CHAPTER IX

Summary and Scope for Future Work

9.1. Summary and Conclusions:

The dissertation entitled "*Development of Liquid Crystalline Materials for Application in Vertically Aligned Mode Liquid Crystal Displays*" submitted for the degree of Doctor of Philosophy (Physics) of the University of North Bengal embodies the results of experimental investigations of the physical properties of dielectrically negative fluorinated pure liquid crystalline compounds and their multi component mixtures suitable for application in Vertically Aligned mode Liquid Crystal Display (VA-LCD). The thesis comprises of eight chapters.

In the first chapter, a brief introduction to liquid crystals and the history of liquid crystals has been presented. The different mesophases exhibited by liquid crystalline materials has been mentioned. However, the discussion on the mesophases is mainly restricted to nematic and smectic phases since the rest phases are not studied in this dissertation. Thereafter, the properties and methods of liquid crystal mixture formulation have been thoroughly discussed. The choice of the materials to be used in this study is an important aspect. Different electro-optic effects which are recently being used in liquid crystal display (LCD) devices have been summarized. Detailed discussion of Vertically Aligned (VA) mode has been given in this chapter and a comparison of the advantages of Vertically Aligned Nematic (VAN) displays over other display devices has been mentioned.

The second chapter includes discussion on both experimental methods and the supporting theories. The physical properties of the liquid crystalline materials have been determined using different experimental techniques. The experimental details to measure the birefringence, dielectric permittivities, bend elastic constant, relaxation time and rotational viscosity are given in this chapter. Phase identification by texture studies and optical transmission, x-ray diffraction technique and the interpretation of the x-ray data and the method of data analysis are also given in this chapter. The method to determine refractive indices and Orientational Order Parameter is also outlined. A small introduction to the concept of pretilt angle and their effect on the material properties of multicomponent mixtures used in VALCD's has been depicted. Basic requirement of the materials to be used in multi component VA mode mixtures, their physical properties, structure-property relationship and the phenomenological difficulties associated with the proper choice of materials in the final mixture preparation have also been discussed.

The third chapter summarizes the physical characterization of ten pure liquid crystalline compounds (compound **1**, **3-9**, **10**, **11**) comprising of 2, 3-difluoro sub-unit, one phenyl cyclohexane (compound **12**) and two bicyclohexane compounds (compound **14** and **15**) from birefringence, dielectric permittivities, bend elastic constant, relaxation time and rotational viscosity measurements. The main material research target was to identify suitable liquid crystalline compounds with low melting point, broad nematic range and large negative dielectric anisotropy to be used as component of multicomponent mixtures functional for VA-LCD's. The structure property relationship of the pure compounds has also been discussed. All of them have low to moderate birefringence values, large dielectric anisotropy ($\Delta\varepsilon$) and lower values of relaxation time. Only compound **10** and **11** show slightly enhanced values of $\Delta\varepsilon$. Additionally, the Orientational Order Parameter (OOP) values ($<P_2>$) and activation energy (E_a) values have also been calculated. The temperature dependence of the visco-elastic ratio and Figure of Merit (FoM) have also been determined. FoM allows a comparison of the relative performance of liquid crystalline molecules in a display device as a function of temperature. It was also observed from this study that of all the terphenyl compounds investigated here, compound **4** emerged as a one of best material to be used in multicomponent mixtures.

The aim of the work in chapter four was to investigate the physical parameters of three selective laterally fluorinated compounds (compound **1**, **10** and **11**). From density, refractive index and $<P_2>$ values determined from the x-ray diffraction and refractive index measurements, the order of the nematic to smectic B phase transition was found to be discontinuous for both **10** and **11**. Fairly good agreement was observed between the experimental and theoretically calculated $<P_2>$ and $<P_4>$ values for **10** and **11**, even though the McMillan model is strictly valid for the smectic A phase. $<P_2>$ values determined from x-ray diffraction measurements were found to be in fairly good agreement with those obtained from refractive index measurements even after considering the different assumptions and approximations involved in the order parameter determination from x-ray diffraction and refractive index measurements.

The fifth chapter contains the formulation of different multicomponent mixtures. The molar ratios and the eutectic points of all the mixtures (mixture **A-G**) were calculated using the Schröder van Laar equation and the theoretical values of the melting and clearing temperatures were found at the eutectic point. The first step started from preparing two three component mixtures (mixture **A** and **B**). These two mixtures consist of two laterally fluorinated compounds and one bicyclohexane compound (different for mixture **A** and **B**). Thereafter, mixture **C** was formulated, which contained three laterally fluorinated compounds, one phenyl cyclohexane and one non-mesogenic compound. For further improving the material parameters, a nine component mixture (mixture **D**) comprising of compounds **1, 3-9** was prepared. In pursuit of improving the rotational viscosity, birefringence and dielectric anisotropy further, a fifteen component mixture (mixture **G**) was prepared which consists of eleven laterally fluorinated pure compounds (compounds **1-11**), two phenyl cyclohexane compounds (compounds **12** and **13**) and compounds **16** and **17**.

In the sixth chapter, the physical properties of seven negative dielectric anisotropy nematic liquid crystalline multicomponent mixtures (mixture **A-G**) have been studied by different experimental techniques, e.g. birefringence, dielectric anisotropy, bend elastic constant, relaxation time and rotational viscosity. All of them show low to moderate values of birefringence and large negative dielectric anisotropy. The bend elastic constant and relaxation time values (as well as rotational viscosity values) are excellent for all of them, especially for mixtures **D-G,** to be used as the main material in VA mode display devices. In addition to this, the Orientation Order Parameter (OOP) values, activation energies (E_a), visco-elastic co-efficient (γ_1/K_{33}) and Figure of Merit (FoM) have also been calculated for all of these multicomponent mixtures. Mixture **D, E** and **F** were found to be the most suitable mixtures.

In chapter seven, the work is concentrated on the study of the effect of pretilt on different multicomponent mixtures. The variation of threshold voltage (V_{th}) and relaxation time (τ_o) has been determined as a function of relative temperature for all of the mixtures (mixtures **A-G**). At T = 20°C the relaxation time and V_{th} values for mixture **A-G** have been compared for 2° and 5° pretilted cell with those obtained from zero pretilted cell. A drop in the threshold voltage and relaxation time was observed with increasing pretilt angle for all of the mixtures. The voltage dependent transmittance curves for the mixtures **A-G** have also been reported.

In the eighth chapter, the physical properties of seven bicyclohexane compounds have been investigated from polarizing optical microscopy, high resolution optical birefringence, dielectric anisotropy and density measurements. These materials are characterized by low optical anisotropy and are often introduced as dopants in VA mode mixtures to reduce the birefringence (Δn) of the mixtures. Out of the seven alkenyl bicyclohexane compounds studied, five compounds show only nematic phase while other two compounds possesses smectic B phase which is precursor of the nematic phase. The refractive indices as well as the density data have been used to determine the orientational order parameter ($<P_2>$) using the standard Vuks isotropic model and have also been compared with the theoretical mean field values. Optical Transmission (OT) method has also been employed to obtain a high resolution (accuracy~10^{-6}) measurement of the temperature dependences of the optical birefringence (Δn), which provides a macroscopic measure of the anisotropy of the liquid crystalline phase, and can also, be considered as a measure of the orientational ordering.The optical birefringence data obtained from optical transmission method have been compared with the same as obtained from thin prism technique. The high resolution Δn data obtained from temperature scanning measurement of optical birefringence are quite successful in characterizing the transitional anomaly associated with the nematic-isotropic phase transition. For the investigated compounds, the values of the critical exponent β related to the limiting behavior of the nematic order parameter close to the N-I transitions, are found to be close to 0.25 and thus are in well accordance with the tricritical hypothesis and also excludes the possibility of any higher β values. Additionally, the dielectric permittivities parallel and perpendicular to the molecular long axis throughout their mesomorphic range of the seven pure liquid crystalline compounds has also been measured. The structure property relationship of these compounds has also been discussed.

9.2. Scope of future work:

A. One of the difficulties of the VA technique is the switching – on mechanism where the driving electric field tilts the directors randomly in any direction in the ON state, leading to disclination lines between domains of equal orientations thus deteriorating the optical performance. Multi-Domain Vertical Alignment (MVA) TFT LCD's has recently been developed, where each of the multiple domains within each pixel cell channel light at an angle to the substrates, instead of at right angles to it, resulting in all-round increase in viewing angle upto 160^0 in all directions with a contrast ratio of around 300:1. Another very successful approach is the Patterned Vertical Alignment mode (PVA) where Chevron-shaped patterned electrodes produce a fringe electric field with the in-plane component that directs the molecular tilt in the ON state. The resulting multifold symmetry of the director field gives excellent viewing angle performance, high transmittance and contrast ratio. Further work may be done to apply these materials in devices which are fabricated incorporating the above mentioned technologies.

B. Furthermore, due to the increasing number of moving picture internet applications and the overlap of monitor – video – and TV technology, the reduction of switching times is another very important issue for liquid crystal material development. The switching time of 25 ms from black to white state for VA LCD's is not sufficient to realize full moving pictures. This necessitates further development of improved LC materials with still lower values of the rotational viscosity. Moreover, the gray–scale switching of VA LCD's are also relatively slow. This can be significantly improved by the over-driving technique. Further work in this direction may be undertaken to address these problems.