

CHAPTER - VI

INTRODUCTION

Although scientifically liquid crystals have been known for about 80 years, the application of liquid crystals to practical problems has been a development of the last 10 years. The use of liquid crystals as engineering material is in its infancy, and we can expect ever increasing applications of these liquid crystal materials.

At the present time, we can give only a rather limited picture of the ultimate uses of liquid crystals. Thus far, only the nematic and cholesteric phases have found wide spread interest for applications, although I am sure that the smectic phases will prove equally valuable within the next several years. Liquid crystals are of interest because they need amazingly small energies. For instance with a cholesteric phase, a temperature change of only one degree can cause a change to the entire rainbow of visible colours; in the nematic phase, electrical power inputs of as low as one microwatt per sq cm can drive an element from full-on to full-off. Along with this there is a very good resolution, something on the order of 1000 lines per sq inch. These properties lead us to the criteria which make liquid crystal so interesting today. Thus, in places where devices or materials are needed as indicators or detectors which should use low power and detect very low energies with good resolution, the liquid crystal is a natural choice.

The present applications of liquid crystals are primarily limited to devices with optical outputs and/or inputs. The use of liquid crystals as detectors for infrared microwave fields, laser far-field patterns, gas vapour and direct thermal patterns has made enormous strides during the last five years.

Cholesteric liquid crystals have become used in large quantities for temperature measurements. At this stage ultrasonic image converters using nematic materials are just becoming feasible. For display purposes, the nematic phase appears to be most promising. Low power combined with low cost and moderate

driving voltage appears to make the nematic phase the logical choice for seven-segment displays and indicators which depend upon ambient lighting. Because of the relative cost on driver circuits, large area displays are quite feasible - while the, high resolution makes small high density displays quite feasible. These are only forerunners of devices which use no optical output but make possible operations which control other optical properties by electric and magnetic fields. Differences in viscosity and diffusivity depending on directions, apparently can be used in mechanical devices, although studies of these devices have not

At this point, we can say that we have begun to understand and use the non-liquid, non-crystalline properties of liquid crystals. In this chapter we ~~have~~ have given exhaustively fourteen applications of the cholesteric phase.

Application - 1

THERMAL IMAGING DEVICES UTILIZING A CHOLESTERIC LIQUID CRYSTALLINE PHASE MATERIAL.

The present invention provides a device having a thermally sensitive member of a material or materials which are capable, by reason of their unique properties, of converting a heat pattern imposed thereon into a visible pattern by exposure of the thermally sensitive member to visible light.

Referring to Figures 1 and 2, there is shown an enclosure 10 having a generally rectangular cross section. The enclosure 10 has a first face 12 and a second face 14 on opposite sides thereof. The first face 12 of the enclosure 10 is transmissive to radiation in the infrared portion of the electromagnetic spectrum having a wavelength of about 2 microns to 15 microns. The first face 12 may be transmissive to other than infrared radiation. A suitable material from which the first face 12 may be made is NaCl, as is well known in the art. The second face 14 of the enclosure 10 is transmissive at least to visible radiation within the wavelength band of about 4200 to 7500

Angstroms. The second face may also be transmissive to radiation in other portions of the spectrum. Many glasses are suitable materials from which the second face 14 may be made, for example, ordinary window glass. The enclosure 10 may have a cylindrical wall 16 for which tubular brass is one of many suitable materials. In many instances it is desirable to operate the device with the enclosure 10 evacuated in order to avoid temperature non-uniformities therein. For that

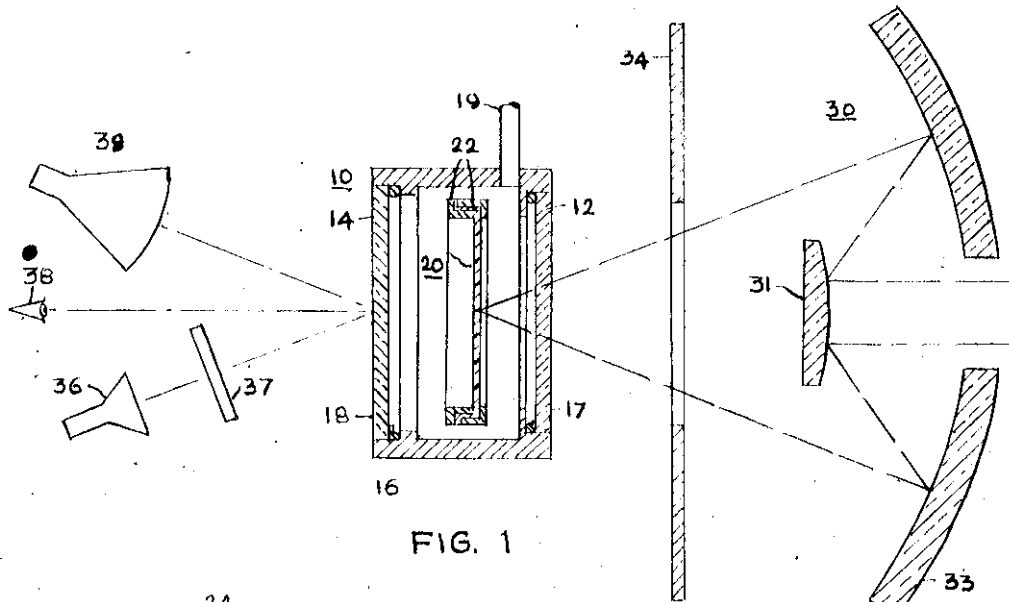


FIG. 1

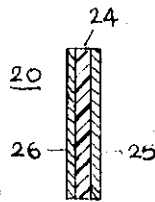


FIG. 2

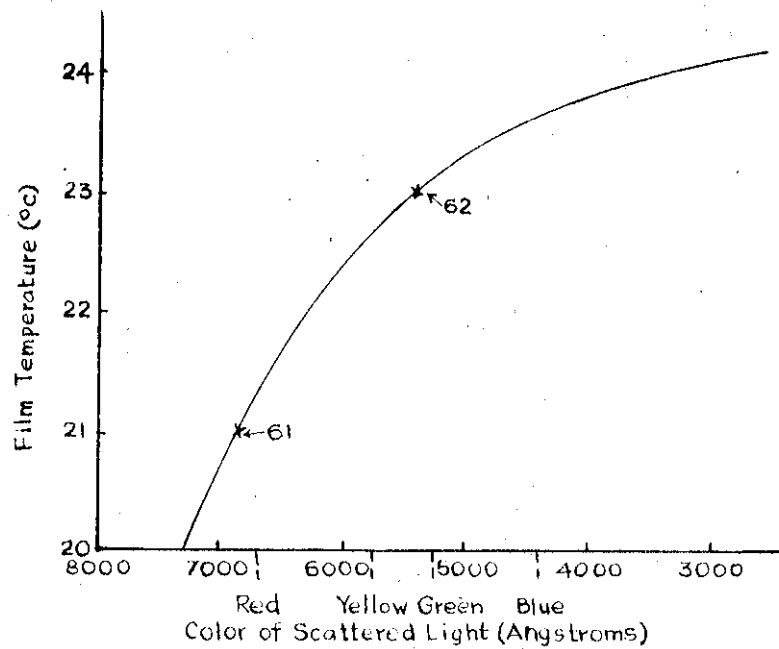


FIG. 3

purpose, conventional O-ring vacuum seals 17 and 18 are employed to provide tight seals where the faces 12 and 14 and the wall 36 join. Other suitable sealing means could, of course, be employed. Continuous evacuation may be achieved, if desired, by providing a fitting 19 for connection to a vacuum pump (not shown). Within the enclosure 10 is disposed a target structure 20 substantially parallel to the first and second faces 13 and 14. The target structure 20 may conveniently be held by annular supports 22 within the enclosure 10.

In the practice of this invention, there is no stringent requirement that the target 20 be placed in a vacuum enclosure. This is merely an expedient to avoid temperature variations on the target 20 due to air currents since it is possible, and often desirable, to form a target of such high sensitivity that even a slight air current would have a noticeable effect thereon. On the other hand, in some applications where a less sensitive target may be employed, the target may be exposed to the atmosphere and the enclosure 10 and transmissive faces 12 and 34 would not be required.

As shown in Fig. 2 the target structure 20 comprises three juxtaposed and coextensive layers of material 24, 25 and 26. The inner layer 24 is a thin support film of a material such as a polyester plastic such as polyethylene terephthalate, sold as "Mylar", or such as aluminum oxide. The support film has a thickness of only about .00025 inch or less. It is desirable for this purpose to use a material which may be fabricated in a

very thin sheet but which still retains sufficient strength to support the other two layers 25 and 26. On one side of the thin support film 24 is a layer 25 of infrared absorbing material. This material may be gold black, for example, evaporated on the thin support film 24 in an inert atmosphere such as about 1-10 millimeters of nitrogen. Nickel is also suitable as the infrared absorbing layer 25 and may be evaporated on to the support layer 24 in a vacuum. The thickness of the infrared absorbing layer 25 is not critical but should be such as to absorb a large percentage of the infrared radiation incident thereon. A thickness of the order of about one micron of gold black is usually sufficient for this purpose, as is a layer of the order of about 1-10 angstroms of evaporated nickel. The infrared absorbing layer 25 would not be necessary if it were not for the fact that most if not all of the materials suitable for use as the thermally sensitive film 26 are substantially transparent to infrared radiation, which would result in only a negligible temperature change in the film. On the side of the thin support film 24 opposite the infrared absorbing layer 25 is a film 26 of a thermally sensitive material. Suitable materials for this film will be discussed hereinafter.

The target structure 20 is disposed within the enclosure 10 such that the infrared absorbing layer 25 faces the first face 12 of the enclosure 10 and the thermally sensitive film 26 faces the second face 14 of the enclosure. It is thereby made possible that the infrared absorbing layer 25 may be irradiated with infrared radiation and the thermally sensitive film 26 may be irradiated with visible radiation.

External to the enclosure 10 is shown an optical system 30 disposed between the source of infrared radiation (not shown) and the first face 12 of the enclosure. The optical system 30 includes mirrors 31, 32 and 33 and apertured member 34 which comprise a concentric spherical optical system. Many other optical systems are also suitable.

Infrared radiation from an object or scene to be viewed is directed by the optical system 30 through the first face 12 of the enclosure and focused upon the infrared absorbing layer 25 of the target structure 20. Radiation absorbed in the infrared absorbing layer 25 is converted to heat and causes a thermal image to be transmitted through the target structure. Thereby a temperature pattern is established on the thermally sensitive film 26 in accordance with the intensity of infrared radiation radiated by the objects in the scene viewed by the optical system 30. The support film 24 should be so thin as to be practically no barrier to the transmission of the temperature image from the infrared absorbing layer 25 to the thermally sensitive layer 26. Support film 24 serves primarily only as a support and its presence as an influence upon the thermal properties of the target 20 is not essential to our invention. It would often be desirable to omit the support film 24 and employ a target comprising only an infrared absorbing layer and a thermally sensitive film, if either of these layers were sufficiently strong to support the structure. The support film 24 should have a low thermal time constant, that is, the time required for it to reach a state in which it radiates as much energy as it absorbs should be short. The film 24 should also have low lateral heat conductivity to preserve

resolution. These desired properties are best obtained by making the support film 24 as thin as possible in keeping with mechanical requirements.

On the side of the enclosure 10 opposite the optical system 30 is an illuminating means such as the lamp 36 directing visible radiation through a filter 37, which allows the passage of a desired portion of the spectrum, onto the second face 14 of the enclosure 10. The visible radiation is transmitted through the second face 14 and impinges upon the thermally sensitive film 26. A viewer 38 may look through the second face 14 of the enclosure 10 and view the thermally sensitive film 26 which displays a visible image corresponding to the temperature pattern imposed thereon. The viewer 38 may be human or a suitable image pickup tube or some other type of detector.

It should be noted that while it is believed most useful that the lamp 36 provide visible radiation so as to produce a visible image, the lamp 36 might be emissive in some other portion of the spectrum, such as the ultraviolet, in which case the resulting image would also be in that portion of the spectrum. Of course, it may be the case that ambient lighting provides light in the desired portion of the spectrum, in which case additional illumination by a lamp 36 would not be necessary.

The image is produced by the interaction of the light from the illumination means 36 with the thermally sensitive

film 26 upon which the temperature pattern exists. The interaction takes place in a temperature dependent manner.

The thermally sensitive film 26 is a thin film of a material which has an optically active liquid crystalline phase and is in that phase when the device is operated. Materials having a liquid crystalline phase do not pass directly from the solid into the liquid state upon heating. They have an intermediate state which is not a true solid and not a true liquid. This state may also be reached by cooling a material of this type in the liquid state. In addition, materials having a liquid crystalline phase may be caused to go into that phase by treating the material with a suitable solvent such as chloroform or petroleum ether. Once having entered the liquid crystalline phase the material will remain in that phase so long as environmental conditions are controlled within certain limits.

Materials in the liquid crystalline phase are generally characterized by their having fluidity as well as birefringence. That is, while materials in this phase have some properties of liquids, they have some optical properties which are characteristic of true crystals. As used herein, the expression "Materials having a liquid crystalline phase" is intended to be synonymous with "materials in the mesomorphic state." For further general information on this broad class of materials, reference should be made to the article by G.H. Brown and W.G. Shew In CHEMICAL REVIEWS, vol.57, No. 6, December 1957, p. 1049, entitled "The Mesomorphic State - Liquid Crystals."

It has been found that compounds having a mesomorphic state have elongated molecules, which are in some cases flattened as well, and which have one or more polar groups. By a polar group is meant a real separation of electrical charge centres. Because of the shape of the molecules, a parallel alignment to one another is favored. In the crystalline state, the molecules are arranged in this manner and are held together by attachments through the polar groups as well as by weaker Van der Waals forces. It is believed but is not essential to the successful practice of the present invention, that in going from the solid state to the liquid state, the weaker Van der Waals bonds are broken first leaving the molecules with some degree of freedom of relative movement, but retaining to a great degree the tendency for the molecules to align themselves parallel to one another.

Liquid crystalline materials have been categorized to be of three types : smectic, nematic and cholesteric. The smectic structure is characterized by the fact that the molecules are arranged in layers with their long axes approximately normal to the planes of the layers. In the nematic structure, there is no necessary layer-like arrangement, the only restriction on the arrangement of the molecules being that they preserve a nearly parallel orientation. Usually, liquid crystalline substances will show either the smectic or the nematic structure exclusively; some substances, however, can exhibit both structures, passing from one to the other upon a certain temperature change.

The arrangement of molecules in the cholesteric structure has not been definitely determined. The theory has been put forth that the cholesteric structure is a particular form of a nematic structure. The distinction of the cholesteric structure over the smectic and nematic structures is in its markedly different optical properties. Materials having the cholesteric structure are optically negative, while those having the nematic and smectic structures are optically positive. Of the three types of liquid crystalline materials only cholesteric liquid crystals have properties suitable for use in the device shown in Fig. 1.

A temperature stabilization means 39 is provided to maintain the thermally sensitive film 26 at a background temperature which is uniform over the film surface and; in addition, can vary only within a restricted temperature range.

This is necessary because the optical properties of the thermally sensitive film utilized in the present invention depend upon the film material being in the liquid crystalline phase. A particular material is only in the liquid crystalline phase, within a definite temperature range. Therefore, it is necessary to maintain the temperature of the film in this temperature range.

Further temperature control is often desirable and may also be effected by the temperature stabilization means 39, in order to maintain the film at its most sensitive temperature range in which it is in the liquid crystalline phase. For the foregoing purposes, the temperature stabilization means 39 is shown as an incandescent heat lamp. It is obvious that other temperature stabilization means are suitable but it must be remembered that it is desirable that the film background temperature be as uniform as possible. Control of the temperature stabilization means may be made adjustable in order that the film may have an adjustable sensitivity. This would be useful, for example, to reduce sensitivity where too high a sensitivity would lead to the formation of a misleading image.

While shown in the drawing as a heat lamp, the temperature stabilization means 39 may or may not, depending on the material used for the thermally sensitive film 26, elevate the temperature of the film appreciably above ambient. Its function is to stabilize the film background temperature in the proper region so that it is thermally sensitive. Conceivably the temperature stabilization means 39 would in some cases be used to extract heat from the film 26 to maintain it at a background temperature which is below ambient. Automatic control

of the heating means 39 by means of suitable feedback circuitry, which is well known in the art, is possible. Where ambient temperature is not expected to vary beyond the range in which the film 26 is in the liquid crystalline state, no temperature stabilization is required but may be used to enhance sensitivity.

Thin films of cholesteric liquid crystals exhibit a property, upon interaction with light, which may be termed selective scattering. The term scattering is used rather than reflection in order to distinguish from the effect occurring on mirror surfaces wherein light is reflected at an angle equal to the angle of incident light. A scattered light ray may leave the scattering material at an angle unrelated to the angle of incident light. A selectively scattering film, when observed with light impinging the film on the same side as that which is viewed, has an apparent color which is the complement of the color of the light transmitted by the film. That is, the light scattered from the film is within a wavelength band which, if added to the light transmitted through the material, would form white light, if white light was incident to the film.

The terms "light" and "color" as used herein have the broad connotation of referring to electromagnetic radiation generally, rather than to solely visible radiation.

Most materials do not selectively scatter light in that the light transmitted through them is not complementary to the

light scattered by them but rather is within the same wavelength band. The difference in effect between selectively scattering materials and ordinary materials is believed due to the fact that in ordinary materials same light is absorbed by electron-photon interaction while in selectively scattering materials there is very little absorption. This explanation is not essential to the successful practice of our invention but may aid in understanding the operation thereof.

The phenomenon of selective scattering as exhibited by cholesteric liquid crystalline films is independent of whether the light illuminating the film is polarized or not. The color and intensity of the scattered light depends upon the temperature of the scattering material and upon the angle of incidence of illumination.

If such a film is illuminated with circularly polarized light, in addition to the property of selective scattering, it will also exhibit the property of circular dichroism. This latter effect may be defined as the differential interaction of a material upon circularly polarized light of different senses. Unpolarized light comprises right and left handed circularly polarized components of equal intensity. Upon interaction with a film of circularly dichroic material the right handed component is transmitted with a different intensity than the left handed component. The extent of the difference is a function of temperature in cholesteric liquid crystalline materials. This difference is believed to be the result of preferential scattering or absorption within the material but it is not known that this explanation has been confirmed.

Another property exhibited by cholesteric liquid crystalline material is that is commonly known as optical activity. Optical activity is observed by illuminating the material with linearly polarized light. Due to the optical activity of the material, also called optical rotatory power, the polarization vector of the light is caused to rotate. The amount of this rotation has been found to be dependent upon the temperature of the material.

Cholesteric liquid crystalline materials which are suitable for use as the thermally sensitive film 26 include derivatives and compounds of cholesterol. All these compounds are characterized by having a cholesteric liquid crystalline phase. Mixtures of two or more compounds have also been used. The advantage of mixing the pure compounds is to obtain certain properties desired for a particular application; for example, to obtain high sensitivity within a particular temperature range which may be made as broad or narrow as one desires for most practical purposes.

As a particular example of a film used in the practice of this invention a mixture was made of cholesterol crotonate and cholesterol oleate. The cholesterol oleate was prepared by a reaction of oleic acid with cholesterol in the presence of an acid catalyst. A suitable catalyst is p-toluenesulfonic acid. The cholesterol crotonate was prepared by the direct reaction of crotonyl chloride with cholesterol. A mixture of equal quantities of these compounds was then dissolved in

chloroform in a concentration sufficient to form a readily flowing solution. The thermally sensitive film was formed by pouring the solution onto the support film, which in this case was polyethylene terephthalate to which the infrared absorbing layer had already been applied, and allowing the solvent to evaporate. The resulting film has a high viscosity. The particular example just described is sensitive near room temperature.

An example of another film is one of the following composition :

	percent :
Cholesterol nonanoate.....	45
Cholesterol linoleate.....	50
Cholesterol chloride.....	5

This composition is sensitive over a temperature range of from about 1° to 100°C.

An alternative target structure may be formed by sandwiching the thermally sensitive film between a thin film of silicon monoxide and a thin film of aluminum oxide. On the free surface of the aluminum oxide a layer of infrared absorbing material is deposited. To make such a target, potassium bromide was first evaporated upon a clean glass slide followed by depositing a layer of silicon monoxide in the same manner. The material from which the thermally sensitive film was to be made was then melted on the slide and a thin film of aluminum oxide was placed over it. The target was removed

from the glass slide by dissolving the potassium bromide with water which allowed the target to float free. This method has been found somewhat less desirable than the previously described because of the relatively greater number and size of nonuniformities occurring in the fabricated target. Such a target, however, has been found to have a low thermal time constant and low lateral heat conductivity.

Because of the exceptional optical properties of cholesteric liquid crystalline films there are several modes of operating the device in accordance with the present invention. As before stated a film of the thermally sensitive material exhibits selective scattering of light incident to it. This light may be linearly polarized, circularly polarized or unpolarized and in addition may be either monochromatic or white light.

Referring now to Fig.3 there is shown a characteristic curve 60 resulting from the illumination of the thermally sensitive film 26 of Fig.2 with visible white light. As shown there, the color of the scattered light is determined by the temperature of the film at the point of scattering. Visible colors will appear corresponding to the temperature of each point on the film. For example, an elemental area having a temperature of about 21°C . would appear red to a viewer while an area having a temperature of about 23°C . would appear green, as is shown at points 61 and 62, respectively, of the curve 60. The values shown in Fig. 3 are merely typical, other films would be thermally sensitive in other temperature ranges.

If a thermal image were imposed upon the thermally sensitive film, illumination with white light would result in a color pattern because of the temperature dependent selective scattering as shown in Fig.3. For this purpose the lamp 36 would be a broad band light source whose output is substantially unfiltered before striking the film 26.

Referring now to Fig.4 there is shown a curve 70 of temperature versus intensity of scattered light for the case in which the thermally sensitive film 26 of Fig.2 is illuminated with monochromatic light. The resulting visible image is an intensity pattern. The light from an elemental area having a temperature of 22.25°C is of markedly different intensity from that from an elemental area having a temperature of 22.5°C . as shown at points 71 and 72, respectively, of the curve 70. For this purpose the film should be illuminated by a light of a wavelength to which it is thermally sensitive. In this case the lamp 36 may be a mercury discharge light source used with a filter 37 allowing the passage of only the 5540 Å. radiation. A6

The curves 60 and 70 of Figs.3 and 4, respectively, closely approximate the results obtained when using a thermally sensitive film having a composition of about 30 per cent cholesterol butyrate and about 70 per cent cholesterol myristate made in accordance with the foregoing teachings.

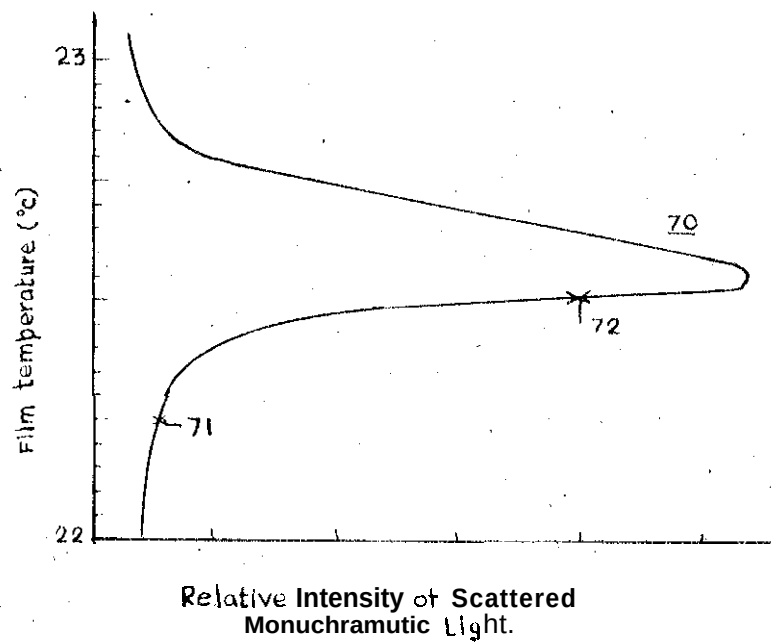


FIG. 4

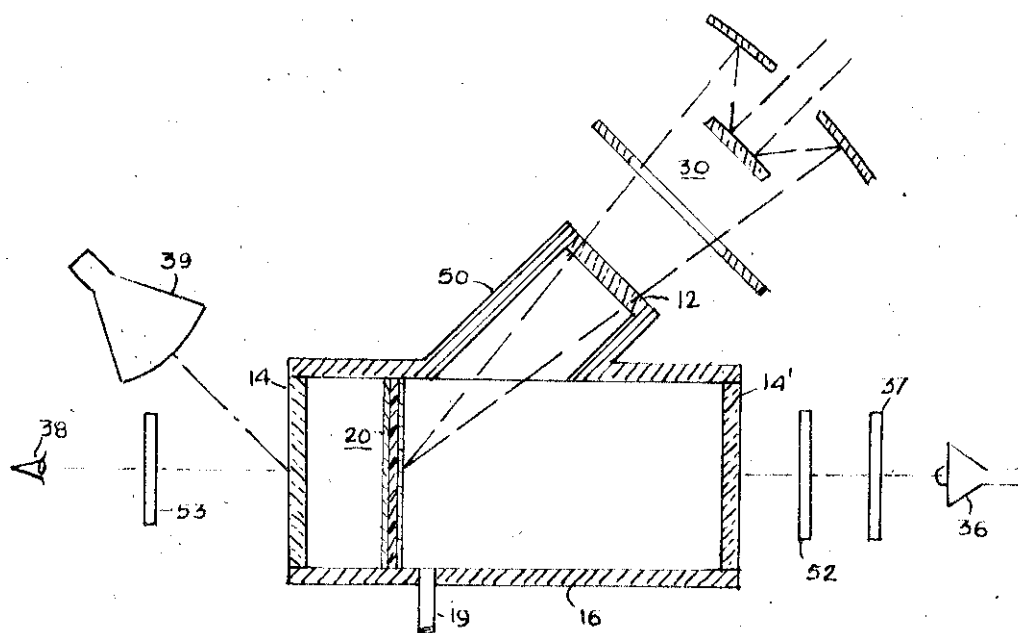


FIG. 5

Fig.5 is an alternate embodiment of the present invention wherein parts corresponding to those shown in Fig.1 are given like reference numbers. A modification has been made in order to provide an additional face 14' on the enclosure 10 so that impinging infrared radiation passing through the face 12 will strike the target 20 on the same side on which the target is illuminated by the lamp 36. The windows 14 and 14' are transmissive to the radiation from the lamp 36. Between the lamp 36 and the input face 14', there is provided a polarizer 52. There may also be provided a pass band filter 37. Between the output window 14 and the viewer 38, there is provided an analyzer 53.

In accordance with the teaching of copending application Serial No. 821, 567, by J.H. Lady, filed June 19, 1959, and assigned to the same assignee as the present invention, a thermal image on a thermally sensitive film may be made visible by the transmission of linearly or circularly polarized light there-through. For this purpose either white or monochromatic light may be used and is provided by the lamp 36. If monochromatic light is to be employed, the filter 37 is provided. The light is passed through the polarizer 52 before striking the target 20 and transmitted light is passed through the analyzer 53 for viewing.

In Fig.5 the target 20 comprises the same layers 24, 25, and 26 as are provided in the target of Fig.1 and as are shown in Fig.2. Particularly, a thermally sensitive film 26 of a material having a cholesteric liquid crystalline phase is provided in the target. Analogous to the operation of the embodiment in Fig.1, when the film 26 is illuminated with monochromatic light, an intensity image is obtained, and when illuminated with white light, a color image is obtained. Heat stabilization means 39 is provided to maintain the film 26 at a uniform background temperature within the region in which it is liquid crystalline. The operation of the device of Fig.5 is made possible by the optical activity of the thermally sensitive film 26 when it is illuminated by linearly polarized light. The viewed image is obtained by the light transmitted rather than scattered by the film. Therefore, it is necessary that the infrared absorbing layer 25 be transparent to the visible radiation to be transmitted through the film. A layer of evaporated nickel is suitable.

The device of Fig. 5 may be operated also by illuminating the target with circularly polarized light. Here the images are achieved by reason of circular dichroism of the thermally sensitive film. In this case it is not necessary to use the analyzer 53. An important point is that the resulting image formed by devices in accordance with this invention is scattered from or transmitted by the thermally sensitive member 26 without frequency change. This is believed due to the fact that essentially no energy transfer occurs upon interaction of the light from the illumination source 36 with the thermally sensitive film 36.

DISPLAY DEVICE

The invention resides in a display screen comprising a heat sensitive layer comprising a cholesteric phase liquid crystal film exhibiting a change in selective scattering properties in response to temperature changes, and thermal distribution means for impressing a thermal image on said heat sensitive layer, wherein said thermal distribution means comprises an array of magnetic elements disposed in thermal contact with and extending over the area of said heat sensitive layer.

Referring to Fig.1, a display system is illustrated. The display system consists of a display screen assembly 10. The display screen assembly 10 may include a heat sink member 12 and an associated cooling means 14 in which a liquid such as water is directed therethrough for controlling the temperature of the display screen assembly 10. A thermoelectric cooling means may also be utilized. The display screen assembly includes a display screen 16 that may be mounted on the heat sink 12 and on which a visible image is presented. A light source 18 provided for illuminating the display screen 16 by a suitable light such as white light. The illumination of the screen 16 by white light source 18 provides a visible display which may be viewed by an observer illustrated by the numeral 19.

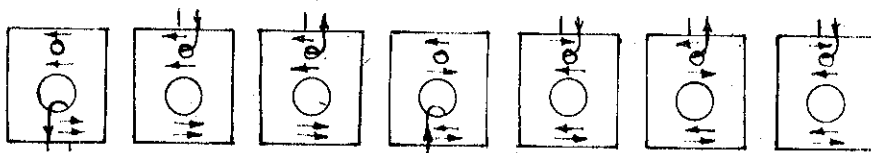
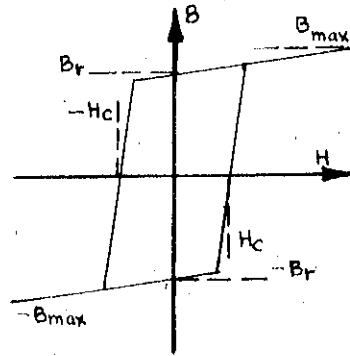
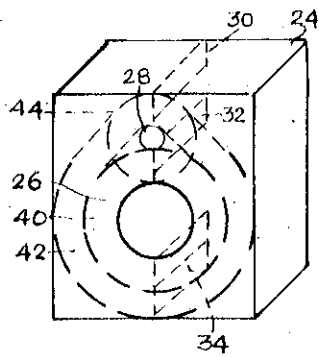
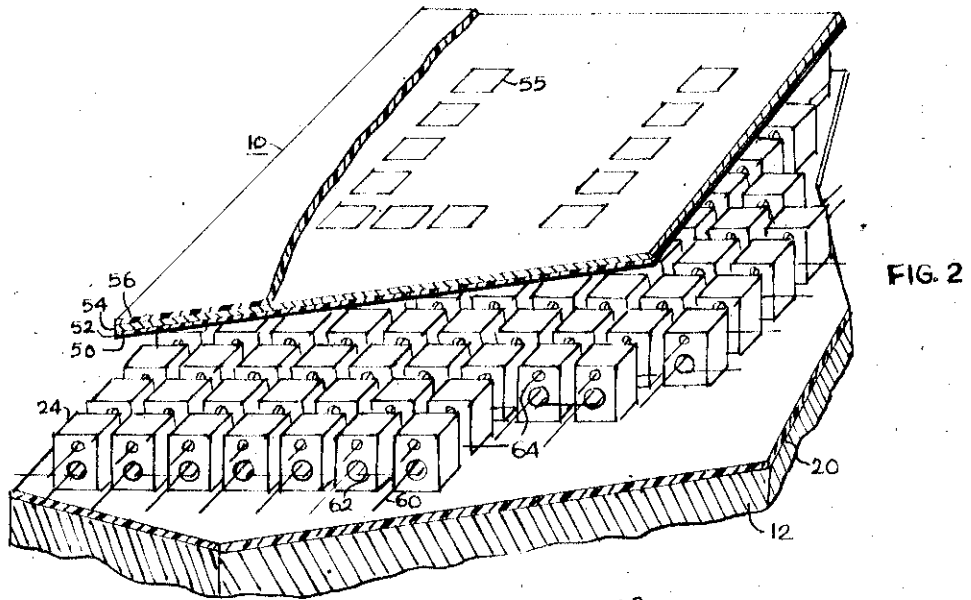
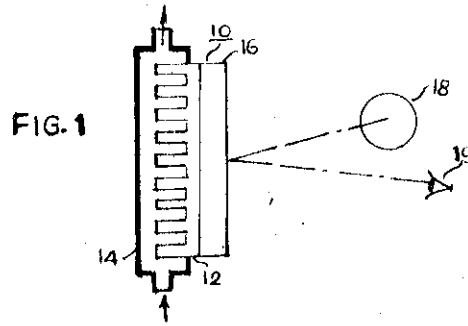


FIG. 5a **FIG. 5b** **FIG. 5c** **FIG. 5d** **FIG. 5e** **FIG. 5f** **FIG. 5g**

In the embodiment of Fig.2 the display screen assembly 10 is shown to be mounted on the heat sink 12. The heat sink 12 may be of any suitable good thermally conductive material such as a metallic layer of a material such as copper or aluminum. A thermal barrier layer 20 may be provided on the heat sink ~~12~~ of a suitable thermal insulating material such as polyethylene terephthalate. The thermal barrier layer 20 is to reduce thermal conductance from the sensitive screen portion to the heat sink layer 12 if less excitation power desired. The layer 20 may not be required in some applications.

The screen includes a heat distribution structure that in the illustrated embodiment is disposed on the thermal barrier layer 20. In the exemplary embodiment shown here, the thermal distribution structure consists of an array of magnetic elements, such as magnetic memory devices, for example, the two-aperture transfluxors 24 illustrated. Each of the transfluxors 24 provides a small area display element and in the normal embodiment, by way of example, about ten of these transfluxors could be provided per linear inch. Thermal distribution structure is made up of a plurality of magnetic elements 24 of a ferromagnetic material. The elements 24 are normally made up and pressed from a mixture of ferric oxide powder and other materials and then baked in an oven. The magnetic memory devices 24 may be in many different shapes and configurations and if desired, may be simply a well known magnetic core if storage is not required. The specific device illustrated herein provides a magnetic structure which has storage features incorporated.

The transfluxor 24 which is shown enlarged in Fig.3 consists of a major aperture 26 and a minor aperture 28. If a section is taken of this transfluxor 24 along the center lines of the two apertures 26 and 28, the cross-sectional area of the region 30 is equal to the cross-sectional area of the region 32 and the sum of these two areas 30 and 32 is equal to the area of the region 34. Fig.4 shows an idealized B-H curve of the material in element 24 where B_r is the residual flux density following maximum magnetization B_{max} and H_c the coercive force of the major hysteresis loop. If it is assumed that I_{40} is the current in a single turn winding necessary for reaching H_c in every part of the shaded magnetic path 40 which encloses only the major aperture 26, that I_{42} is the corresponding current for a shaded magnetic path 42 which encloses both apertures 26 and 28, and that I_{44} is the corresponding current for a path 44 enclosing only the minor aperture 28, then the relationship of these currents may be expressed as $I_{42} > I_{40} > I_{44}$.

Referring now to Fig.5 for an explanation of the general operation of the transfluxor element 24. In clearing current I_c , which is somewhat greater than I_{42} is passed through the larger aperture 26 in a direction as indicated in Fig.5a, a magnetic flux in all three regions 30, 32 and 34 saturates in a counter-clockwise direction about the larger aperture 26.

When this current is removed, the flux density is reduced only slightly to the residual value B_r . Complete saturation in each of these areas 30, 32 and 34 is achieved because of the cross-sectional area relationship stated above. When a small excitation current I_r , where $I_{44} = I_r$ is then passed through the smaller aperture 28 as indicated in Fig. 5b, no flux reversal takes place because in every portion of the region 32 the material is already saturated in the direction of the magnetic field produced by the current I_r . If the current I_r is passed through the small aperture 28 in the opposite direction as indicated in Fig. 5c, no flux reversal takes place because of the saturation in region 30. In these two cases illustrated by Figs. 5b and 5c, only a minute amount of energy is dissipated because flux changes from B_r to B_{max} are only possible and the hysteresis loop illustrated in Fig. 4 is not traversed.

If after the clearing current I_0 has been applied (see Fig. 5a), a writing current I_w equal to I_{40} is passed through the major aperture 26 in the opposite direction as I_0 as shown in Fig. 5d, flux is reversed in the shaded region 40. I_w is smaller than the minimum current to reverse any residual flux in region 42, and residual flux after termination of I_w is reversed only in the region 32 and not in 30. The result is that a counterclockwise residual flux is found around the minor aperture 28, in region 44. Now, if the excitation current I_r is passed through the small aperture 28, a flux reversal takes place as shown in Fig. 5e in the region 44. After the removal of this

current, the residual flux around that small aperture 28 is in a clockwise direction and can again be reversed to the counterclockwise direction by an excitation current I_r in the opposite direction as shown in Fig. 5f. Such reversals can be continued with current pulses of alternating polarity without affecting the residual flux in region 34 and therefore its memory state. During these flux reversals the hysteresis loop is traversed in the shaded path 44 of Fig. 3 and an amount of energy much larger than in cases illustrated in Figs. 5b and 5c is dissipated during each current pulse.

The above explanation shows that, if an alternating current pulse I_r is passed through the smaller aperture 28, the amount of energy dissipated in the memory core 24 and therefore its temperature rise is determined by the presence or absence of a writing pulse I_w after a clearing pulse I_0 . The characteristics of the core geometry and its material determine the ratio between the dissipations in the two cases, but the absolute power dissipation can be controlled by the choice of excitation current pulse frequency.

The amount of writing current is such as to exceed the switching threshold, that is the minimum drive necessary to switch any remanent flux from counterclockwise to clockwise as illustrated by Figs 5c and 5d and determines the amount of remanent flux that is acted upon by the excitation current. It is found that a high degree of linearity can be achieved between the remanent magnetic flux and the applied drive and this information may be stored for an infinite time. Thus, the writing current can determine the

regions in magnetic path 44 in which flux reversals occur in response to the excitation current. The larger the extent of these regions the greater will be the heating found in the transfluxor element 24. The properties of the transfluxor elements 24 are well known in the art and the above-description is given to fully appreciate and understand the operation of the transfluxor as a heating element in the screen structure and the manner in which varying degrees of heating can be obtained for display of information. How this heating property is utilized will be more fully explained with respect to Fig.6.

Referring again to Fig.2, the next layer provided upon the thermal distribution structure is a coating 50 of a suitable material such as a black dye. Positioned on the black coating 50 is a protective film 52 of a suitable material such as polyethylene terephthalate. Positioned on the layer 52 is a layer 54 of a liquid crystalline material of the cholesteric phase which is sensitive to heat. Suitable materials are described in U.S. Pat.No. 3,114,836. A specific material may be a mixture of 80 per cent by weight cholesteryl nonanoate, 20 per cent by weight of oleyl cholesteryl carbonate, and 10 per cent by weight of cholesteryl benzoate. The response of this liquid crystalline material to heat is illustrated by the curve of Fig.7. A protective coating 56 of a similar material as layer 52 may be provided on the layer 54. Heating of selected transfluxor elements 24 results in a display of elemental areas 55 as illustrated in Fig.2.

Referring in detail to Fig. 6 a 4 by 4 circuit assembly or

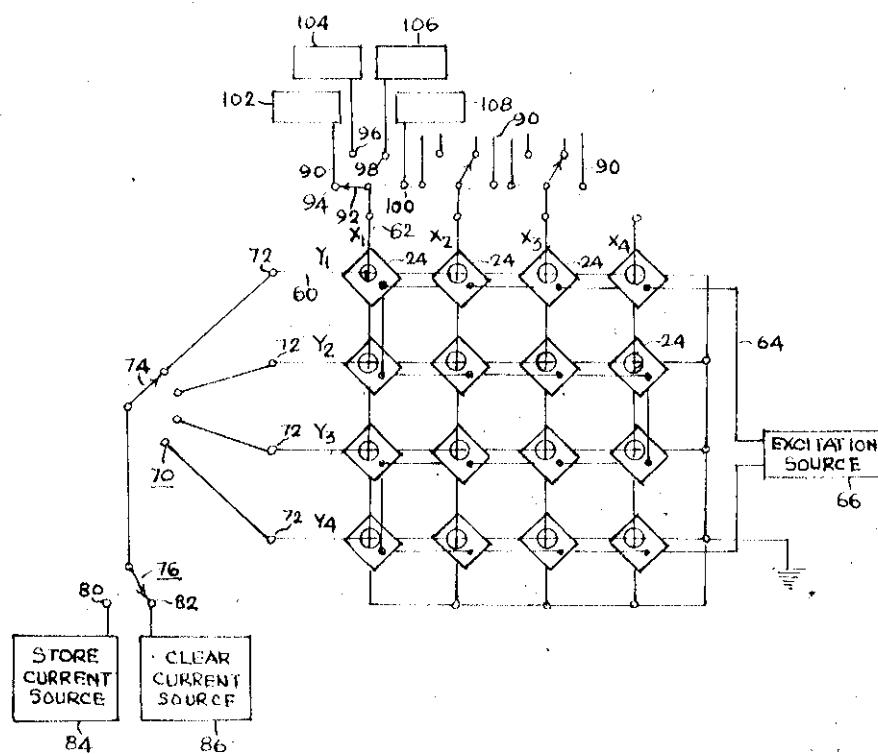


FIG. 6

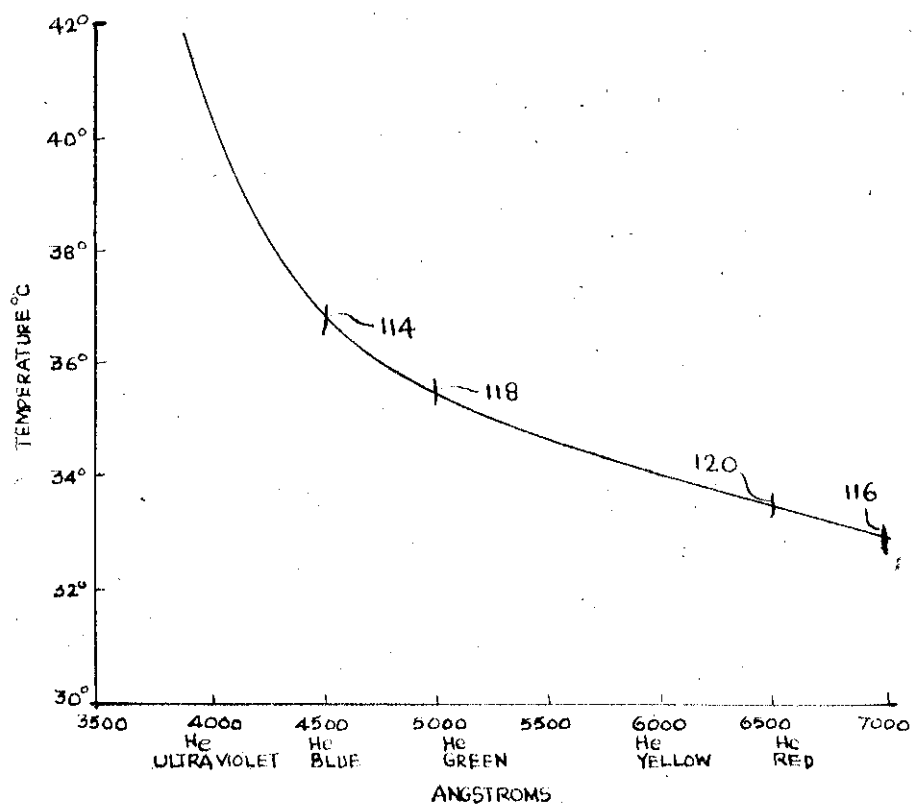


FIG. 7

transfluxor matrix is illustrated. Two single Cum windings 60 and 62 pass through the large aperture 26 and carry the control signal current pulses. The winding 60 is the Y winding and is common to a whole column of transfluxors and permits the selection of an element 34 in the horizontal direction. The winding 60 is the Y winding and is common to a whole column of transfluxors and permits the selection of an element 24 in the horizontal direction. The winding 62 is the X winding and is common to a whole row of transfluxors and permits the selection of an element 24 in the vertical direction of the display panel. A single turn winding 64 passes through the smaller aperture 28 of the transfluxor elements 24 and is common On all the elements in the matrix and supplies the excitation signal from a source 66.

Each of the Y windings 60 is connected to a separate terminal 72 of a first switching means 70. The awttch 70 includes a rotating contact 74 for contacting any of the terminals 72. The rotating contact 74 is connected to the rotating contact of a second switching means 76. The switch 76 includes two terminals 80 and 82 which are in turn connected respectively to current sources 84 and 86. The currant source 84 provides suitable value of current, Par exemple a 300 mA positive pulse to provide a pulse to the Y winding 60 during the store operation. The current source 86 provides a current source of about 600 mA which is of negative polarity and is utilized Lo erase or clear information Pram the transfluxors 24.

Each of the X windings 62 la connected to a separate switch 90 and specifically to the rotating contact member 92. The

switch 90 consists of four terminals 94, 96, 98 and 100 which are connected respectively to a blue information current source 102, a green information current source 104, a red information current source 106. The current pulse of these respective sources 102, 104, and 106 might be of the values of 150 mA, 100 mA, 80 mA, and 0 respectively.

In the operation of the device, assuming that the switch 76 is connected to the source 86 and all of the transfluxors 24 have been cleared as indicated by the representation in 5a, then the switch 76 would be thrown to the terminal 80 to connect the current source 84 which is the store pulse to winding Y. If the switch 90 is placed on terminal 94 as to connect the blue source to the winding X_1 , then an adequate signal will pass through the transfluxor common to X_1 and Y_1 and information will be written or stored on the transfluxor in a manner represented by Fig. 5d. Current flowing through the excitation winding 64 from the current source 66 which may provide a current of 250 mA both in the negative and positive direction and at a frequency of about 200 kilocycles, will cause heating of the transfluxor common to X_1 and Y_1 to a point 114 on the curve in Fig. 7. This is at a temperature of about 37° C. Light directed from the source 18 onto the liquid crystalline layer 54 will result in light of Blue color being reflected from an element 55 of the screen. The transfluxor common to X_1 and Y_1 will continue to reflect this light until a signal from the erase or clear source 86 is applied so as to remove this write information. If the switch 90 is thrown to connect the black source 108, then a point 116 on the

black element will be seen by the viewer. In this condition, the transfluxor 94 does not have any flux reversals but simply remains in a clear state due to the erase pulse and the source 84 is inadequate writing current to write any information in the transfluxor. Corresponding switching of the switch 90 to pulse source 104 in the liquid crystal operating on point 118 and source 106 results in operation on point 120. The reflected colors in this instance would be respectively green and red.

In the above manner, a color image may be written onto the display screen and will be stored thereon to provide a visual color image until the information is cleared from the transfluxors.

Application 3

DISPLAY SYSTEM

This invention relates to display systems and, more particularly, to display systems for the visual display of information by means of a cholesteric phase liquid crystal film.

The present invention resides in a display system for the visual display of information by means of a light control element comprising a cholesteric phase liquid crystal film exhibiting a change in optical properties in response to temperature changes, wherein said light control element is disposed in the path of a radiation beam from a control radiation source representative of the information to be displayed for impressing on said liquid crystal film a thermal pattern corresponding to the information-representative radiation beam.

The described embodiments of the display system according to the present invention employ illumination of, preferably large area, light control elements by a suitable light source and ambient lighting to provide a high intensity light image by reflection of light from or transmission through the light control element. Generally, in preferred embodiments the thermal pattern impressed on the liquid crystal film is utilized for modulation of a high intensity light source.

Liquid crystals of the cholesteric phase have significant optical properties. The cholesteric phase has an index of refraction which varies with direction of propagation of light through the material. For light traveling through a thin sheet

of cholesteric crystalline material, the index of refraction will be a minimum for normal incidence. As the angle of incidence becomes more oblique, the index of refraction will increase.

If linear polarized light is transmitted along the optical axis (the direction along which the optical index of refraction is a minimum), the plane of the polarized light will be rotated through an angle which will depend upon the thickness of the material and upon the particular wavelength with which it is illuminated. This property is called optical activity. The cholesteric phase of liquid crystal is found to be the most optically active substance known. It is found that the plane of polarization may be rotated as much as up to $18,000^\circ$, i.e. up to 50 rotations per millimeter.

Another important property of a cholesteric liquid crystal is the iridescence appearance when illuminated by ambient light. The colors that the crystals exhibit are due to a scattering within the material, which in some ways bears the resemblance to the scattering of light from an oil film on water. However, the differences are quite remarkable. An oil film will scatter light when its thickness is an exact multiple of half of the wavelength. The cholesteric films scatter only one wavelength at one angle. The light scattered from an oil film is not polarized when it is scattered. A circularly polarized wave is one which has two equal components of electric fields that are in space and time quadrature. It may be either right- or left-hand circularly polarized, depending upon the type of material used*. It is also found that with a cholesteric liquid crystal the circular polarized light is reflected or scattered in the same sense

to the ordinary mirror reflection. That is, right-hand circularly polarized light when reflected from a cholesteric material is right-hand when it is scattered. The left-hand circularly polarized light will not be scattered but will be transmitted through the film. This gives rise to a property which is called circular dichroism or selective scattering of right- or left-hand circularly polarized light. It is found that a liquid crystal absorbs no energy so that the light energy directed thereon is either transmitted or reflected. It is found that at selected wavelength and the normal angle of incidence that about 50 per cent of the incident radiation is scattered. At larger angles the amount of energy reflected increases and the peak (wavelength of maximum scattering) shifts toward the shorter wavelength. If the temperature of the film is varied, the peak of the reflection curve will shift to shorter wavelengths with increase in temperature. This temperature effect is completely reversible. At any temperature the wavelength of maximum scattering depends on the sum of the incident angle of the light radiations and the observation angle.

In Fig.1, there is shown a projection system which includes a polarizer 11 and an analyzer 13 which are disposed in parallel spaced relationship. The polarizer 11 and the analyzer 13 may be of tourmaline, nicol prisms or any other suitable material which will permit light to pass in only one plane.

A light modulator 15 is provided between the polarizer 11 and the analyzer 13. The modulator 15 includes a layer 17

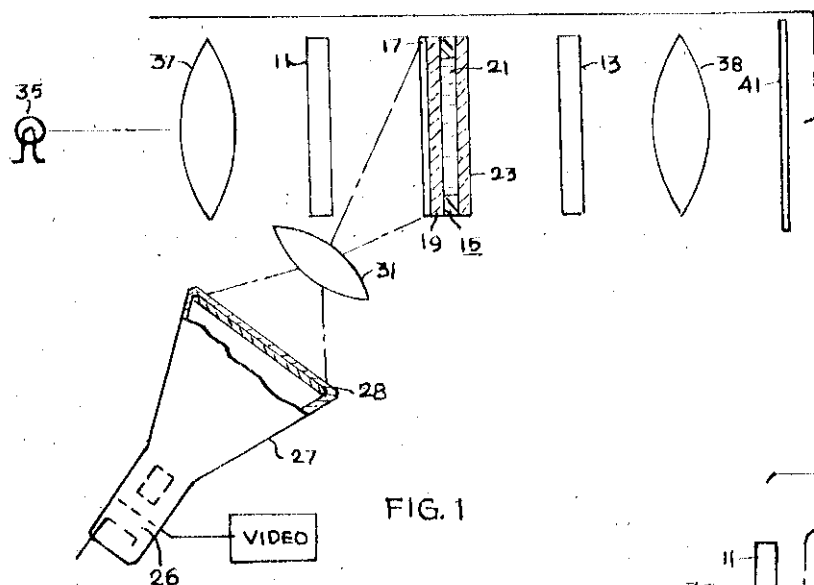


FIG. 1

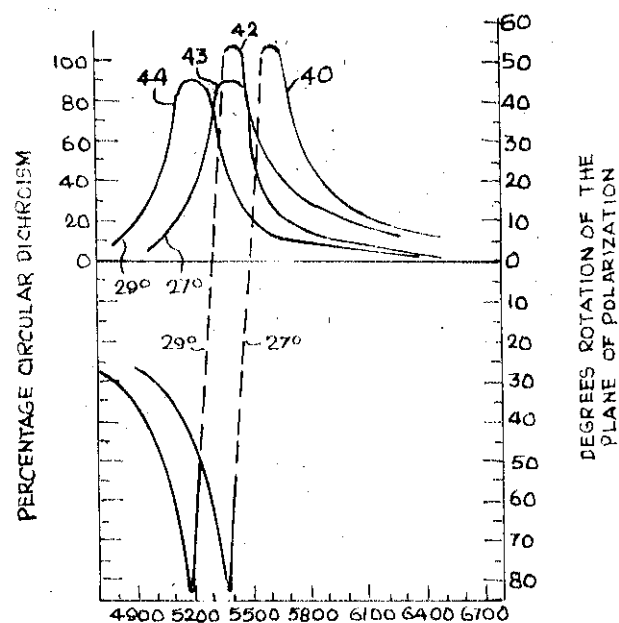


FIG. 3

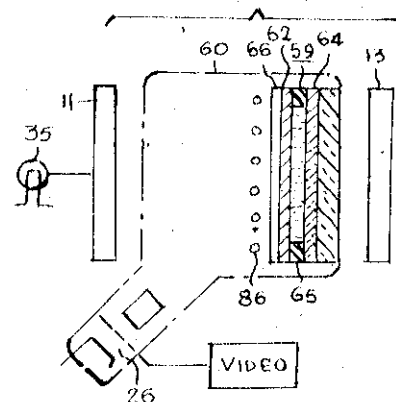


FIG. 2

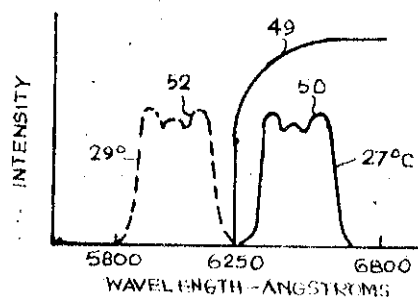


FIG. 4

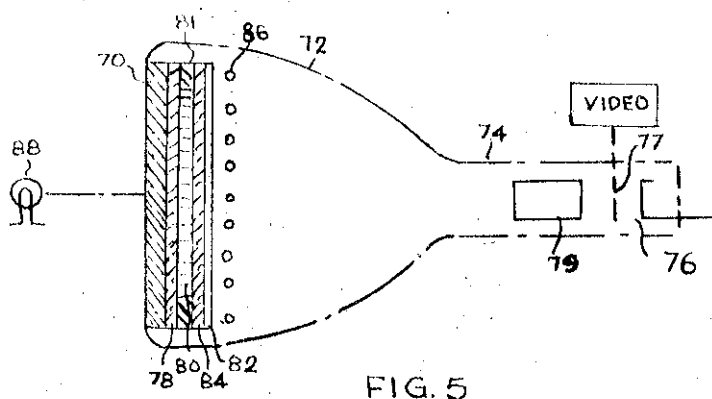


FIG. 5

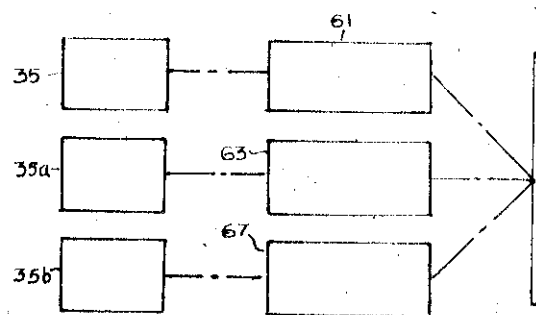


FIG. 6

exhibiting the property of absorbing an input electromagnetic radiation image and converting the radiation image into a heat or thermal image. The layer 17 absorbs those wavelengths emitted by a modulation system while permitting radiation of a projection source to be transmitted. In the specific embodiment shown, the modulation radiation is in the ultraviolet portion of the spectrum and the projection source radiation is in the visible portion of the spectrum. A suitable material for the layer 17 is tartrazine of a thickness of a few microns. Any suitable dye including organic or inorganic dyes may be used for this purpose. Their suitability is determined by their absorption characteristics. Other materials suitable for ultraviolet range are anthracene and phenanthrene. A support layer 19 of low heat capacity and transmissive to at least the visible region of spectrum is provided and supports the layer 17. The layer 19 has a thickness of about 10 microns and may have a suitable material such as polyvinyl fluoride.

A layer 21 of a suitable liquid crystalline material of the cholesteric phase is provided on the layer 19. The layer 21 is in good thermal contact with layer 19. A suitable material for the layer 21 is a mixture including 20 per cent by weight of cholesterol benzoate, 30 percent by weight of cholesterol nonanoate and 50 percent by weight of cholesterol oleyl carbonate. This is only one specific liquid crystalline material of cholesteric phase that will function in this embodiment. Several other suitable materials are described in U.S Patent 3,114,836. Another layer 23 of polyvinyl fluoride is provided on the

opposite surface of the liquid crystalline layer 21 and the resulting structure may be sealed by any suitable means to retain the liquid crystalline material layer 25 confined within between layers 19 and 23.

A cathode ray tube 27 is provided for directing modulated radiation onto the light modulator 15. The cathode ray tube 27 includes a phosphor layer or screen 28 on the face plate which generates ultraviolet radiation in response to electron bombardment. An electron gun 26 is provided for generating an electron beam. Suitable deflection means are provided for scanning the electron beam to form a raster on the screen 28. The video signal is applied to an electrode of the electron gun 26 for modulating the electron beam in well known manner.

A lens 31 may be provided between the cathode ray tube 27 and the light control element 15 for focusing the radiation from the ultraviolet phosphor layer 28 onto the light control element 15. A suitable light source 35 is provided on the opposite side of the polarizer 11 with respect to the light control element 15. In the specific embodiment, the light source 35 is monochromatic and provides radiation of a wavelength of about 5,700 Å. Suitable filters may be utilized with the light source 35 in order to provide this substantially single wavelength transmission. Lens elements 37 and 39 may also be provided for focusing of the light from the source 35 directed onto the control element 15 and a viewing screen 41, respectively.

'She beat explain the operation of the system, reference is made to Fig.3 (see next page). Curves 40 and 42 in Fig.3 represent certain properties of the, layer 21 at two different temperatures. If it is assumed thnt the temperature is 27° C. as represented by curve 40, then the light is rotated about 45 degrees by the la er 21. The polarizer 11 and the analyser 13 may be adjusted so that substantially no light from the source 35 is projected onto the screen 41 at this temperature. By raising the temperature to 29° C. so as to be on curve 42, the rotation by the light control element 15 will now be transmitted through the system onto the screen 41. By modulating the intensity of the electron beam generated by the gun 26 with the video information, the amount of radiation from the screen 28 may be controlled. The amount of radiation directed on the light control element 15 controls the temperature of the light element control 15 and accordingly the amount of light transmitted from the source 35 do the screen 41. In this manner, a high intensity light image may be displayed on the screen 45 corresponding to the video information. The polarizer 11 will linearly polarize the emergent light beam from the source 35. The light emerging from the polarizer 11 will illuminate the light control, assembly 15. The temperature pattern is impressed on the layer 21 by means of the cathode ray tube 27. The light control element 15 will be illuminated by a weaker control source in the form of the ultraviolet beam from the cathode ray tube 27. It is normally desirable that the light beam from the cathode ray tube 27 be at different wavelength than the source 35 but it is not essential to the operation of the system. The radiation

from the cathode ray tube 27 is directed onto the light control assembly 15. The radiation absorbing layer 17 will absorb the radiation from the cathode ray tube 27 and generate a heat pattern which is impressed on the optically active film 21. The layer 17 will not substantially absorb the visible radiation from the source 35.

The layer 17 may be also be of metal such as nickel having an electrical resistance of about 377 ohms per square which absorbs about one-half of the incident radiation including the source 35 and the cathode ray tube 27 and transmits one-fourth of the remaining. Under these conditions, the radiation source 35 together with the radiation of the cathode ray tube 27 can be used to elevate the temperature of the layer 21 to a suitable operating temperature at which temperature the primary radiations of the source 35 are transmitted through the analyzer 13. If one-twentieth of the total power needed to reach the optimum film temperature is provided by the cathode ray tube 27, then this amount of power is more than adequate to modulate the transparency of the system.

It is also possible to use the circular dichroic properties of the film 31 by removing the polarizer 11 and analyzer 13 and positioning a circular polarizer between the light source 35 and the control element 15. The light source 35 would be set at a wavelength of 5,400 Å. At a temperature of 27°C. the film transmission will be at one level, as shown on curve 43 of Fig. 3. By raising the temperature to 29°C., the film transmission would be at a second level that is vastly different from said one level.

as shown on curve 44 of Fig.3. The polarizer and the film should be of the same polarization, that is right- or left-handed.

If the source 35 is modified to provide a given band of wavelengths rather than a single wavelength as previously described with respect to Figs.1 and 3, then the system may be utilized in the following manner: The light source 35 in this case would emit radiation from the infrared end of the spectrum to about 6,250 Å. This is represented by curve 49 in Fig.4. Curve, 50 in Fig.4 represents the transmission properties of the polarizer 11, analyzer 13 and light control element 15 for a temperature of 27 degree Centigrade. The curve 52 represents the transmission characteristics of the same assembly at a temperature of 29° C. Thus by shifting the temperature of the control element 15 to a higher temperature, the transmission of light through the system from the source 35 may be cut off. By lowering the temperature to about 27°C, light from the source 35 will be transmitted through the assembly to the screen 41. Only about 50 percent of the light from the source 35 will be transmitted through the assembly. This is due to the fact that within the optical activity range of the material in layer 21, the circular dichroism effect is also found such that only the right- or left-hand portion of the light will be transmitted and the other portion will be reflected from the liquid crystal layer 21.

In Fig.2 a modified light controlled unit is shown in which a light control assembly 59 is provided within an evacuated anvelope 60 so that the electron beam bombards the light control assembly 59. The target assembly or light control structure 59 in this embodiment consists of light transmitting layers 62 and 64 of polyvinyl fluoride with a thin layer 65 of a cholesteric liquid crystalline material positioned between the two layers 62 and 64. A layer 66 of a material such as tin oxide or gold is provided on the layer 62. The electron beam bombards the layer 66 and generates a heat image which is impressed on the layer 66. In this manner, the electron beam is utilized directly on the light, control struatuss 59 rather than through the radiation as illustrated in Fig.1. Under this condition the gain of the system can be at least 100.

The operation of the system is similar to Fig.1. The speed of response of the device can be optimized by coating the inner surface of the cathode ray tube with a plastic film of sufficient thickness to provide the right amount a4 heat conductivity to reduce the thermal time constant of the system. This can be accomplished without a great sacrifice in the power sensitivity of the liquid crystal film which is sandwiched between these films. It is also possible to provide a plastic film on the target facing the electron gun of a material having a second crossover in its secondary emission characteristics at a high voltage so as to absorb maximum energy from the bombarding beam. The maximum transparency of the composite layer in this case should be made as high as possible to the wavelength of the

light from source 35 to be amplified. By locating the writing gun 26 at an angle with respect to tube face, the polarized light from the high intensity source 35 may be modulated by projecting the light through the face of the tube as illustrated in Fig.2.

In Fig.6 there is illustrated a projection system utilizing three separate systems 61, 63 and 67 similar to Fig.1 and in which the three light sources 35, 35a, 35b would be sources capable of radiation respectively in the red, green, or blue band of the spectrum. In this manner, the light projected from the system 61 would project a red image onto a viewing screen corresponding to the light modulation or red video signal applied to the cathode ray tube of the system 61. In a similar manner, the source 35a would provide a green image by system 63 and 35b a blue image by system 67. The video information of these three colors would be applied to their respective cathode ray tubes. The resulting image of the viewing screen could be a sequential type of display or simultaneous type of display to provide a high intensity color television image.

In Fig. 5 there is illustrated a display tube capable of presenting an image by utilizing the reflection properties of the liquid crystalline layer. The display tube is of substantial conventional cathode ray tube design and consists of a face plate portion 70, a flared portion 72 and a neck portion 74. An electron gun 76 is provided within the neck portion 74 of the envelope. The electron gun 76 may be of any suitable design for producing a pencil-like beam and is well known in the art.

The video signal may be applied to a control grid T1 of the electron gun 76.

The screen 81 includes a coating 78 of an electrically conductive light transmissive material such as stannic oxide provided on the inner surface of the face plate 70. A layer 80 of a liquid crystalline material of a mixture such as 45 percent by weight of cholesterol nonanoate, 45 percent of oleyl cholesterol carbonate and 10 percent of cholesterol benzoate is provided on the electrically conductive coating 78 of a thickness of about 25 microns. Provided on the inner surface of the liquid crystal layer 80 is a layer 84 of polyvinyl fluoride having a black coating provided on the surface facing the liquid crystal layer 80. A layer 82 similar to layer 66 of Fig.2 is provided on the inner surface of the polyvinyl fluoride layer 84. An electrically conductive grid 86 may be provided between the screen 81 and the electron gun 76 for acceleration and focusing of the electron beam. A suitable light source 88 of white light is provided exterior of the envelope for illuminating the screen 81.

During the operation of the device, the electron beam from the electron gun 76 is directed onto the surface and generates a heat pattern in layer 82 corresponding to the video intelligence applied to the control grid 77 of the electron gun 76. Suitable deflection means 79 are provided for scanning the electron beam over the screen 81. The heat image established in the layer 82 is impressed in the layer 80 and a visual image is obtained when illuminated by the light source 88. By proper

design, the target will provide the proper amount of heat conductivity and speed of response. By adjustment of the video signal, the color may be selected. The intensity of the color can be varied by simple modulation of the electron beam to provide a multi-color image. The screen may be viewed in high ambient light condition. The brighter the ambient light the brighter will be the display on the display screen. It is also possible to provide a single color on a black background by utilizing a monochromatic light from the source 88.

Application 4

ELECTRIC FIELD DEVICE

This invention relates to electric field responsive devices for the detection and visual indication of electric fields.

In many applications, It is desirable to provide an electric field sensitive device for giving a visual indication of the fact that a field is present and also visual indication in response to a change or different values of the field thereacross. Certain organic materials have been found, that modify their optical properties in response to an electric field. These materials are liquid crystalline materials of the cholesteric phase.

The unique molecular architecture of the cholesteric liquid crystals give rise to a number of optical properties which differ from the smectic or nematic phase. The characteristic properties of the cholesteric structure may be summarized as follows :

(1) It is optically negative, while smectic and nematic structures are optically positive. An optically negative layer provides that light entering perpendicular to the molecular layers has a maximum velocity.

(2) The structure is optically active. If linearly polarized light is transmitted perpendicularly to the molecular layers, the direction of the electric vector of light would be rotated progressively to the left along the helical path. Thus the plane of polarization, which is determined by the

repeated (10)

electric vector in the direction of propagation, will be rotated to the left, to an angle that will be proportional to the thickness to the transmitting materials. The magnitude of the rotation of the plane of polarization is also a function of the wavelength input. This property may be referred to as wavelength dependent optical activity.

(3) It selectively scatters light directed onto the molecular structure. The term scattering is used rather than reflection in order to distinguish from the effect occurring on a mirror surface wherein light is reflected at an angle equal to the angle of incidence. A scattered light ray may leave the scattering material at an angle unrelated to the angle of incident light. A selectively scattering film when observed with light impinging on the film from the same side as that which is viewed, has an apparent color which is the complement of the color of the light transmitted by the film. That is, the light scattered from the film is within a wavelength band which, if added to the light transmitted through the material, would form white light, if white light was incident on the film. The terms light and color as used herein have a broad connotation of referring to electromagnetic radiation generally, rather than to solely visible radiation. Most materials do not selectively scatter light in that light transmitted through them is not complementary to light scattered by them but rather is within the same wavelength band. The difference in effect between selectively scattering materials and ordinary materials is believed due to the fact that in ordinary material some

light is absorbed by electron photon interaction while in selectively scattering materials there is very little absorption. A cholesteric material exhibits a scattering peak having a narrow bandwidth over the electromagnetic spectrum. The bandwidth in the visible spectrum is about 100 angstroms. The phenomena of selective scattering as exhibited by cholesteric liquid crystal films is independent of whether the light illuminating the film is polarized or not. This is the property that gives the iridescence appearance of the material under ambient light.

(4) Another optical property exhibited by the cholesteric liquids is circular dichroism. When ordinary white light is directed onto cholesteric material, the light is separated into two components, one with the electric vector rotating clockwise and the other with the electric vector rotating counterclockwise. Depending upon the material, one of these components is transmitted and the other is scattered. This gives the property of circular dichroism or the selective scattering of right or left-hand circularly polarized light.

(5) Another property is that when circularly polarized light is directed onto cholesteric materials, the sense of polarization of the scattered light is unchanged from the incident light.

(6) The mean wavelength of the scattering band depends upon the angle of incidence of the light. The type of material and the temperature also affect the mean wavelength of the scattering band.

The molecular structure of a cholesteric liquid crystal substance is very delicately balanced and can be easily upset. Thus any small disturbance that interferes with the weak forces between the molecules and produces marked changes in such optical properties as scattering, transmission, birefringence, circular dichroism, optical activity and color.

One of the most striking optical transformations that occurs in certain cholesteric substances is in response to changes in temperature. Although most cholesteric substances are colorless as liquids, they pass through a series of bright colors when they are cooled through their liquid crystal phase. All cholesteric liquid crystals do not respond in the same way to fluctuations in temperature. The colors may vary and the sequence of colors with cooling may vary. It is also possible to obtain certain materials that have very little reaction at all to changes in temperature. The properties of the liquid crystal materials of the cholesteric phase with regard to response to thermal change is discussed in U.S. Patent 3,114,836.

Another effect that has been noted with certain cholesteric liquid crystals is its response to certain chemical vapors. The addition of extremely small amounts of certain chemical vapors can change the basic molecular structure and thereby affect the optical properties, such as the selective scattering effect.

The present invention is based on the observation that electric fields can affect the structure of cholesteric liquid

crystals so that one or more optical properties thereof is changed. The device according to the present invention may be utilized for detection of a field with an indication by color of the value or a voltage or a current impressed thereon. It may also be utilized for display of a visual image. Various embodiments of the devices may be constructed to bring about and utilize this phenomenon. The optical property readily utilized in the practice of this invention is that of selective scattering since it does not require polarization for observation. The change in transmission properties of light through the liquid crystal device may be utilized and controlled. This transmission shift is in the same direction and to the same extent as the scattering band.

Referring to Fig.1, there is illustrated a simplified voltage sensitive device including a layer 11 of a mixture of liquid crystalline materials of the cholesteric phase that exhibit a change in optical properties in response to an electric field impressed across the layer 10. Examples of liquid crystal materials of the cholesteric phase exhibiting a change in optical properties in response to an electric field include cholesterol, cholestanol, sitosterol, cholesteryl halide, e.g., cholesteryl iodide, cholesteryl chloride and cholesteryl bromide, cholestanyl halide, e.g., cholestanyl chloride, cholestanyl bromide and cholestanyl iodide, sitosteryl bromide and sitosteryl iodide, or mixture thereof. Usually these materials or mixtures thereof may be mixed with other substances such as stanol

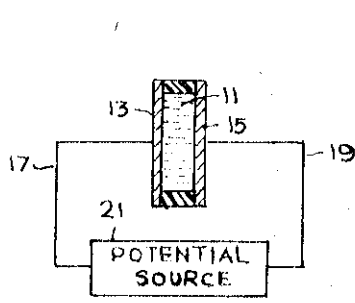


FIG. 1

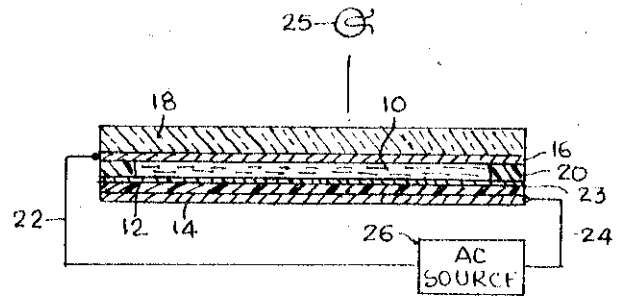


FIG. 2

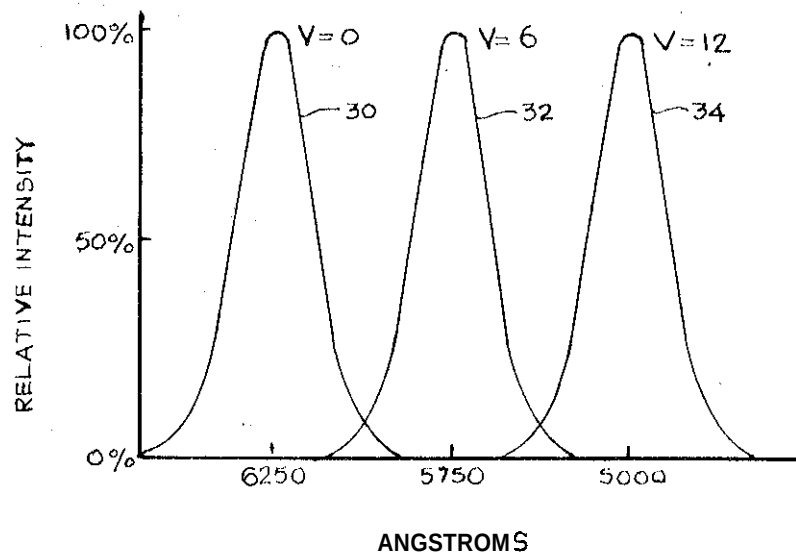


FIG. 3

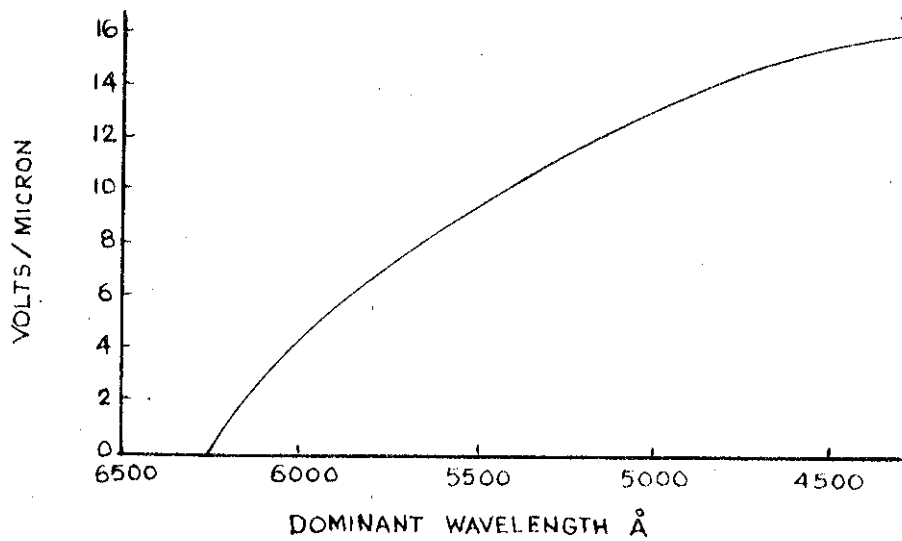


FIG. 4

derivatives, and up to 20 percent of fatty acids and compounds thereof. The following Table gives a listing of specific mixtures of materials by per cent weight which exhibit the field effect. These materials are stable at room temperature.

MIXTURE :	COLOR AT ROOM TEMPERATURE
20% Cholesteryl Chloride (CC)	
80 % Cholesteryl Oleyl Carbonate (OCC)	Blue
25 percent Cholesteryl Chloride	
75 percent OCC	Green
30 percent CC	
70 percent OCC	Red
20 percent CC	
20 percent Cholesteryl Nonanoate (CN)	
80 percent OCC	Blue
25 percent CC	
75 percent cholesteryl Oleate (CO)	Green
25 percent Cholesteryl Bromide (CB)	
75 percent OCC	Green
30 percent CB	
70 percent OCC	RED
25 percent CC	
25 percent OCC	
25 percent CO	
25 percent CN	Green

In Fig.1 thereis shown a voltage-sensitive device including a layer 11 of a suitable liquid crystal material of the cholesteric phase exhibiting a change in optical properties in response to electric fields impressed thereacross. The layer 11 may consist of 20 per cent by weight of cholesteryl chloride with 80 percent by weight of cholesteryl oleyl carbonate. The percentage of cholesteryl chloride may vary from 15 percent to 50 percent by weight of the mixture.

The layer 11 is sandwiched between two transparent electrical conductive layers 13 and 15. Electrical conductive leads 17 and 19 from the respective conductive layers 13 and 15 provide means of applying an electric potential illustrated as source 21.

The application of a voltage across the layer 11 by the source 21 results in a field across the layer 11. The electric field modifies the optical properties of the layer 11. These properties include optical rotation, selective scattering and selective transmission. The apparatus and the methods of visual display of these effects will be discussed with respect to the following embodiment.

Referring to Fig.2, there is illustrated a voltage sensitive device including a liquid crystalline material of the cholesteric phase. This device utilized the selective scattering properties of the liquid crystalline layer. The device consists of a layer 10 of suitable liquid crystal materials, for example a layer consisting of 45 percent by weight of cholesteryl bromide, 30 percent cholesteryl oleate and 25 percent cholesteryl nonyl-

phenyl carbonate. This layer 10 when illuminated by white light, which provides uniform intensity over the spectrum, exhibits properties as best illustrated by the curves in Figs. 3 and 4. The electric field sensitive device illustrated in Fig.2 consists of a layer 12 of suitable electrically conductive layer of a material such as aluminum, a layer 14 of suitable insulating material such as aluminum oxide, a suitable black coating 23 of a suitable dye, the layer 10 of a suitable liquid crystalline material, a layer 16 of a suitable electrical conductive material transmissive to visible light of a suitable material such as stannic oxide and a support layer 18 of a suitable material transmissive to visible light such as glass and supporting layer 16. The function of the layer 14 is to provide a carrier for the light absorbing layer 23 and to insure against electrical breakdown of the cell. In some applications, the layers 14 and 23 could be omitted.

In specific device shown in Fig.2 may be constructed by providing a sheet of commercial grade aluminum of about 0.5 inch in thickness. The sheet of aluminum may be of any desired thickness and may be of any desired dimensions, such as about 3 inches in diameter. The sheet of aluminum may be cleaned in an aqueous solution of ammonium nitrate 3 percent by weight and anodized to provide the desired thickness of aluminum oxide by the adjustment of voltage. An electrode of lead may be utilized for the cathode in this operation. By this procedure, an aluminum oxide coating 14 of a desired thickness of about 1 micron is formed on both surfaces of the aluminum sheet simultaneously. The anodized aluminum sheet is then removed from the electrolyte and washed in distilled water and then pure acetone. Next, the

anodized layer on one side of the aluminum layer 12 is removed by treatment with a suitable caustic reagent, such as sodium hydroxide. After the sodium hydroxide has had an opportunity to act on one of the aluminum oxide films, the aluminum mat be washed in distilled water and the aluminum oxide film on one surface of the aluminum layer 12 is removed leaving the other layer 14 of the aluminum oxide. The resulting structure provides an aluminum oxide layer 14 of aluminum of a thickness of about .5 inch. The aluminum oxide layer 14 is then treated with a suitable dye to provide a black coating 23 for light absorption.

The other electrically conductive electrode 16 is provided by evaporating a coating of a suitable material such as stannic oxide to a thickness of about 0.1 micron onto a substantially transparent sheet of glass of a suitable material and of a thickness of 0.125 inch. An annular spacer 20 of a suitable electrically insulating material such as polyethylene terephthalate is positioned on the aluminum oxide surface and the liquid crystalline material is deposited on the coating 23. Since this liquid crystalline material may be squeezed onto the surface from a container, applied by a dropper, painted or by other means applied onto the exposed surface of this layer 23. The other electrode 16 is then positioned over the liquid crystalline layer 10 and the structure may be sealed by a suitable sealing compound such as epoxy to mechanically secure the structure.

Electrode leads 22 and 74 connected respectively to the layer 16 and the layer 12 are connected to a voltage source 26. A suitable light source 25 such as a tungsten filament light source is provided to illuminate the liquid crystalline layer 10 through the substantially transparent layers 16 and 18 with white light. It should be noted that ambient lighting can provide this white light illumination or at least supplement.

Referring to Fig.2, on application of potential across the layer 10 by means of a voltage source 26 the light from the source 25 will be selectively scattered back from the layer 10 in accordance with the voltages applied. For example, as illustrated in Fig.3, with no voltage or a very small voltage from source 26 applied, light will be scattered from the liquid crystalline layer 10 to give a red color to an observer as illustrated by curve 30. With a field of about 6 volts per micron applied across the layer 10 the light scattered from the liquid crystalline film 10 will be in the range as indicated by curve 32 so as to give off a green light. On application of a higher voltage of about 12 volts per micron light will be scattered from layer 10 so as to give a blue color and in the range indicated by curve 34. The bandwidth of scattering is about 200 angstroms. In Fig.4 there is a plot of the dominant wavelength of scattering with respect to the electric field for the device shown in Fig.2.

The molecular structure of the layer 10 is illustrated in Fig.5. The molecules are arranged in layers 31 substantially with the molecules within such layer oriented in parallel alignment.

The molecular layers 31 are very thin with the long axis of the molecules parallel to the plane of the layers. Because of the peculiar shape of the cholesteryl molecules, the direction of the long axis of the molecules in each layer 31 is displaced slightly from the corresponding direction in the adjacent layers. The overall displacement traces out a helical path indicated by the line 33. In Fig.5, about every three hundredth layer is illustrated. The line 35 is the optical axis of the crystal. It is found that when selected liquid crystals are placed in an electric field parallel to the direction of alignment or optical axis, the wavelength of maximum scattering or color will be shifted from long wavelengths to short wavelengths that is from red toward blue. The effect appears to be associated with substituted sterol molecules containing polar functional groups.

Another suitable mixture that may be used in Fig.2 is one consisting of 27 percent cholesteryl chloride and 73 percent cholesteryl oleate. In the absence of any electrical field and at room temperature $28^{\circ}\text{C} \pm 15^{\circ}\text{C}.$, this material is yellowish-green to blue as the electric field is increased. For example, with a sample 20 microns thick, this change occurs between zero and 100 volts or the range of color occurs over zero to five volts per micron. This material has a resistivity in excess of 10^{12} ohm centimeters so that a charge may be placed across this material which will maintain a steady state field, the liquid crystal material behaving as a dielectric of a capacitor. The energy estimated to change the color a maximum amount is less than 10^{-6} joules per square centimeter for a 20 micron thick sample.

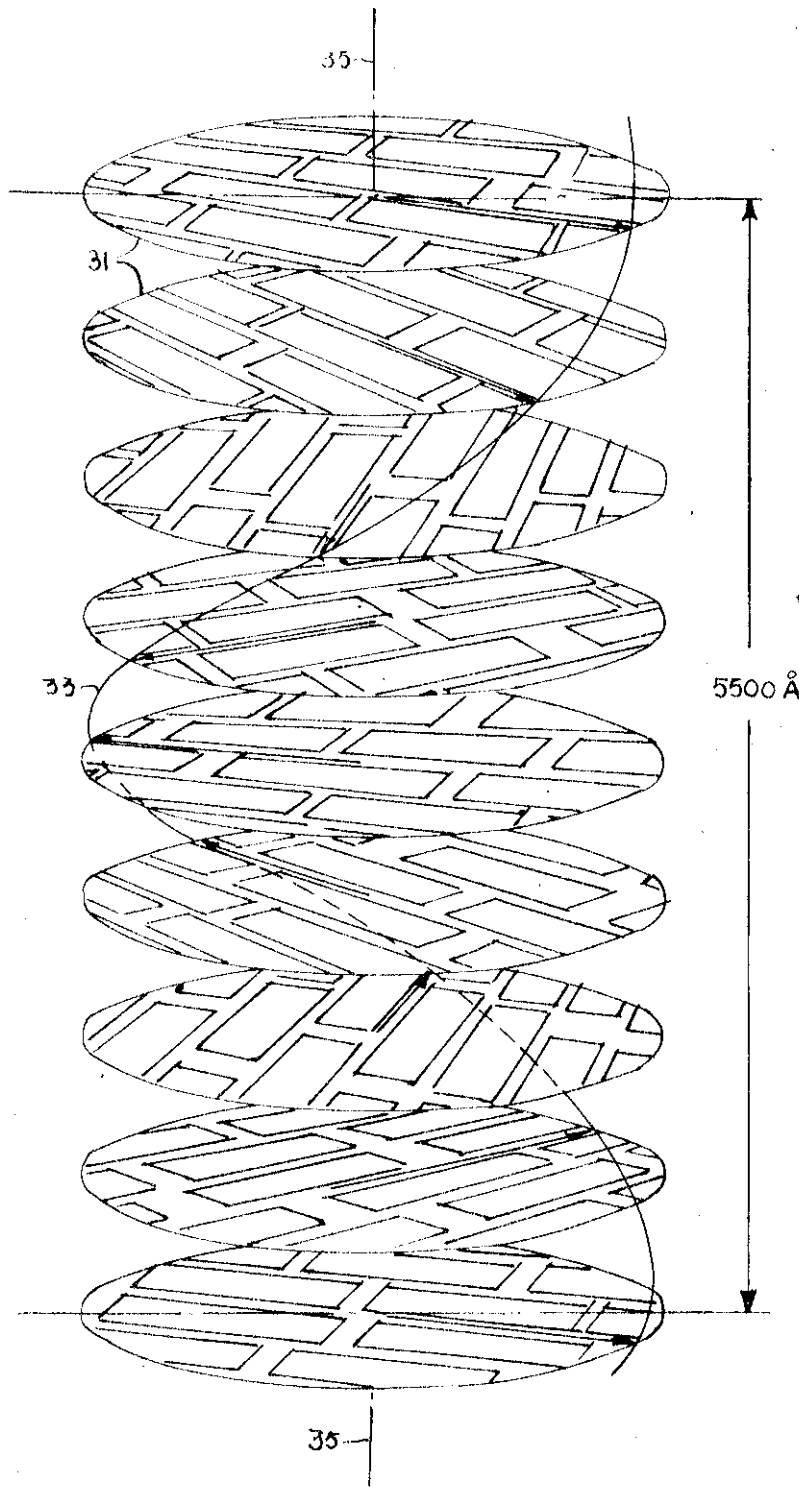


FIG. 5

It is found that such a device as illustrated in Fig.2 is usable as a voltmeter, having a very high impedance in excess of 500 megohms. It can also store charge for several seconds thus retaining Z's color once charged. By placing an a.c. field on the material, it was found that the liquid crystal could change its color at a rate in excess of 100 cycles per second indicating a response time as fast or faster than the human eye. Further, it has been shown that only fields in the direction of the liquid crystal axis are effective, thus making very high definition possible. That is, if two areas of charge are very close together only that part of the fields which are in the normal direction parallel to the optical axis will have an effect on the liquid crystal, thus improving resolution. It is estimated that the resolution of a 20 storm thick film would be in excess of a thousand lines per inch. The properties of this device make this material ideally suited to a number of high resolution and fast display systems. The material is ideally matched with an electron beam since both are of very high impedance.

In Fig.6, there is illustrated a storage tube incorporating a liquid crystal display screen. The storage tube be of suitable design and consists of a face plate portion 40, a flared portion 42 and a neck portion 44. An electron gun 46 is provided within the neck portion 44 of the envelope. The electron gun 46 may be of suitable design for providing a pencil-like beam and is known in the art. The video signal may be applied to a control grid 47 of the electron gun 46. A coating 48 of electrically conductive light transmissive material such as stannic oxide is

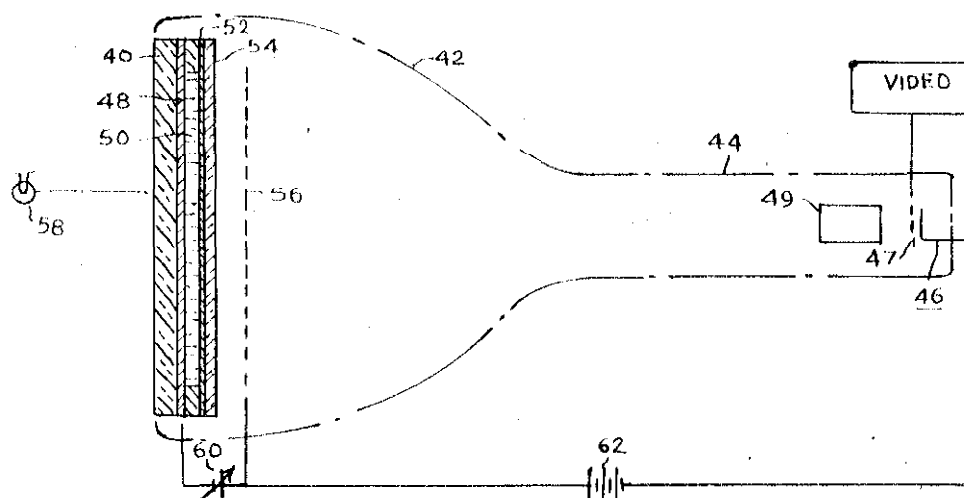


FIG. 6

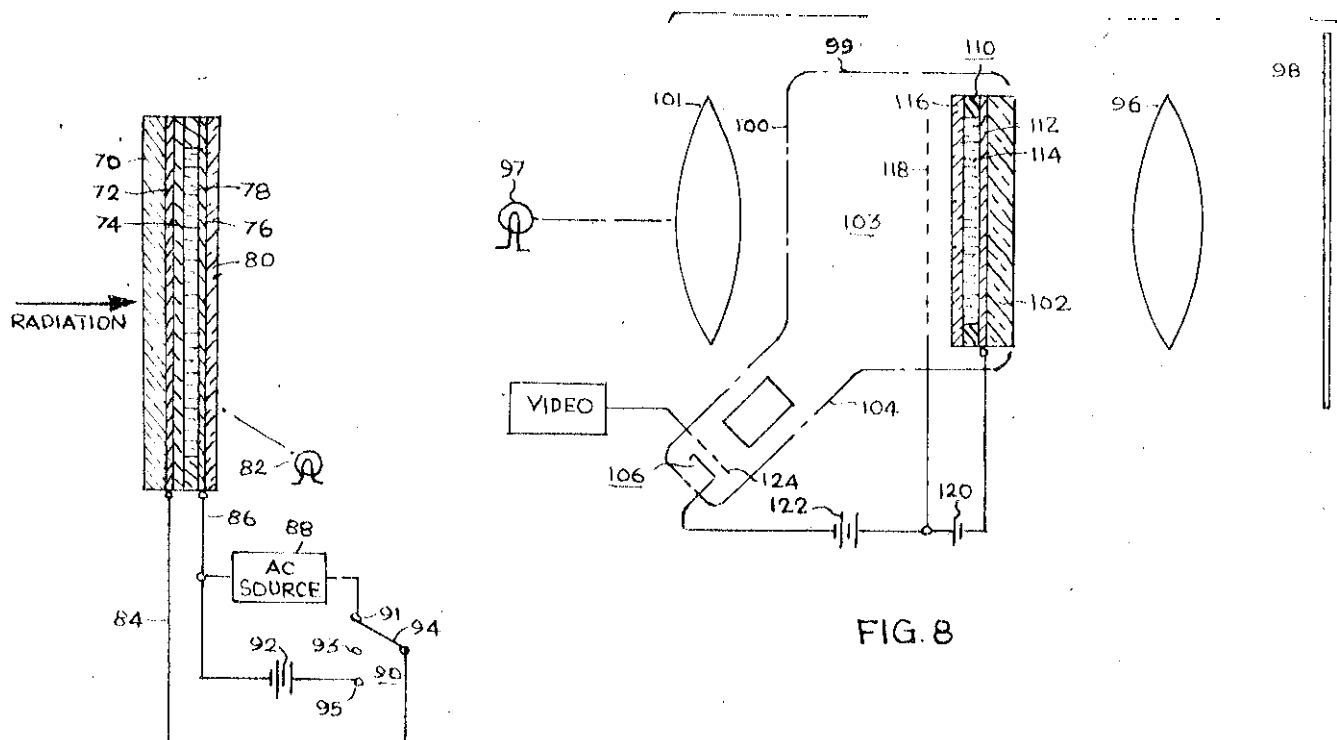


FIG. 7

FIG. 8

provided on the inner surface of the face plate 40. A layer 50 of liquid crystalline materials of a mixture such as described with respect to Figs. 2, 3 and 4 is provided on the electrical conductive coating 48 and of a thickness of about 25 microns. Provided on the inner surface of the liquid crystal layer 50 is a layer 54 of dielectric material having a black coating 52 provided on the surface facing the liquid crystal layer 50. The dielectric may be of a suitable material such as glass or resinous material (for example polyethylene terephthalate). The thickness of the dielectric material layer 54 is about 6 microns. Provided between the screen structure and the electron gun 46 is an electrically conductive mesh 56, which forms the second electrode for the layer 50. A suitable light source 58 of white light is provided exterior of the envelope for illuminating the screen assembly including layer 50. A suitable voltage source 60 is provided between the conductive coating 48 and conductive mesh 56 and a voltage source 62 is connected between the conductive mesh 56 and the cathode of the electron gun 46. The potential of the source 60 may be about zero to 200 volts and the potential of the source 62 may be about 500 volts to 15 kilovolts.

During the operation of the device, an electron beam of several hundred ^{e.v. energy} ~~volts~~ is directed onto the surface of the dielectric layer 54 and generates a charge pattern at the surface corresponding to the video intelligence applied to the anode 41 of the electron gun 46. Suitable deflection

means 40 are provided for scanning the electron beam over the screen. The charge pattern may be established by secondary emission and the surface will tend to approach the potential of the conductive mesh 56. If it is desired to write in a negative direction then the conductive mesh 56 would be operated at a sufficiently negative potential by control of voltage source 60 and the secondary electrons emitted from the dielectric surface will be returned thereto. The beam current in this case will determine the amount of charging. It is also possible to operate with the dielectric member at a more negative potential than this mesh 56 in which case the writing will be in a positive direction. In this case, the electron beam will cause the emission of secondary electrons which will be collected by mesh 56. This tube will be able to hold a charge for long periods of time thus displaying the charge or electric field image established on the dielectric surface. The charge established on the dielectric surface will establish an electric field across the liquid crystal layer 50 and vary the color of the scattered light from the source 58 in a similar manner as described with respect to Figs. 2, 3, and 4.

The charge image may be erased by changing the potential on the mesh 56 and flooding the target with electrons from the gun 40 or by a separate flood gun. This device will provide fast write time and long storage capability. The screen may be viewed in high ambient light conditions such as in an aircraft. Since the material has the property of

scattering the light incident thereon, the brighter the ambient light the brighter the display will be on the display screen. It is, of course, obvious that any means of providing a charge image on the dielectric layer 54 will be successful in displaying a color image with the color dependent upon the magnitude of electric field. A plurality of horizontal and vertical conductors with associated switches could be used in a well known manner. It is also possible to provide a single color on black background by using a monochromatic light source. Several colors could be presented by providing a plurality of monochromatic light sources of different colors. A white source with selective filters could also be utilized.

Because of the extremely low power needed to activate the liquid crystal material, several other devices not related to electron beam writing can be adapted to use liquid crystals. The material exhibits the ability to respond in the same manner independent of the polarity of the field. In Fig. 7, a radiation image converter is illustrated. The radiation sensing device illustrated in Fig. 7 consists of a glass support member 70 having an electrical conductive coating 72 of a suitable material such as stannic oxide thereon. The layers 70 and 72 are of a material transmissive to the radiation input. A layer 74 of a suitable photoconductive material sensitive to input radiations such as cadmium sulfide in the case of visible light is deposited on the conductive coating 72. A layer 76 of a suitable liquid crystal material

exhibiting field effects and of similar material as used in layer 10 of Fig.2, is deposited and the photoconductive layer 74. An electrical conductive coating 78 of a material such as stannic oxide is provided on the, liquid crystal layer 76 and a support member 80 of a suitable material such as glass is provided on the conductive coating 78. The layers 78 and 80 are transmissive to light radiations from a source 82 which may provide illuminations of white light. It is generally desirable to utilize materials in layers 78 and 80 that are transmissive to the ambient lighting to obtain the benefit of this illumination also. Lead-in members 84 and 86 are connected respectively to layers 72 and 78 for providing the necessary potential across the liquid crystal layer 76 and the photoconductive layer 74. The lead 86 is connected to the first terminal of an alternating current source 88 connected to a fixed contact 91 of a switch 90.

A d.c. potential source 92 is connected from the first terminal of the source 88 to a fixed contact 95 in the switch 90. The lead 84 is connected to the movable member 94 on the switch 90 and may engage contacts 91, 93 or 95. In the specific embodiment shown, the contact 93 is left open.

In the operation of the device, the movable member 94 of switch 90 is connected to contact 91 and the radiation input such as visible light is directed onto the radiation

detector. The photoconductive layer 74 will become conductive and form a conductivity image corresponding to the radiation image and, therefore, more voltage from source 88 will be applied across the liquid crystal layer 76. In this embodiment, the photoconductive layer 74 serves simply as a capacitance voltage divider. When the light is directed onto the photoconductive layer 74 more voltage is applied across the liquid crystal layer 76 and the optical properties of the liquid crystal will be modified in accordance with the voltage.

Here again, as previously described with respect to Figs. 2, 3 and 4, the light source 88 may be white light. One could obtain a blue or green image on a background of red with materials used in layer 76. By proper selection of materials, one could obtain various color displays. By use of monochromatic light for the source 88, one would be able to provide a black background for color images. Since the source 88 provides an alternating voltage across the layer 76 there will be no permanent charging. In the case where the contact 95 is connected to the movable member 94 of switch 90, a direct current field will be placed across the layers 14 and 76. When the input signal is directed onto the photoconductive layer 74 the structure will become conductive and a charge image will be established across the liquid crystal 76 and will be maintained thereon until removed by application of the source 88.

The optical affect utilized in the devices in Figs.2, 6 and 7 is the light scattering prt property of liquid crystal materials of the cholesteric phase. It is also possible ta utilize the transmission properties of tho liquid crvstals.

In Fig.8, there is illustrated a projection system utilizing liquid crystalline materials. The liquid crystalline materials of the cholesteric phase exhibiting the field effect are largely temperature insensitive and do not absorb light. High light intensities may be controlled by an electron beam by the system shown in Fig.8. In Fig.8, there is illustrated a light source 97, a lens system 101, a control tube 103 and a lens system 96 for focusing the light into a viewing screen 98. The control tube 103 includes a body portion 99 with an input window 100 and output window 102. A neck portion 104 extends from the body portion 99. The input window 100 is transmissive to the radiation transmitted through source 87 and the output window 102 is transmissive to radiation transmitted through the tube. An electron gun 106 is provided within the neck portion 104 with means for directing and scanning a raster over a light control structure 110. The light control structure 110 consists of an electrically conductive electrode 112 provided on the inner surface of the face plate 102 and transmissive to radiation passing through the output window 102. A suitable material for the layer 112 is stannic

oxide. A liquid crystal layer 214 is provided on the conductive layer 112 and a radiation transmissive dielectric layer 126 is provided on the surface of the liquid crystal layer or coating 114. Here again the materials in layer 114 may be the same as those described with respect to Figs. 2, 3 and 4. The layer 116 may be of a suitable material such as glass. The control structure 110 is similar to the screen structure shown in Fig. 6 with the omission of the black coating 52. A control grid 118 is positioned in front of the dielectric layer 116. A voltage source 120 is connected between the conductive coating 112 and the control grid 118. A voltage source 122 is also connected between the cathode of the electron gun 106 and the control screen 118. This tube operates in a similar manner to that described with respect to Fig. 6 as far as the electrostatic charge written onto the dielectric coating 116 and the establishment of a field across the liquid crystal layer 114. The video intelligence is applied to the control grid 124 of the electron gun 106. Suitable deflection means, not shown, are utilized for the deflecting of electron beam over the dielectric surface. The light source 97 is monochromatic such as red of about 6250 angstroms.

The materials in the liquid crystalline layer 114 may be the same as in Fig. 2. The transmission characteristics of the layer 114 with different voltages applied are illustrated