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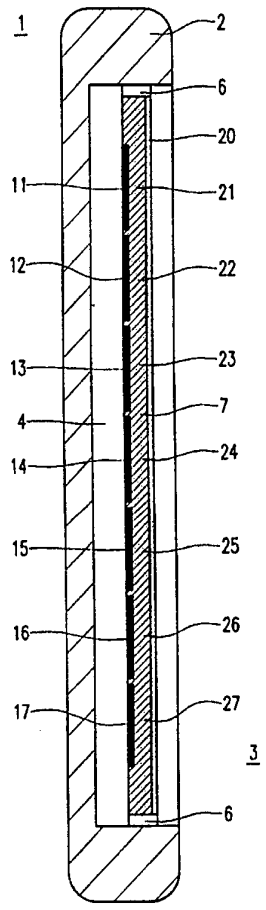
(54) Title: DISPLAY DEVICE COMPRISING AN ELECTRO-OPTICAL MEDIUM

(57) Abstract

A display device (1) has a display panel (3) which comprises a first substrate (6) on which a first picture electrode (11-17) is provided as well as a second substrate (5) on which a second picture electrode (20) is provided, both substrates (4, 5) sandwiching an electro-optical medium (7). Said electro-optical medium (7) is capable of switching between an at least substantially transparent state and a scattering state under the influence of an electric field. Such an electric field can be applied between a first picture electrode (11-17) and a second picture electrode (20) which demonstrate an overlap with each other. The first and second picture electrodes (11-17, 20) thus define, at the location of the overlapping portions, picture elements (21-22) which can be observed without an additional light source, using only the ambient light. In the scattering state, captured light is backscattered to the observer, whereas in the at least substantially transparent state an observer can see through the medium (7) and sees the relevant first picture electrode (11-17) which is at least substantially opaque at least to visible light. The first picture electrode (11-17) comprises an electrically, relatively well-conducting material, which leads to a much lower series resistance and hence a much shorter RC time as compared to a similar picture electrode of a tansparent conductor.



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Display device comprising an electro-optical medium.

The invention relates to a display device having a display panel comprising a first substrate provided with a first picture electrode and a second substrate provided with a second picture electrode, both electrodes overlapping at least partly and both substrates sandwiching an electro-optical medium at least at the location of the overlap between both picture electrodes, said electro-optical medium being capable of switching between an at least substantially transparent state and a scattering state under the influence of an electric field.

The electro-optical medium is generally formed by a layer comprising a liquid-crystalline material, in which case such a device is commonly referred to as LCD, which is the abbreviation for Liquid Crystal Display.

The invention particularly, although not exclusively, relates to a display device in which the electro-optical medium is formed by a combined system of a birefringent liquid-crystalline material and a suitable polymer, and said liquid-crystalline material may be dispersed in a polymer matrix, for example in the form of droplets. An electro-optical medium of this type is generally referred to as PDLC, which is the abbreviation for Polymer Dispersed Liquid Crystal.

In the absence of an electric field, the birefringent droplets in such a medium are randomly oriented and incident light will be randomly scattered at the interface between the droplets and the polymer matrix and between the droplets themselves. Under the influence of an electric field, however, the droplets are oriented in conformity with the electrical lines of force, so that incident light has a uniform refractive index in the liquid-crystalline material.

By a suitable choice of the liquid-crystalline material on the one hand and the polymer material on the other hand, it can be achieved that this uniform refractive index substantially corresponds to the refractive index of the polymer matrix, so that scattering occurs neither at the interface between the polymer matrix and the droplets nor between neighbouring droplets, as a result of which the system is transparent to incident light. Thus, the electro-optical medium is capable of switching between a scattering state and a substantially transparent state under the influence of an electric field.

In United States Patent Specification No. 4,591,233 a description is given of a device of the type described in the opening paragraph, the electro-optical medium being formed by a layer of encapsulated liquid-crystalline material which is sandwiched between two substrates in the form of two flat, transparent support plates. Both support plates are provided with a picture electrode on the side facing the liquid-crystalline layer, both picture electrodes demonstrating an overlap with each other and defining a picture element at the location of said overlap. A first of the two substrates further comprises an opaque layer which absorbs visible light and which is provided as a continuous layer on the entire substrate surface facing away from the liquid-crystalline layer.

Such a device can be operated without an additional light source, utilizing only ambient light. In the absence of an electric field, the liquid-crystalline material is randomly oriented and incident light will be randomly scattered. The incident light will be partially reflected back to an observer, so that the material will appear bright to said observer. Conversely, if a sufficiently strong electric field is applied between both picture electrodes, the liquid-crystalline material will be oriented in conformity with the lines of force and the material is transparent. In the latter case, incident light is absorbed by the black, absorbing layer on the rear side of the first substrate, so that an observer sees a black, or at least dark, picture element on a light(er) background.

As is customary in LCD technology, both electrodes of the known device are transparent to visible light. To this end, the electrodes are made of tin oxide which may or may not be doped with antimony, and which, just like indium-tin oxide, is commonly used as a transparent conductor in LCD technology. Although these materials are electrically conductive, their resistivity is much higher than that of most metals and many metal compounds. For example, the sheet resistance of an average conductor track of aluminium typically is below 0.5 Ω/□, which is approximately a factor of 40 smaller than the sheet resistance of approximately 20 Ω/□ of an average track of indium-tin oxide which forms a transparent conductor which is commonly used in LCD technology. As a result, particularly in the case of relatively long and narrow picture electrodes, ITO leads to a relatively high series resistance and hence to a relatively long RC time, which is an important disadvantage for, in particular, display devices having a relatively large number of picture elements. Consequently, in the known device the series-resistance of the picture elements seriously limits the maximum number of picture elements of the known device.

In addition, in comparison with many metals, for example indium-tin oxide is difficult to handle from a technological point of view, and to enhance the contrast of

the picture elements in the known device, a separate opaque layer is applied to the bottom side of the first substrate, which requires an additional process step.

The invention *inter alia* aims at overcoming these drawbacks by providing a device of the type mentioned in the opening paragraph, in which such an additional process step is superfluous and in which, in addition, the series-resistance of the individual picture elements can be much lower than in the known device.

To achieve this object, a device of the type mentioned in the opening paragraph is characterized according to the invention in that the first picture electrode is at least substantially opaque to visible light and that the first electrode comprises an electrically, relatively well-conducting material.

In accordance with the invention, the first electrode is at least substantially opaque to visible light. Consequently, a separate opaque layer on, for example, the rear side of the first substrate, as in the known device, can be dispensed with, so that in this respect an additional process step is rendered superfluous. In addition, it is no longer necessary to use a transparent conductor for the first electrode and, in accordance with the invention, for the first electrode use is advantageously made of a generally opaque, electrically, relatively well-conducting material. Within the scope of the invention, an electrically, relatively well-conducting material is to be understood to mean a material having a resistivity which is lower than that of the transparent conductors used in the known device. Apart from, for example, carbon, this condition is met by many metal-containing materials such as most metals and many metal compounds. The use, in accordance with the invention, of such a material for the first picture electrode enables the series resistance and hence the RC time of the individual picture elements to be substantially reduced as compared to the known device.

Within the scope of the invention, a metal-containing material is to be understood to mean any metallic material comprising whatever form of metal, so that both pure metals and metal alloys such as metal compounds are included.

Unlike conventional LCD technology, the invention is based on the insight that when an electro-optical medium is used which can be switched between an at least substantially transparent state and a scattering state, the display panel in the device in accordance with the invention need not be transparent throughout its thickness because the ambient light on the viewing side, *i.e.* the side where an observer is present during operation of the display panel, can be captured as well as emitted. Consequently, the light does not have to pass through the entire display panel and hence one of the two picture electrodes can

be opaque.

In accordance with the invention, the first electrode can be made of, for example, a metal such as aluminium, molybdenum, tungsten, tantalum and chromium, a metal alloy such as titanium-tungsten or a metal compound such as a metal silicide, which are all compatible with present-day LCD processes and the resistivity of which is much lower than that of the transparent conductors conventionally used in LCD technology.

To attain a high contrast and a satisfactory readability of the display panel, the first picture electrode in accordance with the invention comprises a light-absorbing top coating which is applied, in particular, at least to the side facing the electro-optical medium. Said top coating may be provided completely independently of the first picture electrode and may be manufactured from, for example, a completely different material. However, preferably use is made of a first picture electrode and a top coating which are made of the same metal, which may or may not be combined, in particular a metal selected from the group consisting of chromium, tungsten, molybdenum and tantalum, the top coating having a higher porosity than the metal of the underlying first picture electrode. Light which is incident on the porous top coating is captured in the pores thereof and finally absorbed, so that the top coating has a truly black appearance although the metal itself would normally be shiny. If desired, the porosity of the top coating can be further increased by etching said top coating and/or oxidizing it over its entire thickness or part of its thickness.

By so constructing the picture electrode in its entirety or only the top coating, and by giving it a black appearance, the picture element in the transparent state will appear truly black to an observer. This leads to an extremely great contrast with the scattering state, in which light emerges and the picture element is bright, and with the background. In this manner, a so-called *paper-white* display can be achieved, which is similar in appearance to printed matter.

In a particular embodiment of the device in accordance with the invention, the display element is driven *via* an active switching element. In accordance with the invention, the switching element is preferably arranged, in this case, between the first picture electrode and the first substrate, a first main electrode of the switching element being connected to the first picture electrode and a second main electrode of the switching element being coupled to a connection conductor. By virtue of the fact that the switching element is invisible, a very good "paper white" display is also obtained when the display element is actively driven. Thus, the switching element and the picture element demonstrate an overlap with each other so that the useful display surface area is not adversely affected by the

switching element. Thus, the invention enables an extremely large useful display surface to be attained in proportion to the overall surface of the display panel. This ratio is commonly referred to as aperture ratio and typically ranges between approximately 40% and approximately 50% in conventional LCD devices. In the present, particular embodiment of the device in accordance with the invention the aperture ratio may be as high as 80-90% and is limited only by the interspaces between neighbouring picture electrodes, which are necessary for electrically insulating the individual picture elements relative to each other. An additional advantage of arranging the switching elements in the manner described in this particular embodiment is that the often light-sensitive switching elements are effectively shielded from the incident light by the opaque first picture electrode.

The invention will now be explained in greater detail by means of a number of exemplary embodiments and with reference to a drawing, in which

Fig. 1 is a cross-sectional view of a first embodiment of the display device in accordance with the invention; and

Fig. 2 is a cross-sectional view of a second embodiment of the display device in accordance with the invention.

It is noted that the Figures are diagrammatic and not drawn to scale. For clarity, some dimensions have been exaggerated strongly. To the extent possible, like references refer to like parts.

In Fig. 1, a display device 1 comprises a, diagrammatically shown, housing 2 accommodating a display panel 3. The housing further accommodates electronics and a voltage source (not shown for the sake of clarity) for driving the display panel 3. The display panel comprises a first substrate 4 in the form of a substantially flat plate of glass, quartz or a suitable transparent synthetic resin on which a number of first picture electrodes 11-17 is arranged in a side -by-side relationship. The panel further comprises a second substrate 5 which is arranged substantially parallel to the first substrate 4 and which, like said first substrate, comprises a substantially flat plate of glass, quartz or a suitable transparent synthetic resin on which a transparent second picture electrode 20 is provided. Said second picture electrode 20 comprises indium-tin oxide or another suitable transparent conductor and forms part of a plurality of such second picture electrodes which are arranged in a side-by-side relationship and demonstrate an overlap with the first picture electrodes 11-17.

Both substrates 4, 5 are arranged at a fixed distance from each other by regularly placed spacers 6 and sandwich, over substantially their entire surface, an electro-

optical medium 7 which, in this example, is formed by a so-called PDLC layer, which is the abbreviation for Polymer Dispersed Liquid Crystal. Such a layer 7 comprises a matrix of a suitable polymer such as, in this case, a polyacrylate in which a liquid-crystalline material in the form of spherical or ellipsoidal droplets is dispersed. The liquid-crystalline material has a positive dielectric anisotropy and is birefringent with a refractive index of approximately 1.5 transverse to the director and a refractive index of approximately 1.7 parallel thereto. Up to approximately 80% of the layer 7 consists of this material which is commercially available.

The PDLC layer 7 is capable of switching between an at least substantially transparent state and a scattering state under the influence of an electric field. By means of the first and second picture electrodes 11-17, 20 such a field can be locally applied at the location of the overlap, thereby forming a system of separate picture elements 21-27.

In the absence of an electric field between a first picture electrode 11-17 and a second picture electrode 20, the birefringent LC droplets are randomly oriented and incident light will be randomly scattered at the interface between the droplets and the polymer matrix and between neighbouring droplets. In this case, light will be reflected back to an observer at the location of a picture element which is associated with the relevant electrode as well as at the location of the interspaces between the picture elements. To an observer these parts of the display panel appear bright. An extra high brightness is achieved by virtue of the fact that the PDLC material used causes anisotropic instead of isotropic scattering, at an average scattering angle above 90°, so that most of the incident light is reflected back to the observer.

Conversely, under the influence of an electric field between a first picture electrode 11-17 and a second picture electrode 20 the droplets in an associated picture element are oriented in conformity with the electrical lines of force, so that light which is incident on the liquid-crystalline material has a uniform refractive index. The PDLC layer 7 is so selected that this refractive index corresponds substantially to the refractive index of the polymer matrix, so that scattering will occur hardly, if at all, at the interface between the LC droplets and the polymer matrix or between neighbouring LC droplets, so that the picture element is at least substantially transparent to incident light. Consequently, no light is emitted at the location of the picture element. In this case, at the location of the picture element an observer will look right through the medium 8 and sees the relevant first picture electrode 11-17 which, according to the present invention, is opaque to visible light.

In the present example, the first picture electrodes 11-17 comprise

chromium and the sides of said picture electrodes facing the PDLC layer 7 are coated with a light-absorbing top coating which also comprises chromium but the porosity of which is much greater than that of the underlying picture electrode. For the sake of clarity, the top coating is not separately shown in the Figure.

Such a construction can be realised in a simple manner by applying the metal layer from which the first picture electrode is formed by sputtering and, when the desired thickness has been attained, increasing the sputtering pressure, *i.e.* the pressure of the atmosphere in which sputtering is carried out and which comprises, for example argon, by for example approximately a factor of ten. In practice it has been found that in this case the growth of the metal layer continues with a substantially increased porosity, so that ultimately the metal layer is covered with the desired, porous, light-absorbing top coating. If desired, the porosity and hence the light-absorbing power of the top coating can be further increased by slightly etching the top coating and, if necessary, oxidizing it at least partially. In this manner a porosity in excess of 50% and a reflection coefficient below 5% of the top coating can be attained, while the electrical conductance of the electrode is preserved.

Light which is incident on the top coating is captured in the pores, which may occupy more than 50% of said coating, and is finally absorbed. As a result, the top coating has a completely black appearance, thereby avoiding disturbing reflections of, in particular, the substantially perpendicularly incident ambient light. Instead of chromium, use can be made of, for example, molybdenum, tantalum and tungsten which can be used in a similar manner.

Due to the completely black appearance of the picture electrodes 11-17, an observer sees a truly black background at the location of the transparent picture elements. This results in a very high contrast relative to the scattering and hence bright picture elements, and relative to the background which is also bright. By virtue thereof, a so-called *paper white* display can be attained which is similar in appearance to conventional printed matter. As a result, an additional black coating on the rear side of the display panel, as in the known device, as well as the required process step(s) can be dispensed with in the device in accordance with the invention.

In the present exemplary embodiment, the invention thus provides a display device of the type mentioned in the opening paragraph, which has an extremely good electrical conductance of the first picture electrodes, so that the RC times thereof are also acceptable for display panels having relatively many picture elements, and which has an extremely high contrast. Consequently, this device imposes significantly fewer limitations on

the overall number of picture elements of the display panel than the known device. Thus, the device in accordance with the invention can very suitably be used for video applications as well as datagraphic applications in which higher resolutions of, for example, 1280 x 1024 pixels for monochrome display and 3 x 1280 x 1024 pixels for colour display, as required in present-day datagraphic applications, are readily attainable.

A second exemplary embodiment of the display device in accordance with the invention is shown in Fig. 2. The device 1 of Fig. 2 corresponds to that of Fig. 1, except that, in the present exemplary embodiment, the picture elements are driven *via* active switching elements 31-37, which are arranged between the first picture electrodes 11-17 and the associated connection conductors, and which are formed, in the present example, by thin-film diodes, each having a first main electrode 25 and a second main electrode 27 of tantalum which are separated from each other by a comparatively thin insulating layer 26 of tantalum oxide. The connection conductors are made of the same conductive layer as the second main electrodes 27 of diodes 31-37, but they are situated outside the plane of the drawing. However, other metals and insulating materials can alternatively be used for the main electrodes 25, 27 and the insulating layer 26, respectively. The switching elements 31-37 can be integrated on the first substrate 6 in a simple manner by using three relatively thin layers, of the order of 50 nm, for the switching elements 31-37 and, if desired, said layers can be conventionally provided in accordance with a pattern in a single process step.

With a view to a flat base for the first picture electrodes 11-17, the diodes 31-38 are covered with a comparatively thick planarizing and passivating layer 28 of silicon nitride in which contact windows are provided at the location of the first main electrodes 25 of the switching elements. Said contact windows are filled in with titanium-tungsten 29, a so-called *via*, to establish an electric connection between the first main electrodes 25 of the switching elements 31-37 and the relevant first picture electrodes 11-17. Each of the second main electrodes 27 of the diodes 31-37 is coupled, outside the plane of the drawing, to the connection conductor associated with the relevant picture element.

The thin-film diodes 31-37, as well as the connection conductors required for driving purposes, are situated between the first substrate 4 on the one hand and the opaque first picture electrodes 11-17 on the other hand, so that they are situated outside the light path of the light captured at the front of the panel and hence disturbing influences thereof on the light-sensitive diodes 31-37 are counteracted. In addition, the switching elements 31-37 thus demonstrate an overlap with the first picture electrodes 11-17, so that they do not take up any additional space. Thus, in the present exemplary embodiment, the

invention provides a display device of the type mentioned in the opening paragraph in which the picture elements are driven *via* active switching elements 31-32. Nonetheless, the useful display surface, *i.e.* the ratio between the overall surface area of the picture elements and the overall surface area of the panel, commonly referred to as the aperture ratio, is limited only by the interspace ℓ which is necessary for the mutual electrical insulation. By virtue thereof, the aperture ratio, which for conventional active LCD devices typically amounts to approximately 40%-50%, can increase to approximately 80%-90% in the device in accordance with the invention.

It is additionally attained that between or next to the electrodes no switching elements can be seen which could give the impression that the picture electrodes are "completely black" as a result of reflections at the switching elements.

It will be obvious that although the invention has been explained by means of only two exemplary embodiments, it is intended that the invention not be limited to said examples. Many variations and embodiments are possible to those skilled in the art without departing from the scope of the invention.

For example, in both exemplary embodiments use is made of a PDLC layer as the electro-optical medium. However, within the scope of the invention other electro-optical media can alternatively be used provided that they can switch between a scattering and an at least substantially transparent state under the influence of an electric field. Apart from a PDLC layer or a closely related, so-called NCAP layer, which is the abbreviation for Nematic Curvilinear Aligned Phase, other combined systems of a polymer and a liquid-crystalline material, such as a polymer network liquid crystal (PNLC) and an anisotropic (scattering) gel or, for example, a dynamically scattering layer of purely liquid-crystalline material can alternatively be used. In both cases the scattering effect is greater as the difference between the highest and the lowest refractive index of the LC material used is greater, so that a higher brightness is obtained and/or the thickness of the LC layer and hence the drive voltage thereof can be smaller.

Further, if desired a suitable dye can be added to the electro-optical medium to increase, for example, the contrast of the display panel and a colour other than black can be used for the light-absorbing top coating on the first picture electrodes.

Although the device can be operated using only ambient light, if desired an auxiliary light source can be used when the ambient light is insufficient.

Further, the second substrate can be provided with complementary colour filters in a conventional manner, thereby making the device suitable for colour display.

For driving purposes use can be made of thin-film diodes or other types of switching elements, such as a so-called TFT, which is the abbreviation for Thin Film Transistor, or one or more than one pn-, zener or PIN diodes. Further, the device in accordance with the invention is suitable for direct drive as well as matrix drive.

Claims:

1. A display device having a display panel comprising a first substrate provided with a first picture electrode and a second substrate provided with a second picture electrode, both electrodes overlapping at least partly and both substrates sandwiching an electro-optical medium at least at the location of the overlap between both picture electrodes, said electro-optical medium being capable of switching between an at least substantially transparent state and a scattering state under the influence of an electric field, characterized in that the first picture electrode is at least substantially opaque to at least visible light and in that the first electrode comprises an electrically, relatively well-conducting material.

2. A display device as claimed in Claim 1, characterized in that the first picture electrode is provided with at least a light-absorbing top coating on the side facing the electro-optical medium.

3. A display device as claimed in Claim 2, characterized in that the first picture electrode and the top coating both comprise the same metal, the top coating having a higher porosity than the first picture electrode.

4. A display device as claimed in Claim 3, characterized in that the top coating is at least partially oxidized.

5. A display device as claimed in Claim 3 or 4, characterized in that the metal is selected from a group consisting of chromium, tungsten, molybdenum and tantalum and, preferably, comprises chromium.

6. A display device as claimed in Claim 1, characterized in that an active switching element is arranged between the first picture electrode and the first substrate, a first main electrode of said switching element being connected to the first picture electrode and a second main electrode being coupled to a connection conductor.

7. A display device as claimed in any one of the preceding Claims, characterized in that the electro-optical medium comprises a layer which is sandwiched by both substrates and which comprises a polymer matrix in which a birefringent liquid-crystalline material is dispersed.

8. A display device as claimed in any one of the preceding Claims, characterized in that, at least in the scattering state, the electro-optical medium scatters anisotropically at an average scattering angle above 90°.

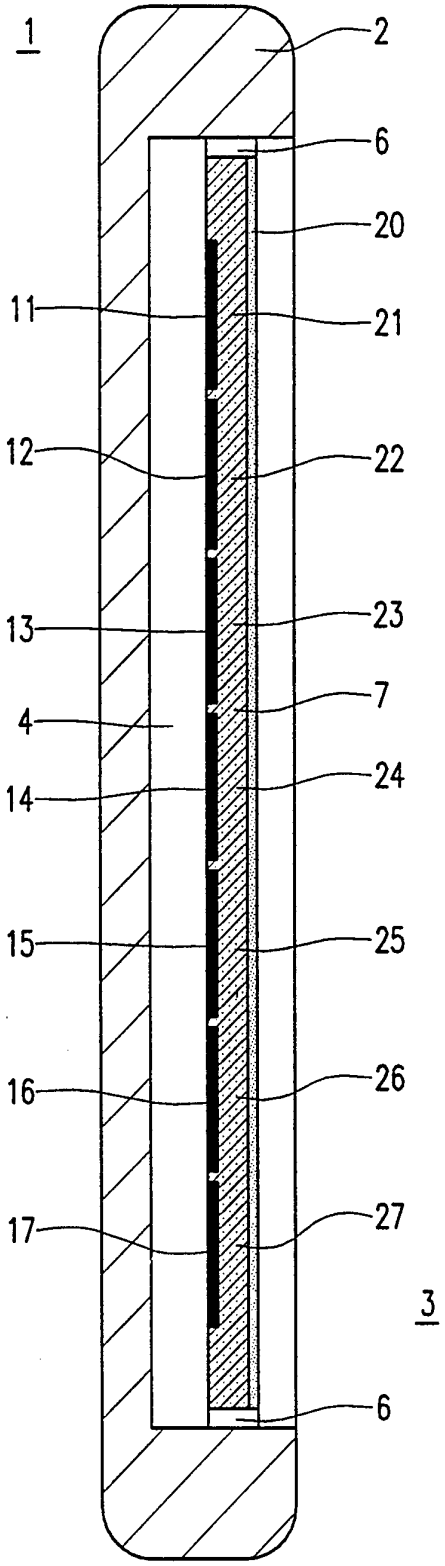

FIG. 1

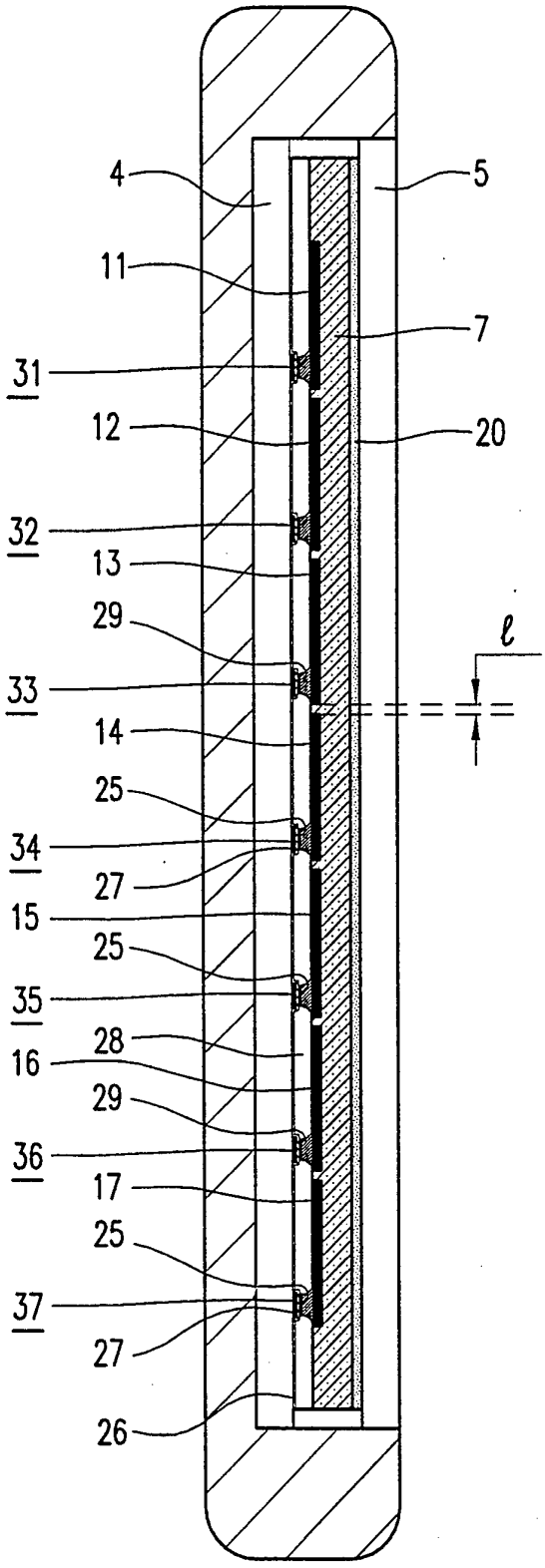
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FIG.2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 94/00270

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G02F 1/1333, G02F 1/1343
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP, A1, 0019208 (SIEMENS AKTIENGESELLSCHAFT BERLIN UND MüNCHEN), 26 November 1980 (26.11.80), page 2, line 11 - line 19; page 5, line 11 - page 6, line 7, figures 1-2, claims 1,4,13, abstract	1-5
A	page 2, line 11 - line 19; page 5, line 11 - page 6, line 7, abstract	6-8
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X	EP, A2, 0507639 (SHARP KABUSHIKI KAISHA), 7 October 1992 (07.10.92), column 11, line 21 - line 34; column 15, line 32 - line 37, figure 6, abstract	1,6-8
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
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Date of the actual completion of the international search	Date of mailing of the international search report
2 December 1994	09 -12- 1994
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Roland Landström Telephone No. +46 8 782 25 00

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 4431272 (S. YAZAWA ET AL), 14 February 1984 (14.02.84), column 3, line 45 - line 54, figure 1a, abstract	1-2
A	column 3, line 45 - line 54, figure 1a, abstract	3-8
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A	US, A, 5000545 (T. YOSHIOKA ET AL), 19 March 1991 (19.03.91), column 1, line 21 - line 29; column 2, line 65 - line 68, figures 1-5	1-8
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A	US, A, 5056895 (F.J. KAHN), 15 October 1991 (15.10.91), figures 1-3, claim 4	1-8
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INTERNATIONAL SEARCH REPORT

Information on patent family members

29/10/94

International application No.
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