## SYNTHESIS AND PHYSICAL PROPERTIES OF COMPOUNDS EXHIBITING FERRO-, FERRI-, ANTIFERROELECTRIC AND TWIST GRAIN BOUNDARY PHASES

by

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A thesis submitted to the Bangalore University for the award of the degree of

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DOCTOR OF PHILOSOPHY



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## CERTIFICATE

I certify that this thesis has been composed by Miss. S.Shubashree based on the investigations carried out by her at the Liquid Crystal Laboratory, Raman Research Institute, Bangalore – 560 080, under my supervision. The subject matter of this thesis has not previously formed the basis of the award of any Degree, Diploma, Associateship, Fellowship or any other similar title.

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## DECLARATION

I hereby declare that the entire work embodied in this thesis is the result of the investigations carried out by me independently in the Liquid Crystal Laboratory, Raman Research Institute, Bangalore – 560 080, and that no part of it has been submitted for the award of any Degree, Diploma, Associateship or any other similar title.

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TO

## MY BELOVED PARENTS

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### LIST OF ABBREVIATIONS USED IN THE TEXT

Cr	crystal
Ι	isotropic
Ν	nematic
N*	cholesteric
BP	blue phase
Sm	smectic phase
Sm A	smectic A
Sm C	smectic C
Sm C*	chiral smectic C
Sm C <sup>*</sup> <sub>A</sub>	antiferroelectric smectic C
Sm C*,	chiral smectic C alpha
$\operatorname{Sm} C^*_{\gamma}$	ferrielectric smectic C
Sm C <sup>*</sup> <sub>F11</sub>	ferrielectric smectic C one
Sm C <sup>*</sup> <sub>F12</sub>	ferrielectric smectic C two
TGB <sub>A</sub>	twist grain boundary smectic A
TGB <sub>C</sub>	twist grain boundary smectic C
TGB <sub>C*</sub>	twist grain boundary smectic C*
UTGB <sub>C*</sub>	undulated twist grain boundary smectic C*
DSC	differential scanning calorimeter
•	phase exists
	phase does not exist
ţ	enthalpy could not be measured
()	brackets in tables indicate monotropic transition

d	decompose
tlc	thin layer chromatography
HPLC	high performance liquid chromatography
IR	infrared
NMR	nuclear magnetic resonance
TMS	tetramethylsilane
CDCl <sub>3</sub>	deuterated chloroform
ppm	parts per million
S	singlet
d	doublet
t	triplet
m	multiplet
DCC	N,N'-dicyclohexylcarbodiimide
DMAP	4-N,N'-dimethylaminopyridine
МНРОВС	1-methylheptyl-4-(4'-n-octadecyloxybiphenyl
	carbonoyloxy)benzoate
Ch	cholesterol
Ch'	cholestanol
Р	helical pitch
Ps	spontaneous polarization
SHG	second harmonic generation

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#### PREFACE

Liquid crystals are intermediate states of matter whose properties lie between that of a crystalline solid and an isotropic liquid. These intermediate phases are known as mesophases and a compound which exhibits such a phase is called a mesogen. Liquid crystals are broadly classified into two types: (i) Thermotropic, which are formed by the action of heat on pure compounds or mixture of compounds; (ii) Lyotropic, which are formed from amphiphilic compounds by the action of solvents. Thermotropic liquid crystals may be further classified into: Calamitic liquid crystals, which are formed by rod-like molecules; **Discotic** liquid crystals, which are formed by disc-shaped molecules and Polymeric liquid crystals, in which high molecular weight long chain materials arrange themselves to form different types of mesophases. Polymeric liquid crystals may be classified into: Main chain liquid crystalline polymers, in which the monomeric mesogenic units form the backbone of the main chain and are separated by spacers and Side chain liquid crystalline polymers in which the mesogenic groups in the form of pendants, are attached to the main chain polymeric backbone. Suitable modifications in the basic molecular structures (calarnitic, discotic) can lead to new types of liquid crystals like polycatenar liquid crystals, sanidic liquid crystals, etc. This thesis deals with only low molar mass thermotropic liquid crystals.

Calamitic liquid crystals may be broadly classified [1] into three categories based on the molecular ordering, *viz.*, Nematic, Smectic and Cholesteric. In a nematic liquid crystal, there is a long-range orientational order of the molecules but no positional order. In a smectic liquid crystal the molecules have a layered arrangement and may possess both orientational and positional order. Depending upon the way in which the molecules are arranged within the layers, different smectic modifications like smectic A (Sm A), smectic C (Sm C) *etc.*, have been identified [2]. In the Sm A phase, the molecular arrangement is such that, the average orientation of the long molecular axis is along the layer normal. The molecular arrangement in the Sm C phase is similar to that of Sm A phase except that the molecules are tilted with respect to the layer normal. Cholesteric phase is similar to that of a nematic phase, except that the molecules in the cholesteric phase are optically active. This molecular chirality induces the formation of a helical macrostructure with the screw axis normal to the director of the molecules. This phase is also known as a chiral nematic  $(N^*)$  phase.

The Sm C phase composed of chiral molecules was found to exhibit a helical macrostructure due to the rotation of the tilt direction of the individual layers about an axis normal to the layer planes on passing from one layer to the next layer. This phase is known as the chiral smectic C (Sm c\*) phase. Based on symmetry arguments, Meyer *et al.* [3] discovered ferroelectricity in the Sm C\* phase. According to them, a simple Sm C phase possesses the following symmetry elements:

- 1. A two fold axis of rotation
- 2. A mirror plane perpendicular to the principal axis
- 3. Center of inversion.

Hence it possesses a  $C_{2h}$  symmetry. However in a chiral smectic C\* phase, the symmetry reduces to a simple  $C_2$  axis. This low local symmetry forces the transverse dipole moment to orient along the  $C_2$  axis perpendicular to the tilting plane, leading to a macroscopic polarization within the smectic layers. Due to the formation of the helical macrostructure in the smectic C\* phase, the net spontaneous polarization averages to zero. However, under the influence of an external electric or magnetic field, the helix can be unwound, resulting in a net spontaneous polarization *ie.*, the medium becomes ferroelectric.

In 1989 Chandani *et* al. [4] discovered another chiral smectic phase, in 4-(1methylheptyloxycarbonyl)phenyl-4'-n-octyloxybiphenyl-4-carboxylate (MHPOBC) which they described as an antiferroelectric phase. In this phase, the molecules in adjacent layers are tilted in opposite directions. As a result, for the bulk unwound state (zero electric field), the net polarization averages to zero. Following this, they also discovered a few sub phases like ferrielectric (Sm  $C_{\gamma}^*$ ) and chiral smectic  $C_{\alpha}$  (Sm  $C_{\alpha}^*$ ) phases in the same compound. The antiferroelectric phase exhibited a tristable switching from antiferroelectric to ferroelectric phase under the influence of an electric field, while the ferrielectric phase showed a tetrastable switching on application of an electric field. As a result some materials exhibiting such phases have found useful applications in the field of display technology. In the year 1972, de Gennes [5] predicted the possibility of the formation of a defect stabilized intermediate phase by subjecting the liquid crystal to twist or bend distortions at the nematic-Sm A phase transition. This prediction was further developed by Renn and Lubensky [6] who suggested the possibility of formation of such an intermediary phase at the cholesteric to Sm A transition; this phase could be stabilized by an array of screw dislocations and they called this phase the Twist grain boundary smectic A (TGB<sub>A</sub>) phase. Later, in the year 1989, Goodby *et* al. [7] first discovered this theoretically predicted phase in some chiral propiolate derivatives. In the TGB<sub>A</sub> phase, smectic A blocks rotate to form a helical structure, with the axis of the helix perpendicular to the long axes of the molecules and the blocks are in turn separated from one another by screw dislocations. Other modifications like twist grain boundary C (TGB<sub>C</sub>) phase, in which Sm C blocks rotate to form the helix and twist grain boundary C\* (TGB<sub>C</sub>) phase which has Sm C\* blocks have been theoretically predicted. However, only the TGB<sub>C</sub> phase has been experimentally observed and characterized [8] in some detail.

In the year 1997, a new twist grain boundary phase which has a two-dimensional undulation of the smectic C\* blocks in the form of a square lattice was discovered [9] in a binary mixture in our laboratory. This phase was termed as the undulated twist grain boundary smectic C\* (UTGB<sub>C\*</sub>) phase. This phase is perhaps one of the most non-uniform liquid crystalline phases, with helical axes both along and normal to the Sm C\* layers. This phase can occur either between Sm C\* and TGB<sub>A</sub> or between Sm C\* and N\* phases.

More recently, compounds composed of achiral bent- or banana- or bow-shaped molecules have attracted the attention of the researchers, due to their remarkable property of exhibiting ferro- and **antiferroelectric** switching behaviour [10,11]. These compounds exhibit new liquid crystalline modifications, which are entirely different from those exhibited by the calamitic or **discotic** liquid crystals. In view of the bent or bow shape of the molecules, which have also been described as banana molecules, the code letter B has been used to describe these new mesophases.

The object of this thesis has been to synthesize different types of new compounds exhibiting chiral phases and evalute the different parameters required for the same. Some of the physical properties of the chiral mesophases exhibited by the synthesized compounds have also been examined. The thesis has been divided into four chapters and a summary of each of these is given below.

Chapter I begins with a general description of the molecular organization in different types of liquid crystalline phases that are discussed in this thesis. Since the main subject of the present investigation has been on chiral phases, viz., ferroelectric (Sm  $C^*$ ) antiferroelectric (Sm  $C^*_A$ ), and twist grain boundary (TGB) phases, the molecular arrangement in these phases and the existence of ferroelectricity and antiferroelectricity in the Sm C\* and Sm  $C^*_A$  phases have been dealt with in some detail. Also, the recent investigations have shown that the compounds composed of achiral bent or banana-shaped molecules show some of these chiral phases and the proposed molecular organization in these have been described in some detail. At the end of the chapter a brief description of some of the general applications of liquid crystals is given.

In chapter II, a brief account of the mesomorphic properties of triesters containing three phenyl rings with particular reference to ferroelectric properties has been presented. The type of chiral moiety and the effect of substituents (non-fluoro / fluoro) on the mesomorphic properties have also been discussed. In this regard, the influence of a lateral fluoro substitution on the stabilization of antiferroelectric phase has been emphasized. The synthesis and characterization of the following series of compounds have been described.



n= 7,8,9,10,11,12,14,16,18

Compounds of the above series with two fluoro substituents exhibited very rich polymesomorphism with Sm  $C_A^*$ , Sm  $c^*$ , Sm  $C_\alpha^*$ , Sm  $C_\alpha^*$  and Sm A phases. The melting and the clearing temperatures of these compounds are relatively lower when compared with those of unsubstituted and mono fluoro substituted compounds. To establish the identity of the different mesophases, a miscibility study of the n-nonyloxy homologue was conducted with the well known standard material MHPOBC [4] and a binary phase diagram was constructed. This diagram shows continuous miscibility of all the mesophases in all compositions. A plot of transition temperatures against the number of carbon atoms in the n-alkoxy chain shows smooth curve relationship for like transitions. Spontaneous polarization in the ferroelectric phase as a function of temperature was measured for a few compounds. The spontaneous polarization for the n-decyloxy homologue was found to be in the range 60-70 nC/cm<sup>2</sup>.

Chapter III is divided into two parts. Part I begins with a brief account of the various factors affecting the occurrence and stabilization of the  $TGB_A$  phase with particular reference to increase in the peripheral terminal chain length adjacent to the chiral center, number of chiral centers and fluoro substitution on the core of the mesogen. A survey of the literature indicated that not many compounds with cholesterol as the chiral moiety exhibited TGB phases. In this part we describe the synthesis and mesomorphic properties of lateral fluoro substituted single phenyl ring esters with cholesterol as the chiral moiety exhibiting  $TGB_A$ , Sm A, cholesteric(N<sup>\*</sup>), and blue phases. The compounds have the following general molecular structure.



n = 12, 14, 16, 18.Ch = Cholesteryl moiety



Cholesteryl moiety

The mesomorphic properties of the above series of compounds have been compared with those of the unsubstituted parent compounds. The unsubstituted compounds show Sm A, Sm C<sup>\*</sup>(monotropic), N\*, and blue phases. The fluoro substituted compounds with n = 18, 16 and 14 showed a short-range TGB<sub>A</sub> phase along with the above mentioned phases. Though the transition from Sm A to TGB<sub>A</sub> and TGB<sub>A</sub> to N\* were difficult to detect in the DSC experiment, they could be easily observed under a polarizing microscope as a clear change in the texture. The melting and clearing temperatures of the above series of compounds. The helical pitch was measured as a function of temperature for the n-tetradecyloxy homologue. The pitch was found to increase steeply with decrease in temperature within the TGB<sub>A</sub> phase from 0.2µ reaching a value of 1µ at the TGB<sub>A</sub>-Sm A phase transition.

Part II of this chapter begins with a brief description of the twist grain boundary phases with particular reference to the discovery of the new mesophase made in our laboratory. This is the undulated twist grain boundary smectic  $C^*(UTGB_{C^*})$  phase. This phase was first discovered in binary mixtures of the chiral compound  $4(2^{-1})$ -methylbutyl)phenyl-4'-n-octylbiphenyl-4-carboxylate and 2-cyano-4-n-heptylphenyl-4'-n-pentylbiphenyl-4-carboxylate, which have very similar lengths and molecular structures. It was our desire to obtain this phase in pure single component systems. We succeeded in this effort and a number of compounds were synthesized exhibiting this phase. These represent the first examples of single component systems exhibiting the UTGB<sub>C\*</sub> phase. The identity of this phase was established using a combination of optical polarized microscopy, x-ray diffraction studies *etc.* The compounds have the following general molecular structure,



n = 8,9,10,11,12,14,16,18







(ii)



n = 7,8,9,10,11,12,14,16,18

(iii)

The above three series of compounds exhibited the following phases: Sm c\*, UTGB<sub>C\*</sub>, and N\* phases. The overall thermal range of the UTGB<sub>C\*</sub> phase in all the three series lies between 1°C and 14°C, with the n-hexadecyloxy homologue of series (iii) having the least (1°C) and n-dodecyl homologue of series (ii) having the largest (14°C) range. These compounds have fairly high clearing temperatures (>230°C) and were found to thermally decompose at such high temperatures. A few other structurally related compounds were synthesized in order to examine the molecular structural requirements for the occurrence of the UTGB<sub>C\*</sub> phase. These compounds have the following general molecular structure,











(vii)



(viii) Ch = Cholesteryl moiety.







Ch' = Cholestanol moiety.

Compounds (iv), (v) and (x) exhibit Sm c\*, Sm A,  $TGB_A$  and N\* phases, while compounds (vi), (viii) and (ix) show Sm c\*,  $UTGB_{C^*}$  and N\* phases. Compound (vii) exhibits only N\* and blue phases. In addition to the above phases compounds (iv a) (n = 16) and compound (v) show a blue phase (BP) near clearing temperature which could be clearly observed under an optical microscope as the sample was cooled slowly from the isotropic phase. However, the exact temperature could not be determined due to thermal decomposition of the compounds. All the above compounds clear at high temperatures (>220) and were found to thermally decompose at such high temperatures. In addition to this a couple of more compounds were synthesized in order to explore the possibility of getting the UTGB<sub>C\*</sub> phase without using the cholesteryl moiety. The structures of these compounds are shown below,





Unfortunately, both these compounds did not exhibit the  $UTGB_{C^*}$  phase, but showed Sm C\* and Sm A phases. In addition to these phases compound (**xi**) also showed  $TGB_A$  phase having a small thermal range.

In chapter IV, a brief survey of the mesomorphic properties of compounds composed of banana-shaped molecules is given. Banana liquid crystals, as they are called were discovered a few years ago. So far only five mesophases have been identified and the structural details of the mesophases have been understood to some extent. The most interesting aspect of this class of compounds is their ability to form chiral phases, though the individual molecules themselves are achiral. One of the mesophases identified as  $B_2$ , shows antiferroelectric characteristics.

In this chapter, the synthesis and mesomorphic properties of four different homologous series of compounds containing 2-methyl resorcinol as the central unit have been described. The four series of compounds have the following general molecular structure:



n = 10, 11, 12, 13, 14, 15, 16, 18.



n = 9,10,11,12,14,16,18.



n = 9,10,11,12,14,16,18.

(xvi)



n = 7,8,9,10,11,12,14,16,18.

(xvii)

Series (**xiv**) : n = 10,11,12,13,14,15,16,18. Series (**xv**) : n = 9,10,11,12,14,16,18. Series (**xvi**) : n = 9,10,11,12,14,16,18. Series (**xvii**): n = 7,8,9,10,11,12,14,16,18.

The mesophases have been characterized using techniques like DSC, X-ray, polarizing microscopy etc. The mesomorphic properties of the above series of compounds have been compared with those of the unsubstituted parent compounds (resorcinol as the central unit). In series (xiv), where n = 13,14,15,16 and 18 show a monotropic  $B_2$  phase while compounds with n = 9,10,11 and 12 are non-In series (xv), homologues with n = 11,12 and 14, exhibit a mesomorphic. monotropic  $B_2$  phase while those with n = 16 and 18 show a enantiotropic  $B_2$  phase. The homologues with n = 9 and 10 are non-mesomorphic. The lower homologues with n = 8,9 and 10 of series (xvi) exhibit  $B_1$  phase and the rest of the homologues show an enantiotropic  $B_2$  phase with fairly wide thermal range. All the compounds have high clearing temperatures and they undergo thermal decomposition at such temperatures. Compounds belonging to series (xvii) are all non-mesomorphic. The mesomorphic unsubstituted analogues of the above series of compounds exhibit a  $B_2$ phase expect those of series (xvii) which shows an unidentified smectic phase. A comparative study between the two indicates that presence of 2-methyl group in the resorcinol moiety does not favour the formation of the B2 phase in particular and other mesophases in general.

The following papers have been submitted for publication.

- New chiral fluoro substituted benzoyloxybenzoates exhibiting antiferroelectric mesophase (S.Shubashree, B.K.Sadashiva and Surajit Dhara)
  Part of this work was presented at the International Union of Materials Research Societies International Conference in Asia, Bangalore, India, October 13-16, 1998, Abstract No. I, Pos 07, p 296.
- (2) Synthesis and mesomorphic properties of cholesteryl 2-fluoro-4-n-alkoxybenzoates(S.Shubashree and B.K.Sadashiva).
- (3) Synthesis and mesomorphic properties of compounds exhibiting undulated twist grain boundary smectic C\*phase (S.Shubashree and B.K.Sadashiva).
- (4) Effect of 2-methyl substituent of the resorcinol moiety on the mesomorphic properties of compounds composed of bent-core molecules (S.Shubashree, B.K.Sadashiva and Surajit Dhara).

#### REFERENCES

- [1] G.Friedel, Ann. Physique, 18, 237 (1922).
- [2] G.W.Gray and J.W.Goodby, "Smectic Liquid Crystals-Textures and Structures" Leonard Hill, (1984).
- [3] R.B.Meyer, L.Liebert, L.Strzelecki and P.Keller, J. Phys. (Paris)., 36, L69 (1975).
- [4] A.D.L.Chandani, E.Gorecka, Y.Ouchi, H.Takezoe and A.Fukuda, Jpn. J. Appl. Phys., 29, 131 (1989).
- [5] P.G.de Gennes, Solid State Commun., 10,753 (1972).
- [6] S.R.Renn and T.C.Lubensky, *Phys. Rev. A.*, **38**, 2132 (1988).
- J.W.Goodby, M.A.Waugh, S.M.Stein, E.Chin, R.Pindak and J.S.Patel, Nature, London., 337, 449 (1989); J.W.Goodby, M.A.Waugh, E.Chin, R.Pindak and J.S.Patel, J. Am. Chem. Soc., 111, 8119 (1989).
- [8] N.Isaert, L.Navailles, P.Barois, and H.T.Nguyen, J. Phys. II France, 4, 1501-1518 (1994); L.Navailles, R.Pindak, P.Barois, and H.T.Nguyen, Phys. Rev. Lett., 74, 5224 (1995).
- [9] P.A.Pramod, R.Pratibha and N.V.Madhusudana, Current Science, 73, 761 (1997).
- [10] D.R.Link, G.Natale, R.Shao, J.E.Maclennan, N.A.Clark, E.Körblova and D.M.Walba, Science, 278, 1924 (1997).
- [11] D.M.Walba, E.Körblova, R.Shao, J.E.Maclennan, D.R.Link, M.A.Glaser and N.A.Clark, Science, 288,218 (2000).