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INTRODUCTION

1.1. BACKGROUND

Liquid crystals represent a special state of matter, assigned a place between highly ordered solid state and completely disordered isotropic liquid state. Usually this phase is associated with the melting of long molecular crystals. On heating, instead of changing directly to liquid phase, these molecules form an intermediate phase. In this mesophase the orientational order of the molecules is retained while they loss the translational order. As a result the material can flow freely, though along certain selected directions, while retaining the aniosotropy of almost all its physical properties, similar to crystalline solids. These types of phases are termed Liquid crystalline phases. Subsequent heating of these mesophases leads to breakup of their residual ordering and the material becomes an isotropic liquid.

Though these thermotropic liquid crystals have been discovered a century ago [1 & 2], it is the potential applications of these materials in electro-optic devices that brought about the renewed interest in them. Further their applications as light modulators, image converters, choppers and temperature sensors render these materials technologically important.

Displays have become a field of tremendous importance during the last few decades as they provide the best means for interface between man and machine through man's most versatile and sophisticated sense- the vision. Out of the two major types of displays, the electro-optic desplays are becoming more popular than mechanical displays. Electro-optic displays allow direct indication and reading of symbols, letters and numbers and can display more information in less space compared to analog meters and devices.

A large number of displays such as vacuum flourescent, incandescent lamps, nixie tubes, light emitting diodes, electroluminicence and liquid crystals are presently available. Of all these displays liquid crystal display has emerged as the most promising display during the last decade, capturing 30% of the market for displays (excluding cathode ray tubes). Though there are a number of operating modes, the basic working principle of all liquid crystal displays remains the same, namely the control of light from selected pixels or small areas of the display. Since liquid crystals retain the flow properties and are anisotropic, their molecules can be arranged in a specified direction by means of an electric or magnetic field of relatively lower strength. This orientation of the director in an applied field is the basis of all electro-optic effects in liquid crystals. Thus liquid crystal displays are passive electro-optic displays which modulate the light passing through it ie they do not generate light. On application of a voltage on desired segments these areas become visibly different from the rest of the background giving rise to numeric, alpha numeric, dot matrix etc. characters. The extremely low power consumption (microwatt per square centimeter), low voltage operation, readability in glaring sunlight, compactness and flexibility of size are some of the distinct features which make liquid crystals displays preferable over other types of displays. Another important advantage is its capability to interface directly with integrated circuits. Liquid crystal displays are truley flat panel and do not emit any harmful radiation as in the case of cathode ray tubes.

The first generation of liquid crystal displays operate on a mechanism termed dynamic scattering mode (DSM), which requires a liquid crystal material of negative dielectric anisotropy. In the absence of an electric field a thin layer of liquid crystal looks transparent. When a field is applied, due to the flow of ions these materials exhibit a marked turbulence that turn them from transparent to white. Thus the reflection of light in the medium can be electronically controlled. Dynamic scattering mode operates only at low frquencies (1kHz) and consumes more power milliwatt per square.cm).

Another important mode of operation is the twisted nematic liquid crystal display which is based on a field effect. In such a device, normally light polarisation is twisted through 90 degrees in the liquid crystal. When an electic field is applied the twisting structure is neutralised and light cannot be transmitted (in the crossed polariser set up). In recent years this device has dominated the electronic watch display.

With the increased use of fiber-optic communication systems, during the last decade greater attention is being paid to fibre-optic devices like sensors, modulators, couplers and switches involving novel concepts. Liquid crystals can serve as external passive modulators, as even weak signals can bring about a change in molecular orientation of the liquid crystal that results in a change in the refractive index along a given direction of the material. When light is passed through such a liquid crystal medium, the output intensity varies according to variations in the applied electric field (signal). Such intensity modulation of light has been obtained using nematic liquid crystals by many research groups.

Another important area of application of liquid crystals is in light valves or spatial light modulators. They convert an input image written in a certain wavelength, intensity and coherence conditions to an output image in which some or all of these parameters are varied. They find application in image amplifiers, wavelength converters and incoherent to coherent image converters. A series of siicon-photoconductor based liquid crystal light valves have been developed by Hughes Research Laboratories in recent years [3].

The most significant advances in the liquid crystal devices are in material synthesis and device fabrication. A variety of high purity liquid crystal materials have been developed with reasonable operating ranges and high response to fields. Alignment techniques like oblique evaporation of silicon monoxide, Polymer coating and rubbing, application of a low frequency ac, coating with a silane etc. have been developed for obtaining the desired molecular orientations in various cell configurations.

In large screen and high resolution displays the switching speeds of the material should be very high. The drawbacks arising from the comparatively low switching speeds of liquid crystal are overcome either by using a charge storing device such as varactor diodes, solid ferroelectrics along with the liquid crystal or by employing multiplexed addressing schemes.

1.2. MOTIVATION

Though much progress has been achieved in the production of liquid crystal displays, the electro-optic performance of these displays, mostly using nematic liquid crystals presents some fundamental limitations.

One of the main drawbacks is the low switching time. The main driving force in these displays is the interaction of the applied electric field with the dielectric anisotropy of the material. The rise time of these displays depend also on the electrical conductivity, elastic moduli and viscosity of the material and is usually of the order of milliseconds. (20 ms to 10 ms). Such a low response becomes a serious drawback at increased multiplexing rates. Moreover it is very difficult to obtain memory states as well as sharp threshold voltages for electro-optic effects in these nematic materials.

In matrix addressed displays usually a capacitance is connected along with nematic liquid crystal cell to the drain of the switching transistor to overcome this slow response. This capacitor stores the signal charges and discharges it to the liquid crystal in due course. This reduces the scanning time required for each frame, thus improving the effective respone of the display, matching it with the requirements of some of the consumer products like television.

Instead of capacitors, solid ferroelectric materials are also used along with the liquid crystal to store the signal charges [4]. Here voltage levels are stored as polarisation states in the ferroelectrric. This method also provides the sharp threshold voltage necessary for switching. Even here the integration process of the matrix junction is tedious and calls for much involved techniques.

All these difficulties can be solved to a large extent if a ferrolelectric liquid crystal (FLC) is used as the display element. Ferroelectric liquid crystals have a spontaneous polarisation moment which can be used as a memory state. Further this polarisation can be reversed by appling an electric field. Also the response time of the device can be brought down to sub-microseconds range, since an additional driving force is derived from the field-polarisation interactions.

Ferroelectric liquid crystal displays (FLCD) in different configurations like Surface Stabilised ferroelectric liquid crystal, ac stabilised ferroelectric liquid crystal, Transient Scattering Mode and those using electroclinic effect (Soft Mode ferroelectric liquid crystal) have been demonstrated by various groups of researchers, after the discovery of ferroelectricity in liquid crystal by Meyer [5].

The main motivation of this thesis is to investigate the possibilities of establishing well defined optical levels in an ferroelectric liquid crystal corresponding to the parameters of the applied electric field. To this end the electro-optic switching properties of the ferroelectric liquid crystal 4`-[Octyl benzoyloxy]-4-[2- Octyloxy]- biphenyl (OBOB) are studied and measurements of the risetimes, decaytimes as well as transmission levels for specified values of the voltage and pulse width of electrical pulses are carried out. Further it is intended to study the potential use of ferroelectric liquid crystals as optical modulators. Such a device can find application as transmitters in optical fiber communication and as spatial light modulators in image converters. A special technique is developed, where the modulating signal is applied to an ferroelectric liquid crystal cell, biased with a dc voltage to obtain intensity modulation. The variation of modulation depth with frequency is also studied. A qualitative explanation of this modulation is also attempted on the basis of partial unwinding of the helical structure of the ferroelectric liquid crystal under an applied electric field.

1.3. OUTLINE OF THE WORK AND RESULTS

The thesis is presented in six chapters. Chapter.2 reviews the recent developments in liquid crystal displays, mainly in ferroelectric liquid crystal displays and is meant to establish necessary background for the following chapters. Various techniques used to evaluate the material constants of ferroelectric liquid crystal like spotaneous polarisation, rotational viscocity, tilt and dielectric constant have been reviewed briefly.

The main ferroelectric liquid crystal display configurations, their electro-optic effects and experimental results as regards to rise time, decay time, grey scale capability etc. have been surveyed in this chapter.

The application potential of a material depends primarily on a thorough knowledge of its material constants. In chapter.3, the material constants of the ferroelectric liquid crystal, OBOB are studied. The liquid crystal cell is made of two conducting transparent glass plates (SnO_2 coated). Thickess of liquid crystal material is controlled by Mylar spacers (20 microns) and thin films of silicon monoxide coated on the glass plates (2 microns). Homogenous alignment is acheived by coating the glass surface with polyvinyl alcohol (PVA), rubbing and using a low frequency electric field. Oblique evaporation of silicon monoxide also is used for this purpose.

The temperature of the specimen is controlled to an accuracy of $\pm 1^{\circ}$ C by a microprocessor based temperature controller and by keeping the specimen in vacuum.

The phase transition temperatures are studied using differential scanning calorimetry (DSC) and optical polarising microscope. OBOB shows chiral smetic phase in the temperature range of 62°C to 74°C.

The spontaneous polarisation of OBOB is evaluated by square wave method [6] and triangular wave method [7]. Spontaneous polarisation varies from 28 nC/ square cm to 3nC/square cm with increase in temperature of the SmC* phase. Rotational viscocity, another important parameter for display application is also measured by square wave and triangular wave methods at various temperatures.

Chapter.4 presents the detailed investigation of electro-optic switching behaviours of OBOB for pulses of varying pulse widths and voltages. The experimental arrangement uses a Helium-Neon laser as the optical source and photodiode as the detector along with a memory scope.

The ferroelectric liquid crystal shows a sharp threshold in its voltage/ pulse width transmission characteristics. At higher temperatures of SmC* phase (74°C) bistable switching is observed for pulses of voltage higher than the threshold. At lower temperatures (66°C) and for small pulsewidths (below 10 ms) intermediate optical transmission levels are observed for the sample. These levels are found to depend both on height and width of the applied pulses. Another important result is that a pulse of height just lower than the threshold voltage can reset the switched state back to the opaque state.

In chapter.5 the electro-optic effects of ferroelectric liquid crystals for low voltage continuous signals of varying frequency are investigated. At first a pure sine wave is applied to the specimen. It is found that the electro-optic output does not follow the variations in the input. But on biasing the ferroelectric liquid crystal with a constant dc voltage (less than Ec, the critical unwinding voltage) and then applying a sine wave signal along with the dc, the output variations followed exactly the input signal.

The experiments are repeated for a sweeping sine wave and it is found that the depth of modulation decreases with increase in frequency of the modulating signal. Finally speech signals are applied to the ferroelectric liquid crystal with proper dc biasing. Corresponding optical output recorded in the oscilloscope shows that the output is a replica of the input though there is a reduction in amplitude at higher frequencies. The above results are explained on the basis of partial unwinding of the deformed helical structure of the ferroelectric liquid crystal under the resultant action of dielectric and ferroelectric forces.

Experiments are also conducted for comparatively thin samples(1 to 2 microns) of OBOB. In this case alignment of molecules is obtained by oblique evaporation of silicon monoxide. Thin films of SiO coated in vacuum serve as spacers also. At these thicknesses modulating properties similar to those of thicker samples are obtained, but at lower voltages.

Chapter.6 concludes this work and suggests a few directions for future research.