

[54] **NEMATOGENIC MATERIAL WHICH EXHIBIT THE KERR EFFECT AT ISOTROPIC TEMPERATURES**

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[22] Filed: **July 11, 1972**

[21] Appl. No.: **270,789**

[30] **Foreign Application Priority Data**

June 21, 1972 Great Britain.....28987/72

[52] U.S. Cl. **350/150, 252/408, 350/160 LC, 260/465 E, 260/465 D**

[51] Int. Cl. **G02f 1/16**

[58] Field of Search **350/150, 160 LC; 252/408**

[56] **References Cited**

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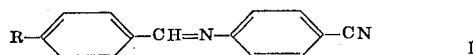
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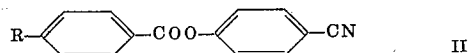
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[57] **ABSTRACT**

An electro-optical light-modulation cell having a dielectric disposed between electrodes and being comprised of a nematogenic fluid in the isotropic state, is described. Said dielectric, upon application of a voltage to the electrodes, becomes double refracting. More particularly the nematogenic fluid comprises compounds of the general formula

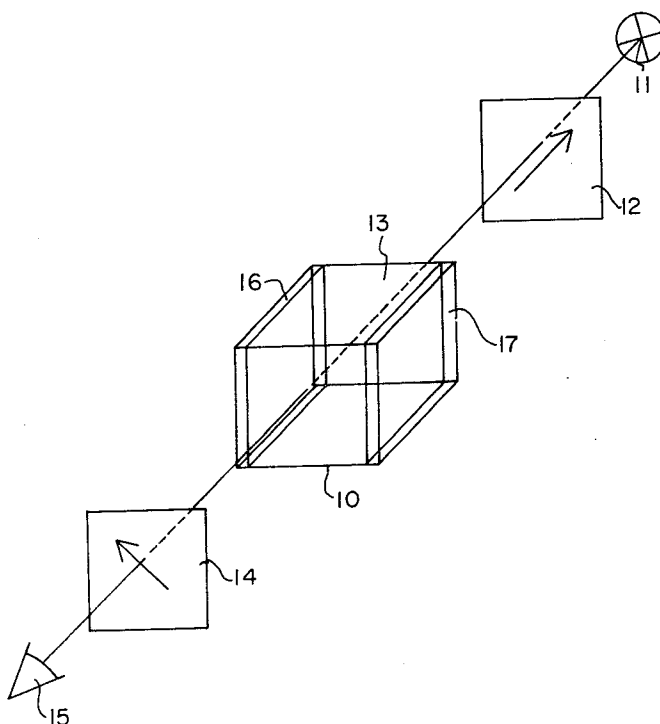


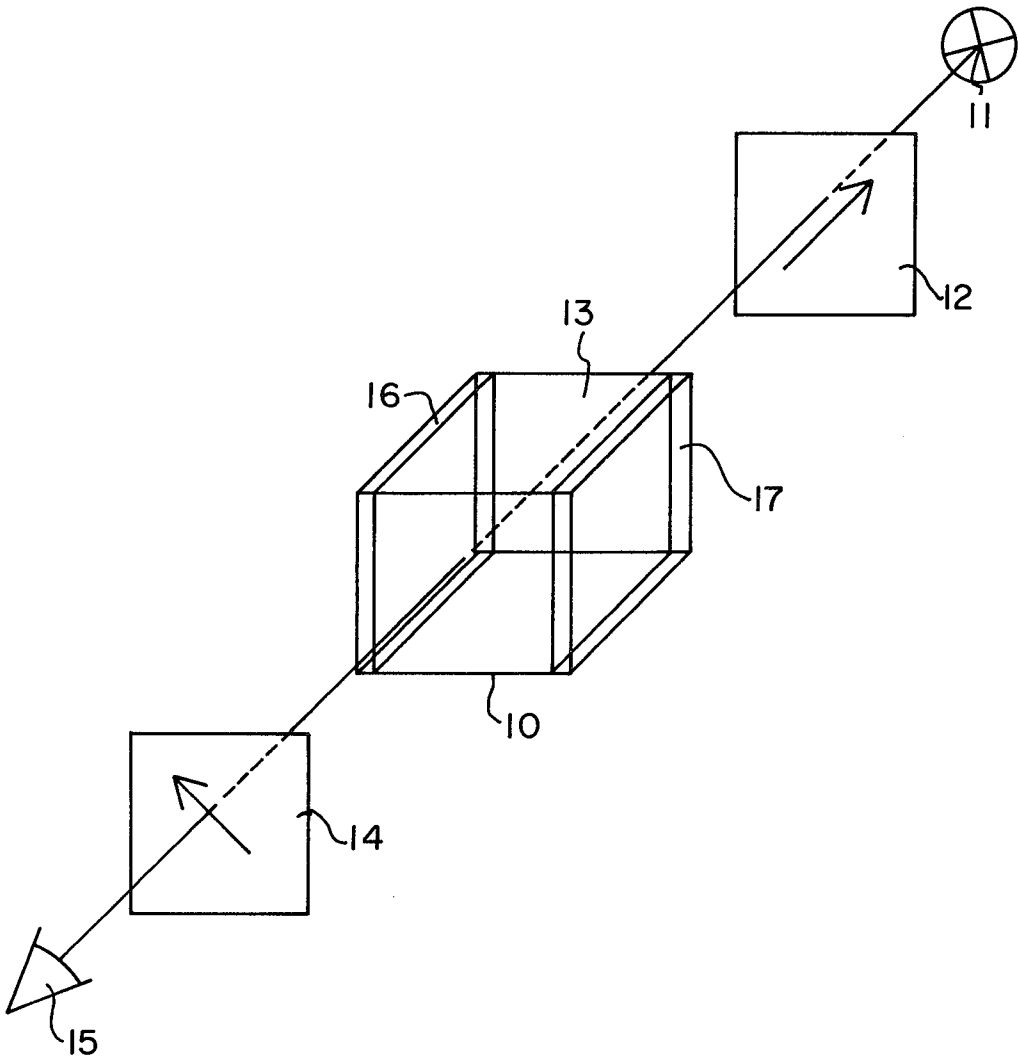
wherein R is ethyl, n-propyl, n-butyl, n-pentyl, n-hexyl, isohexyl, n-heptyl or n-octyl or compounds of the general formula



wherein R is n-butyl, n-pentyl, n-hexyl, n-heptyl or n-octyl, or mixtures thereof or mixtures of these compounds with other nematogenic substances.

17 Claims, 1 Drawing Figure





NEMATOTENIC MATERIAL WHICH EXHIBIT THE KERR EFFECT AT ISOTROPIC TEMPERATURES

The invention relates to an electro-optical light-modulation cell, including a dielectric which is disposed between electrodes and which, being comprised of a nematogenic fluid in the isotropic state, upon application of a voltage to the electrodes, becomes doubly refracting as a result of the electro-optical Kerr effect. The nematogenic fluid used comprises compounds of formula I and/or II and/or mixtures with other nematogenic substances.

Detailed Description of the Invention

Light modulation cells or Kerr cells are known and until now nitrobenzene, because of its high Kerr constant, has been the only substance used as the dielectric.

However, Kerr cells having a nitrobenzene dielectric have the disadvantage of requiring operating voltages of several kilovolts. Operation of such a cell places exacting requirements on the rise times and the high-voltage breakdown strength of an associated electronic control system. Consequently, when the cells are intensively modulated, it is impossible to make use of the theoretically very short response time of nitrobenzene. A further disadvantage of Kerr cells having a nitrobenzene dielectric comprises the fact that they need to be relatively thick in the direction of the light beam. For example, the thickness of the dielectric parallel to the light beam must be 5 cm. in order to produce a phase difference of $\delta = 0.835 \lambda$ ($\lambda = 583 \mu\text{m}$, $T = 24^\circ \text{C}$.) at a field strength of 24 kV cm^{-1} . Cells of this thickness are unsuitable for a number of practical applications.

The present invention provides an electro-optical light-modulation cell which is very quickly responsive and one requiring a control voltage in a range which only necessitates the utilization of relatively inexpensive circuitry, using transistors where possible.

In particular, the present invention relates to an electrooptical light-modulation cell having a dielectric disposed between electrodes which becomes doubly refracting upon an application of a voltage to the electrodes, in which the general formula I and/or II and/or mixtures with other nematogenic substances.

Preferably, the nematogenic fluid compound of the above mentioned compounds is at a temperature near the temperature T_c of the phase change between the isotropic and the anisotropic state.

In order that the invention may be readily understood, an embodiment thereof will now be described in more detail, by way of example, with reference to the accompanying drawing. The drawing shows a light-modulation arrangement including a light-modulation cell embodying the invention.

As shown in the drawing, a light-modulation cell 10 comprises two parallel rectangular electrodes 16 and 17 between which is disposed of a dielectric 13 composed of a nematogenic substance. The electrodes are made of stainless steel, but can be made of any other metal, which does not react with nematogenic substances, for example, gold or the like.

The distance between the electrodes depends on the diameter of a light beam which is to be modulated. In the example, this distance is so small that the nematogenic substance is held between the electrodes by capillary forces. In such a case, no additional walls are

needed for laterally binding the space between the electrodes. If the distance between the electrodes is greater, the space for the dielectric must be sealed on all sides, using plates of suitable size and made of electrically insulating material. At least two opposite insulating plates must be transparent to the light beam, i.e., they should advantageously be made of glass, acrylic glass or the like.

The dielectric is made of a nematogenic substance, i.e., a substance having a nematic liquid-crystal phase over a certain temperature range. Specially good results are obtained with nematogenic substances which are dielectrically and optically strongly anisotropic and which have a pronounced electric dipole moment extending parallel to the direction of maximum polarizability of the molecules. The substances must also have a marked tendency for parallel orientation over a number of molecular spacings, i.e., the tendency to form clusters. Since the tendency to form clusters is particularly marked in the immediate neighborhood of the temperature T_c at which there is a change from the isotropic to the nematic state, the cell is desirably operated in the temperature range $T_c - 1^\circ \text{C} \leq T \leq T_c + 1^\circ \text{C}$.

Particularly preferred are mixtures of p-[(p-n-hexylbenzylidene)amino]benzonitrile and p-[(p-n-butylbenzylidene)amino]-benzonitrile in a molar ratio of 2:1

to 1:2;
a mixture of p-[(p-n-propylbenzylidene)amino]benzonitrile and p-[(p-n-hexylbenzylidene)amino]benzonitrile in a molar ratio of 1:2;

a mixture of p-[(p-n-heptylbenzylidene)amino]benzonitrile and of p-[(p-n-butylbenzylidene)amino]benzonitrile in a molar ratio of 2:1;

a mixture of p-[(p-n-octylbenzylidene)amino]benzonitrile and p-[(p-n-pentylbenzylidene)amino]benzonitrile in a molar ratio of 2:1;

a mixture of p-n-heptyl benzoic acid-p'-cyanophenyl ester and p-n-butylbenzoic acid-p'-cyanophenyl ester or p-n-pentylbenzoic acid-p'-cyanophenylester in a molar ratio of 2:1;

a mixture of p-n-octylbenzoic acid-p'-cyanophenyl ester and p-n-butylbenzoic acid-p'-cyanophenyl ester or p-n-hexylbenzoic acid-p'-cyanophenyl ester in a molar ratio of 2:1; or

a mixture of p-n-hexylbenzoic acid-p'-cyanophenyl ester and p-n-butylbenzoic acid-p'-cyanophenyl ester in a molar ratio of 2:1.

Compounds of formula I can be manufactured in analogy to the following example:

150 mg p-toluenesulfonic acid were added to 5.9 g (0.05 Mol) p-aminobenzonitrile and 6.7 g (0.05 Mol) p-ethylbenzaldehyde in 100 ml benzene. The resulting mixture was heated in a nitrogen atmosphere during 1 hour under reflux (temperature of the bath 120°). The water formed was removed in a water separator. The benzene condensed in the reflux condenser was passed through a layer of 50 g aluminiumoxide and returned into the reaction flask. After cooling, 2 g potassiumcarbonate were added, the mixture was filtered and the filtrate separated from the solvent under vacuum (bath temperature 50°C). 11.5 g yellow oil which crystallized after cooling, were obtained. The resulting product was recrystallized several times in iso-propanol until the melting point remains constant and the gaschromatography shows no impurities. The pure p-[(p-ethylbenzylidene)amino]-benzonitrile melted at $76.2-77.0^\circ$ and forms liquid crystals after cooling to $63.0-59.7^\circ$. UV

(EtOH); $\epsilon_{277} = 25,800$ (shoulder at 316 nm) NMR, MS, IR and microanalyse correspond to the structure attributed to the substance.

Compounds of formula II can be manufactured in analogy to the following example.

5,6g (28,5 mMol) p-n-butylbenzoyl chloride in 12 ml dry benzene were added to 3,1 g (26 mMol) p-hydroxybenzonitrile in 25 ml dry pyridine. The resulting mixture was stirred overnight at room-temperature and then 2 hours at 60° C. After cooling the mixture was extracted with ether and the extract washed with diluted hydrochloric acid and water. 9 g crude p-n-butylbenzoic acid-p'-cyanophenyl ester were obtained. This product was dissolved in toluene and was submitted to chromatography using 250 g silica gel. From the resulting pure fractions, 4 g of product were obtained after recrystallization from hexane. Melting point 67° C. Liquid crystals are formed at 41,5° C. NMR and IR correspond to the structure attributed to the substance.

The light modulating arrangement shown in the drawing comprises, in addition to cell 10, a polarizer 12 disposed upstream of the cell and an analyzer 14 disposed downstream of the cell. A beam of light from a source 11 travels through polarizer 12 and cell 10 parallel to the electrodes and strikes analyzer 14. If the polarizer 12 and analyzer 14 are rotated 90° relative to one another as shown by the arrow in FIG. 1 and if the dielectric of cell 10 is isotropic, the light beam does not reach the eye of an observer downstream of the analyzer 14.

If a d.c. (direct current) voltage is applied to the electrodes of cell 10, the dielectric 12 becomes doubly refracting, so that the linearly polarized light from polarizer 12 is converted to elliptically polarized light, some of which can travel through the analyzer 14. The observer therefore notices a brightening of his field of view through the analyzer.

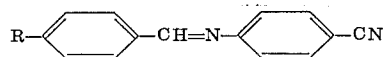
Maximum brightening occurs at an optical phase difference of $\delta = (2i + 1) \lambda/2$, with $i = 0, 1, 2 \dots$. The optical phase difference is directly proportional to the wavelength, the thickness of the cell or dielectric parallel to the light beam, the Kerr constant and the square of the electric field strength.

An important criterion of the capacity of electro-optical light-modulation cells is the attainable contrast between the light intensity when no voltage is applied to the electrodes and the light intensity at maximum drive. The contrast obtainable in a cell embodying the invention is of the order of 1:1,000, and varies with the fourth power of the field strength.

Electro-optical light-modulation cells embodying the invention are suitable for a number of applications. In general, they can be used for controlling and modulating light far beyond the acoustic frequency range. An important application is to electronic shutters, particularly in cases in which large apertures are required. In very specific applications the double refraction may be optically induced, e.g. by the field of high-powered light sources.

We claim:

1. In an electro-optical light-modulation cell having a dielectric which is disposed between electrodes and which becomes doubly refracting on application of a voltage to the electrodes, the improvement which comprises a dielectric in the isotropic state comprised of a compound characterized by the formula



wherein R is ethyl, n-propyl, n-butyl, n-pentyl, n-hexyl, isohexyl, n-heptyl or n-octyl, mixtures thereof and/or mixtures with other nematogenic substances.

2. A cell in accordance with claim 1, wherein the nematogenic fluid is at a temperature near the temperature T_c of the phase change between the isotropic and the anisotropic state.

3. A cell in accordance with claim 2, wherein the temperature t of the nematogenic fluid is in the range $T_c < t \leq T_c + 1^\circ \text{C}$.

4. A cell in accordance with claim 3, wherein the dielectric comprises a mixture of p[(p-n-hexylbenzylidene)amino]-benzonitrile and p[(p-n-butylbenzylidene)-amino]benzonitrile in a molar ratio of 2:1 to 1:2.

5. A cell in accordance with claim 3, wherein the dielectric comprises a mixture of p[(p-n-propylbenzylidene)-amino]-benzonitrile and p[(p-n-hexylbenzylidene)amino]benzonitrile in a molar ratio of 1:2.

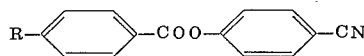
6. A cell in accordance with claim 3, wherein the dielectric comprises a mixture of p[(p-n-heptylbenzylidene)-amino]-benzonitrile and p[(p-n-butylbenzylidene)amino]benzonitrile in a molar ratio of 2:1.

7. A cell in accordance with claim 3, wherein the dielectric comprises a mixture of p[(p-n-octylbenzylidene)amino]-benzonitrile and p[(p-n-pentylbenzylidene)amino]-benzonitrile in a molar ratio of 2:1.

8. A cell in accordance with claim 3, which comprises polarizers for continuously modulating light transmitted through the cell, one polarizer being disposed upstream of the cell and the other being disposed downstream of the cell in the direction of light traveling through the cell.

9. A cell in accordance with claim 8 wherein the two polarizers are crossed.

10. In an electro-optical light-modulation cell having a dielectric which is disposed between electrodes and which becomes doubly refracting on application of a voltage to the electrodes, the improvement which comprises a dielectric in the isotropic state comprised of a compound characterized by the formula:



wherein R is n-butyl, n-pentyl, n-hexyl, n-heptyl or n-octyl,

mixtures thereof and/or mixtures with other nematogenic substances.

11. A cell in accordance with claim 10, wherein the nematogenic fluid is at a temperature near the temperature T_c of the phase change between the isotropic and the anisotropic state.

12. A cell in accordance with claim 11, wherein the temperature t of the nematogenic fluid is in the range $T_c < t \leq T_c + 1^\circ \text{C}$.

13. A cell in accordance with claim 12, wherein the dielectric comprises a mixture of p-n-heptylbenzoic acid-p'-cyanophenyl ester and p-n-butylbenzoic acid-

p'-cyanophenyl ester or p-n-pentylbenzoic acid-p'-cyanophenyl ester in a molar ratio of 2:1.

14. A cell in accordance with claim 12, wherein the dielectric comprises a mixture of p-n-octylbenzoic acid-p'-cyanophenyl ester and p-n-butylbenzoic acid-p'-cyanophenyl ester or p-n-hexylbenzoic acid-p'-cyanophenyl ester in a molar ratio of 2:1.

15. A cell in accordance with claim 12, wherein the dielectric comprises a mixture of p-n-hexylbenzoic acid-p'-cyanophenyl ester and p-n-butylbenzoic acid-

p'-cyanophenyl ester in a molar ratio of 2:1.

16. A cell in accordance with claim 12, which comprises polarizers for continuously modulating light transmitted through the cell, one polarizer being disposed upstream of the cell and the other being disposed downstream of the cell in the direction of light traveling through the cell.

17. A cell in accordance with claim 16 wherein the two polarizers are crossed.

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