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[54] **DISPLAY DEVICE**
10 Claims, 6 Drawing Figs.

[52] U.S. Cl. 117/212, 73/356, 117/215, 117/217, 117/226
[51] Int. Cl. G01k 11/16, G01k 11/20, B44d 11/8
[50] Field of Search 117/212, 215, 217, 226; 73/356; 161/410; 252/408

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ABSTRACT: The present disclosure is directed to articles of manufacture, e.g., display devices, having self-contained controlled resistor means for generation of heat upon electrical activation, which means can be formed in any desired configuration and thickness, and an encapsulated liquid crystal layer responsive to variations in heat to present a display, which can be polychromatic. The resistor is comprised of conductive ink deposited on one major surface (usually the lower surface) of an opaque, substantially electrically nonconductive layer having a layer of encapsulated cholesteric liquid crystals in direct contact with at least a portion of the other major (e.g., upper) surface of the opaque layer. Heating due to the resistor produces reversible color changes in the encapsulated liquid crystals resulting in the display.

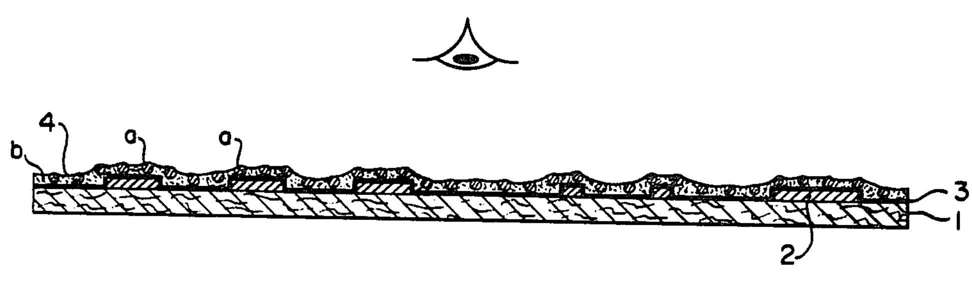

FIG. 1

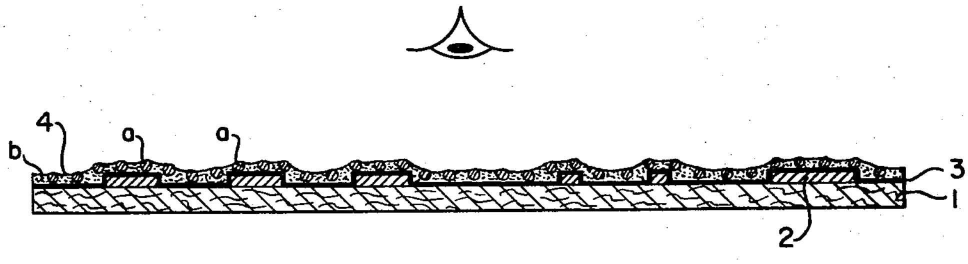

FIG. 2

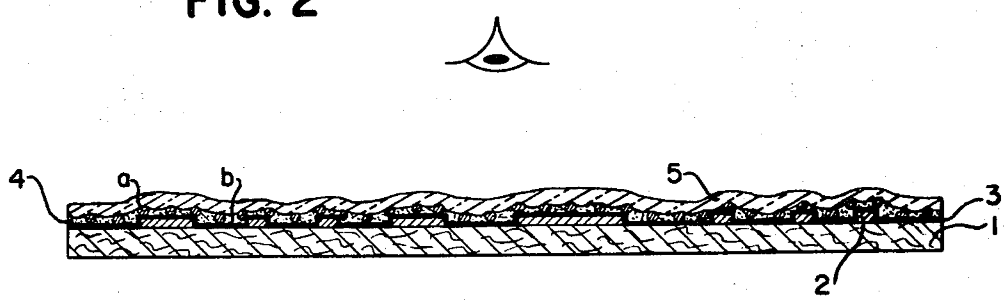

FIG. 3

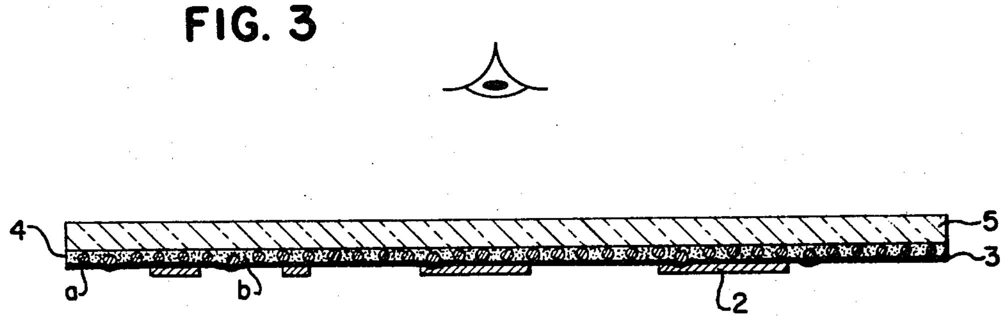

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FIG. 4

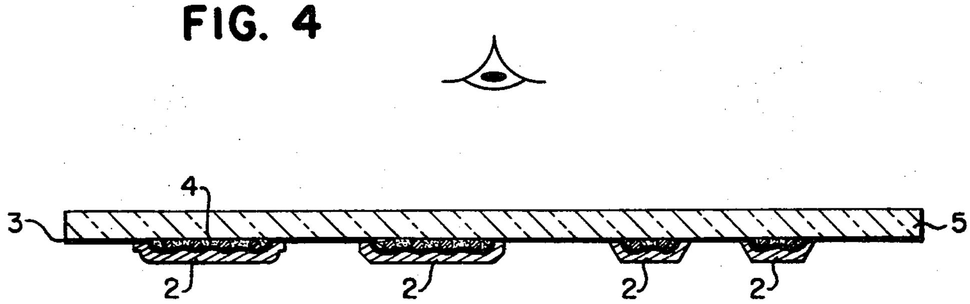


FIG. 5

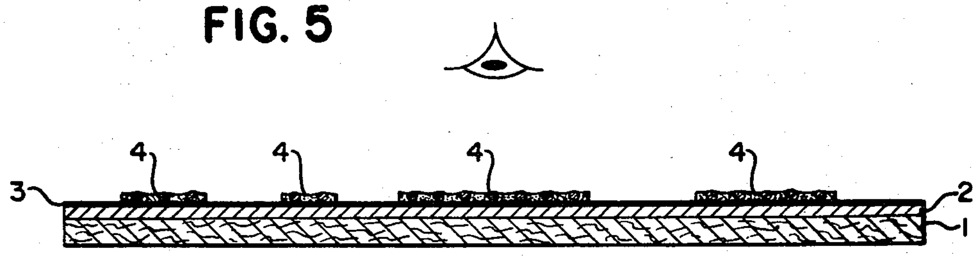
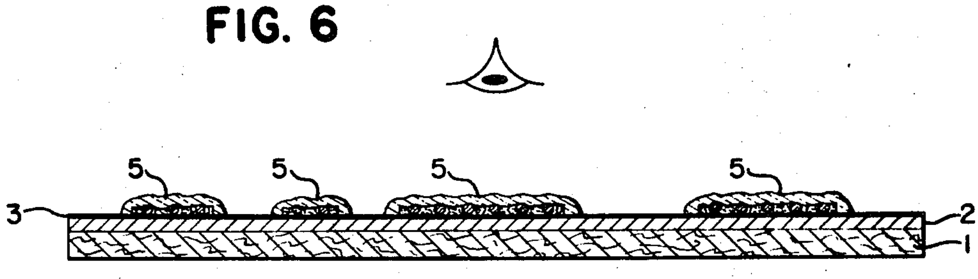


FIG. 6



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DISPLAY DEVICE

The display configuration can be determined by either the configuration of the encapsulated liquid crystal layer or the conductive ink layer. In the former case, the opaque film is heated over the entire extent of the conductive ink layer, but the color effects are observable only where the encapsulated liquid crystals are present. In the latter case, the heating occurs only in that portion of the opaque layer which overlies the configuration of the conductive ink layer. Thus, only a portion of the opaque layer is heated and this portion is then translated into color effects by the portion(s) of the encapsulated liquid crystal layer in thermally responsive contact therewith.

Provision can be made at desired sequential times for operating partial displays by using various portions of either the conductive ink layer, the encapsulated liquid crystal layer, or both. For example, by providing separate leads to various unconnected portions of the conductive ink configuration, these unconnected portions can be sequentially switched on and off to sequentially thermally generate sequential color effects in the overlying portions of the encapsulated liquid crystal layer. On the other hand, by utilizing portions of the encapsulated liquid crystal configuration (connected or unconnected portions) having different color advent temperatures (or ranged thereof) and color-temperature responses, sequential mono- and polychromatic displays can be achieved. Sequential color effects can also be produced by supplying more heat via varying the current to the conductive ink layer. Moreover, sequential polychromatic color effects and displays can be achieved by a combination of switching to various elements defining the configuration of the conductive ink layer and the use of different encapsulated liquid crystal compounds and mixtures for various portions of the encapsulated liquid crystal layer configurations, viz, using encapsulated liquid crystal formulations having different color advent (and response) temperatures to achieve different color effects in different areas of the encapsulated liquid crystal layer.

In accordance with this invention, a low-cost display is provided which is capable of almost infinite variation from one article to the next because of the adaptability of the encapsulated liquid crystals to deposition procedures enabling use of a high resolution and complex definition, e.g. silk screen and related printing procedures. In like manner, the conductive ink resistors can be printed in complex configurations by silk screening and related procedures thereby ensuring a highly variable display of portable nature, low unit price and high resolution.

The invention will be discussed in greater detail in conjunction with the drawings. All six figures of the drawings are cross-sectional views illustrating the various component layers contained in these articles of manufacture. The articles of FIGS. 2, 3, 4 and 6 have a smooth, essentially transparent brightness-enhancing top layer contiguous with the encapsulated liquid crystal layer and of similar index of refraction with respect to the capsular wall material and binder therein. The articles of FIGS. 3 and 4 are formed by inverse coating, viz, coating of the various layers on a transparent substrate which is then inverted for viewing of the display. The articles of FIGS. 2 and 6 are formed by top coating procedures, and the substrate need not be transparent. The articles of FIGS. 1 and 5 have no such top layer and likewise can use nontransparent substrates.

As shown in FIG. 1, base or substrate 1, which need not be transparent, has deposited thereon various conductive ink elements 2 to define a pattern or configuration. An opaque substantially nonconductive layer 3 is located on and in direct contact with electroconductive ink elements 2 and overlying encapsulated liquid crystal layer 4 which, in turn, is comprised of encapsulated liquid crystals *a* and binder b. FIG. 2 is like FIG. 1 with the addition of a top layer 5 deposited by a top-coating procedure. FIG. 5 is like FIG. 1 except that in the article of FIG. 5 the configuration of the display is determined by the configuration of the various elements 4 of the encapsulated liquid crystal layer, the conductive ink layer 2 being coated over substantially the entire other major surface of opaque layer 3. In FIG. 1, the configuration of the display is determined largely by the configuration of the conductive ink elements 2 defining the conductive ink layer with the encapsulated liquid crystal layer 4 being deposited over a substantially larger portion of opaque layer 3. FIG. 6 is like FIG. 5 but it contains a smooth transparent top layer (deposited by top coating) over each portion 4 of the encapsulated liquid crystal layer pattern or configuration.

In the article of FIG. 3, the transparent top layer 5 also serves as a forming support for depositing the encapsulated liquid crystal layer 4 followed by the opaque nonconductive layer 3; and the configuration of the conductive ink layer is defined by conductive ink portions 2. Upon deposition of all the aforementioned layers, the article is inverted so that the display can be viewed by the observer through the transparent, brightness-improving layer 5. Such articles are referred to herein as "inverse coated" due to the aforementioned inversion prior to use. FIG. 4 is prepared by inverse coating as in FIG. 3 but the encapsulated liquid crystal layer 4 is placed thereon in selected areas thereof to define a pattern instead of covering substantially the entire surface of transparent top layer 5, as in FIG. 3.

The article of the present invention offers great flexibility in that the color response in the liquid crystal capsules can be varied by varying the resistance of the conductive ink elements. The resistance of the conductive ink elements can be controlled in any one, more or all of the following manners: (1) by controlling the thickness of the conductive ink coating itself, (2) by controlling the total area of the coating, and (3) by varying the very composition of the conductive ink layer, e.g., by diluting the conductive ink with solvent (thinner) thereby reducing the intensity of the conductive pigments, and/or by introduction of adjuvant materials, such as plasticizers, in varying concentrations. Also, the chromatic display effects can be varied by controlling the power input to the respective elements defining the conductive ink layer thereby varying the extent of thermal excitation. This latter factor can be utilized to produce a selective color response in an encapsulated liquid crystal capsular layer containing a profusion of capsules having liquid crystal compounds and mixtures possessing varying color response temperatures, thus exhibiting varying colors at the color advent temperatures and at temperatures above said advent temperatures. The composite articles of this invention can operate at low power input, can product display characters and images of high visual resolution, and possess the ability of controlled color response achievable via a variety of readily controlled easily variable approaches.

As noted above, substrate 1 can be transparent of opaque as desired. Additionally, it can be of an electrically insulating material such as plastic, paper, wood or any similar materials. Of course, instead of paper or organic plastics, inorganic materials such as glass (e.g., conventional soda-lime-silica glass), etc. can be employed.

LIQUID CRYSTAL MATERIALS

The term "liquid crystal," as used herein, is employed in the generic, art-recognized sense to mean the state of matter often referred to as a mesophase, wherein the material exhibits flow properties associated with a liquid state but demonstrates long-range ordering characteristics of a crystal. The term "cholesteric liquid crystal" refers to a particular type of mesophase most often demonstrated by esters of cholesterol. Many of the cholesteric liquid crystals exhibit a reflective scattering of light giving them an iridescent appearance. In addition to using individual liquid crystal compounds, the encapsulated cholesteric liquid crystalline layer can be and usually is comprised of a mixture of two or more such compounds. The encapsulated cholesteric liquid crystal layer, itself, can be composed of a plurality (and usually a profusion) of capsules containing the same or different cholesteric liquid crystal compositions. Suitable individual cholesteric liquid crystal materials and mixtures which exhibit chromatic response to varying temperatures include, but are not limited to, the following cholesteryl nonanoate; cholesteryl chloride, cholesteryl nonanoate and cholesteryl chloride, cholesteryl nonanoate and cholesteryl bromide; cholesteryl nonanoate, cholesteryl bromide and cholesteryl cinnamate; cholesteryl nonanoate, cholesteryl iodide and cholesteryl cinnamate; cholesteryl nonanoate, cholesteryl iodide and cholesteryl benzoate; cholesteryl nonanoate, cholesteryl chloride and oleyl cholesteryl carbonate; cholesteryl nonanoate, cholesteryl chloride, oleyl cholesteryl carbonate and cholesteryl bromide; oleyl cholesteryl carbonate and cholesteryl iodide; oleyl cholesteryl carbonate and cholesteryl p-chloro benzoate; etc.

Also, it should be understood that included within the term cholesteric liquid crystalline mixtures are mixtures of two or more individual materials, one or more of which individually does not form a cholesteric liquid crystal phase but which in admixture exhibit a cholesteric liquid crystal phase. Hence, one or more materials which individually are not cholesteric liquid crystals can be employed in accordance with this invention if, when in admixture, they do exhibit cholesteric liquid crystal behavior, viz, they form a mesophase which demonstrates the property of reflection (light scattering). One such mixture is cholesteryl nonanoate, oleyl cholesteryl carbonate and cholesterol. The matter material, by itself, does not form a cholesteric liquid crystalline phase; but cholesterol does form a chromatically responsive mesophase in combination with the other materials.

ENCAPSULATION PROCEDURES

A wide variety of procedures can be employed to adequately prepare capsules and liquid crystalline layers containing the encapsulated liquid crystals. The capsule diameters can vary from about 2 to about 1,000 microns or more; but usually capsule diameters range in size from about 5 to about 500 microns and preferably from about 15 to 30 microns for screen printing purposes. The 20- to 25-microns size capsules are more preferred due to their uniform coatability, color properties and resolution characteristics. One satisfactory method of preparing capsules suitable for containing liquid crystal materials is disclosed in U.S. Pat. No. 2,800,457 issued on July 23, 1957, to Barrett K. Green and Lowell Schleicher. While the aforementioned capsules preparation system is sometimes preferred, it should be understood that the capsules employed in this invention can be obtained by any of the many later-developed encapsulation procedures which are capable of the dimensions required for a given use. The final form of the capsular material to be coated is preferably 20 to 25 microns in diameter; but it has been found that virtually any size of capsules can be successfully utilized; the larger capsules showing a somewhat decreased extent of visual resolution when used, e.g., in a data display system. While U.S. Pat. No. 2,800,457 discloses a pioneer invention concerning encapsulation on a minute scale, reference is also made to application Ser. No. 591,023 filed Oct. 31, 1966 now U.S. Pat. No. 3,341,466, which is a continuation of application Ser. No. 137,992 filed Sept. 14, 1961, by Carl Brynko et al., now abandoned, which application discloses a procedure for making larger than microscopic capsules. The entire disclosures of these applications are incorporated herein by reference as illustrative in the area of making large capsules. This same procedure is also discussed in the corresponding British Pat. No. 935,312. While the foregoing encapsulation procedures are chemical in nature, it should be realized that mechanical encapsulation procedures (as well as other chemical procedures) can be used to make the liquid crystal capsules. Further details concerning satisfactory procedures can be obtained in "Microencapsulation" by Anderson et al., published by Management Reports, Boston, Mass. (1963), the entire disclosure of which is incorporated herein by reference.

Another feature of the incorporation of encapsulated cholesteric liquid crystalline materials into a sensing or display system is the utilization of a mixture of capsules, as to size and content, for indicating and/or displaying a wide range of specific levels of temperature. Such a system, in one case, can comprise a plurality of layers, or areas in the same layer, each comprising one, two or more types of capsules having different mixtures of chromatically responsive cholesteric liquid crystalline materials. These devices can be tailor-made to accomplish a desired task by adjustment of characteristics imparted thereto by any one or more of the following variables: (a) temperature response range of the encapsulated liquid crystal material used; (b) size of the liquid crystal core; (c) type and thickness of the capsules cell wall material; (d) specific composition of the liquid crystalline material, and the like, all to the purpose of choosing a response suitable for a given proposed use or product.

In accordance with this invention, capsules can be prepared which contain from about 50 to about 99 weight percent of internal phase payload (cholesteric liquid crystal material) with the remainder being cell wall material. Usually, however, the internal phase represents from about 70 to 95 weight percent of the total capsule weight.

It is also within the purview of this invention to employ a coloring material to tint the capsules cell wall color. The capsule cell walls thus colored serve not only as liquid crystal contains but also as color filters for the light traveling to and from the encapsulated cholesteric liquid crystalline materials. Capsules cell walls are easily tinted by any stain capable of coloring the gelatin-gum arabic or other cell wall material selected for use. Such a controlled system finds use in display devices and other devices in cases where a broad spectrum iridescent effect (that obtained from the incident light emanating from an encapsulated cholesteric liquid crystalline member) is objectionable for certain uses.

A wide variety of encapsulating (external phase) materials can be employed to encapsulate the cholesteric liquid crystals in accordance with this invention. Such suitable materials include those referred to hereinabove in said Green et al. U.S. Pat., said Brynko et al. patent applications, said British Pat. and the Microencapsulation report. Usually the encapsulating material is one or a combination of the following: a gelatin-gum arabic system (with or without aldehydic cross-linking agents), a polyvinyl alcohol-based system, a zein-based system, or phenol-plast or amino-plast condensates, e.g., phenol-formaldehyde, resorcinol-formaldehyde, urea-formaldehyde-based systems, etc.

BINDER MATERIALS FOR LIQUID CRYSTAL LAYER

Various natural and synthetic polymeric materials can be employed to constitute the polymeric binder matrix of the encapsulated cholesteric liquid crystal layer. Any transparent or substantially transparent polymeric material can be used. Usually such binder has an index of refraction in the range of about 1.40 to about 1.70. Suitable polymeric materials for this purpose include, but are not limited to, the following: acrylates poly alkyl acrylates and methacrylates, e.g., poly methyl acrylate, poly ethyl acrylate, poly n-butyl acrylate, poly methyl methacrylate, poly n-butyl methacrylate, etc.; poly vinyl alcohol; gelatin; latex (natural rubber and synthetic rubber latexes); zein, poly ethylene homo- and copolymers; poly propylene homo- and copolymers; and any of the materials mentioned hereinbelow as suitable top layer materials. The encapsulated cholesteric liquid crystals can be associated intimately with the polymer binder in a variety of ways. For example, the capsule-binder mixture can be deposited onto a polymer film, e.g., as a coating simply by spraying from a dispersion or emulsion of the encapsulated liquid crystal in a binder or by screen printing thereof.

OPAQUE BACKGROUND LAYER

The opaque background layer, which can be a preformed opaque film or an opaque coating, e.g., black coating, is substantially nonconductive. Black nonconductive paint can suffice for this purpose. The function of this opaque background layer is to aid in viewing the chromatic effects produced in the encapsulated liquid crystal layer due to the heat generated by the conductive ink resistor elements. Since the observable color effects produced due to the change in temperature on the liquid crystals are observable by reflection of incident light; an opaque background is usually necessary to enable the human eye to accurately observe the display.

CONDUCTIVE INK LAYER

The conductive ink layer, 2, can be any material which is electroconductive and is preferably readily deposited upon a substrate by coating procedures affording good definition. In cases where the article is produced by inverse coating (as in FIGS. 3 and 4), the conductive ink layer in the form of patterned elements 2 thereof can be coated onto the nonconductive opaque layer 3. Moreover, the area encompassed by the conductive ink can be coextensive with that of opaque layer 3 in such inverse coated articles. On the other hand, when the articles are made by a top-coating procedure, the conductive ink elements are usually coated upon the substrate 1 and an overlying opaque coating, e.g., of nonconductive black paint, is coated thereon prior to deposition of encapsulated liquid crystal layer, e.g., as indicated in FIGS. 1, 2, 5 and 6. The conductive ink layer 2 characteristically contains a conductive pigment (or other finely divided conductive material colored or uncolored), a binder, a plasticizer (optional depending upon the flexibility desired) and a liquid coating carrier.

TOP LAYER (OPTIONAL, BUT PREFERRED)

As noted in FIGS. 2, 3, 4 and 6, the composite articles of this invention can contain a brightness-improving, substantially smooth, essentially transparent top layer 5. This top layer enhances the color purity, color contrast and visual resolution characteristics of the color effects produced in the encapsulated liquid crystal layer. The top layer is essentially transparent and has an index of refraction which approximates that of both the capsule cell wall material and any polymeric or other binder employed in the encapsulated liquid crystal layer. Moreover, it will be observed that the top layer is in direct contact with the underlying encapsulated liquid crystal layer throughout substantially the entire extent of said encapsulated liquid crystal layer (or the disconnected individual portions thereof which define the configuration of the encapsulated liquid crystal layer). Also, the outer surface, that is, the portion closest to the observer, is substantially smooth. The term "smooth" as used herein means that the average ratio of the horizontal distances or lengths between crests (high points) on the outermost (exterior) surface of the top layer divided by the vertical distances between said crests and troughs (low points on the outermost surface of the top layer) is at least 4.0, viz, said average lengths divided by said average vertical distances are equal to 4.0 plus. When the articles of this invention are formed by top-coating procedures, some of the crests can be the tops of capsules which protrude through the polymer top layer whereas other crests can be the polymer top layer material, itself, as it overlies capsules therebeneath. Usually the depth of surface irregularities is small in comparison to the size (diameter) of the capsules, and the undulations are generally continuously variable rather than sharply discontinuous, e.g., as is the experience when no top layer is present and when a capsule layer (encapsulated liquid crystal plus a binder) constitutes the outermost surface.

When the top layer is plastic, it can be produced from a wide variety of essentially transparent natural and synthetic organic materials, such as polyolefins, e.g., polyethylene, polypropylene, polybutylenes, polyesters, e.g., polyethylene glycol terephthalate, acrylic resins, e.g., polyalkyl acrylates and methacrylates, such as polymethylacrylate, polyethylacrylate, polymethylmethacrylate, polybutylmethacrylate, polystyrene, polyvinylidene chloride homo- and copolymers, e.g., "Saran" materials, nylons and other polyamides, polyvinyl aldehydes, e.g., polyvinyl formaldehyde, polyvinyl butyraldehyde; copolymers of mono-olefinically unsaturated monomers with vinyl esters, such as ethylene-vinyl acetate copolymers; cellulosic plastics, e.g., cellulose acetate, ethyl cellulose; polycarbonates; polyurethanes; silicone resins, poly alkyl siloxanes, e.g., poly methyl siloxane; alkyd resins and varnishes; shellac; and other polymers and resins usually in the form of sheets, films or coated layers.

Under certain circumstances, it is preferable to employ a polymer which can be deposited, e.g., cast from an organic, water-immiscible solvent since the presence of water could partially dissolve the capsular cell wall and impair the quality thereof, viz, with respect to the encapsulated cholesteric liquid crystal member. In any event, when depositing the transparent, smooth-surfaced film, 5, especially while employing water or a water-miscible solvent; care should be exercised to avoid exposure of the capsules for extended periods of time to a solvent which is also a solvent for a capsule wall material.

While organic plastic materials, e.g., polymeric materials, have been mentioned hereinabove for use in conjunction with the transparent, smooth top layer 5, other materials, e.g., inorganic materials such as glass, e.g., conventional soda-lime-silica glasses (in the form of sheets), alkali metal silicates such as sodium silicate, potassium silicate, etc., (in the form of coating compositions) can be employed.

Instead of forming the top layer by overcoating the encapsulated liquid crystal layer (as shown in FIGS. 2 and 6); preformed films, layers or sheets of organic or inorganic material can be used via inverse coating to constitute top layer 5, e.g., as noted in conjunction with the description of the articles of FIGS. 3 and 4. The thickness of top layer 5 can be varied widely from approximately 10 microns to one-eighth inch or greater, esp., in the case of sheets of polished plate glass where a one-eighth inch thickness has been utilized quite satisfactorily.

As previously noted, the index of refraction of the smooth-surfaced, transparent top layer is usually close to that of the material employed to form the capsules cell wall and also that of the polymer or other material employed to serve as binder in the encapsulated liquid crystal layer. Usually the index of refraction of the top layer, binder and cell wall ranges from about 1.40 to 1.70. More usually, the index of refraction of the top layer ranges from about 1.45 to about 1.60, preferably from about 1.48 to 1.59 and more preferably between about 1.50 and 1.54.

While it will be observed that in all cases as shown in the drawings, the encapsulated liquid crystal layer and the conductive ink layer (and a top layer where one is utilized) are separate and distinct; both the encapsulated liquid crystal layer and the conductive ink layer can be deposited in any desired configuration, pattern or design, both linear and nonlinear (curved), e.g., by stencilling, screen printing, gravure roll printing, or any other equivalent deposition procedure. It will be observed that when a top layer is employed; the top layer is in direct contact with the encapsulated liquid crystal layer throughout substantially the entire extent thereof. However, this can mean only a portion of the entire upper surface of the display article, viz, as where the encapsulated liquid crystal layer is printed thereon in a pattern.

Also, it will be realized that an additional insulating layer (not shown), e.g., one of plastic, can be employed in conjunction with the articles shown in FIGS. 3 and 4. Such insulating layers would in fact serve the same purpose as the substrates 1 shown in FIGS. 1, 2, 5 and 6 with respect to providing insulation for conductive ink elements 2.

The present invention will be illustrated in great detail in the following examples. Since these examples are included to illustrate the invention, they should not be construed as limiting thereon. In the examples, all percentages and parts are by weight unless indicated otherwise.

EXAMPLE I

This example illustrates formation of an inverse-coated article having a polyester top layer, a capsular layer coated over the entire surface thereof, and a patterned printed coating of conductive ink, e.g., as shown in FIG. 3 of the drawings.

A liquid crystal mixture having the below-indicated composition is encapsulated in a conventional manner using a standard two-way gelatin coacervation.

TABLE

Liquid Crystal Component	Concentration (weight percent)
Cholesteryl Pelargonate	63.8
Cholesteryl Chloride	4.8
Oleyl Cholesteryl Carbonate	31.4

The encapsulation is conducted specifically as follows: into an aqueous solution of 1 weight part of acid-extracted pigskin gelatin (having a Bloom strength of 285 to 305 grams and an isoelectric point of pH 8 to 9) in 8.09 weight parts of distilled water at 55° C., there are placed 14.0 weight parts of said liquid crystal melt. The liquid crystal melt is milled with a shear agitator until the desired particle size is achieved, viz, from 15 to 30 microns. While the milling progresses, an aqueous solution of 1 weight part gum arabic in 93.0 weight parts of distilled water is prepared in a separate container and maintained at a temperature of 55° C. When the desired particle size is achieved, the gelatin-liquid crystal emulsion is added slowly to the gum-arabic solution. The pH is adjusted to 4.85 and the coacervate is permitted to cool to 27° C. over a period of 2¼ hours. The resultant capsules are cooled to below 15° C. and hardened with 0.5 weight parts of a 25 weight percent aqueous solution of glutaraldehyde for 12 to 15 hours. The resulting capsular slurry is then concentrated by filtration to a slurry having approximately 40 to 45 weight percent capsular solids.

Upon completion of encapsulation and subsequent concentration of the slurry, approximately 75 weight parts of the thus-concentrated slurry is mixed with 25 weight parts of a 10 weight percent solution of commercially available polyvinyl alcohol ("duPont 72-60") in water as a binder for the coating mixture forming the encapsulated cholesteric liquid crystal layer.

The above-formulated liquid crystal capsules are then coated onto a "Cronar" sheet using No. 12 nylon printing screen using two passes. "Cronar" is a commercially available transparent polyester film marketed by E. I. duPont de Nemours and Co. When the capsular layer is dry, a coating of opaque, nonconductive "Zephyr R-M" black ink is applied to the capsular layer using a No. 12 nylon screen and the opaque background is allowed to dry. Then a conductive ink pattern is printed on the dried opaque background layer using a No. 20 nylon printing screen. The conductive ink utilized is a commercially available black conductive ink ("Conductive Ink EL 796" marketed by the Excello Color and Chemical Division of Advance Supply Company) having carbon black and titanium dioxide conductive particles in a conventional binder.

The printing operations are conducted at ambient room temperatures, which range from about 24° to 28° C. by screen printing in the following manner. The "Cronar" transparent support is laid on a flat surface. A nylon screen mounted on a soft white pine wood frame is positioned over the substrate. A supply of the aforementioned encapsulated liquid crystal material is then poured onto the screen and a neoprene rubber squeegee is used to pull the supply of encapsulated liquid crystal coating formulation across the screen, at the same time pressing it through the open mesh of the screen. The screen is then lifted from the substrate leaving the encapsulated liquid crystals affixed to the "Cronar." The deposition of the black background ink and the electroconductive ink is done in similar fashion after the encapsulated liquid crystal layer dries. The electroconductive ink is deposited upon the dried opaque background layer in a pattern configuration of lines having a length of 4 inches, a width of one-sixteenth inch and a thickness of 0.0005 inch.

Upon drying of the conductive ink layer, the article is inverted thereby allowing a viewer to observe color changes occurring in the encapsulated liquid crystal layer when viewed by incident white light through the transparent "Cronar" top layer. The transparent "Cronar" layer originally serving as a transparent support for the deposition of the respective coatings, then serves as a brightness-enhancing and spectral purity (for color intensity) improving top layer in the manner noted hereinabove.

The thus-prepared display article having the integral conductive ink resistor means is then connected to a supply of electric power, and the voltage is adjusted until color is produced in the area of the encapsulated liquid crystal layer which is thermally activated by the printed conductive ink pattern. At a potential of 40 volts, the entire area overlying the printed conductive ink line is violet indicating maximum color response at a low current input of less than 1 milliampere.

Another electroconductive display article containing encapsulated liquid crystals and electroconductive ink is produced in essentially the same manner except that the printed electroconductive ink lines have a length of 4 inches, a width of one-eighth inch and a thickness of 0.0005 inch. At a voltage of 25 to 30 volts, the area overlying the line appears violet at a noted current of between 1 and 2 milliamperes. Further articles were prepared by inverse coating wherein the display configuration was printed by use of encapsulated liquid crystal images and conductive ink images, respectively.

EXAMPLE II

This example illustrates a composite article prepared by top coating, e.g., as in FIG. 1.

Using the same encapsulated liquid crystal formulation as described above in example 1, a conductive ink coated article having a nontransparent substrate is prepared by a top-coating procedure in the following manner. A paper substrate (commercial Star Sapphire paper having a dull white enamel finish and a basis weight of 80 pounds per ream—one ream being equal to 500 sheets, each of which has a length of 38 inches and a width of 25 inches) is provided with a printed line one-eighth inch wide by 4 inches long utilizing the conductive ink formulation of example 1 printed via a No. 20 nylon screen at ambient room temperature in the manner indicated in example 1. When this coating is dried; an opaque, nonconductive black ink, "Zephyr R-M" ink, is applied thereto (by nylon screen printing) and dried. Then an encapsulated liquid crystal layer having the same composition as given in example 1 is printed over substantially the entire surface of the opaque-coated article utilizing two passes with a No. 12 nylon screen in accordance with example 1. Upon drying of the encapsulated liquid crystal layer, electric leads are attached to the conductive ink resistor to thermally activate portions of the encapsulated liquid crystal layer overlying said line. A violet color is readily observable by the naked eye during such thermal excitation. As the electric current is switched off, the color rapidly disappears and the display article returns to an overall black color.

EXAMPLE III

This example illustrates preparation of an article as shown in FIG. 2. The procedure of example II is followed using a Star Sapphire opaque paper substrate, a screen-printed conductive ink pattern, an opaque top-coated layer deposited over substantially the entire surface of the paper-conductive ink assembly, and the aforementioned encapsulated liquid crystal layer covering the entire surface of the opaque layer.

Upon drying of the encapsulated liquid crystal layer, a substantially smooth, essentially transparent top layer is deposited by top coating the encapsulated liquid crystal layer. The transparent top layer applied is a mineral spirits solution containing 40 weight percent "Acryloid B-67," an acrylic resin, which is screen printed over the capsular layer resulting in the formation of a substantially smooth, essentially transparent top layer. "Acryloid B-67" is a commercially available acrylic resin marketed by Rohm & Haas Co. Upon thermal excitation of the conductive ink pattern, the chromatic effects are readily observable in the areas of the encapsulated liquid crystal film immediately overlying the conductive ink. The observable color effects of the article produced in this example appear brighter and clearer to the naked eye than those observed in respect of the articles of example 2. Thus, it is readily apparent that the utilization of a substantially smooth, essentially transparent top layer aids in forming an improved display article.

EXAMPLE IV

This example illustrates varying the resistance of the conductive ink layer by compositional variation thereof. Thus, the resistance can be varied readily by use of a plasticizer(s), thinner(s) and combinations thereof as will be illustrated by the data tabulated hereinbelow. The data is obtained by preparing samples in accordance with the procedures of example I utilizing conductive ink strips approximately 4 inches long by one-eighth inch wide and 0.0005 inch thick. The basic conductive ink formulation given in example I is varied in some cases by use of a thinner, viz, ethyl acetate; in other cases, by introduction of varying amounts of a plasticizer, viz, dibutyl phthalate; and in other cases by introduction of varying amounts of both the thinner and the plasticizer. Fourteen comparisons are conducted to illustrate control of resistance from 2,600 ohms to approximately 16,000 ohms. All resistance measurements are taken with a vacuum tube volt meter after allowing the conductive ink to dry for a period of 2 days after deposition. The observed data are measured at an ambient room temperature of 26° C. and are tabulated hereinbelow:

Run No.	Composition of Conductive Ink Component	Weight percent	Resistance (ohms)
1	Conductive Ink (as given in Example I)	100	2,600
2	Conductive Ink	95	3,200
	Dibutyl Phthalate	5	
12	Conductive Ink	93	4,600
	Dibutyl Phthalate	7	
13	Conductive Ink	91	7,500
	Dibutyl Phthalate	9	
3	Conductive Ink	90	11,000
	Dibutyl Phthalate	10	
4	Conductive Ink	95	2,600
	Thinner	5	
5	Conductive Ink	90	3,200
	Thinner	10	
14	Conductive Ink	92	4,200
	Dibutyl Phthalate	5	
	Thinner	3	
6	Conductive Ink	90	5,200
	Dibutyl Phthalate	5	
	Thinner	5	
7	Conductive Ink	85	6,200
	Dibutyl Phthalate	5	
	Thinner	10	
10	Conductive Ink	89	8,500
	Dibutyl Phthalate	10	
	Thinner	1	
11	Conductive Ink	87	10,000
	Dibutyl Phthalate	10	
	Thinner	3	
8	Conductive Ink	85	16,000
	Dibutyl Phthalate	10	
	Thinner	5	
9	Conductive Ink	80	16,000
	Dibutyl Phthalate	10	
	Thinner	10	

What is claimed is:

1. A display article having a self-contained controlled means for generation of heat upon electrical activation comprising an opaque, electrically nonconductive layer, a layer of encapsulated cholesteric liquid crystals on and in direct contact with at least a portion of one major surface of said opaque layer and a layer of electrically conductive ink in direct contact with at least a portion of the other major surface of said opaque layer and wherein the configuration of the display is substantially the same as at least a portion of the configuration of either the encapsulated liquid crystal layer or the conductive ink layer.

2. A display article as in claim 1 wherein the display configuration is substantially the same as at least a portion of the configuration of the conductive ink layer.

3. A display article as in claim 1 wherein the display configuration is substantially the same as at least a portion of the configuration of the encapsulated liquid crystal layer.

4. A display article as in claim 1 wherein said opaque layer is black.

5. A display article as in claim 1 wherein said encapsulated liquid crystal layer contains encapsulated liquid crystals having different color-temperature responses.

6. A display article as in claim 1 wherein encapsulated liquid crystals having different color-temperature responses are employed in different areas of said encapsulated liquid crystal layer.

7. A display article as in claim 1 wherein said encapsulated liquid crystal layer has a substantially smooth, essentially transparent, display brightness-improving top layer.

8. A display article as in claim 2 wherein said conductive ink layer is comprises of a plurality of unconnected portions at least some of which function independently from a remaining portion when electrically activated to generate heat.

9. A display article as in claim 2 wherein said conductive ink contains carbon black.

10. A display article as in claim 3 wherein said encapsulated liquid crystal layer is comprised of a plurality of unconnected portions.

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