FORCED CLOSURE DIPOLAR ELECTRO-OPTIC SHUTTER AND METHOD

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References Cited
UNITED STATES PATENTS
3,527,525 9/1970 Marks

FORCED CLOSURE DIPOLAR ELECTRO-OPTIC SHUTTER AND METHOD

Abstract
Electro-optical devices are disclosed which employ a layer of minute dipolar particles in a non-ionic suspension carried between two transparent sheets. A series of spaced wirelike electrodes straight line parallel to each other are carried by the transparent sheets on each side of the dipolar layer. Electrical circuits including switching means and a source of direct electrical potential are connected to the electrodes to set up and control electric field patterns within the dipole suspension to positively randomize or orient the dipoles.

16 Claims, 14 Drawing Figures
FORCED CLOSURE DIPOLAR ELECTRO-OPTIC SHUTTER AND METHOD

BACKGROUND OF THE INVENTION

This application is a continuation-in-part of an application filed on June 8, 1966, Ser. No. 556,113, entitled Forced Closure Dipolar Electro-Optic Shutter and Method by Alvin M. Marks (now U.S. Pat. No. 3,527,525) and is also a continuation of application, Ser. No. 42,813 now abandoned, entitled Forced Closure Dipolar Electro-Optic Shutter and Method, filed June 2, 1970.

The electro-optical devices of the present invention are hereinafter referred to as VARAD panels. Such devices comprise transparent electrodes containing therebetween a layer of a fluid suspension of dipolar rod-like particles, for example, metal rods or herapathite crystals. The dipolar rod-like particles generally have a length of about 2,000 A. and a width of about 100 A. and are capable of reacting with visible light or other electro-magnetic radiation. (1 A. = 10^-10m)

Normally with no potential difference applied between the transparent electrodes, the dipolar rods are oriented at random due to the impacts of the fluid molecules, known as Brownian motion. Light incident upon the panel is absorbed and the panel is almost opaque (closed). When a potential difference is applied between the transparent electrodes, the dipolar rods orient normal to the panel and the light transmittance increases; that is, the optical density decreases to a minimum, exponentially. The opening or "alignment time" is defined as the time for the dipole suspension layer to reach 1/e or 37 percent of the minimum optical density. If the potential difference is suddenly cut off, the dipoles disorient to random directions by Brownian motion and the optical density increases exponentially. The closing (disorienting) or "relaxation time" is defined as the time for the dipole suspension layer to attain 1/e or 37 percent of the maximum optical density. The relaxation time of a dipole suspension is linear with viscosity, and inversely proportional to the cube of the dipole length.

The Z axis is defined as the axis normal to the major plane of the VARAD panel, and the X and Y axes are rectangular in the said plane. As an example, using a dipole of dimensions about 5,000 x 200 x 50 A. in a suspension layer 0.75mm thick, in a fluid of about 20 millipoise viscosity and with a potential difference of 500 volts applied parallel to the Z axis, between transparent electrodes 1mm apart, the dipolar rods substantially orient parallel to the Z axis. In this example, the VARAD panel "opens" in less than 100 microseconds, but more than about 1,000 microseconds is required to "close" or randomize the dipoles by Brownian motion alone. The present invention is intended to decrease the "closing time" such that it is equal to, or less than the "opening time."

The minimum possible relaxation time of an optimum dipole suspension due to Brownian motion only may be computed using the data from the above example, and the known physical laws relating relaxation time, dipole length and fluid viscosity.

1. The optimum dipole dimension for visible light of 5,600 A. mean wavelength is about 1/2 or about 1,880 A. The dipole dimensions of the above example thus may be advantageously decreased by a factor of

5,000/1,880 = 2.66, whereby the relaxation time is decreased by a factor of (2.66)^2 = 19 times.

2. The smallest viscosity fluid available is about 2 milipoise. Thus, the fluid viscosity of the above example may be decreased by a factor of 10.

3. From (1) and (2) therefore, the fastest relaxation time attainable by Brownian motion, with an optimum dipole suspension, appears to be less than that measured in the above example by a factor of about 19 x 10 or 190 times; that is, about 5 microseconds.

With such an optimum dipole suspension, the forced closure process itself disclosed would nevertheless enable a further decrease in the relaxation time to about 10^-7 sec or 100 nanoseconds. Thus, whatever the improvement in Brownian motion closure time may be achieved by a decrease of dipole dimensions and fluid viscosity, a still further substantial improvement in relaxation time by a factor of 20 or more is achievable by a forced closure process according to the present invention.

For many purposes, as for protection from flash blindness, the closure time must be 100 microseconds or less. Such speed is accomplished by the present invention, as hereinafter described.

SUMMARY OF THE INVENTION

The invention comprises electrode structures and associated circuits designed to permit the Z-X switching. During the Z-X switching, the electric field may be shifted and interlaced to provide a uniform positive disorientation of the dipoles, hereinafter referred to as "force disorientation."

Critical multi-electrode conducting line dimensions have been determined so that electrode structures are invisible to the eye, and absorb only about 2 to 8 percent of the light passing therethrough, with little or no deterioration of the image cause by the diffraction effect.

It is an object of this invention to provide a dipole shutter having a rapid closure time suitable for use as a display device, a photographic shutter, or as a panel for the protection against light flashes, nuclear or otherwise.

It is an object of this invention to rapidly disorient or realign an initially aligned dipole suspension.

It is an object of this invention to us an electrical field to force-disorient a previously aligned dipole suspension.

It is an object of this invention to provide an electrode structure and associated circuits suitable for aligning a dipole suspension placed between said electrode structure in the Z direction and to force disorient and/or realign said dipoles in the X and/or Y direction.

It is an object of this invention to rapidly decrease the transmittance of a previously aligned single layer dipole suspension by realigning a portion of the dipoles on one surface of the layer in the X direction and realigning another portion of the dipoles on the other surface of the layer in the Y direction.

It is an object of this invention to provide a transparent invisible electrode structure on a transparent sheet comprising conducting lines, alternate pairs of which may be excited independently and in which all terminals are brought out on one face of the sheet.

It is an object of this invention to utilize conducting line multi-electrodes on a transparent sheet in which
the electric fields are shifted and interlaced to uniformly and rapidly opaque the sheet. It is an object of this invention to provide isolation circuits so as to avoid cross talk between pairs of alternate electrodes.

It is another object of this invention to use the rotational inertia of the dipoles produced by a pulse comprising an alternating potential difference of large amplitude, within a gate of short time duration, applied to a dipole suspension whereby the dipoles continue to rotate for some time after the electrical pulse ends.

It is an object of this invention to provide an optimum dipole suspension having a minimum relaxation time due to Brownian motion alone.

This invention utilizes novel electrode structures and circuits which enable the application of electric fields in the Z direction, and subsequently in the X and/or Y direction.

A uniform opaquing of the visual field is produced by a shift and interlacing of the field pattern in the X and/or Y directions between interlaced conducting line pairs.

The shifting and interlacing of the electric field in the X and/or Y direction is necessary to produce a uniform opaquing of the visual field. If the electric field pattern remains stationary it has been found that strips of alignment and disalignment result in a visual field having alternate transparent and opaque strips.

The shift and interlacing of the electric field may be produced by a translation of the electric field in the X and/or Y direction by a succession of voltage pulses.

Starting with a dipole suspension initially aligned in the Z direction, a rapid decrease in the transmittance of the panel from an initial high transmittance is forced by one or more of the following processes:

1. One or more pulses of a potential difference is applied with field shifting in the X direction between parallel line conductors. The time duration of these pulses is adjusted to be just sufficient to cause randomization but not reorientation of the dipoles.

2. One or more pulses of a potential difference applied with field shifting to each side successively to a single layer dipole suspension, adjacent one surface of the layer in the X direction and adjacent the other surface in the Y direction, to obtain dipoles aligned at 90° to each other, result in opaquing by cross polarization. Opaquing a pair of dipole layers by crossed polarization was previously described in U.S. Pat. No. 3,167,607, in which each dipole layer had a single pair of electrodes.

The present invention utilizes special multi-electrode structures and a single dipole layer. One or more pulses are applied in the X direction of a time duration just sufficient to produce X orientation; then by one or more pulses applied in the Y direction of a time duration just sufficient to cause Y orientation. The conducting line structures on each side of the dipole layer are at right angles, one set of conducting lines being along the X direction, the other set of conducting lines being along the Y direction.

3. An inertial dipole effect.

With conductors in direct contact with dipole suspension layer, it is preferred to employ an insulating nonionic fluid containing a suspension of stable dipole particles, such as metal particles, as described in U.S. Pat. No. 3,512,876 issued May 19, 1970 and continuation in part application Ser. No. 16,280 filed Mar. 4, 1970.

The invention consists of the construction, combination and arrangement of parts as herein illustrated, described and claimed.

DESCRIPTION OF THE DRAWINGS

In the accompanying drawings forming a part hereof, there is illustrated several forms of embodiment of the invention in which drawings similar reference characters designate corresponding parts, and in which:

FIG. 1 shows an electrooptic panel utilizing thin electrodes embedded in sheets with the dipoles omitted for the sake of clarity. The electrodes are shown applying an electrical field in dashed lines in the Z direction to align the dipoles parallel to the Z axis for maximum transmittance.

FIG. 2 shows the same electrooptic panel shown in FIG. 1 but with the electric field pattern applied momentarily in the X direction to produce forced disorientation. All regions are disoriented equally by periodically shifting and interlacing the electric field pattern in the X direction.

FIG. 3 shows for an electrooptic panel having electrodes as in FIG. 1, the potential difference V, for Z alignment of the dipoles and the successive gated potential differences $V_{x1}$ and $V_{x2}$, applied successively to shift and interlace the electric field structure in the X direction, to provide a uniform disorientation of the dipoles.

FIG. 4 shows a plan view of a conducting line electrode structure deposited on a transparent supporting plate.

FIG. 5 shows an electrooptic cell assembly utilizing the electrode structures shown in FIG. 1.

FIG. 6 shows a portion of an electrooptic cell having another electric field configuration in which the forced disorientation or realigning electric field is applied between electrodes on opposite sides of the dipole suspension.

FIG. 7 shows an isolation circuit for Z-X alignment.

FIG. 8 is a graph showing the inertial alignment effect on a herapatite dipole suspension by a short gated potential difference $V_e$, applied along the Z axis; compared to the slow disorientation of Brownian motion alone.

FIG. 9 shows a comparison of the speeds random closure vs. forced closure showing optical density vs. time traces displayed on the storage scope.

FIG. 10 shows a plan view of the simplified structure of a sheet having conducting line electrodes in which alternate lines are each connected to a common bus bar.

FIG. 11 is a sectional view taken on line 11-11 in FIG. 10 included in a forced closure electrooptic cell assembly; and a circuit for ZX switching.

FIG. 12 shows a section through an electrooptic panel having a circuit for ZX switching.

FIG. 13 shows a fragmentary front view of an electrooptic panel employing electric fields directed along the X and Y axes.

FIG. 14 shows a fragmentary section of FIG. 13 parallel to the Y Axis, taken along line 14—14 in FIG. 13.

Referring now to FIGS. 1, 2 and 3; 20 indicates an electrooptic panel adapted for forced disalignment having multi-electrodes 21, 22 for Z-X electric field switching. In carrying out the Z-X electric field switch-
ing shown in FIGS. 1 and 2, the circuits hereinafter described are used.

FIG. 1 shows electric field lines 23, applied parallel to the Z direction between the multi-electrodes 21, 21b, 21c, 21d, 21g on transparent sheet 24 and the corresponding multielectrodes 22a, 22b, 22c, 22d, 22g on transparent sheet 24'. An electric field applied parallel to the Z axis, between the conductors 21g and 22g aligns the dipoles (not shown) with their long axes normal to the transparent sheets 24, and 24' resulting in maximum transmittance.

FIG. 2 shows the same panel shown in FIG. 1, in which the X electric field is shifted alternately between multielectrodes 21a, 21c, 21e, 21g; 22a, 22c, 22e, 22g, and 21b, 21d, 21f; 22b, 22d, 22f. An electric field pattern in the X direction is thus shifted from position 27 (dashed lines) to position 28 (dotted lines) and vice versa. The space 29 between the fields which has a zero electric field when the electric field patterns 27 are established, is replaced by the shifted electric field pattern 28 shown in dotted lines. Thereby the entire dipole layer 26 (dipoles in the suspension between the sheets 24, 24') is uniformly disoriented.

FIG. 3 shows actuating potential differences as applied to an electrooptic panel, as shown in FIG. 1. To produce the rapid opaquing the gated potential difference \( V_{d1} \) and \( V_{d2} \) are applied to produce the shifting and interleaved electric field patterns as shown at 27, 28 in FIG. 2. The pulses \( V_{d1} \) and \( V_{d2} \) are applied at times \( t_1 \) and \( t_2 \) respectively with pulse durations \( t = t_2 - t_1 \) sufficient to disorient the dipoles, but not of a longer duration which would reorient them in the X direction.

The forced closure process shown in FIGS. 1 and 2 may be performed with an electrooptic panel having the conducting line electrode structure shown in FIG. 4 between the transparent supporting plates 24, and 24'.

With the conducting line electrode structure of FIG. 4 all connections are on one side of one plate. A glass plate 24 is prepared with conductive lines of thickness \( d \), ruled a distance \( D \) apart. The conducting lines are connected as follows: Lines 2, 6, 10, etc. are brought out through busbar 30 and terminal 36. An insulating strip 31 of width \( w \) and length \( L_3 \) is then deposited over the busbar 30 to terminal 36. The lines, 1, 5, 9 are connected to busbar 32 and terminal 37. In a similar manner the lines 4, 8, 12 are brought out to busbar 33 and terminal 39. An insulating strip is deposited thereover. Lines 3, 7, 11 are then deposited over the strip 34 and onto the surface of the glass plate 24 and connected to busbar 35, and terminal 38. As an example, suitable dimensions for the plate shown in FIG. 4 are:

<table>
<thead>
<tr>
<th>Conducting Line</th>
<th>Plate Dimensions mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d )</td>
<td>1</td>
</tr>
<tr>
<td>( w )</td>
<td>0.01-0.001</td>
</tr>
<tr>
<td>( L_3 )</td>
<td>75</td>
</tr>
<tr>
<td>( L_4 )</td>
<td>55</td>
</tr>
<tr>
<td>( L_5 )</td>
<td>50</td>
</tr>
<tr>
<td>( L_3 )</td>
<td>75</td>
</tr>
<tr>
<td>( L_4 )</td>
<td>50</td>
</tr>
<tr>
<td>( a )</td>
<td>6</td>
</tr>
<tr>
<td>( b )</td>
<td>1</td>
</tr>
</tbody>
</table>

For the conductive lines to be invisible at 45cm from the eyes requires at least four lines per mm. The transmittance of the panel depends on the proportion of the area taken up by the lines as compared to the space between the lines.

The characteristics of electrooptic panels with conductive lines space so as to be invisible is given in the following Table II:

<table>
<thead>
<tr>
<th>Lines per mm</th>
<th>4</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of conductive lines mm</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Distance between lines mm</td>
<td>0.250</td>
<td>0.125</td>
</tr>
<tr>
<td>Ratio ( = (0.250/0.005) )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absorption per panel %</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Dipole layer thickness mm</td>
<td>0.250</td>
<td>0.125</td>
</tr>
</tbody>
</table>

FIG. 5 shows another embodiment of an assembled dipole cell. Wires 40 are parallel and equally spaced. The wires are engraved onto a glass plate 41. A spacer 45 provides space for the dipole layer. The assembly is joined around the edges with the epoxy cement 43. Each wire is brought out to a terminal (not shown).

To apply the electric field in the X direction, as in FIG. 2, a potential difference is applied between every other wire on one lamina and the corresponding wires on the opposed lamina. The dipole suspension layer may have a dielectric constant of about 2. The torque on the dipoles is greater in a fluid medium having a small dielectric constant. It is important, of course, to keep the turning force on the dipoles at a maximum with a given applied electric potential difference. It is not advisable, therefore, to increase the dielectric constant of the fluid dipole suspension.

A way of avoiding the loss of flux in the X direction by shorting through the glass layers 41 and 41', is shown in FIG. 6 in which the electric fields are applied across the dipole suspension layer 26 between 1-3; or 2'-4', the electric field being shifted as shown in FIG. 2. With this arrangement all the electric flux passes through the dipole suspension and causes a maximum torque on the dipoles.

FIG. 8 illustrates the inertial dipole effect, showing transmittance and optical density versus time for a dipole suspension, to which has been applied a potential difference within a gate having the time duration \( t_4 \). The alignment continues after the pulse reaches peak at time \( t_4 \). The transmittance increases from the minimum random \( T_r \) to maximum \( T_m \) at time \( t_1 \); then decreases more slowly by Brownian motion.

Table III shows experimental results on the inertial alignment effect for an herapathite dipole suspension. In this experiment a gate of time duration \( t_4 \) containing an alternating potential difference of frequency of 100kc of about 500 volts rms is applied in the Z direction across an electrooptic cell. The observations show the inertial dipole effect exists.
TABLE III

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse duration ( t_1 )</td>
<td>50</td>
<td>100</td>
<td>200</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>Time to attain a maximum transmittance</td>
<td>1000</td>
<td>1000</td>
<td>1100</td>
<td>1200</td>
<td>1300</td>
</tr>
<tr>
<td>Time for which alignment continues after the applied pulse</td>
<td>950</td>
<td>900</td>
<td>900</td>
<td>700</td>
<td>300</td>
</tr>
<tr>
<td>Random transmittance at start of pulse</td>
<td>0.15%</td>
<td>0.18%</td>
<td>0.18%</td>
<td>0.18%</td>
<td>0.18%</td>
</tr>
<tr>
<td>Transmittance at end of pulse</td>
<td>0.16%</td>
<td>0.19%</td>
<td>0.4%</td>
<td>0.3%</td>
<td>0.11%</td>
</tr>
<tr>
<td>Maximum transmittance</td>
<td>1.2%</td>
<td>4.0%</td>
<td>7.0%</td>
<td>10.0%</td>
<td>15.0%</td>
</tr>
</tbody>
</table>

In FIG. 9 there is shown for an herapathite suspension, the experimental trace on a storage scope of optical density vs. time as shown for random closure and forced closure. The sweep time is 100 microseconds per division. Random closure by Brownian motion only was approximately 0.2 of an optical density unit per millisecond, or approximately 5,000 microseconds per density unit. This is an increase in speed by a factor of 100 times.

A dipole suspension having a smaller viscosity shorter dipoles, and subjected to a greater electric field intensity would show faster alignment or disalignment times.

This data is illustrative of results which may be obtained utilizing the methods of the present invention but not to be considered limiting. Further decreases in the time to force disorient, may be obtained by the use of greater voltages, smaller viscosities and smaller dipoles. The voltage can be increased by a factor of 5, the viscosity can be decreased by a factor of 2, and the dipole length decreased by a factor of 3. The speed varies linearly with the voltage and viscosity, and as the cube of the dipole length, hence a speed increase of about 2 \( \times 5 \times 3^3 = 270 \times \) is considered feasible. Thus, random closure speeds can be ultimately decreased to: (5,000/270) 20 microseconds, and the forced closure to about 0.2 microseconds.

Theory and experiment also has shown that forced disorientation occurs in a shorter time than forced orientation. This follows because the disorientation process proceeds from a condition of order to disorder, while the orientation process proceeds from a condition of disorder to order. Brownian motion aids the disorientation process and opposes the orientation process.

FIGS. 10 and 11 show an electrooptic panel having line conductors and a circuit for applying thereto an interlaced time displaced electric field for including uniform forced closure.

FIG. 10 shows a plan view of a transparent support 89 containing conducting lines 90 wherein each alternate conducting line is brought out to a single bus bar 91, 92, there being two terminals per sheet.

FIG. 11 shows a cross section through an assembly of conducting line transparent supporting panels similar to that shown in FIG. 10, together with the switch coupled circuit for actuating the alignment, and for providing forced disalignment when required. FIG. 12 also shows a novel interlaced field pattern which lends itself to the simplified circuitry shown.

Referring to FIG. 10, there is shown a support sheet 89 having conducting lines 1, 2, 3, 4, 5, 6, etc. deposited on the face thereof. Alternate lines 1, 3, 5, 7 are connected to busbar 92 at one end and thence to terminal 93.

FIG. 11 shows a cross section of FIG. 10 along the line 11, 11'. The potential differences shown in FIG. 3 are utilized in connection with FIG. 11. The potential difference \( V_{s2} \) applied as long as the dipole suspension is to be oriented in the Z direction across the terminals 96. The terminals 96 are isolated from the circuit by switches 95 and 95' which connect respectively to the center taps of resistor pairs 97–98 and 97'–98'. When the dipole suspension 26 is to be disaligned, the alternating potential difference \( V_{s2} \) is applied across terminals 99; and immediately thereafter the gated potential difference \( V_{s2} \) is applied across the terminals 99'. The terminals 99 are connected through switch pairs 100–101 across the resistor pairs 97–98. In similar manner, the terminals 99' are connected to the switch pairs 100'–101', and thence across the resistor pairs 97'–98'. The effect of applying \( V_{s2} \) is to establish the field pattern 102 which causes the disorientation of dipoles near one major surface of the dipole layer.

As previously described, the field lines change from the X direction and loop toward the Z direction as they approach the conducting lines, causing the panel to opaque non-uniformly, showing alternate opaque and light strips. This is avoided by the immediate application of \( V_{s2} \) after the application of \( V_{s2} \), which gives rise to time displaced interlaced field patterns 102 and 102'. Field 102' has an X component where the field 102 has a Z component, and vice versa; the interlacing being such that a uniform opaquing now occurs across the entire face of the pattern. The field pattern shown in FIG. 11 should be compared with the field patterns of FIG. 2.

In FIG. 2, the field pattern is symmetrical and simultaneous with reference to the center plane of the dipole suspension layer. The field patterns of the upper and lower plates of 89 and 89' are established simultaneously and are the same about the upper and lower conducting lines.

FIG. 11 shows the time displaced interlaced electric field pattern suitable for forced closure.

In FIG. 11 the electric field structures from the upper plate 89 and from the lower plate 89' are not symmetrical about the center plane of the dipole suspension. The effect of applying the gated potential differences \( V_{s2} \) shown in FIG. 3, is to establish the upper electric field pattern first, and the lower electric field pattern second. The interlacing of these electric field patterns assures the uniformity of the opaquing effect across the face of the panel. The plate structure in FIG. 10 is much simpler than the plate structure of FIG. 4. In FIG. 10, each supporting sheet 11 has only one pair of elec-
trodos. In FIG. 4 there are four conductors on each plate, and a more complex method of preparation is required. Moreover, the circuit shown in FIG. 11 is simpler than the circuit shown in FIG. 7 which is required to actuate the conducting line structure of FIG. 2, in which it is preferable to isolate the intermediate line structures to prevent the local shorting out of the electric field on the alternate conducting lines.

FIG. 12 shows another embodiment of this invention, as a sectional cutaway view of an electrooptic panel suitable for actuation of the forced closure of a display or other pattern, which employs direct voltage fields for alignment and closure. In FIG. 12, glass sheets 110 and 111 are engraved with conducting lines 112, 113, and 114 on sheet 110; and corresponding conducting lines 112', 113', and 114' are engraved on sheet 111. Alignment voltage \( V_a \) is applied to the pair of lines 114-114' through terminals 115 and 116, which establishes the alignment electric field 117 in the \( Z \) direction. The forced-closure electric field 118 is applied in the \( X \) direction between lines 112 and 113 and 112' and 113' from terminals 119 and 120. In this case, a uniform closure field is obtained, without interlacing, because during alignment, only the local area between the lines 114 and 114' is made transparent by the field 117. The dipole medium 121 is everywhere else opaque because the dipoles are at random. When the direct field 118 is switched on, the area between the electrodes 114 and 114' is subjected to the nearly uniform field in the \( X \) direction, which causes the entire space between the lines 114-114' to opaque uniformly.

This principle may be applied to large area displays, display numerals, and other patterns. The lines may form a grid or may curve on the surface in any suitable manner to show designs or patterns.

An advantage of this forced-closure method is that a more viscous dipole medium 121 may be employed with somewhat larger particles, because the alignment time is considerably shortened by forced closure relative to the Brownian Motion closure time.

It will also be evident that the electrodes 22 may be disposed normally to the electrode 21 so that the fields may be applied alternately and at right angles in order to momentarily align the dipole particles in the \( X \) and \( Y \) directions on the opposing surfaces of the dipole layers. This enables a more complete randomization to be obtained. FIGS. 13 and 14 show an electro-optic panel which is similar to that shown in FIG. 3, comprising two plates, 24 and 24', in which the electrode line structures are mutually at a right angle. The space between the plates 24 and 24' contains the dipolar fluid suspension layer 26. The electric field patterns on each plate are interlaced in the manner described in connection with FIGS. 2 and 3; except that the directions on each side of the dipole layer 26 are mutually at right angles. The interlaced field patterns on plate 24 are in the direction of the \( X \) axis; and the interlaced field patterns on plate 24' is in the direction of the \( Y \) axis; and tend to produce corresponding dipole alignment. The dipole particles in the center of the dipole fluid layer 26 are shown momentarily in a randomized condition.

To provide maximum transmission, the particles are aligned along the \( Z \) axis as shown in FIG. 1. In this case, all the conducting lines shown in FIG. 13, at 1, 2, 3, 4, 5, are connected together to one pole and all the conducting lines 1', 2', 3', etc. on the adjacent face are connected to the opposite pole and the field is applied substantially in the \( Z \) direction. The spacing, between the lines is made small in comparison to the dipole layer thickness, so that the direction of the aligning field is almost parallel to the \( Z \) axis.

During forced closure, a rapid interlacing electric field pattern is applied alternately between lines 1, 3, 5, 7 and 2, 4, 6, 8, causing the dipoles particles 127 adjacent to the inner surface of plate 24 to momentarily tend to align among the \( Y \) axis. The pulse is then discontinued and another interlacing series of pulses are applied alternately between lines 1', 3', 5', 7', and 2', 4', 6', 8', to tend to align the dipole particles 126 on the inner surface of plate 24' in the direction of the \( X \) axis.

The aligning pulses referred to may be continued only so long as to partially rotate the dipole particles in their respective directions, stopping short of actual alignment. This procedure causes a rapid cross randomization of the particles 126 and 127 respectively. The application of electric field pulses to the dipolar fluid momentarily increases the energy per unit volume of the dipole fluid, and momentarily increases the instantaneous Browning Motion, in the dipole layer 26 and causes a more rapid randomization. Moreover, the cross-interlacing produces a more uniform opaque field.

The pulses applied to the conducting line structures along the \( X \) and \( Y \) axes, may be of any duration to obtain partial alignment, complete alignment, or randomization of the dipole particles and the pulses may be applied in any suitable time succession.

A greater opacity is obtained by simultaneously aligning particles in layer 126 in the \( X \) direction and aligning the dipole particles in 127 in the \( Y \) direction as shown by successively applying the pulses for a sufficiently long time.

The device shown in FIGS. 13, 14 may be used as an electrooptic polarized sheet, whose plane of polarization may be rapidly switched from the \( X \) to the \( Y \) direction or vice versa. Such electrically switched XY polarizers have wide applications to the arts. For example, they may be used in the production of three-dimensional movies, in which the planes of polarization of successively projected images are rapidly switched from the \( X \) to the \( Y \) direction to successively project right and left stereo images.

When a D.C. electric field is applied, ions tend to migrate toward the positive electrodes or conductors.

Ionic shielding is obviated by conductors in direct contact with the dipole suspension. D.C. or A.C. or pulses may be used. The ions are discharged as they migrate to and contact the electrodes. However, dipoles in a relatively nonionic, nonreacting fluid must be used in contact with the transparent conductive coatings.

With insulating nonionic fluids containing a suspension of stable dipole particles such as metal particles the conductors may be in direct contact with the dipole suspension fluid and a D.C. electric field may be used. In this case the ions discharge on the conductors. There is little or no deterioration of the suspension or the transparent conductors provided the suspending fluid is substantially nonionic. Examples of nonionic fluids are: aromatics, such as benzene and toluol; aliphatics, such as hexane, decane; diphenyl chloride; esters such as dimethyl phthalate, dioctyladipate; silicone oil etc. having resistivities in excess of 30 megohm-cm.
Having thus fully described the invention what is claimed and new and sought to be secured by Letters Patent of the United States is:

1. A light controlling device comprising at least a pair of spaced transparent sheets, a transparent suspending medium between said sheets, a layer comprising a plurality of elongated dipoles freely carried within the suspending medium, each said dipole having a first dimension in a direction of elongation on the order of one-half the wavelength of light and a second dimension normal to the direction of elongation substantially smaller than said first dimension, said dipoles presenting a cross-section to electromagnetic radiation which is a function of their orientation, whereby light transmission through the layer is at a maximum when the direction of elongation of said dipoles are oriented parallel to a light path and at a minimum when said dipoles are in random directions, a first series of spaced wire-like electrodes straight line parallel to each other disposed in a plane and carried by one of the transparent sheets, a second series of spaced wire-like electrodes straight line parallel to each other disposed in a plane parallel to the plane of the first series and carried by the other transparent sheet, means for electrically interconnecting selected electrodes into a plurality of electrode sets, and electrical circuit means selectively applying direct electrical potential differences to said electrode sets for creating interlaced electric field patterns within the dipole suspension layer to control the disposition of the dipoles within the suspension.

2. A device according to claim 1 in which said electrical circuit means create interlaced time displaced electric field patterns within the dipole suspension layer.

3. The process of inducing a rapid randomization of dipoles within a dipole suspension layer comprising, applying a first direct potential difference across the suspension layer in the Z direction normal to the plane of the layer, to orient the dipoles in the Z direction, terminating the said potential difference and immediately upon said termination momentarily applying a second direct potential difference to the dipole suspension layer in a direction substantially normal to said Z direction, said second potential difference being applied between electrodes disposed on opposite sides of said dipole layers, whereby said dipoles are swung out of their Z orientation and into an X and Y orientation.

4. A light controlling device comprising at least a pair of spaced transparent sheets, a transparent suspending medium between said sheets, a layer comprising a plurality of elongated dipoles freely carried within the suspending medium, each said dipole having a first dimension in a direction of elongation on the order of one-half the wavelength of light and a second dimension normal to the direction of elongation substantially smaller than said first dimension, said dipoles presenting a cross section to electromagnetic radiation which is a function of their orientation, whereby light transmission through the layer is at a maximum when the direction of elongation of said dipoles are oriented parallel to a light path and at a minimum when said dipoles are in random directions, a first series of spaced wire-like electrodes straight line parallel to each other disposed in a plane and carried by one of the transparent sheets, a second series of spaced wire-like electrodes straight line parallel to each other disposed in a plane parallel to the plane of the first series and carried by the other transparent sheet, second series of spaced wire-like electrodes being parallel to and laterally offset from the first series of spaced wire-like electrodes a distance equal to one-half the spacing between adjacent ones of said first series of electrodes, electrical interconnection means combining selected electrodes in each series into a plurality of electrode sets, electrical circuit means selectively applying direct electrical potential differences to said electrode sets for controlling electric field patterns within the dipole suspension layer to control the disposition of the dipoles within the suspension, the electric field patterns being on opposite sides of said dipole suspension layer and being shifted by one-half said electrode spacing with respect to one another.

5. A light controlling device comprising at least a pair of spaced transparent sheets, a transparent suspending medium between said sheets, a layer comprising a plurality of elongated dipoles freely carried within the suspending medium, each said dipole having a first dimension in a direction of elongation on the order of one-half the wavelength of light and a second dimension normal to the direction of elongation substantially smaller than said first dimension, said dipoles presenting a cross-section to electro-magnetic radiation which is a function of their orientation, whereby light transmission through the layer is at a maximum when the direction of elongation of said dipoles are oriented parallel to a light path and at a minimum when said dipoles are in random directions, a first series of spaced wire-like electrodes straight line parallel to each other disposed in a plane and carried by one of the transparent sheets, a second series of spaced wire-like electrodes straight line parallel to each other disposed in a plane parallel to the plane of the first series and carried by the other transparent sheet, second series of spaced wire-like electrodes being parallel to and laterally offset from the first series of spaced wire-like electrodes a distance equal to one-half the spacing between adjacent ones of said first series of electrodes, electrical interconnection means combining selected electrodes in each series into a plurality of electrode sets, electrical circuit means selectively applying direct electrical potential differences to said electrode sets for creating electric field patterns on each side of the dipole suspension layer adjacent the electrodes which field patterns are disposed in mutually perpendicular relationship with respect to one another.

6. A device according to claim 1 in which said electrical interconnection means includes means for causing the electric potential differences to be first applied in the Z direction and then in the X direction normal to the Z direction to force randomize the dipoles.

7. A device according to claim 1 in which the means to apply the electrical potential differences includes a plurality of circuits electrically isolated from each other by switches, corresponding ones of said first and second series of electrodes forming conducting electrode pairs, whereby non-adjacent conducting electrode pairs are electrically isolated.
9. A device according to claim 1 in which alternate electrodes are connected together by a busbar disposed at each end of said electrodes.

10. A device according to claim 8 in which there are two busbars disposed on each end of said electrodes whereby a first one of every four adjacent electrodes is connected as a first set to the first busbar on one end of said electrodes, a second one of every four adjacent electrodes is connected as a second set to a second busbar adjacent to the said first busbar, a third one of every four adjacent electrodes is connected as a third set to a third busbar on the other end of said electrodes, and a fourth one of every four adjacent electrodes is connected as a fourth set to a fourth busbar adjacent to the third busbar, insulating strips positioned upon said second and fourth busbars, and terminals extending outwardly from each of said four busbars, whereby shifting interlacing electric fields are generated upon the application of potential differences between the first and third sets of electrodes and between the second and fourth sets of electrodes, respectively.

11. A device according to claim 1 in which said electrical circuit means create interlaced space displaced electric field patterns within the dipole suspension layer.

12. A device according to claim 1 in which said electrode sets comprise first electrode sets comprising selected electrodes from said first series of spaced electrodes and second electrode sets comprising selected electrodes from said second series of spaced electrodes.

13. A device according to claim 12, in which said electrical circuit means creates said mutually perpendicular electrical field patterns in alternating relationship by creating one of said electric field patterns on one face of said dipole suspension layer and thereafter creating the other of said electric field patterns on the other face of said dipole suspension layer upon the cessation of said direct electrical potential difference for creating said one of said electric field patterns.

14. A device according to claim 13, in which said electric field pattern on said one face of the dipole suspension layer is interlaced, and said electric field pattern on said other one of said faces of the dipole suspension layer is interlaced.

15. A device according to claim 7 in which said conducting electrode pairs are disposed in alternate nonadjacent relationship with respect to one another.

16. A device according to claim 9 in which said alternate connected electrodes are disposed in one of said transparent sheets.

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