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By

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I would like to dedicate my book to my beloved parents, especially to my late father and mother.

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LIST OF ACRONYMS/ABBREVIATIONS

LC	Liquid Crystal
LCD	Liquid Crystal Display
PDLC	Polymer Dispersed Liquid Crystal
TIPS	Thermally Induced Phase Separation
SIPS	Solvent Induced Phase Separation
PIPS	Polymerization Induced Phase Separation
NCAP	Nematic Curvilinear Aligned Phase
ITO	Indium Tin Oxide
$\varepsilon\parallel$	Dielectric anisotropy parallel to the director
$\varepsilon\perp$	Dielectric anisotropy vertical to the director
$\Delta\varepsilon$	Dielectric anisotropy
no	Ordinary refractive index
ne	Extra ordinary refractive index
np	Refractive index of the polymer
neff	Effective refractive index
Δn	Birefringence
n	Director
Toff	Off state transmittance
Ton	On state transmittance
V_{th}	Threshold Voltage
V*sat*	Saturation Voltage
CR	Contrast Ratio
τ_R	Rise time
τ_D	Decay time
SEM	Scanning Electron Microscopy
POM	Polarize Optical Microscopy
LCT	LCD parameters tester
AgNPs	Silver Nanoparticles
RI	Refractive Index

CHAPTER 1

INTRODUCTION

Abstract

Smart glass technology has become increasingly prevalent in modern applications. One prominent type is a polymer-dispersed liquid crystal (PDLC), which consists of epoxy monomers with liquid crystals dispersed throughout. By incorporating silver nanoparticles in varying concentrations, PDLC can achieve different sizes of nanometer distributions, enhancing its properties. The characterization of these silver nanoparticles is typically conducted using UV-visible spectroscopy, with sodium borohydride used as a reducing agent to control their size. The electro-optical properties of PDLC are analyzed with a liquid crystal detector and an Abbe refractometer for refractive index measurements. Compared to traditional LCD materials, PDLC thin film technology offers numerous advantages, such as simplified manufacturing processes, elimination of polarizers, and mitigation of viewing angle limitations. Additionally, it does not require precise control over the spaces between substrates, making it suitable for large-area displays. The production of thin PDLC films is achieved through a method known as polymerization-induced phase separation (PIPS), using mixtures of curing monomers, liquid crystals, hardeners, and silver nanoparticles. Research indicates that the inclusion of silver nanoparticles at various sizes significantly influences the polymer network's structure, particularly increasing the crosslinking density when combined with curing monomers that contain -NH2 groups in epoxy monomer/liquid crystal/hardener mixtures. This allows the film to transition from a transparent to an opaque state, enabling a broader range of applications in PDLC technology and other optical devices.

The "smart" windows are used for the construction of a smart building as privacy glass. It is used for decreasing the energy usage in buildings. Energy in the form of radiation and heat is used as stimuli for smart materials the smart material can control the transmission of light in smart materials consisting of liquid crystal used as a matrix. Smart display devices are used as privacy windows and energy-saving windows (Castellón & Levy, 2018). The display devices might have some electric and optical signal issues that contain an uneven distribution of electric fields non-uniform optical behavior has occurred at a large area of displays. To overcome these issues more efforts are required.

1.1 Smart Glass technology

Smart glass technology is an advanced glass technology that is used for privacy glass, switchable glass, magic glass, and smart windows. In three decades, three generations of smart glass were discovered and used by retailers. First-generation (1G) used emulsion technology, in which water-soluble polyvinyl alcohol is dispersed in liquid crystal droplets. The second-generation (2G) is composed of epoxy dispersed in droplets of liquid crystal known as polymer dispersed liquid crystal PDLC technology and the third-generation (3G) synthesizes by a nonlinear polymer to disperse in a liquid crystal called non-linear PDLC technology.

The advancements from 1G to 2G demonstrated improvements in features, but 3G technology significantly enhanced usability for both indoor and outdoor applications. This generation stands out as it provides better electro-optical properties and higher-quality performance compared to its predecessors. As a result, 3G has become more widely adopted, showcasing its effectiveness in various environments (Pandian, Karthikeyan, Rajasimman, & Dinesh, 2015).

1.2 Historical view of Polymer Liquid Crystal Composites

Since the beginning of life, polymers and liquid crystal (LC) materials have been integral to biological processes. The structures of Deoxyribonucleic acids (DNA) exhibit polymer-like characteristics. Lyto-tropic liquid crystals made up of macromolecules display various LC phases. Cell membranes consist of atoms, featuring hydrophilic liquid heads and hydrophobic organic compound tails. Naturally occurring plant polymers include rubber-like polyose and resin. Despite their widespread presence, liquid crystals were not discovered until the late nineteenth century due to the heating of plant materials. In the mid-1900s, the development of plastic emerged through the process of polymerization, specifically using phenol (C6H5-OH) and formaldehyde (CHOH), leading to the synthesis of more complex macromolecular compounds (Carothers, 1929). Numerous explorations have been conducted on solid-liquid interactions and compounds, although the application of these materials has been performed in various ways. Fluid gems initially evolved as dynamic displays, temperature sensors, and novelty toys. Polymers have been integrated for a long time, serving as traditional elastic alternatives and plastics. The primary usage of polymers in fluid jewellery lies in their arrangement on substrates, as the chemical compound chains influence the direction and alignment of the fluid gem particles.

In the 1980s, significant advancements were made in the study of intermediate solid-liquid substance composite compounds. A notable figure, James Fergason, co-designed the aromatic nematic fluid jewellery display in 1984. He elaborated on two key types of compound-dispersed liquid crystal films (PDLC). These films were characterized by being sandwiched between two conductive substrates, with liquid crystal materials mixed with polyvinyl alcohol (PVA). This innovation paved the way for the development and application of fluid gems in various technologies (Fergason, 1985). Moreover, in 1985, William Doane and his colleagues at the Liquid Crystal Institute at Kent State University further advanced the development of PDLC films. They innovated a method that involved blending epoxy with liquid crystals, allowing the two materials to coexist independently. This approach facilitated the creation of more versatile and effective PDLC films, contributing to the ongoing evolution of liquid crystal technology and its applications. (Drzaic & Drzaic, 2006).

Thereafter, when an electric field is applied to the dual-stage substances, the material transitions from a hazy state in the absence of an electric field to a clear state when the field is activated. From that point on, there has been a wide range of chemical compounds that have evolved, varying from simple mixtures to more complex formulations. Additionally, the use of resins in liquid crystal applications has become notably significant. The polymer matrix remains intact, encasing the liquid crystal droplets, which allows for switchable light scattering. Furthermore, the polymer matrix also acts as a stabilizer, enabling the liquid crystal to maintain its desired phase or to facilitate a specific liquid crystal state (J. Doane, Vaz, Wu, & Žumer, 1986). Indeed, even fluid gem liquids could be formed into gel or solid with receptive to improvements (i.e., light, Temperature) when polymeric substances are available.

1.3 Introduction to PDLC

PDLC, or Polymer-Dispersed Liquid Crystal, is a material that combines liquid crystals with lower molecular weight and a polymer matrix. This is achieved by creating micro-sized transparent solid droplets dispersed within the polymer. PDLC finds applications in various fields including smart displays, privacy glass, high-contrast reflective displays, and projection displays. These materials are typically used as thin films for a range of products as switchable windows, privacy glass, large advertising screens, and television displays. The versatility of smart displays highlights the wide-ranging commercial applications of this technology in today's market. There are two main types of privacy glasses: the first is a polymer-dispersed liquid crystal (PDLC) the second is a polymer-stabilized liquid crystal (PSLC), each offering unique properties suited to different uses (Mormile, Musto, Petti, Ragosta, & Villano, 2000).

Polymer Dispersed Liquid Crystal (PDLC) techniques have already found their applications in various advanced technologies, including optical communication, 3D screens, switchable zoom lenses, and wavelength division multiplexing waveguides. These applications leverage the unique properties of PDLC materials to enhance functionality and performance in visual displays and communication systems, allowing for innovative solutions in both consumer electronics and professional settings (Liu, Zheng, Shen, Wang, & Zhuang, 2019). PDLC devices have gained significant attention over the years due to their numerous benefits, making them increasingly popular. The PDLC technology continues to evolve, with advancements such as the incorporation of surfactants, cross-linking agents, and doping additives, all aimed at enhancing its reliability and effectiveness for various applications (M. Zhang et al., 2013).

In PDLC (polymer dispersed liquid crystal) technology, the liquid crystal is crucial for display preparation, particularly concerning its electro-optical properties. The droplets of liquid crystal contribute unique electro-optical and magneto-optic characteristics to PDLCs, enhancing their functionalities. However, since liquid crystal is a costly material, minimizing its content can significantly reduce the overall cost of the PDLC displays, ultimately making them more affordable for consumers. This balance between performance and cost is key to making PDLC technology more accessible while maintaining its desirable features (Kashima et al., 2010). PDLC exhibits a unique property where it becomes transparent in the off-state and appears milky when activated in the on-state. Currently, Liquid Crystal Displays (LCDs) are undergoing rapid development, making them a prominent technology within the industry and a significant factor in economic growth. The liquid crystal sector is crucial in the polymer field, continuously evolving to meet rising consumer demands. However, as display materials improve, there is a growing expectation for advancements that address existing limitations, such as slow and lagging transmittance and the need for high drive voltages. These enhancements are essential for meeting modern requirements in display technology (Chen, Chen, Sun, & Wu, 2006).

1.4 Polymer Dispersed Liquid Crystal Formation

A homogeneous tropic solution of polymers and pre-polymers is prepared with a lower molecular weight of liquid crystalline substance via way of means of the separation method. The boom takes place with the dissolved liquid crystal in solution liquid crystal section separates and droplet formation is achieved. The instruction mechanisms are solvent-induce phase separation (SIPS), thermal induced induce phase separation (TIPS) and polymerization-induced phase separation (PIPS) methods. The main principle is illustrated in every method and applies to the TIPS, PIPS, and SIPS methods.

In the 1980s, PDLC (Polymer Dispersed Liquid Crystal) was developed using the phase separation method, which involved using UV-curable epoxy pre-polymers and thermoplastic polymers for its preparation. Various films of PDLC materials have been produced, showcasing a range of shapes and thicknesses. The predominant technique for preparing these films involves ultraviolet polymerization, specifically the phase separation method (PIPS). This approach facilitates the creation of a polymer network within the PDLC film, influencing its optical properties and overall performance (Hakemi, Khenkin, Tamari, & Gal-Fuss, 2020). PDLC (Polymer Dispersed Liquid Crystal) technology has significant applications in large-area displays and high-definition displays, making it a promising option for projection TVs. This technology offers several advantages, including a wide viewing angle and the ability to easily enlarge the display area. These features contribute to its versatility and attractiveness in various display applications, enhancing both functionality and user experience.

1.4.1Thermal-Induced Phase Separation (TIPS) Method

This separation method uses polymers that do not crosslink and melt at reasonably low temperatures The TIPS method is which that melts below their decomposition temperatures. This method is utilized for thermoplastics and is called as TIPS method.

1.4.2 Solvent induced Phase Separation (SIPS) Method

Initially, in the SIPS method, polymer and crystal liquid form a similar solution with a common solvent. The solvent is then evaporated, thus bringing the solution into the immiscible region. Although the liquid crystal phase separates, droplets grow and appear through polymer solidification (K. Li et al., 2020). The rate of evaporation controls the droplet size. This method of separation is called as SIPS method.

1.4.3 Polymerization induced Phase Separation (PIPS) Method

PIPS method is convenient for pre-polymer materials that are miscible with liquid crystalline phases. Depending on the polymer precursors used, the PIPS method could be either photo-initiated or thermal-initiated. For photo-initiation, reliable PDLCs mostly undergo acrylate or thiol-ene chemistry. These are polymerized by an addition reaction for thermal initiation. The PIPS method can produce PDLC films with droplets less than 10-8 nm.

Phase-separated composite film and PDLC synthesized by polymerization separation (PIPS) technique could be used for the study of the optical function of composite materials. The (PIPS) method is widely used because it's solvent-free, inexpensive, eco-friendly, less contaminant, and controllable. That's why it is mostly used to produce PDLC films (Saeed et al., 2021). Polymerization Phase partition (PIPS) by and large uses polymers framed by a stage development expansion polymerization response. A low-sub-atomic weight fluid liquid crystal is disintegrated in a pre-polymer arrangement. Polymer formation happens either by temperature or photographs artificially, variably the synthetic capability of arrangement and lessening the dissolvability of fluid precious stone. The arrangement goes through the miscibility hole the fluid gem stage isolates into beads.

Stage partition can occur through shaft disintegration or bead nucleation and growth, particularly in the context of liquid crystals of low-molecular-weight distributed within a polymer. The study of polymeric materials has captivated researchers for many years due to their diverse applications. Epoxy, in particular, stands out as a polymeric material noted for its excellent wetting properties, mechanical strength, chemical resistance, and fire retardance, making it suitable for a wide range of industries and applications (Paluvai, Mohanty, & Nayak, 2014). Epoxy resins are indeed crucial in the fields of transportation, construction, and communication. Recent advancements in epoxy resin technology have enhanced their properties, making them even more valuable and reliable. These improvements include increased durability, enhanced adhesion, and better resistance to environmental factors. As a result, epoxy resins are increasingly used in high-performance applications, such as in the manufacturing of composite materials for vehicles, protective coatings for infrastructure, and adhesives in electronic components. This evolution not only expands their applicability but also improves the overall effectiveness and longevity of the products in which they are used (Mohan, 2013).

The diverse usage of epoxy resin is prevalent in applications such as Aeroplanes and wind turbines, where it is utilized as a composite in various industries. Epoxy is favoured for its engineering purposes, adhesive properties, high chemical resistance, and use in 3D printer ink, and it also offers recyclable qualities. When compared to traditional display modes, the advantages of PDLC (Polymer Dispersed Liquid Crystal) technology are significant: it does not require polarizers or specialized substrates, and the surface orientation treatment is unnecessary. Additionally, the spacing between the two substrates can be less controlled, resulting in a product that is thinner, lighter, and exhibits higher brightness (Capricho, Fox, & Hameed, 2020).

Epoxies are a diverse group of heat-curing polymers that are utilized as coatings in the PIPS (Polymer Infiltrated Photonic Structures) process. Epoxy resins are primarily studied for their regulatory compounds due to the abundance of commercially available resin saps and curing agents. These resins and curing agents are combined to form copolymers that exhibit specific characteristics, such as a particular refractive index. In the PIPS method, the chemical curing process can either involve a chain reaction or a phase-separation reaction. The phase-separation reaction is particularly effective because it produces an optimal morphology of liquid crystal droplets dispersed within a continuous polymer matrix. This contributes to the desired optical properties and overall performance of the final product.

Two main concerns that influence drop diameter and thickness within the PIPS cycle are the types and relative convergence of the gear used, as well as the specific temperature. A fixed temperature significantly impacts the rate of chemical change, the thickness of the polymers, the dispersion rate of the liquid crystals, and the solubility of the liquid crystals within the polymers. Maintaining optimal temperature conditions is crucial for achieving the desired morphological and optical properties in the final PIPS product (Kashima et al., 2010). Each element is affected differently by specific temperatures, leading to significant variations in outcomes. Therefore, it is essential to carefully determine the optimal fixed temperature for each formulation. This consideration ensures that the desired results, in terms of both the morphological and optical properties of the final product, can be achieved effectively.

1.5 Epoxy Resin

Epoxy resins represent a broad category of flexible to rigid materials, highly sought after for their ability to be tailored for specific applications. The need for precise control over the properties of each formulation is essential, particularly in terms of the resin's processing capabilities. Epoxy materials are stable under ambient conditions, resulting in an extended shelf life for the resin and its epoxidized oligomers. Furthermore, epoxy formulations can react with a variety of agents. The choice of curing agent allows epoxy resins to be cured under ambient conditions, at elevated temperatures, or with exposure to light, resulting in durable, void-free products.

The field of epoxy resins has witnessed significant advancements, particularly in the realm of tailored formulations that enhance processing and application properties. The ability to fine-tune both resin and curing agent properties provides a tremendous opportunity for extensive research and commercial usage. This overview will focus on the vast array of epoxide materials developed since the 1930s, emphasizing commercially viable resins, curing agents, and supplementary additives. The evolution of these materials has been pivotal in meeting diverse industrial needs.

The recent decade has seen the introduction of novel gums and innovative drivers within the epoxy resin field. Several comprehensive reviews on epoxy materials will be referenced for a more in-depth examination of resin research. The field of Organic Compound Resins Science and Technology covers a wide range of operations, focusing on significant investigations related to the chemical reactions and curing processes of resins. A careful study of the resulting material properties and applications is crucial for understanding their industrial relevance. This ongoing research aims to enhance the performance and adaptability of these materials to meet an expanding array of applications (Tanaka, 2018).

The term 'resin tar' refers to a diverse set of In (Fig. 1-2. A), with chiefs (optic hub) of drops randomly positioned. Due to the refractive index difference between the compound and the fluid, violet light is dispersed upon incidence at PDLC oligomeric and compound materials. Whereas 'epoxy' alludes to an enormous ring having chemical element, the substances termed epoxy tars economically have express one, epoxides (three-membered oxirane rings) (Fig.1). Glycidyl will be used to name mixtures with epoxy for the gatherings. Even if organizations formed under current fix systems lack the epoxide gathering, they are still referred to as epoxy organizations.

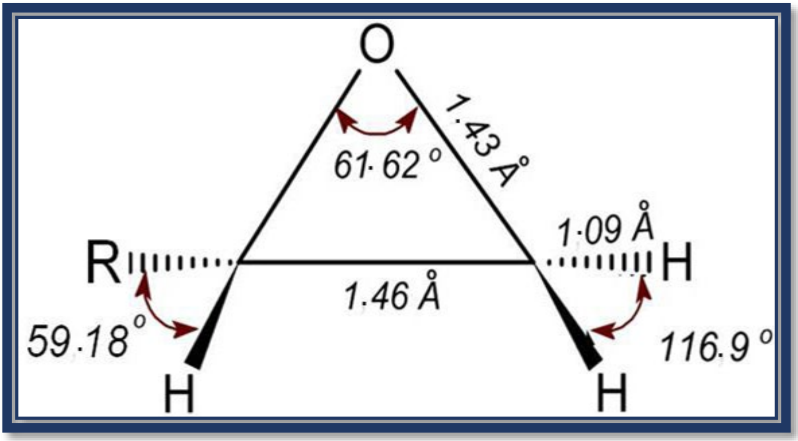

Figure 1-1 Oxirane ring found in common epoxy resins with bond angle and bond distance

1.5.1 Heat Curing Agents and epoxy monomers

Relieving specialists or thickeners are synthetic agents that help epoxy form cross-linked polymers, improving its unique properties. The most commonly used alkene series curing agents react with the oxirane ring along with active aliphatic compounds. The basic aliphatic series can be classified by their utility as primary (with two active hydrogens), secondary (with one active hydrogen), and tertiary (with no active hydrogens). Within the group of aliphatic curing agents, popular options include mercaptans, aliphatic amines, and polyamides. These agents play a significant role in enhancing the performance of epoxy resins in various applications (Vaz &

Montgomery Jr, 1987). Each has its properties, as shown in the below. They are:

A. Tri-ethylene-tetra mine (TETA)

It is used as a cross-linker an important class of epoxy hardener in the cured polymer network. It has two primary amines and two secondary amines. It's a straight amine construction and its refractive index is 1.496.

B. Diethylene-tetramine (DETA)

Diethylene-triamine is the next lowest molecular weight product. Clear and colourless with an ammonia-like odour, DETA is a one-component product containing two primary and one secondary nitrogen. The refractive index is 1.484.

C.Pentaerythritol-tetrakis-3-mercapto propionate (PERTMP)

It is another mercaptan/thiol chain hardener. It had four thiol (-SH) groups attached uniformly. Harder, which is not much more ideal than the amine group (NH2) in the formation of PDLC films.

D. Ethylene glycol diglycidyl ether (EGDE)

It is a bifunctional epoxy monomer. It has four substituted oxygen groups in the structure. In this kind of crosslinking agent, the opening of the epoxide ring must occur simultaneously with the occurrence of the crosslinking reaction, so it is used as a crosslinking agent for opening the epoxide ring and chemical interaction. It has a refractive index of 1.463

E. Bispheno A diglycidyl ether (BADGE)

Bisphenol A is a di-functional heat-curable epoxy monomer, also known as BPA it most commonly serves as a basic building block for polycarbonate and epoxy resin because of its unique properties. Its refractive index is 1.596

F. Neo pentyl glycol di glycidyl ether (NGDE)

Neopentyl glycol glycidyl ether is a penta-functional heat-curable epoxy molecule with two epoxy pendant groups at the end of the chain.it is majorly used as reactive diluent for epoxy resin. Its refractive index is 1.457

G. Nematic Liquid Crystal (NLC)

In a nematic phase, particles tend to align parallel to each other and with the director. The director is a unit vector that gives the preferred average molecular orientation about any point. The 4-Cyano-4'-n-pentylbiphenyl has been variously used. The refractive index value is n20/D 1.532.

1.6 PDLC and applications

The PDLCs are parallel fluid crystal bead scatterings in a constant polymeric framework, drawing a legitimate concern for analysts somewhat recently from both a fundamental and handy perspective. PDLCs are framed by spinodal deterioration instigated by warm extinguishing or polymer formation. These substances have superb magneto-optical character and extraordinary affinity in applications that need productive light dissipating. Now business usage incorporates switchable windows for protection control and enormous scope boards. The optical properties depend upon the world size, shape, and point request, not set in stone throughout the event stage, and reorientation components of the fluid semitransparent atoms restricted to the beads that happen throughout item use. PDLCs are fluid gem drops that are scattered haphazardly in a very complex network (Fig.1-2).

The typical fixation for polymers lies between 30%-50%. At the purpose field is applied at the presentation, the chiefs can organize themselves on course of applied field and light-weight is distributed through with insignificant dissipating (Fig. 1-2). As the purpose field is applied at the presentation, the chiefs organize themselves on the course of the applied field and light-weight is distributed through with insignificant dissipation (Fig. 1-2). The imagined polymers need to file of refraction close to the traditional refractive record (no) of fluid gems thus murkiness at the on-state may be forestalled. Because of their highly lightweight dissipating nature, monumental survey purpose, and splendor, no polarizers' area unit is needed for PDLC show activity. The numerous uses of PDLCs are switchable windows. The foremost well-known assortment of PDLC is the optically dissipating structure.

The convergence of compounds within fluid jewelry typically occurs within a rough timeframe of around half an hour. This process enhances the compound when integrated into LC/polymer emulsions, leading to the separation of fluid gems within the polymer's structure. Beads, which are a common feature, are usually of small size on the scale (Bulgakova et al., 2008). Liquid gem particles inside every drop have a limited request, notwithstanding, every bead can be haphazardly adjusted compared with others. The mix of drop size and isotropic direction of drops prompts a profoundly optically dissipating state and gives the phone a smooth appearance. At the point when a similar material is then exposed to an electric field, electro-optic reorientation of the fluid precious stone beads happens. This then, at that point, lessens the level of optical dissipating through the cell, bringing about a straightforward

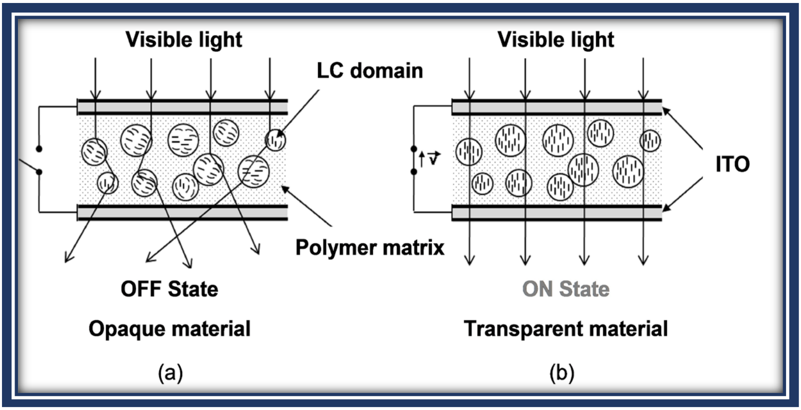

Figure 1-2 Diagram of a polymer-dispersed liquid crystal (PDLC) a.) In the off-state where light is scattered and b.) In the on-state where light is transmitted through the display

Figure 1-3 Schematic drawing of the PDLC film electro-optical application

Dispersing PDLCs utilizing micro-sized drops, for example, has varied usages. Switchable windows/security screens (changeable between a straightforward/clear state and a misty/dissipating state) are currently monetarily accessible and use PDLC innovation. Artificial colours will likewise be incorporated in PDLC combos so that they often particularly dissipate inexperienced, red, or blue lightweight on an individual basis. Besides, the rising bead space region (in between the fluid gem on the polymers) brings solid securing energies and therefore quick exchanging times that are of extra advantage to the presentation business.

Implementing PDLCs is challenging due to their higher voltage requirement of 0.2 to 10 V/micron, compared to 0.1 to 5 V/micron for traditional liquid crystals. This can complicate the design and integration of PDLC systems.It prompts increased power utilization and far more expensive running hardware. However, as a result of impulsive arrangement of the 'off' specific, full fluid jewellery birefringences cannot be used, with gadget transfer occurring with a diminished stroke. All the same, this can be to some extent remunerated by utilizing thicker gadgets, because their exchanging time is generally free of cell thickness as displayed in Fig.4.

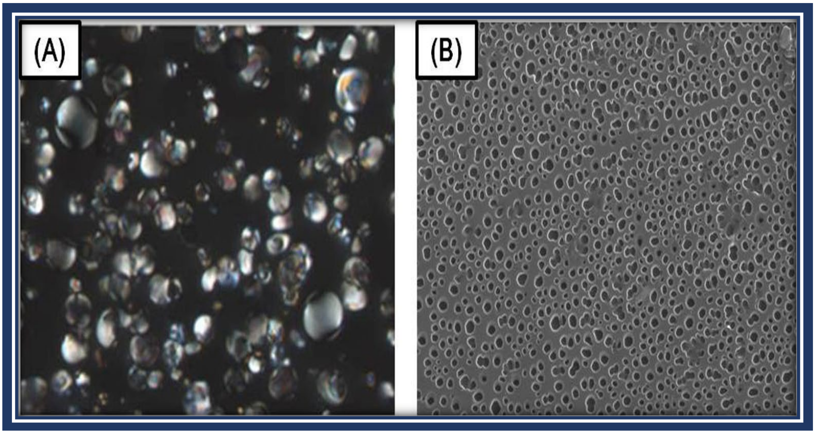

Figure 1-4 (A) A Polarizing microscope image of the PDLC film and **(B)** Scanning electron microscope photograph of a cross-section of a PDLC film.

The setup of the liquid crystal beads in a polymer grid is the focal point of much momentum research. A wide range of arrangements was noticed and they rely upon variables, for example, bead thickness and structure, surface mooring, and applied fields. This part will portray the absolute more normal designs. Schematic delineation of nematic chief arrangements in various round pits, we see in (Fig 5).

For a circular drop, no versatile contortion is required to align a bipolar bead with an electric field. However, the drops in PDLC (Polymer Dispersed Liquid Crystal) substances are often not perfectly circular. The random orientation of bipolar beads in a PDLC film arises from the distribution of shapes and orientations of somewhat elongated drops. By analyzing this variation in drop structure, it is possible to calculate the influence of drop morphology on the driving voltage of a PDLC display that incorporates bipolar beads. This understanding can help optimize the performance of such materials in various applications (McFarland, Koenig, & West, 1993).

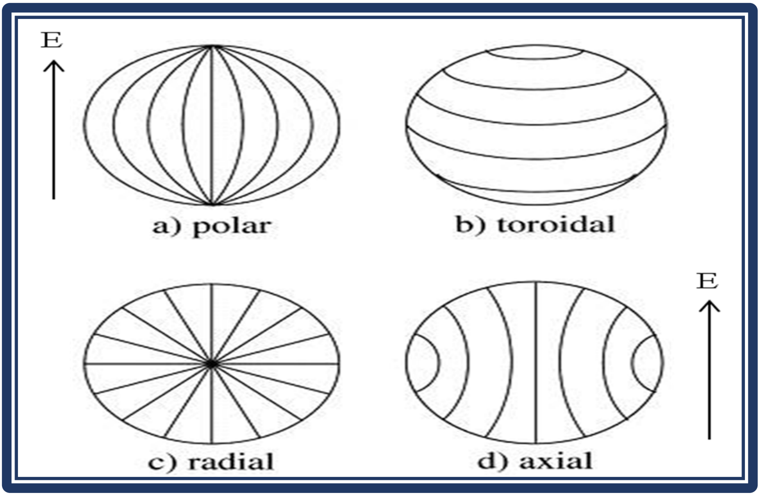

Figure 1-5 Schematic illustration of nematic director configurations in spherical cavities: (a) the bipolar configuration aligned by an electric field,(b) the toroidal configuration (c) the radial configuration, (d) the axial configuration in an applied field

1.7. Discovery of Liquid Crystals: The Intermediate Phase

It was taught in colleges that 3 periods of issue: solids, fluids, and gases. Stages controlled through atoms area unit settled requested regarding each other. The Temperature vacillation builds atoms to vibrate or move which will prompt touch on move between varied phases. Particles in solids area unit mounted and should be exceptionally requested and settled in threelayered clusters (translucent solids) and discretional places (nebulous solids).

In isotropic fluids, such as gases, particles move freely without a fixed orientation or point of reference. This means that the particles are randomly distributed and exhibit no preferred direction for their alignment. As a result, their behaviour is governed solely by thermal motion, leading to a uniform distribution of velocities and directions. This characteristic is a key feature of isotropic media, influencing how these fluids interact with external forces, such as electric or magnetic fields. The distinction between the two states is that the atoms of gases are so much separated from each other, which makes gases compressible. In contrast, the particles in fluids have an attractive force that keeps them close to each other, making fluids non-compressible. As the logical instruments and innovation progressed, therefore did our insight concerning completely different periods of a problem aside from solids, fluids, and gases. In 1888, associate degree Friedrich Reinizter Austrian biologist was warming substances unremarkably occurring in plants on an associate degree shoot underneath a polarizing magnifying lens.

This substance, powerful at 25°C degrees, was heated into associate degree overcast fluid at 145.5°C degrees; because the substance was warm at 178.5°C degrees, the fluid was clad to be clear. He talked about his perception along with his partner Otto Lehmann, a German scientist. Lehmann begat this revelation as a "fluid gem" since it showed each the atomic request of glasslike solids and the progression of the same sort of fluids (Collings, 2002). This substance is known as cholesteryl benzoate (C34H50O2). The structure is shown in (fig. 6).

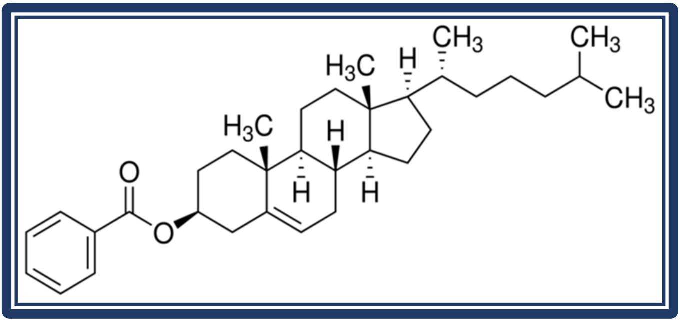

Figure 1-6 Cholesteryl benzoate ($C_{34}H_{50}O_2$).

Liquid crystals can be found in nature as well as synthesized for various applications. Their structures are commonly categorized into two types: calamitic and discotic. Calamitic liquid crystals are typically characterized by an elongated, rigid aromatic core paired with a flexible organic tail. These rod-like molecules tend to align parallel to one another, which gives them their unique properties. In contrast, discotic liquid crystals are shaped differently and can exhibit different behaviours due to their disk-like structure. This distinction between calamitic and discotic forms is essential for understanding their applications in displays and other technologies. Discotic liquid crystals contain hexagonal rings at the centre and these structures tend to stack on high of each other. The additional types of liquid crystals, such as curve-core (or banana) shaped liquid crystals and chemical compound liquid crystals, also undergo transitions depending on their structure and conditions. Thermotropic liquid crystals transition between phases based on temperature variations. For instance, typical thermotropic liquids have a molecular structure that combines both a rigid component, such as benzene or aromatic rings, with a more flexible hydrocarbon arrangement, allowing for notable elasticity. On the other hand, lyotropic liquid crystals are typically amphiphilic, possessing hydrophilic polar head groups and hydrophobic organic tails. Their phase behaviour is influenced by the concentration of the surrounding medium, such as water or other solvents, leading to distinct liquid crystalline phases based on the interactions between these components and the solvent. Understanding these variations helps in optimizing the properties and applications of liquid crystal materials (Dierking, 2009).

The thermotropic calamatic fluid is a crystal modification in between the semi-transparent fluid and therefore the isotropic fluid through mesophases. Fluid gem mesophases are often recognized by setting a fluid gem take a look at between 2 crossed polarizers beneath a magnifying instrument. The atoms within the nematic stage, displayed in (Fig.7), are organized typically one next to the other, having long-range orientation order. Nonetheless, there is no point order (Chandrasekhar, 1978).The approximate leading way of those molecules is understood because of the director which is denoted because of the vector $\vec{n}$.