Physical properties of polar orthogonal smectic phases of bent-core liquid crystals

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Introduction

Bent-shaped liquid crystals have become an essential subfield in the exploration of mesophases since they show unique properties such as chirality and polarity. Thermotropic liquid crystals composed of bent-core molecules exhibit a rich variety of phase structures and phase transitions. Generally, bent-core molecules are comparatively rare to exhibit non-tilted phases. But in recent years, several orthogonal smectic phases are found to be composed of banana-shaped liquid crystals. One of the non-tilted polar smectic phases (SmAP_R) is promising to be utilized in the new generation displays. As a result, the study of such materials is interesting both in academic research and industrial application.

The display mode using SmAP_R phase of bent-core liquid crystal has the advantages of high contrast ratio (3000:1), wide viewing angle (in-plane switching), continues gray level and the most vital point is the quick response (<400μs). However, there are two major shortcomings of this mode. The first one is its high temperature (>130°C). and the second one is the layer stabilization. To realize this display mode at lower temperature and with less energy, new materials have to be synthesized and mixtures made of the bent-core materials with good performance have to be made. Besides, the electric and optical properties of polar orthogonal phases, which mean not only the SmAP_R phase but also other types of ferroelectric and antiferroelectric phases, are also required to be clarified.

Experimental

Bent-core liquid crystals showing polar orthogonal phases are mainly investigated by means of polarizing optical microscopy, X-ray diffraction, second-harmonic generation (SHG) tests, electro-optical (EO) study, and dielectric measurements. For some special materials such as bent core compounds with intermolecular hydrogen bonding, FTIR technique was also used to measure the IR spectra at various temperatures to confirm the effects of H-bond.

In the IR spectroscopy, SrF_2 substrates were used to fabricate cells with 5-μm-spacers and UV curable adhesive between the top and bottom substrates. Cells used in SHG, electro-optical and dielectric measurements were prepared from indium-tin-oxide (ITO) coated glass plates. The polyimide AL1254 (JSR) and SE-1211 (Nissan Chemical) were spin coated as alignment layers for planar and homeotropic cells, respectively. The plates were rubbed antiparallel to achieve homogenous alignment of the molecules. Liquid crystal materials were filled in to cells by capillary action in isotropic phase.

Results and Discussions

A number of series of newly synthesized bent-shaped compounds showing polar orthogonal smectic (SmAP) phases with distinct molecular structures have been investigated through a variety of measurements. Interesting phenomena are found and associated explanations are given as follow.

(1) Unique transition between two SmAP phases

Bent-core mesogens with acetophenone as the central core are the first series of symmetrical materials showing random polarized non-tilted smectic phase (SmAP_R). In contrast to all of the reported SmAP_R liquid crystals which have B_{RevTilted} phase as a lower temperature phase, these compounds exhibit an antiferroelectric orthogonal phase below the randomly polarized uniaxial phase in cooling procedure. What’s more, this phase maintains up to room temperature. Material AP-18NN-18 was selected as a representation for this series of compounds. Fig.1 shows the molecular structure, phase sequence and temperature dependence of layer spacing.

![Molecular Structure](image1)

![Phase Sequence and Temperature Dependence](image2)

SmAP_A 88.97 °C SmAP_R 136.03°C Iso.
Figure 1. (a) Molecular structure and phase sequence of AP-18NN-18; (b) Temperature dependence of the layer space $d$ (obtained from X-ray result).

The unique transition between two polar smectic A phases has been found and studied for the first time.

(2) Polar switching and chirality in the SmA$_{d}$P$_{\lambda}$ phase

SmA$_{d}$P$_{\lambda}$ phase has a bilayer structure and shows antiferroelectric switching under field. In this phase, the free rotation about the longitudinal axis of molecules is hindered by the packing of bent-core molecules and neighboring layers have opposite bending (polarization) directions. In our study, we used a new compound showing the SmA$_{d}$P$_{\lambda}$ phase, and we found electric field induced thresholdless antiferroelectric-ferroelectric transition. The molecule and the model of field induced transition are given in Fig. 2.

Figure 2. Molecular structure of SmA$_{d}$P$_{\lambda}$ banana-shaped liquid crystal and simple model of the field-induced antiferroelectric-ferroelectric transition. Black arrows connected to the arms of bent cores stand for the stronger dipole of CN group.

Another attractive phenomenon is that in this phase chiral domains were also observed in an orthogonal system composed of achiral molecules (Fig. 3).

Figure 3. Homeotropic textures under polarizers decrossed in the opposite direction. White arrows represent polarizer and analyzer. The dark regions with their brightness interchanged by rotating the analyzer clockwise or counterclockwise are chiral domains.

Conclusions

We have characterized several distinct polar smectic A phases composed of bent-core molecules by means of polarizing optical microscopy, X-ray diffraction, SHG, EO and dielectric measurements. Unique and novel phenomena such as transition between polar SmA phases and chirality in SmA$_{d}$P$_{\lambda}$ phases are discovered and investigated. Possible models are suggested to interpret those interesting behaviors of liquid crystals.

Future work

In the first aspect, since the exploration of polar smectic A phases is interesting not only in academic view point but also in the industrial application, I will keep on investigating bent-core liquid crystals and their mixtures showing SmAP phases and try to use them in displays. For example the electro-optical properties of ferroelectric smectic A (SmAP$_{F}$) phase and the mechanism of chirality in SmA phases are two of interesting topics.

On the other hand, I also want to attempt experiments on interdisciplinary subjects. I want to utilize nanofibers and nanoparticles into liquid crystal devises, especially in display. Since nanofibers are able to offer nano-sized porous, it is expected that such porous could help to generate nano-sized droplets of liquid crystals and increase the response speed. What’s more, the displays made of this material do not need any alignment and have very high speed.

Publications

First author


Second author
