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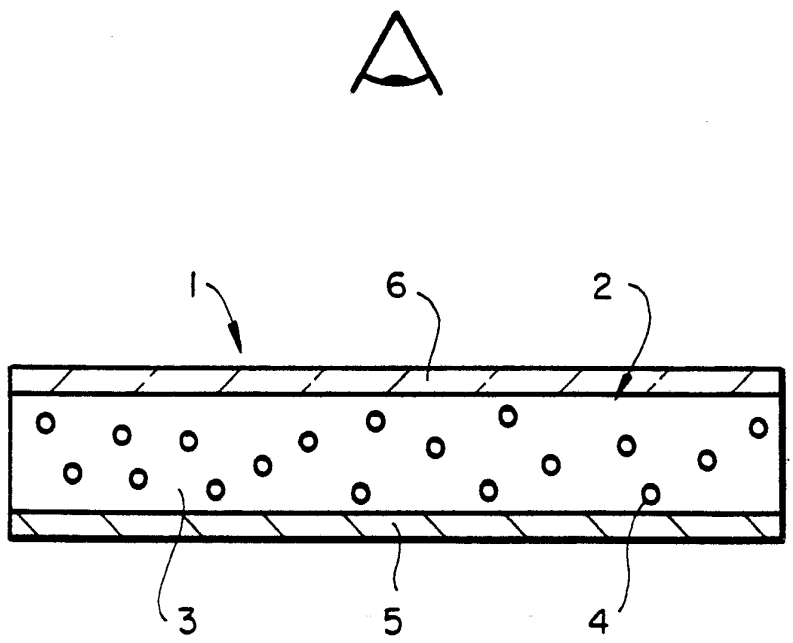
(54) Title: DISPLAY HAVING LIGHT SCATTERING ELECTRO-OPTICAL ELEMENT



(57) Abstract

A display having a first electrode means (6); a second electrode means (5); and a display medium (2) positioned between the first and second electrode means (6 and 5), which display medium (2) contains a pleochroic dye, is switchable between a first state in which incident light is substantially absorbed by the pleochroic dye and a second state in which the amount of such absorption is substantially reduced, and is capable of scattering incident light with a scattering half angle between about 5 and about 40 degrees when the display medium (2) is in its second state, while permetting at least 10 % of the incident light to be transmitted.

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AT	Austria	**FI**	Finland	**ML**	Mali
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DISPLAY HAVING LIGHT SCATTERING ELECTRO-OPTICAL ELEMENT

Field of the Invention

This invention relates to displays having improved viewability.

Background of the Invention

Displays may be transmissive or reflective. In a transmissive display, the display lies between the viewer and the light source. In a reflective display, the viewer and the light source are on the same side of the display. Many displays are liquid crystal displays, in which the element which transitions between one optical state and a second optical state in response to an input (e.g., an electrical signal) comprises liquid crystal material.

A preferred type of liquid crystal display employs encapsulated liquid crystal material, in which liquid crystals are encapsulated or dispersed in a matrix (or containment medium) which can be, e.g., a polymer. When a voltage corresponding to a sufficiently strong electric field is applied across the encapsulated liquid crystal material (the "field-on" condition), the alignment of the liquid crystals is re-oriented in accordance with the field, so that incident light is transmitted. Conversely, in the absence of such a voltage (the "field-off" condition) the alignment of the liquid crystals is random and/or influenced by the liquid crystal-matrix interface, so that the liquid crystal material scatters incident light. The applied voltage at which the liquid crystal material begins to change from its field-off condition to its field-on condition is called the threshold voltage. If a reflector is positioned behind the display, then a reflective display is obtained, which appears bright in the field-on condition and darker in the field-off condition. If a light source is positioned behind the display, then a transmissive display can be obtained.

Encapsulated liquid crystal displays can include a pleochroic dye in the liquid crystal material to provide light control capabilities through absorption. In the field-on condition, the alignment of the pleochroic dye is determined by the alignment of the liquid crystals (which in turn is determined by the electric field). In this alignment, the absorption of

incident light by the dye is at a minimum or substantially reduced, so that a substantial amount of incident light is transmitted. In the field-off condition, the alignment of the pleochroic dye also conforms to the alignment of the liquid crystals (but which are now random or distorted), so that significant light absorption occurs.

Thus, either a reflective or transmissive encapsulated liquid crystal display can be made to appear darker in the field-off condition by the scattering or the absorption of the incident light, or both, and brighter in the field-on condition because scattering and/or absorption is reduced, permitting the incident light to reach the reflector or be transmitted through the display, as applicable.

In reflective displays the reflector can have an important effect on the perceived brightness. At one end of the scale the reflector can be Lambertian, with excellent viewing angle, but low brightness. At the other end of the spectrum would be a specular mirror with viewing angle limited by the surrounding lighting fixtures, but with the brightness of those fixtures.

In a reflective display of the type used in laptop computers, and in particular colored ones, some aperturing of the picture is unavoidable due to the pixel structure. With a Lambertian reflector this leads to excessive light loss. For a specular reflective display obtaining light uniformity and good viewing angles is difficult (e..g, the viewer sees his own reflection in the display). Empirically, some degree of diffusion is needed to produce a pleasing display.

We have invented a display with improved viewability by providing for some residual scattering in the field-on condition.

Summary of the Invention

A display of this invention comprises a first electrode means; a second electrode means; and a display medium positioned between the first and second electrode means, which display medium contains a pleochroic dye, is switchable between a first state in which incident light is substantially absorbed by the pleochroic dye and a second state in which the amount of such absorption is substantially reduced, and is capable of scattering incident light with a scattering half angle between about 2 and

about 40 degrees when the display medium is in its second state, while permitting at least 10% of the incident light to be transmitted.

This invention also provides a liquid crystal display medium switchable between a first state in which incident light is substantially absorbed by a pleochroic dye and a second state in which the amount of such absorption is substantially reduced upon the application of a sufficient electric field, comprising: a containment medium; discrete volumes of liquid crystals dispersed in the containment medium; and pleochroic dye contained in the liquid crystals; wherein the absolute difference between the ordinary refractive index of the liquid crystals and the refractive index of the containment medium is between about 0.05 and about 1.00.

Brief Description of the Drawing(s)

Figures 1 and 2 depict reflective displays according to this invention.

Figure 3 depicts a transmissive display according to this invention.

Figures 4a-b and 5a-b illustrate schematically some possible scattering patterns of displays of this invention.

Description of the Preferred Embodiments

A preferred display medium is encapsulated liquid crystal material, whose preparation is disclosed in U.S. Pat. Nos. 4,435,047 (1984), 4,606,611 (1986), 4,616,903 (1986), and 4,707,080 (1987), all to Fergason; published European patent application EP 156,615 (1985), by Pearlman et al.; U.S. Pat. No. 4,671,618 (1987), to Wu et al.; U.S. Pat. Nos. 4,673,255 (1987) and 4,685,771 (1987), to West et al.; and U.S. Pat. No. 4,688,900 (1987) to Doane et al. In encapsulated liquid crystal material, discrete volumes of liquid crystals are encapsulated, dispersed, embedded or otherwise contained in a containment medium or matrix. "Liquid crystals" denotes a composition having liquid crystalline properties, whether that composition is a single discrete liquid crystalline compound, a mixture of different liquid crystalline compounds, or a mixture of liquid crystalline and non-liquid crystalline compounds. Preferably, the liquid crystals are nematic or operationally nematic. More preferably, they also have a positive dielectric anisotropy.

Liquid crystals have typically elongated molecular shapes, with a tendency to align or orient themselves with their long molecular axes

parallel to each other. This alignment causes liquid crystals to be anisotropic, meaning that their measured physical, optical, and other properties are dependent on the direction of measurement (parallel or perpendicular to the direction of alignment). Further, the alignment direction can be influenced by an external stimulus, such as an electrical or magnetic field, causing the liquid crystals to exhibit a particular value of a physical characteristic in one direction when the stimulus is absent, but rapidly switching to a different value when the stimulus is applied. It is because of their anisotropy and their ready realignment that liquid crystals are useful as materials for displays.

The containment medium is preferably a polymeric material. Suitable containment media include but are not limited to poly(vinyl alcohol) and poly(vinyl alcohol) copolymers, gelatin, polyurethane, poly(ethylene oxide), poly(vinyl pyrrolidone), cellulosic polymers, natural gums, acrylic and methacrylic polymers and copolymers, epoxies, polyolefins, vinyl polymers, and the like. Poly(vinyl alcohol) is a preferred containment medium.

Encapsulated liquid crystal material can be formed by deposition from an emulsion containing both the containment medium and liquid crystals or by the evaporation of liquid from a solution containing both containment medium and liquid crystals. It can also be formed by making an initially homogeneous mixture containing both containment medium and liquid crystals at an elevated temperature, then cooling to phase-separate out liquid crystal volumes contained in the containment medium. Further, it can be formed by an in-situ polymerization process, in which the containment medium is polymerized and simultaneously encapsulates liquid crystal material. The liquid crystal need not be entirely surrounded by the polymer, and may exist as part of a system with co-continuous phases.

The display medium contains pleochroic dyes mixed with liquid crystals to form a solution therewith. The molecules of pleochroic dyes generally align with the molecules of liquid crystals, so that the application of the electric field affects not only the predominant alignment of the liquid crystals, but also of the pleochroic dye. As the extent of the absorption of incident light by the pleochroic dye depends on its orientation relative to the incident light, the application of an external stimulus to a liquid crystal-pleochroic dye combination also provides a means for the controlled

attenuation of light. Generally, the pleochroic dye is in a substantially more light absorbing state in the field-off condition and in a substantially more light transmissive state in the field-on condition. (Thus, as used herein, the term "liquid crystals" also means, in context, liquid crystals containing pleochroic dye dissolved therein.) Pleochroic dyes may be used in encapsulated liquid crystals to form colored displays. Thus, a display capable of displaying colored images can be formed by depositing side by side red, blue, and green pixels.

In the field-off condition, the alignment of the liquid crystals is random or determined by the interfacial forces at the liquid crystal/polymer matrix interface. When the electric field is applied, it induces a change in the alignment of the liquid crystals. If the liquid crystals have a positive dielectric anisotropy and the ordinary index of refraction of the liquid crystals is matched with the refractive index of the containment medium, then in this realigned state the liquid crystal/polymer matrix combination is substantially transparent. Conversely, if these two refractive indices are mismatched, there is some residual amount of scattering. In this invention the refractive indices are selected to be mismatched to the extent of producing a display with improved viewability. The degree of mismatch — i.e. the absolute value of the difference — between the ordinary refractive index of the liquid crystals and the refractive index of the containment medium is preferably between about 0.05 and about 1.00. More preferably the degree of mismatch is between about 0.10 and 0.20.

Referring now to the figures, Figure 1 depicts a display 1 including a display medium 2 comprising droplets of liquid crystals 4 (for example operationally nematic liquid crystals) containing a pleochroic dye, encapsulated in a polymer matrix 3. Behind and in front of display medium 2 are electrode means 5 and 6, respectively, for applying a voltage, which when greater than the threshold voltage, causes display material 2 to switch from one optical state to the other. Electrode means 5 can be reflective, for example made of a thin film of aluminum or other reflective material such as silver or a multilayer dielectric stack, for reflecting light passing through display medium 2 back therethrough, to make a reflective display. Electrode means 6 can be made of a transparent conductive material, such as indium tin oxide (ITO).

In Figure 2 a similar display 1a is shown (like numerals referring to like elements in Figures 1 and 2). Display 1a differs from display 1 in that

the rear electrode means, instead of being monolithic, comprises a plurality of smaller electrodes 5a-d. Such a construction is preferred where the display is intended to display a variable image, ranging from text to graphics, formed from the combination of a large number of pixels, each in the appropriate "on" or "off" state. Each of electrode means 5a-d can apply an electric field to the display material above it, thereby defining a pixel. Each of electrode means 5a-d can be individually controlled by a corresponding switching means 7a-d such as a varistor, as described in Thompson et al., WO 91/17553 (1991), and Becker et al., WO 91/17472 (1991). Other suitable switching means 7a-d include thin film transistors (TFT's), diodes, and metal-insulator-metal constructions (MIM's). As in the instance of electrode means 5 in Figure 1, electrode means 5a-d can be reflective, to make display 1a a reflective display.

Figure 3 shows a transmissive display 11 of this invention, comprising a display material 12 sandwiched between electrodes 15 and 16, which can be made of ITO. Display material 12 comprises a containment medium 13 having dispersed therein droplets of liquid crystal 14. Backlighting is provided by light source 17, at the rear. The mismatch in the refractive indices creates residual scattering which can be used to hide details of light source and to render the brightness of the display more uniform. If a separate diffuser plate were used, light can be lost since highly scattered light is more easily reflected out of the path of the cell. Collimated light, for example from a parabolic mirror, can be used.

The degree of scattering imparted by the scattering centers should correspond to a scattering half angle between about 2 and about 40 degrees, preferably between about 10 and about 20 degrees, more preferably between 15 and 20 degrees. The scattering half angle (θ_s) means the square root of A/π:

$$\theta_s = (A/\pi)^{1/2}$$

where A (in units of (degree)^2) is the area enclosed by the 50% contour(s) corresponding to the area(s) within which the scattering is greater than 50% of the maximum.

In many instances the scattering is symmetric, in which case the 50% contour will be centrosymmetric, but this is not necessarily so, and asymmetric scattering and/or multiple scattering maxima, and consequently asymmetric 50% contours can occur. Figure 4a shows the scattering diagram for a symmetric, unimodal, scattering situation. In

such an instance, the 50% contour defines an approximately circular area A, as shown in Figure 4b. However, where the scattering is bimodal and/or asymmetric, as shown in Figure 5a, then there are multiple areas A_1 and A_2 defined by the 50% contours, as shown in Figure 5b, and A is their sum.

The scattering provides for a more pleasing display. In a reflective display, if the degree of scattering is too low, i.e., as in prior art displays having a highly specular reflector and no scattering as taught in this invention, then the mirror-like reflections are not sufficiently suppressed. This effect is to some extent dependent on the size of the display. A small display, for example about 4 inches diagonal, can tolerate a lower degree of scattering than a larger display, for example about 14 inches diagonal, because the amount of structure seen in the reflector is likely to be much less.

This invention provides several advantages. The brightness is improved over a wider range of viewing angles than with a specular mirror which is only bright when the eye sees the images of the light sources in the room. Glare from the light sources is reduced, making display appearance (contrast, brightness, etc.) less dependent on the exact viewing angles and placement of the light sources in the room. However, this does not mean that the higher the degree of scattering, the better the viewability of the display — rather, the degree of scattering should be within the ranges taught herein. If the degree of scattering is too high, then high angle scattered light is trapped in the display, to be absorbed by any pleochroic dye present, and the optical gain is too low for most viewing purposes.

Claims

What is claimed is:

1. A display comprising:

a first electrode means;

a second electrode means; and

a display medium positioned between the first and second electrode means, which display medium contains a pleochroic dye, is switchable between a first state in which incident light is substantially absorbed by the pleochroic dye and a second state in which the amount of such absorption is substantially reduced, and is capable of scattering incident light with a scattering half angle between about 5 and about 40 degrees when the display medium is in its second state, while permitting at least 10% of the incident light to be transmitted.

2. A display according to claim 1, wherein the display medium comprises positive dielectric anisotropy, pleochroic dye-containing, operationally nematic liquid crystals dispersed in a containment medium.

3. A display according to claim 1 or 2, wherein the second electrode means is reflective, for reflecting light passing through the display medium back through the display medium.

4. A display according to claim 1 or 2, wherein the second electrode means is transparent.

5. A display according to claim 4, further comprising a light source behind the second electrode means.

6. A display according to claim 2, wherein the absolute difference between the ordinary refractive index of the operationally nematic liquid crystals and the refractive index of the containment medium is between about 0.05 and 1.00.

7. A display according according to claim 2, wherein the absolute difference is between about 0.1 and about 0.2.

8. A liquid crystal display medium switchable between a first state in which incident light is substantially absorbed by a pleochroic dye and a second state in which the amount of such absorption is substantially reduced, comprising:

a containment medium;

discrete volumes of liquid crystals dispersed in the containment medium; and

pleochroic dye contained in the liquid crystals;

wherein the absolute difference between the ordinary refractive index of the liquid crystals and the refractive index of the containment medium is between about 0.05 and about 1.00.

9. A liquid crystal display medium according to claim 8, wherein the liquid crystals are positive dielectric anisotropy, operationally nematic liquid crystals.

10. A liquid crystal display medium according to claim 8, wherein the absolute difference is between about 0.10 and about 0.20.

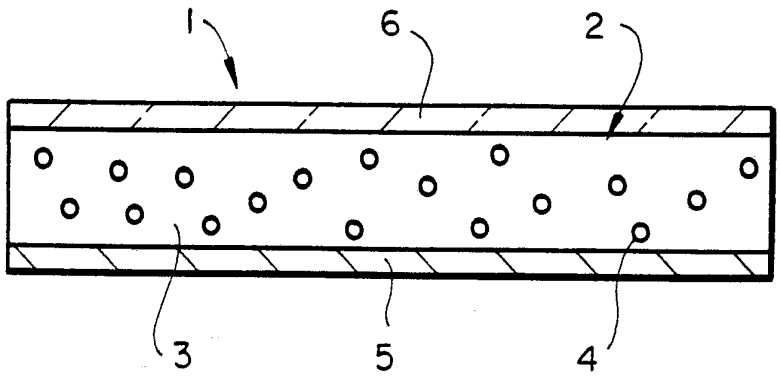

FIG_1

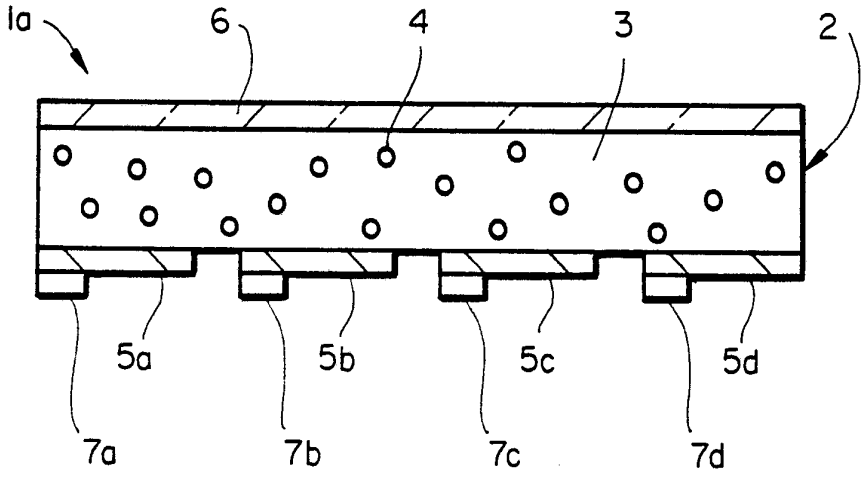

FIG_2

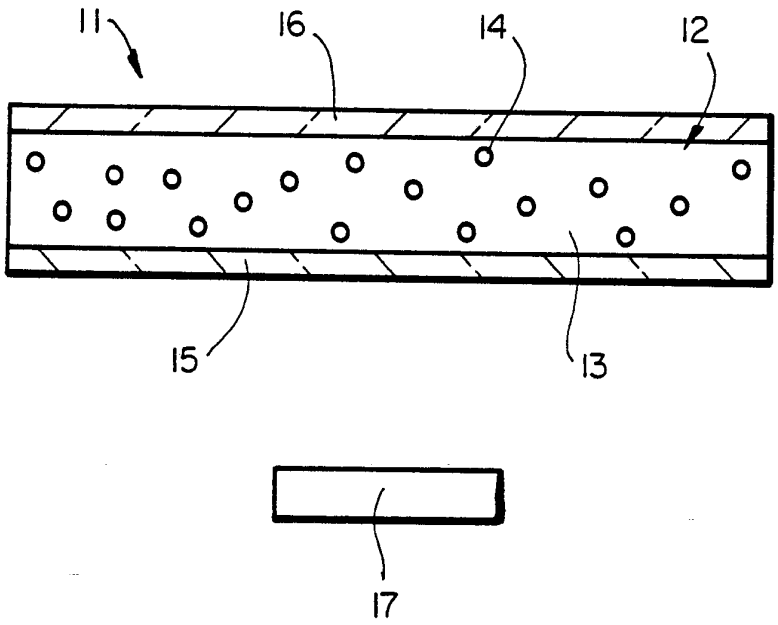

FIG_3

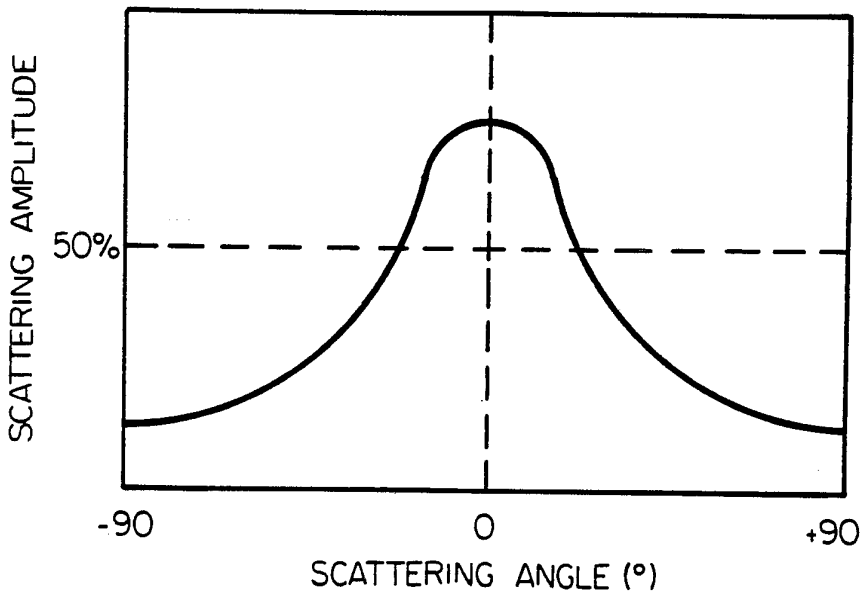
SCATTERING AMPLITUDE
50%
-90
0
+90
SCATTERING ANGLE (°)

FIG_4a

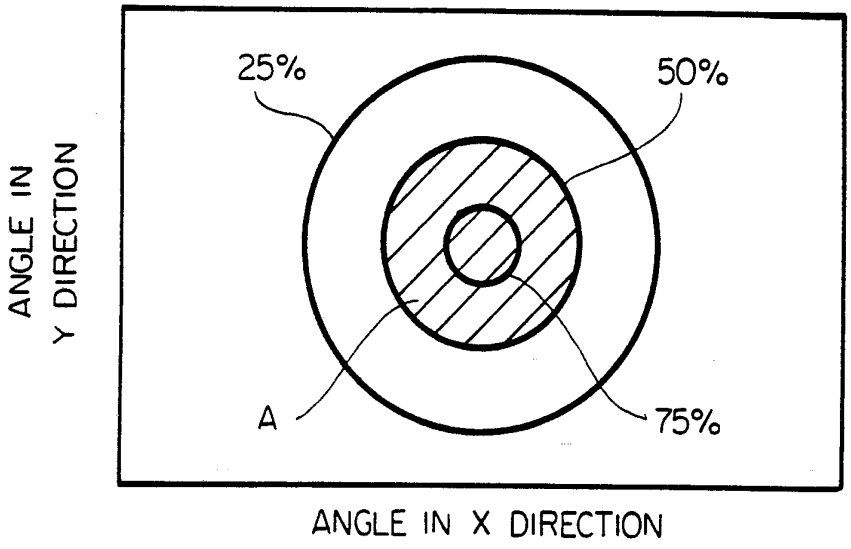
25%
50%
A
75%
ANGLE IN Y DIRECTION
ANGLE IN X DIRECTION

FIG_4b

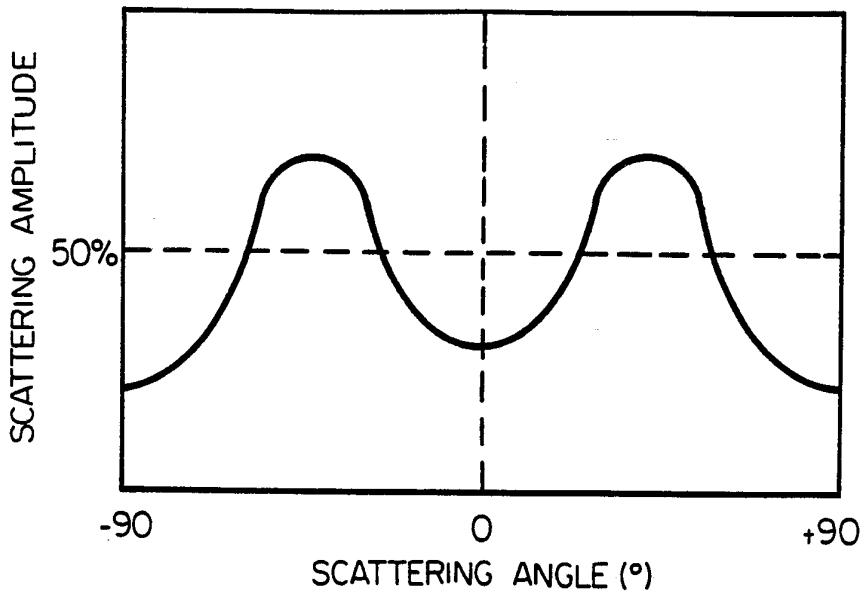
SCATTERING AMPLITUDE
50%
-90
0
+90
SCATTERING ANGLE (°)

FIG_5a

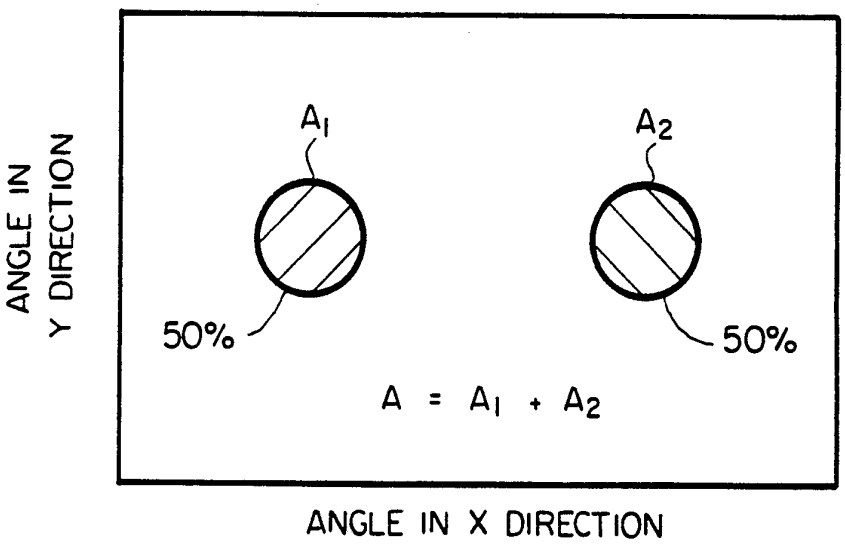
ANGLE IN Y DIRECTION
A1
A2
50%
50%
A = A1 + A2
ANGLE IN X DIRECTION

FIG_5b

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US92/00459

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC (5): G02F 1/13
U.S.Cl.: 359/51,52

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S.Cl.	359/51, 52, 98

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	US, A, 4,606,611 (FERGASON) 19 August 1986 (Note column 3, lines 47-50 and column 4, lines 32-41).	8, 9
y	J. Applied Physics, Volume 62, No. 9, issued November 1, 1987, B. Wu et al., "Angular discrimination of light transmission through polymer-dispersed liquid-crystal films," see page 3927.	8, 9
A	US, A, 4,685,771 (WEST) 11 August 1987 (See entire document).	1-10
A	US, A, 4,688,900 (DOANE) 25 August 1987 (See entire document).	1-10
A	US, A, 4,671,618 (WU) 09 June 1987 (See entire document).	1-10
A	US, A, 4,648,691 (OGUCHI) 10 March 1987 (See entire document).	1-10
A	US, A, 4,616,903 (FERGASON) 14 October 1986 (See entire document).	1-10

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
04 March 1992	20 MAR 1992
International Searching Authority	**Signature of Authorized Officer**
ISA/US	Anita Pellman Gross

Form PCT/ISA/210 (second sheet) (Rev.11-87)

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

A	US, A, 3,984,176 (HIRAI) 05 October 1976 (See entire document).	1-10
A	JP, B, 53-5996 (SUWA SEIKOSHA K.K.) 07 June 1976 (See abstract).	1-10
A	Xerox Disclosure Journal, Volume 3, No. 5, issued September/October 1978, W. Haas, "Scattering Electron-optic Cells," see pages 333-334.	1-10

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers ..... , because they relate to subject matter [12] not required to be searched by this Authority, namely:

2. ☐ Claim numbers ..... , because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

3. ☐ Claim numbers _____, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.