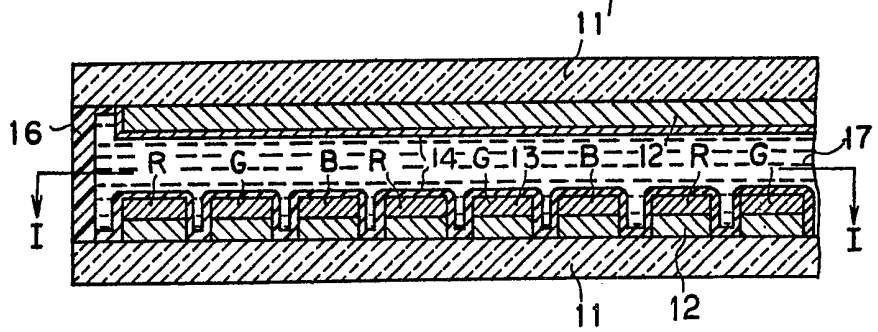


FIG. 4

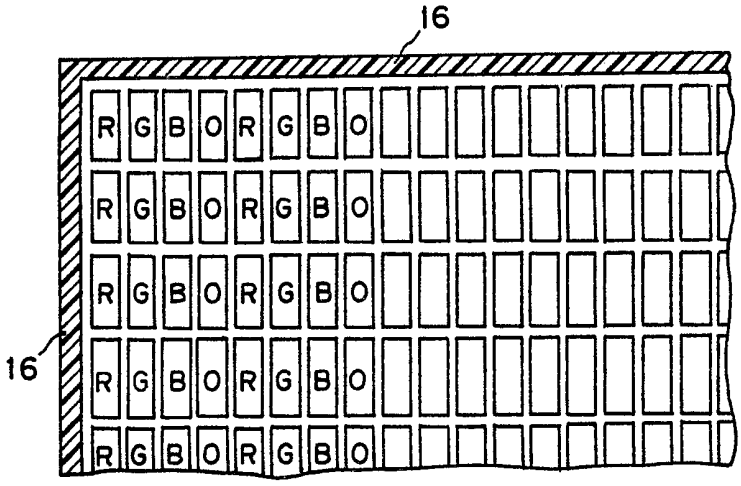


FIG. 3

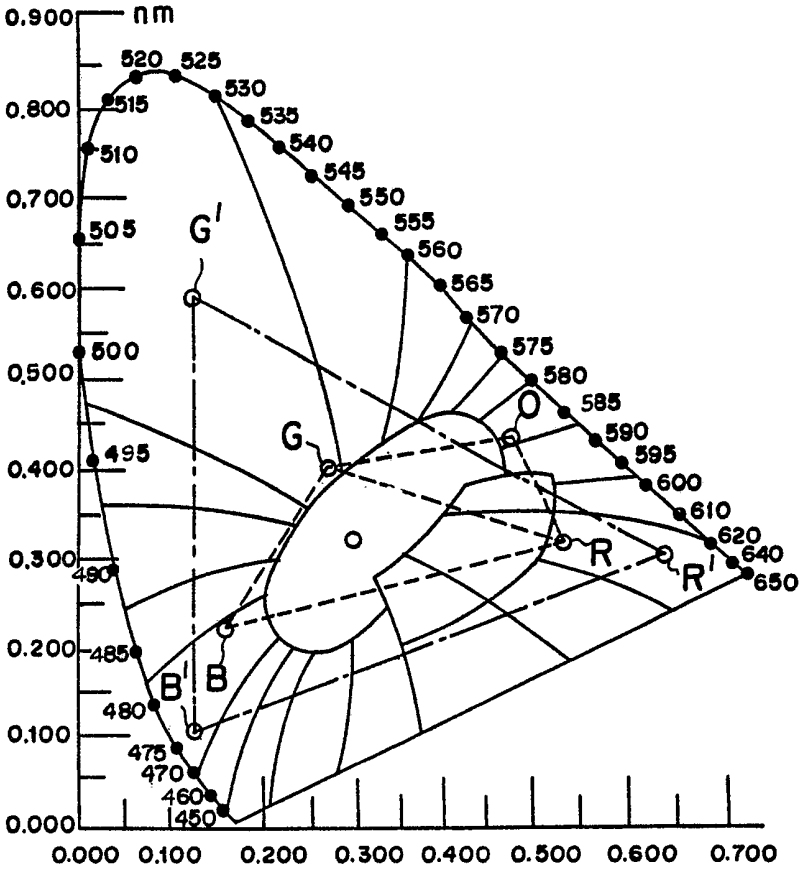


FIG. 5-A

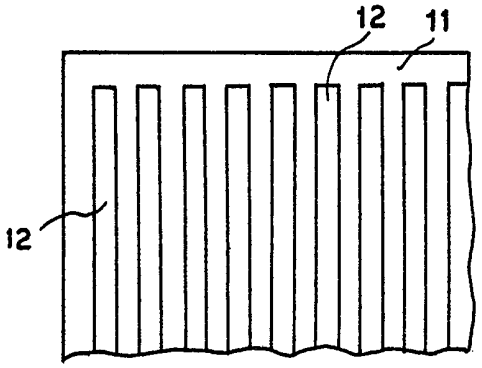


FIG. 5-B

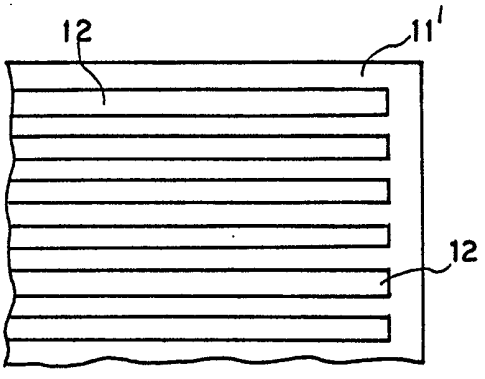


FIG. 6

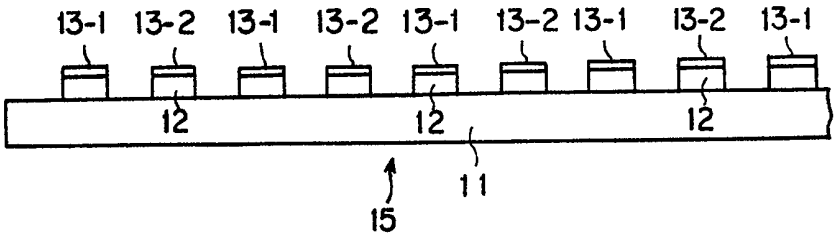


FIG. 7

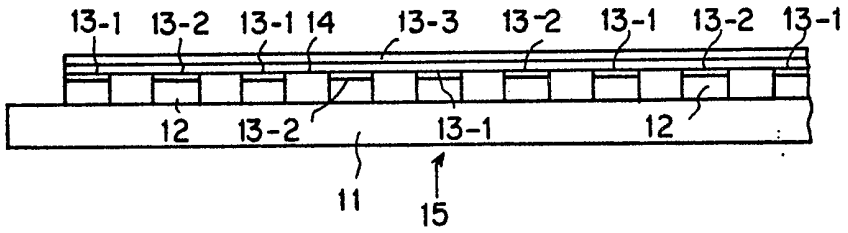


FIG. 8

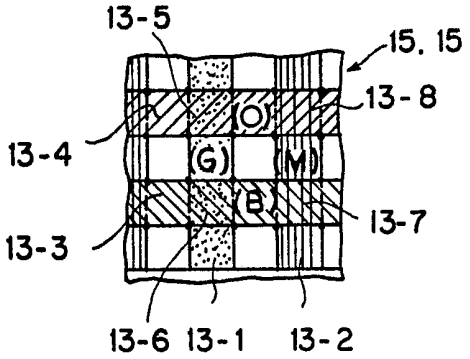


FIG. 9-A

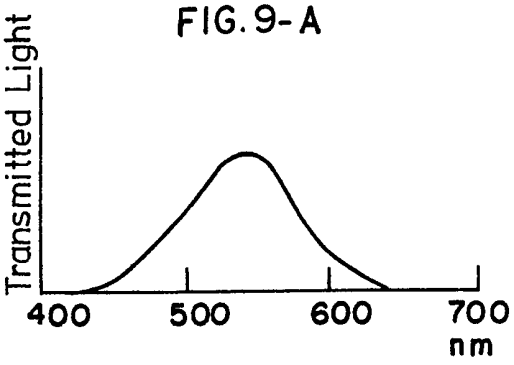


FIG. 9-C

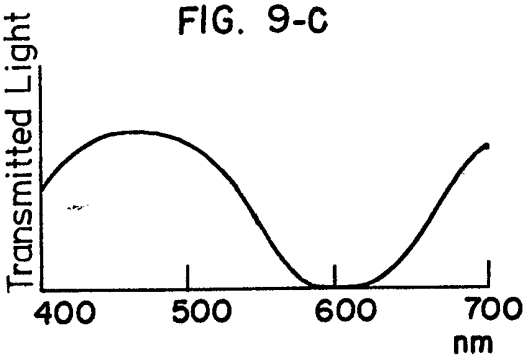


FIG. 9-B

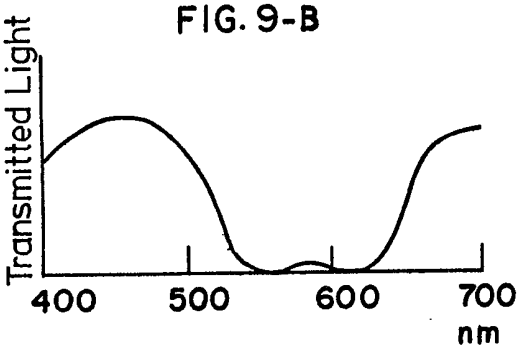


FIG. 9-D

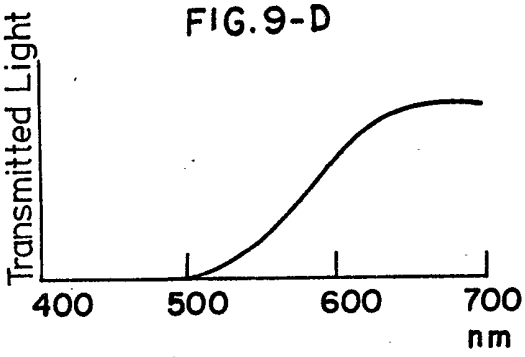


FIG. 10-A

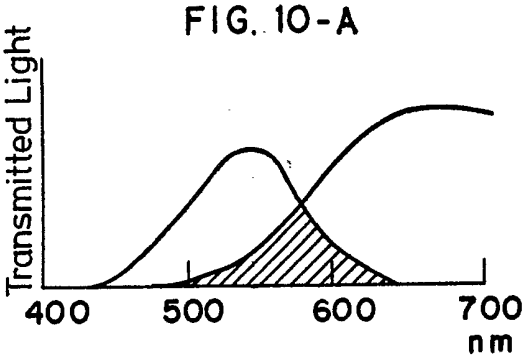


FIG. 10-C

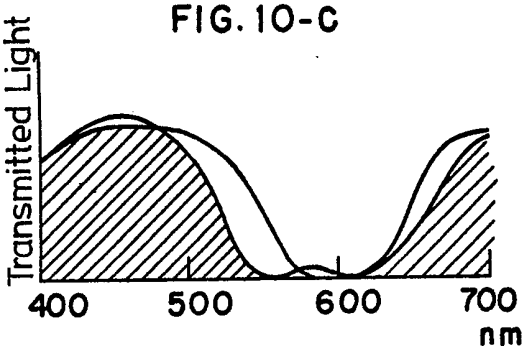


FIG. 10-B

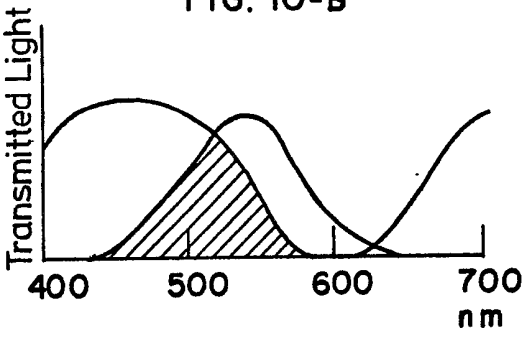


FIG. 10-D

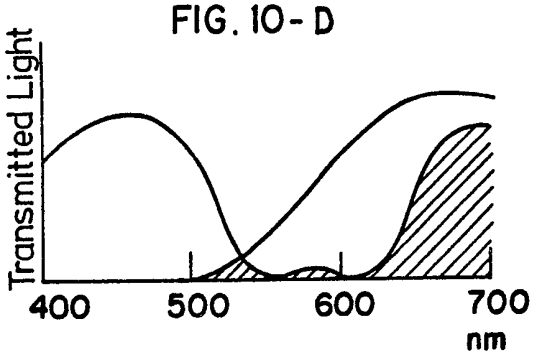


FIG. 11

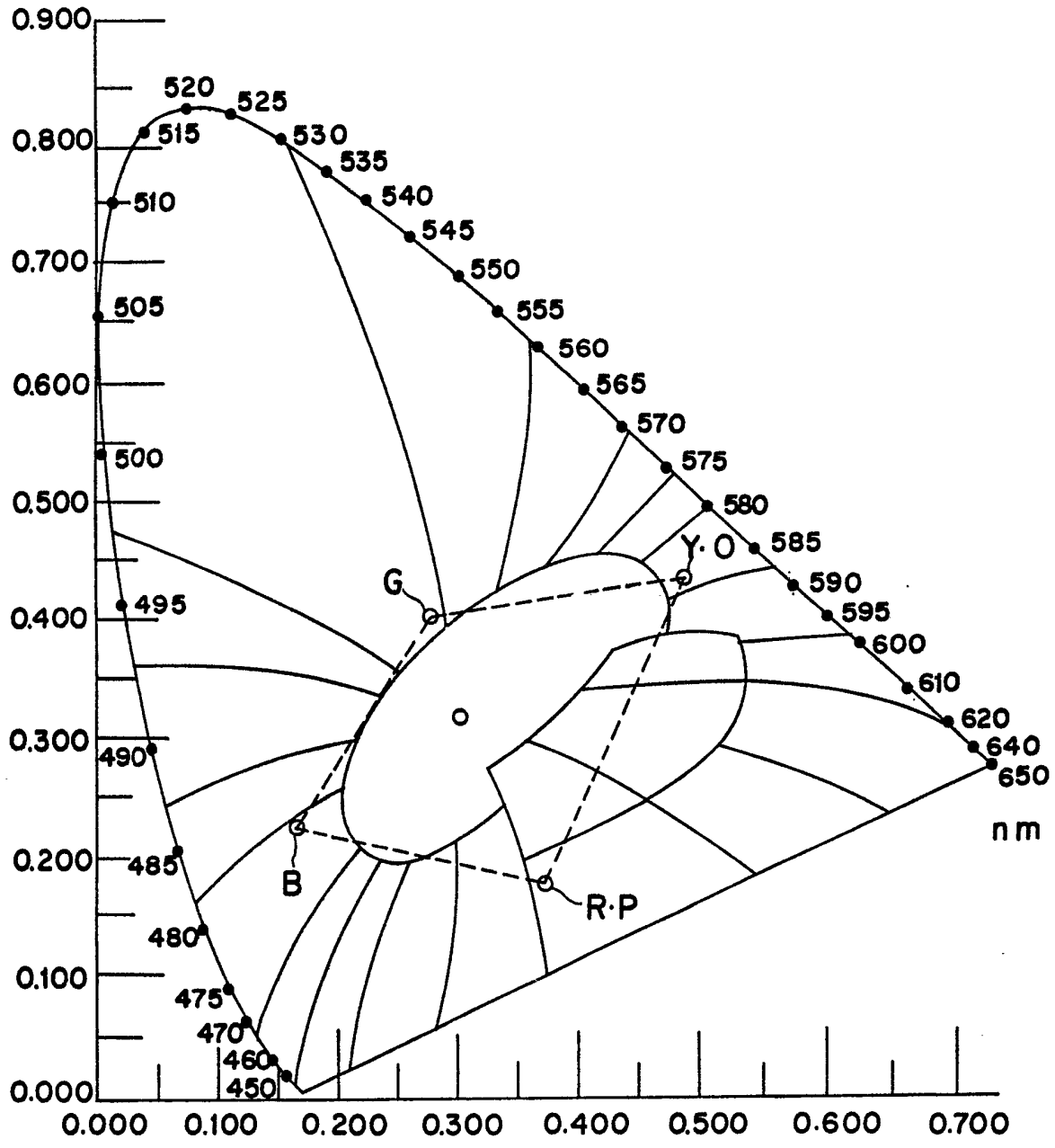
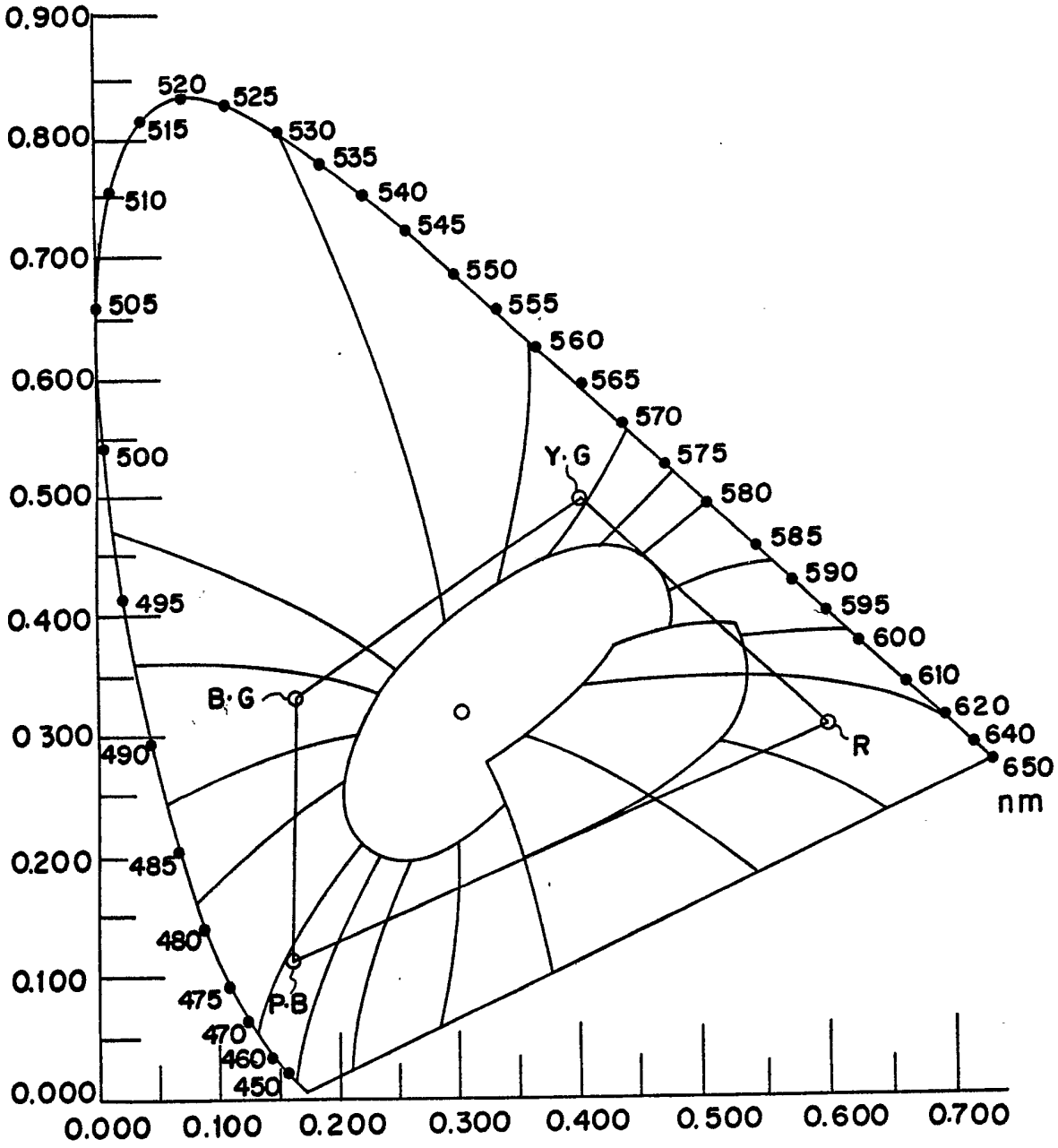

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FIG. 12


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SPECIFICATION

A multi-colour liquid crystal device

This invention relates to a multi-colour liquid crystal device for displaying pictures or images in full colour.

The structure of previously proposed multi-colour liquid crystal devices is shown in Figures 1 and 2 of the accompanying drawings, Figure 1 showing a horizontal cross-section and Figure 2 a vertical cross-section of the device. As can be seen from the Figure 1 and 2, two plates 11 and 11′ of glass are disposed parallel to each other. A plurality of fine electrodes 12 are attached to an inner surface of each of the base plates 11 and 11′. The electrodes 12 on the plate 11 extend in a direction perpendicular to the other electrodes 12 on the other plate 11′. The electrodes 12 of the plate 11 or 11′ are covered with colour filters 13. The filters 13 are coloured red (R), green (G) and blue (B), these colours being the three optical primary colours, by, for example, the method described in the Applicant's copending UK Application No. 8235511.

Spacers 16 are interposed between the plates 11 and 11′ at the peripheries thereof so as to define a sealed space between the plates 11 and 11′. The space is filled with a quantity of liquid crystal 17 and, in operation of the device, a certain voltage will be applied between selected electrodes. The applied voltage controls the intensities of beams of light transmitted through or reflected by the liquid crystal 17 so that an image in full colour appears on the plate 11′. Orientation membranes 14 cover the outer surfaces of the electrodes 12 and the filters 13, respectively. The membranes give an orientation property to the liquid crystal and prevent metallic ions in the dyestuffs of the filters 13 from dissolving in the liquid crystal.

The colour filters 13 have a small and even thickness so that the drive voltage applied between any pair of opposing electrodes 12 is sufficiently low and has no significant variance in its value. The filters 13 are also advantageous in that they have a high degree of colour purity as well as of colour balance. Hence the colour filters can produce multi-colour images at a comparatively high degree of fidelity. It should, however, be noted that the previously proposed multi-colour liquid crystal devices cannot display colours of many different hues. The chromaticity diagram of Figure 3 of the accompanying drawings shows by means of the dash-line triangle RGB, the number of hues available. This narrow range of hues imposes restrictions on the fidelity of the multi-colour images produced by such devices.

In an attempt to solve the abovementioned problem, it has been proposed to increase the colour purities of the colour filters as indicated by the dot-dash triangle R′.G′.B 3 in Figure 3. Such a higher colour purity for each of the filters inevitably requires a deeper dyeing thereof which in turn brings about a decrease of light transmission through the colour filters. Furthermore, such a depper dyeing *per se* is extremely difficult to obtain from a technical point of view.

In another attempt to solve the problem, it has been proposed to have colour filters of four or more different hues. One example of a combination of four colours is illustrated by the quadrilateral G.B.R.O in Figure 3. In this case, red filters (R), green filters (G), blue filters (B) and orange filters (O) are formed on the electrodes. However, this arrangement does not solve the abovedescribed problem because the structure of the liquid crystal display device as shown in Figures 1 and 2 means that the distance between filters 13 of the same colour has to be increased. Such an increase mars the quality of the images produced, considerably decreasing the resolution thereof. The number of different colours applied to the filters is thus limited to three in order to maintain a practically usable quality of liquid crystal device.

A futher disadvantage of the previously proposed devices is that an image of striped appearance is produced thereon because the filter arrangement is such that filters of the same colour are arranged in rows in one direction, for instance in the vertical direction as shown in Figure 1. A dot-matrix type of electrode arrangement has been proposed in which the colour filters are also arranged in a dot-matrix pattern corresponding to the electrodes. However, it is very difficult to dye precisely such minute filters to predetermined colours so as to form the dot-matrix pattern in a manner such that each of the filters is brought into the correct alignment with the corresponding electrode.

It is an object of the present invention to provide a multi-colour liquid crystal display device which overcomes, or at least migitages, the abovementioned problems.

According to one aspect of the present invention, there is provided a multi-colour liquid crystal display device, comprising two plates, each having a plurality of electrodes formed thereon, and a plurality of colour filters disposed between the two plates, two or more of the filters overlapping so that a light path from an electrode on one plate to the corresponding electrode on the other plate passes through one or more of the colour filters.

According to a second aspect of the present invention, there is provided a multi-colour liquid crystal display device, comprising two plates each having a plurality of electrodes disposed thereon in the form of a plurality of elongate members arranged in parallel rows, the rows of electrodes on one plate not being parallel to the rows of electrodes on the other plate and a plurality of colour filters disposed between the two plates, at least one colour filter being formed of rows parallel to each of the plurality of electrodes so that at least two of the colour filters overlap and a light path from an electrode on one plate to the corresponding electrode on the other plate passes

through one or more of the colour filters.

In a preferred embodiment, two mutually perpendicular colour filter layers are formed on each plate, each layer being parallel to the electrodes on one of the plates.

For a better understanding of the present invention, and to show how the same may be put into effect, reference will now be made, by way of example, to the accompanying drawings, in which:

FIGURE 1 is a horizontal crosssection, taken along the line 1—1 of Figure 2, of a previously proposed polychromatic liquid crystal display device;

FIGURE 2 is a vertical cross-section of the device of Figure 1, taken along the line II—II of Figure 1;

FIGURE 3 is a chromaticity diagram showing the range or scope of colours produced by the colour filters in various previously proposed devices and in a device embodying the invention;

FIGURE 4 is a horizontal cross-section of another previously proposed multi-colour liquid crystal display device capable of producing more colours or hues than the device shown in Figures 1 and 2;

FIGURES 5A and 5B illustrate the arrangement of electrodes on respective plates of a device embodying the invention;

FIGURE 6 is a front elevational view of the plate shown in Figure 5A illustrating colour filters formed on the electrodes;

FIGURE 7 also is a front elevational view of a plate of a further embodiment of a device in accordance with the invention having a different arrangement of colour filters;

FIGURE 8 is a schematic plan view illustrating the arrangment of the colour filters of the plate shown in Figure 7;

FIGURE 9A to 9D are graphs illustrating the transmission spectra of respective colour filters shown in Figure 8 over the visible spectrum;

FIGURES 10A to 10D illustrate the transmission spectra over the visible spectrum of various pairs of colour filters arranged to at least overlap to provide "subtractive" colour mixing;

FIGURE 11 is another chromaticity diagram showing the range of colours or hues available using colour filters having the transmission spectrum shown in Figures 9A to 9D; and

FIGURE 12 is another chromaticity diagram showing the range of colours or hues available using colour filters having the transmission spectra shown in Figures 10A to 10D.

Referring now to the drawings, and, in particular, Figures 5A to 5B, at least one of two base plates 11 and 11′ is made of a transparent material such as glass. Both plates 11 and 11′ have electrodes 12 arranged thereon in rows to form striped patterns. The plates 11 and 11′ are spaced by a distance determined by a spacer and arranged so that the electrodes on the plates face each other and the rows of electrodes 12 on one plate 11 are not parallel to, and are preferably perpendicular to, the rows of electrodes on the other plate 11′. The spacer functions to define a sealed inner space for a liquid crystal in a manner similar to that described above for the previously proposed devices.

A toothcomb pattern may be adopted in place of the striped pattern. The angle between the rows of electrodes on the respective plates 11 and 11′ is not limited to 90° but may be any other degree of angle.

Figure 6 shows one arrangement of colour filters 13—1 and 13—2 formed on the electrodes 12 of the base plate 11 shown in Figure 5A. It should be noted that colour filters 13—3 and 13—4 (not shown) are formed on the electrodes 12 of the other plate 11′ shown in Figure 5B.

In an alternative arrangement, the colour filters 13—1, 13—2 provided on the plate 11 may be arranged in rows parallel to the electrodes of the other plate 11′ while the filters 13—3 and 13—4 on the plate 11′ may be arranged in rows parallel to the electrodes of the plate 11.

In a further embodiment shown in Figure 7, both of the two groups of colour filters 13—1 and 13—2 and 13—3 and 13—4 are formed on one of the base plates 11or 11′. For example, the colour filters 13—1, 13—2, may be first formed on the electrodes 12 of one plate 11, then covered with a protective film 14 that protects the filters 13—1 and 13—2 from dyestuff, and finally the other colour filters 13—3 and 13—4 may be superposed on the protective film 14. Each of the base plates may be provided with two or more layers of colour filters.

The hues of the colour filters 13—1, 13—2, 13—3 and 13—4 are described below.

The four filters included in the embodiment shown in Figure 6 or 7 are green (G), reddish purple (RP), blue (B) and yellowish orange (YO) in colour so as to provide the transmission spectra shown in Figures 9A to 9D, respectively. The areas 13—5, 13—6, 13—7 and 13—8 in Figure 8 which correspond to intersections of the colour filters borne on the base plate 11 and 11′ assume colours different from the above colours as a result of subtractive colour mixing of the type discovered by D. Brewster, as indicated by the hatched portions in the spectra shown in Figures 10A to 10D. The intersection of the filters thus means two-level crossings for the electrodes 12. The colours represented by the hatched portions in Figures 10A to 10D are yellowish green (YG), blueish green (BG), purplish blue (PB) and red (R), respectively. These colours are called hereinafter "secondary colours." For example, the colour filter 13—2 of reddish purple colour (RP) and the colour filter 13—3 of blue colour (B) intersect one another at the area 13—7 to assume thereat the purplish is blue colour (PB), that is one of the secondary colours.

Two or more of the elements 13—5 and 13—8 assuming different secondary colours may be selected so that their colours are caused to mix "additively," that is in the manner discovered by T. Y and H. Helmholtz, with each other for a better polychromatic display of images.

The abovedescribed secondary colours *per se*

are the results of "subtractive" colour mixing so that they have a colour purity which is remarkably greater than that of the colours assumed by any single colour filter. This high purity renders the range of obtainable hues wider than ever accomplished when the secondary colors are additively mixed for multi-colour display. It is emphasized here that division of the transmitted light into four equal spectroscopic parts is attained by virtue of the abovementioned secondary colours. The thus naturalized colours produce a beautiful multi-colour image having superior colour balance.

According to another embodiment, the intersecting or overlapping colour filters are provided with the colours of cyan, magenta and yellow which subtractively mix with one another to give other colours, that is red, green and blue. At areas where the filters of same colour intersect one another, the colour will, of course, remain unchanged. Thus, six colours are obtained in this embodiment.

A method of manufacturing a device in accordance with the invention will now be described.

An electroconductive layer of indium oxide (In_2O_3) is initially formed on a glass base plate 11 as it usual in the manufacture of electrodes for a liquid crystal device. Transparent electrodes 12 are thus formed in a striped pattern as shown in Figure 5A. A solution of gelatin is then applied to the whole surface of the base plate 12 by means of a "spinner" so as to form a membrane which is about 0.1 μm thick. The gelatin solution consists of gelatin, ammonium bichromate and water in a ratio of 10:1:200 by weight wherein the bichromate functions as a photosensitive reagent. After the membrane has dried, it is then exposed to suitable, for example ultra-violet, radiation through a masking plate of a predetermined pattern to expose the portions of the membrane above the electrodes 12 so that only these portions are solidified by the exposure treatment. The portions of the membrane remaining unsolidified are subsequently removed using hot water. Dyeable lamellas 13 are thus formed on the electrodes as shown in Figure 6.

The next step is the application of a photoresist (for example, a lipophilic positive photoresist solution "OFPR," a produce of TOKYO OUKA LTD.) onto the dyeable lamellas 13. The abovementioned "spinner" is also utilized for controlling the thickness of photoresist to be about 0.1 μm. After the photoresist has been dried, it is contact-exposed to suitable radiation through a further masking plate which is precisely positioned to expose only the photoresist portions located on the electrodes 12 at which green filters are to be formed. Subsequently, a developing treatment ("photolithography") is performed to reveal the predetermined dyeable lamellas of hardened gelatin which are dyed green by steeping for 1 minute at 50°C in an aqueous solution comprising; 0.1% by weight of Sandolan Brilliant Blue N—5GN (a product of SANDOZ LTD.), 0.1% by weight of Lanasyn Yellow 3GL350 (a product by MITSUBISHI KASEI LTD.) and 0.5% wt. % of acetic acid.

Green colour filters 13—1 having a predetermined transmission spectrum are thus formed as shown in Figure 6.

The remaining photoresist portions are then disssolved into methanol and the lipophilic photoresist solution "OFPR" is reapplied to the while surface and allowed to dry. The photolithography process is carried out again to reveal the dyeable gelatin lamellas that are to be dyed a magenta colour.

Magenta filters 13—2 are subsequently obtained by dyeing the revealed areas using a dyestuff having a pretermined transmission spectrum. Thus, the dyeable lamellas are steeped for 3 minutes at 50°C in an aqueous solution comprising; 5 wt. % of Red Dye for Foods 105 (a product by HODOGAYA KAGAKU KOGYO LTD.)., 0.1 wt % of Kayanolcyanine 6B (a product by NIHON KAYAKU LTD.) and 5.0 wt % of acetic acid.

The colour filters are dried for 10 minutes at 120°C and then a 0.5.% aqueous solution of polyvinyl alcohol is applied to the surfaces of the filters 13—1 and 13—2 and all the other surfaces to a thickness of 0.1 μm to form the orientation membrane 14 as shown in Figure 7. A composite plate 15 having colour filters is thus produced.

The other base plate 11′ opposite to the above base plate 11 is also process in a similar manner. A striped pattern of transparent electrodes 12 is formed on the plate 11′ and thereafter blue filters are formed by steeping the dyeable layers for 1 minute at 50° C in an aqueous solution comprising 0.5 wt. % of Sandolan Brilliant Blue N—5GN (by SANDOZ LTD.), 1.0 wt % Saldolan Cyanine N—G360 (by SANDOZ LTD.) and 3.0 wt % of acetic acid. The remaining photoresist portions are then dissolved and the lipophilic solution is reapplied. After the photolithographic process, the dyeable lamellas are revealed which are then dyed orange by steeping the dyeable layers for 2 minutes at 50° C in an aqueous solution comprising 0.5 wt. % of Lanyl Orange R (by SUMITOMO KAGAKU KOGYO LTD.), 0.2 wt. % of Acidol Brilliant Yellow M—5GL (by BASF) and 1.0 wt. % of acetic acid. The dyed layers are then covered with an orientation membrane 14. Another composite plate 15′ is thus produced.

The composite plates 15 and 15′ are then assembled to form a multi-colour liquid crystal device in the following manner.

The orientation membranes 14 covering the colour filters are rubbed so as to obtain a suitable property and spacers 16, which are of a resin such as epoxy resin and function as sealing members, are printed through a screen onto the peripheries of the composite plates 15 and 15′, that is to say, the spacers are screen printed into the peripheries of the base plates 11 and 11′. The plates 15 and 15′ are finally secured to each other at the spacers 16 so that the colour filters 13—1, 13—2 and 13—3, 13—4 intersect or overlap one another

and, for example, are arranged to be perpendicular to one another. An amount of liquid crystal material 17 is poured into and sealed within the space between the plates to form the multi-colour display device, i.e. a liquid crystal panel of TN (Twist Nematic) type.

Thus, the multi-colour display device will be provided with filters, the colours of which are green (G), reddish purple (RP), blue (B) and yellowish orange (YO). A quadrilateral defined by a dotted line and the points B, G, R.P and Y.O in the chromaticity diagram shown in Figure 11 indicates the range of hues produced when light is transmitted through the filters. It is now apparent that the above colours each have a high degree of colour purity and are in a good colour balance. When two layers of such colour filters are laid upon one another, light will be transmitted through two filters of different colours and therefore the secondary colours mentioned therebefore will be produced due to the subtractive colour mixing effect. The quadrilateral drawn in solid lines in Figure 12 indicates the hues of these secondary colours which are distributed over a wider range than the primary colours and have a better colour balance. It will be understood that the problem of a lower colour purity that is inevitable in case of mixing three popular primary colours, i.e. red, green and blue, does not occur.

In another embodiment, two layers of colour filters are formed on a base plate one upon another as shown in Figure 7 whilst one layer of colour filters is formed on the other base plate in the following manner. Thus, green (G) and reddish purple (RP) colour filters are at first formed as alternate rows in a layer on one of base plates. Subsequently, a solution "POLYJULE" (produced by MIKUNI PAINT LIMITED) is applied to the layer to 0.1 2.0 um, preferably to 0.1 0.5 um, and cured for 20 minutes at 160° C so as to cover the layer with a protective film. A dyeable layer is then formed upon the film in a direction across the green (G) and reddish purple (RP) filters, the dyeable layer being thereafter dyed to alternate strips or rows of blue (B) and yellowish orange (YO). The second layer of colour filters is then covered with an orientation membrane. The other base plate is processed to have transparent electrodes each positioned opposite to respective blue (B) or yellowish orange (YO) filters. An orientation membrane also covers these electrodes. These two base plates are then combined in a manner such that each electrode faces each filter (B) or (YO). Thus, a multi-colour liquid crystal display device constructed in this way will have the same characteristics as the first described device.

With a device embodying the invention, at least part of the light passes through two colour filters to produce secondary colours owing to the subtractive colour mixing effect. The secondary colours have a higher purity and divide the transmission spectrum into four equal parts thereby providing ideal hues that can be additively mixed with each other to produce multi-colour images of well-balanced various colours.

Filters having such a high colour purity are easily produced because they are not deeply dyed but they assume pure colours due to the overlapping thereof.

Where the light rays pass through two overlapping colour filters of the same colour, the colour will merely be deepened to produce a corresponding secondary colour. Thus, the number of the secondary colours is greater than that of the primary colours so that in manufacture of the multi-colour device the types of dyeing solutions can be decreased resulting a cost reduction in the dyeing process. Pictorial elements of the device have thus respectively colour filter that additively mix with one another to produce the natural hues necessary for multi-colour images on said device.

The rough or coarse-grained appearance of images produced by the previously proposed devices caused by the toothcomb-shaped arrangement of colour filters of a maximum of three colours in a single layer, is thus eliminated using the device which provides four or six or more hues.

Further because the rows of electrodes are crossed, a dot-matrix arrangement of pictorial elements is provided.

It should be noted that the colours of the colour filters and therefore the combinations thereof may be different from those described above.

Thus, a multi-colour liquid crystal device embodying the invention can display images coloured with a larger number of colours with a higher resolution than previous devices because the colour filter layers at least overlap so as to be "substractively" mixed. Moreover, the arrangement of the electrodes allows a multi-colour liquid crystal device to be provided which can display images which have a natural, not striped, appearance.

CLAIMS

1. A multi-colour liquid crystal display device, comprising two plates, each having a plurality of electrodes formed thereon, and a plurality of colour filters disposed between the two plates, two or more of the filters overlapping so that a light path from an electrode on one plate to the corresponding electrode on the other plate passes through one or more of the colour filters.

2. A device according to Claim 1, wherein each electrode is an elongate member and the electrodes on each of the plates are arranged in parallel rows.

3. A device according to Claim 2, wherein the rows of electrodes on one plate are not parallel to the rows of electrodes on the other plate.

4. A device according to Claim 3, wherein the rows of electrodes on one plate are perpendicular to the rows of electrodes on the other plate.

5. A device according to Claim 3 or 4, wherein at least one colour filter is formed of rows parallel to each of the plurality of electrodes.

6. A multi-colour liquid crystal display device, comprising two plates each having a plurality of

electrodes disposed thereon in the form of a plurality of elongate members arranged in parallel rows, the rows of electrodes on one plate not being parallel to the rows of electrodes on the other plate and a plurality of colour filters disposed between the two plates, at least one colour filter being formed of rows parallel to each of the plurality of electrodes so that at least two of the colour filters overlap and a light path from an electrode on one plate to the corresponding electrode on the other plate passes through one or more colour filters.

7. A device according to Claim 5 or 6, wherein the colour filters are formed on the plurality of electrodes on one of the plates.

8. A device according to Claim 5 or 6, wherein the colour filters are formed on the plurality of electrodes on both the plates.

9. A device according to Claim 8, wherein the colour filters are arranged to form one layer thereof on the plurality of electrodes on each of the plates.

10. A device according to any one of Claims 5 to 9, wherein the plurality of electrodes on at least one of the plates is divided into two or more sub-groups of electrodes, each sub-group being associated with a differernt coloured filter.

11. A multi-colour liquid crystal display device substantially as hereinbefore described with reference to Figures 3 to 12 of the accompanying drawings.

12. Any novel feature or combination of features described herein.

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