Smectic Layer Reorientation Induced by AC Field

Jun Ho Song[1], Yong Bae Kim[2], Satyendra Kumar[3], Jun Hyung Souk[4], and Sung Tae Shin[1]

[1]Department of Physics and Applied Physics, Korea University, Seoul 136-701, Korea

[2]Department of Chemistry, Kon-Kuk University, Seoul 143-701, Korea

[3]Department of Physics, Kent State University, Kent, Ohio 44242, USA

[4]AMLCD, Semiconductor, SEC, KyungGi-do 449-711, Korea

We have studied electro-optic properties and layer deformations in the smectic phases of 4-(6-ethoxy-1-trifluoromethyl-hexyloxycarbonyl)-phenyl-4-Nonyloxybiphenyl-4-carboxylat (TFMEOHPNBC) having fluorine attached to one of its benzene rings by electro-optical and small angle x-ray scattering techniques. 3 and 5μm thick test cells were prepared using beryllium plates to minimize x-ray beam absorption. Layer structure and orientation was studied while changing the amplitude and frequency of the applied electric field as a function of cell temperature. We observed that the chevron layer tilt angle is reduced and layer spacing is increased as stabilizing in antiferroelectric phase. This result is extraordinary that there is dimerization in antiferroelectric phase. We also found that there is a threshold electric field that changes the chevron structure to bookshelf structure. This threshold electric field depends on the frequency and temperature as shown in Fig.1. We will discuss the dynamics of layer orientation as determined from the x-ray, electro-optic and dielectric spectroscopy.

1. Introduction

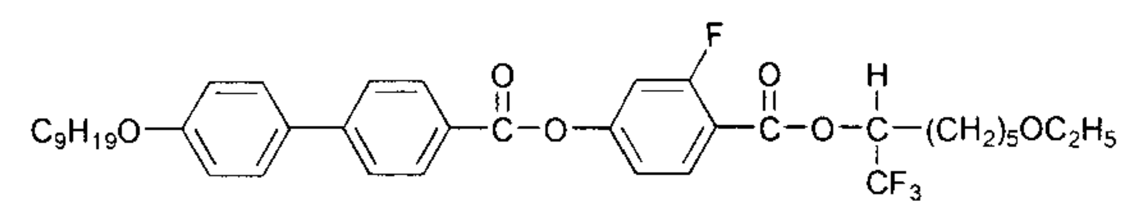
Now a day, the applications of liquid crystals are one of the most important technique for displays and electro-optic switching devices after liquid crystal being found in 1888 by F. Reinitzer [1], Austrian botanist. Conventional TN mode LCD shows good quality of image, but there are still problems of moving picture for AV applications. Accordingly, the new mode of Liquid Crystal being satisfied wide viewing angle and fast response time is needed. The ferroelectric and antiferroelectric liquid crystals have been attracted that they have the big potential of display application because of fast switching and wide viewing properties. But there are several steps to overcome problems, for example low contrast ratio causing zig-zag defects, mechanical durability and so on. Especially, there are many efforts to get rid of the zig-zag defects [2][3].

The x-ray diffraction work of Reiker *et al.* [4] showed a important information of smetic layer. It was found that the smetic layers were bent to form chevrons in ferroelectric liquid crystal cells by using the small angle x-ray diffraction [5][6]. Subsequent x-ray studies tried the influence of applied electric field in FLC cells. In some cases the chevron structure was changed to bookshelf structure by applied electric field but not changed as a function of frequencies [7]. The other cases the chevron structure was not changed even though applied electric field [8]. As a result, the layer changing mechanism has still not been understood due to the several results not showing consistent.

In this work, smetic layers are observed using small angle x-ray diffraction. And, The layer deformation to book shelf from chevron structure is analyzed when it is applied appropriate electric field as a function of frequency

2. Experimental

For the study, we used the liquid crystal molecules of 4-(6-ethoxy-1-trifluoromethyl-hexyloxycarbonyl)-phenyl4-Nonyloxybiphenyl-4-carboxylate(TFMEOHPNBC) having fluorine attached to one of the benzene rings of TFMEOHPNBC which is made by professor Y. B. Kim in Kon-kuk University. The molecular structure of the liquid crystal was same as below.



The cell is prepared by 0.7 mm thick Beryllium substrates to get high x-ray transmittance. The plates were coated with Nissan RN1199 alignment layer which has 1.1° pre-tilt angle and cured 200 °C for 1 hr. The cell was assembled 3 and 5um cell gap with anti-parallel rubbing. An electric field was applied perpendicularly to the conductive beryllium plates.

The high resolution X-ray scattering experiments were done using an 18kW Regaku RU−300 rotating anode generator, with two perfect germanium monochromatic crystal and analyzer crystals, a two-circle diffractometer using copper K_α radiation and its temperature was controlled to better than ±10mK.

The smetic layer spacing depending on temperature in the cell was determined by the peak of 2θ scans through the x-ray diffraction. The layer structure distribution was detected by applied electric field as a function of frequency. Optical observations by the cell using glass substrates were also made to understand the switching mechanism.

3. Results and Discussion

The smetic layer spacing of fluorine attached TFMOHPNBC liquid crystal is shown in Fig. 1. The layer spacing was calculated from the Bragg's law which is $2d\sin\theta = n\lambda$ where d is the layer spacing, θ is the measuring of angle from 2θ , n is the integer and λ is 1.54 Å of the filtered x-ray wavelength.

In the smetic A (SmA) phase, the molecules arranged perpendicular to the layers which size is 35.2 Å. The layer spacing was invariable as decreasing temperature in SmA phase.

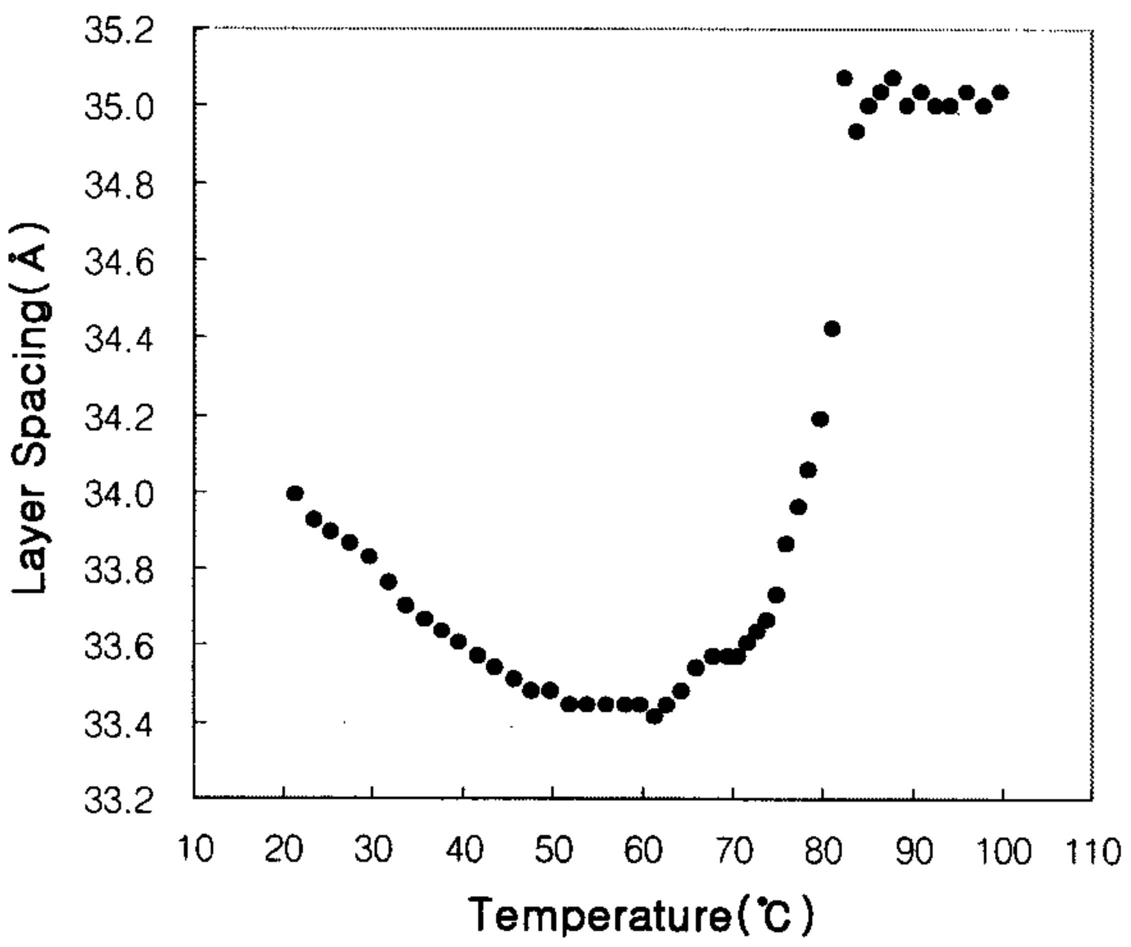


Fig. 1. Temperature dependence of layer spacing in TFMOHPNBC liquid crystal.

In smetic C (SmC) region, layer spacing was steeply decreased around 1.8 Å because of tilting the liquid crystal molecules. There was below 1 °C coexistence of SmA and SmC region. The maximum molecular steric tilted angle of the SmC calculated from the layer spacing was 17°.

The layer spacing in anti-ferroelectric smetic phase was a little bit increased according to decrease temperature. The molecular tilt angle started to decrease at 62 ℃, then the transmittance at 50 ℃ was shown lower than the

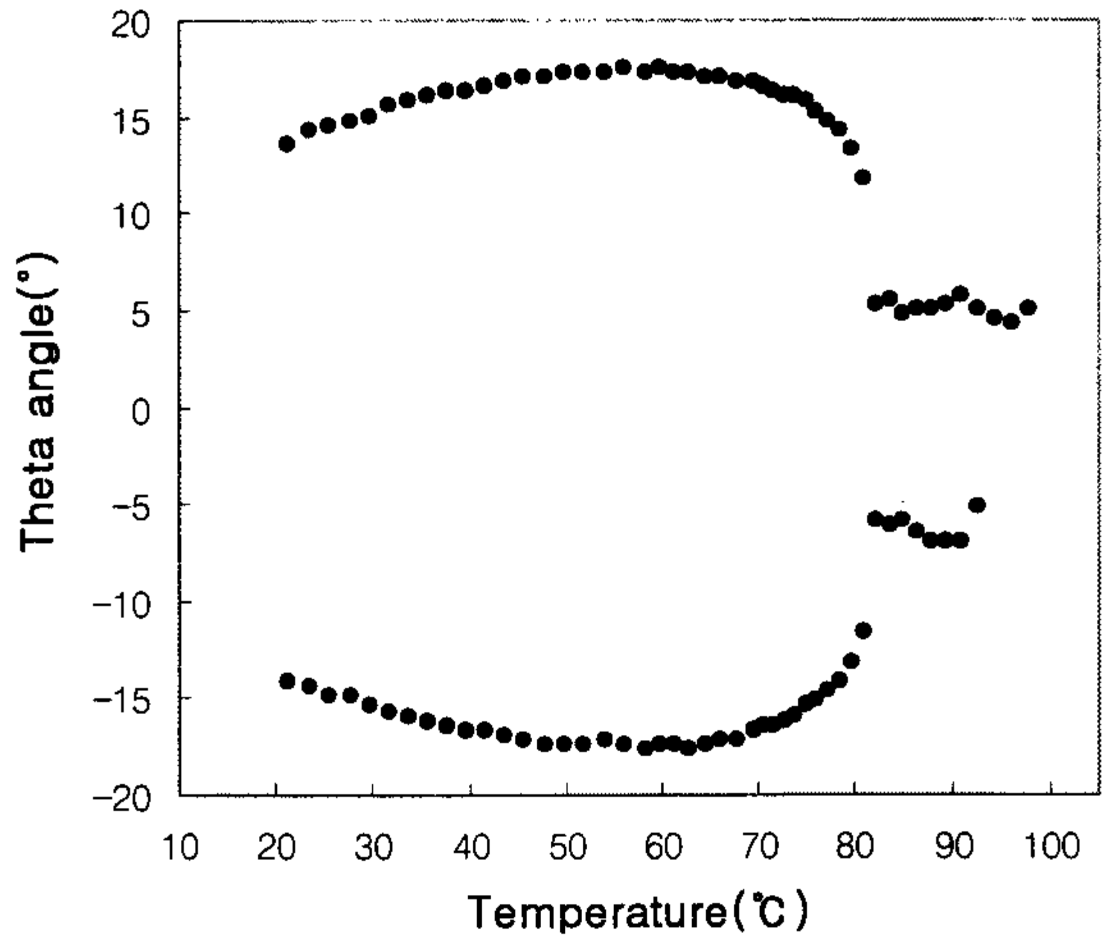


Fig. 2. Layer tilt angle trend depending on temperature.

transmittance at 60 ℃. In SmC_A phase, the transmittance increased even though the molecular tilt angle decreased. In the previous studies[9] [10], Miyachi and Fukuda have investigated about the conformational change from SmC to SmC_A phase. They acquired a result consistent with one of the side chains of the molecules going from being out of the tilt plane to being in the plane from the infrared absorption data. This could be expected to cause the molecular length to increase in SmC_A. We can guess that the optical tilt angle was not decreased according to the decreasing temperature in SmC_A although decreasing the steric tilt angle.

The rocking curves were measured with a sequence of applying electric field with 100 Hz at 40 ℃ (in SmC^*_A phase) for 5 ㎛ cell gap sample. The intensity of rocking curves increased with increasing applied voltage to 70 V (14 V/㎛), but reduced slightly by higher applied voltage of 70 V as shown in Fig.3.

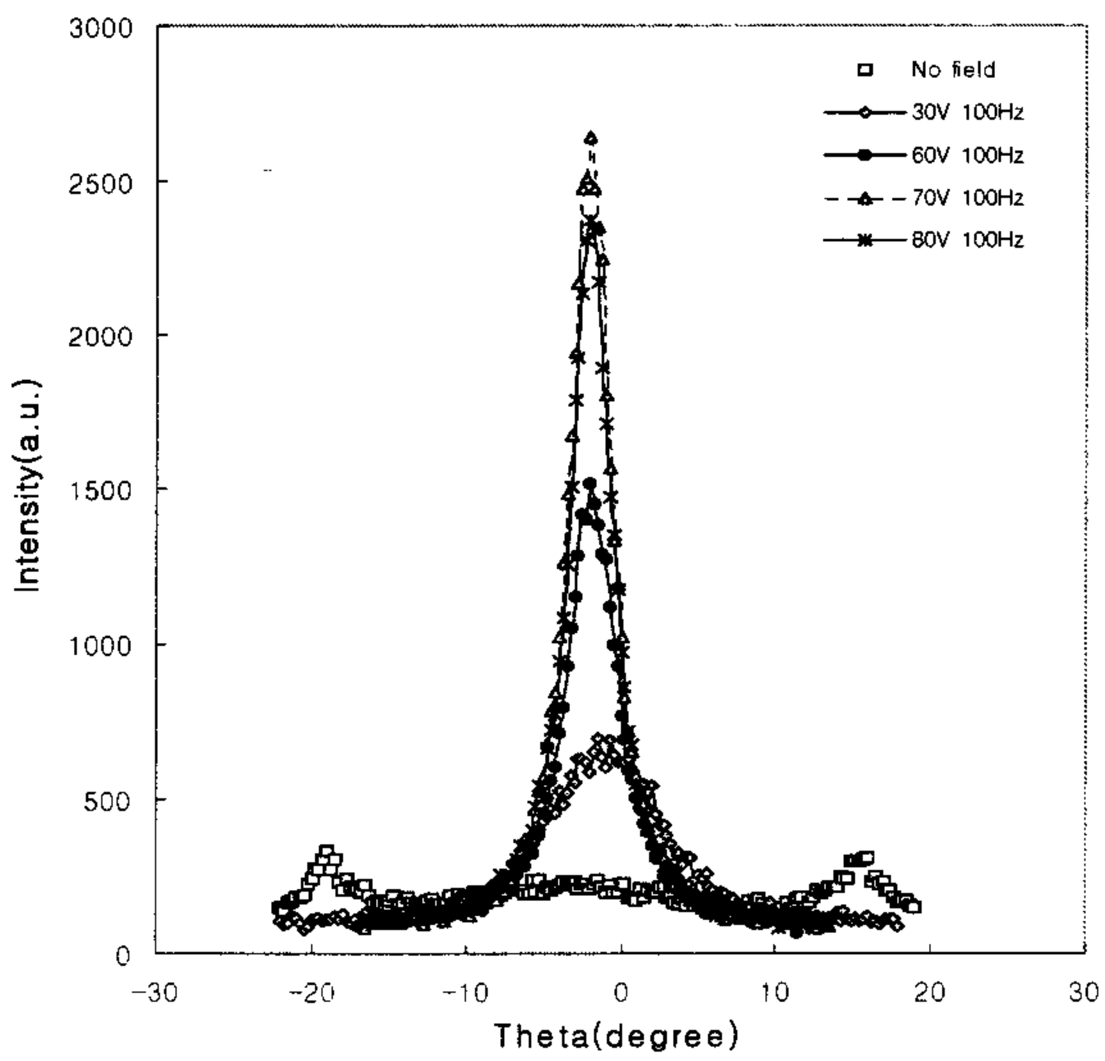


Fig. 3. Rocking curves as a function of electric fields in smectic C_A phase (40) for 5 ㎛ cell gap sample.

The layer reorientation to bookshelf structure was confirmed as an irreversible state from which the relaxed bookshelf structure was obtained 14 hours after turning off the electric field and shorting the electrode as shown in Fig. 4. And the intensity of the rocking curve with 30 V (6 V/㎛) after suffered by high voltage was increased about 6 times comparing to the intensity by initially applied voltage of 30 V.

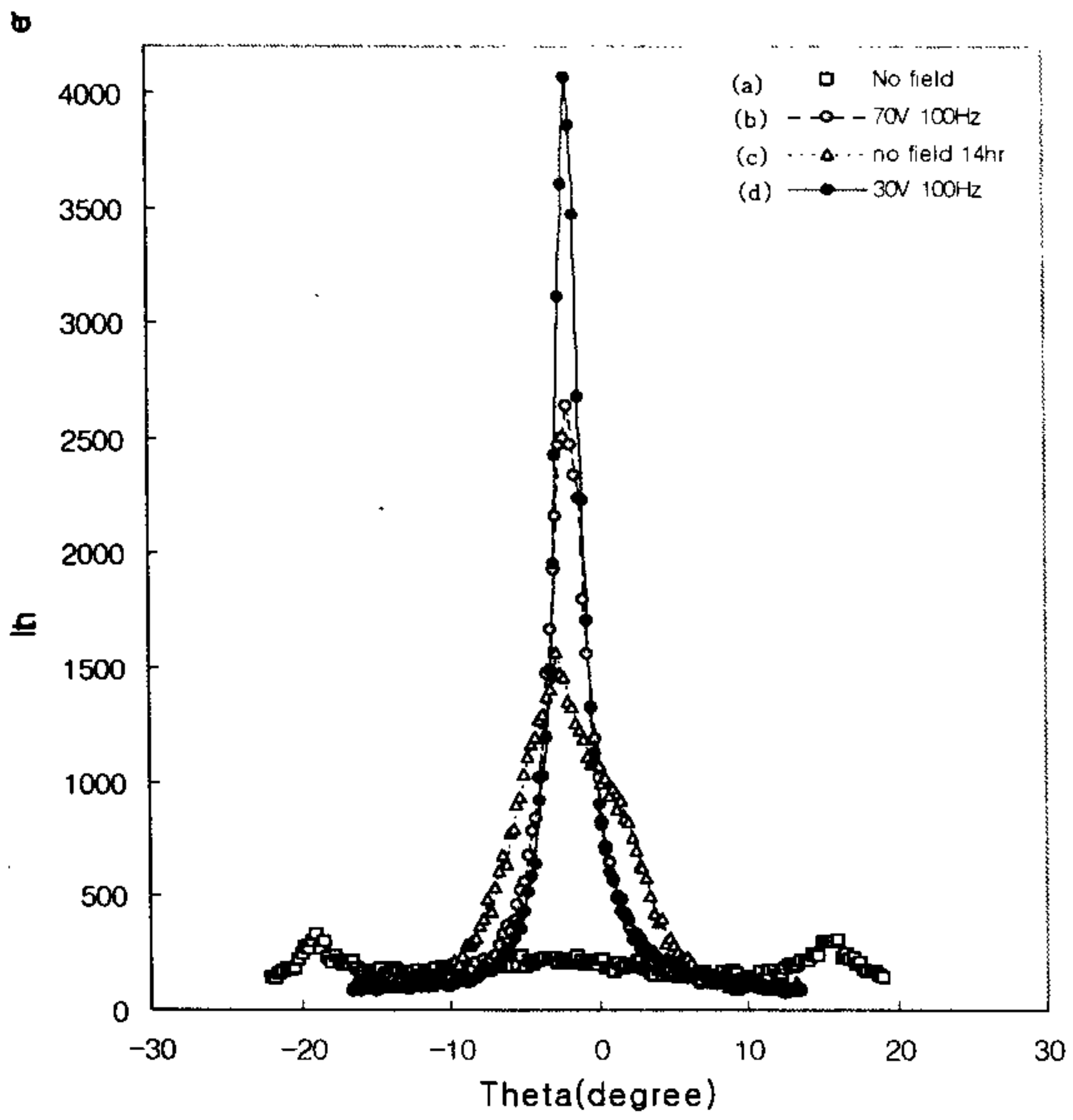


Fig. 4. (a) Initial state of the chevron layer structure (b) The rocking curve after changing to bookshelf layer structure by applying 14 V/㎛ (70 V) (c) The rocking curve with no electric field after 14 hours passed when the electric field was turned off and the electrodes were shorted. (d) The rocking curve during with 6 V/㎛ (30 V) of relatively low applying electric field after measurements of (c)

Finally for the reorientation by x-ray measurements, the full width at half maximum (FWHM), which also known as the bookshelf structure of degree, was measured depending on the applied electric field as a function of temperature and frequencies. All measurements for this experiments, each different temperature and frequency scan was performed after cooling slowly to the required temperature to produce identical structures prior to the application of the electric field from isotropic temperature. Fig. 5 showed the full width half at maximum (FWHM) after changing to the rocking curves of the bookshelf structure depending on applied electric field at 70, 55 and 40 ℃ with 10 Hz, respectively. The threshold electric field, which was the chevron to bookshelf transition, was about 2 V/㎛ with the FWHM of 10° at 70 ℃ in the phase of ferroelectric. The FWHM of the rocking curve was reduced steeply to below 1° by applying electric fields of between 4~10 V/㎛, and slightly increased by applying the electric fields over 10 V/㎛. The trend of the rocking curve at 55 ℃, near transition temperature of SmC^* and SmC_A, was shown similar to the trend at 70 ℃. At 40 ℃ in the phase of antiferroelectric, the threshold of 6 V/㎛ was obtained and the FWHM was reduced gradually by increasing the application of electric field.

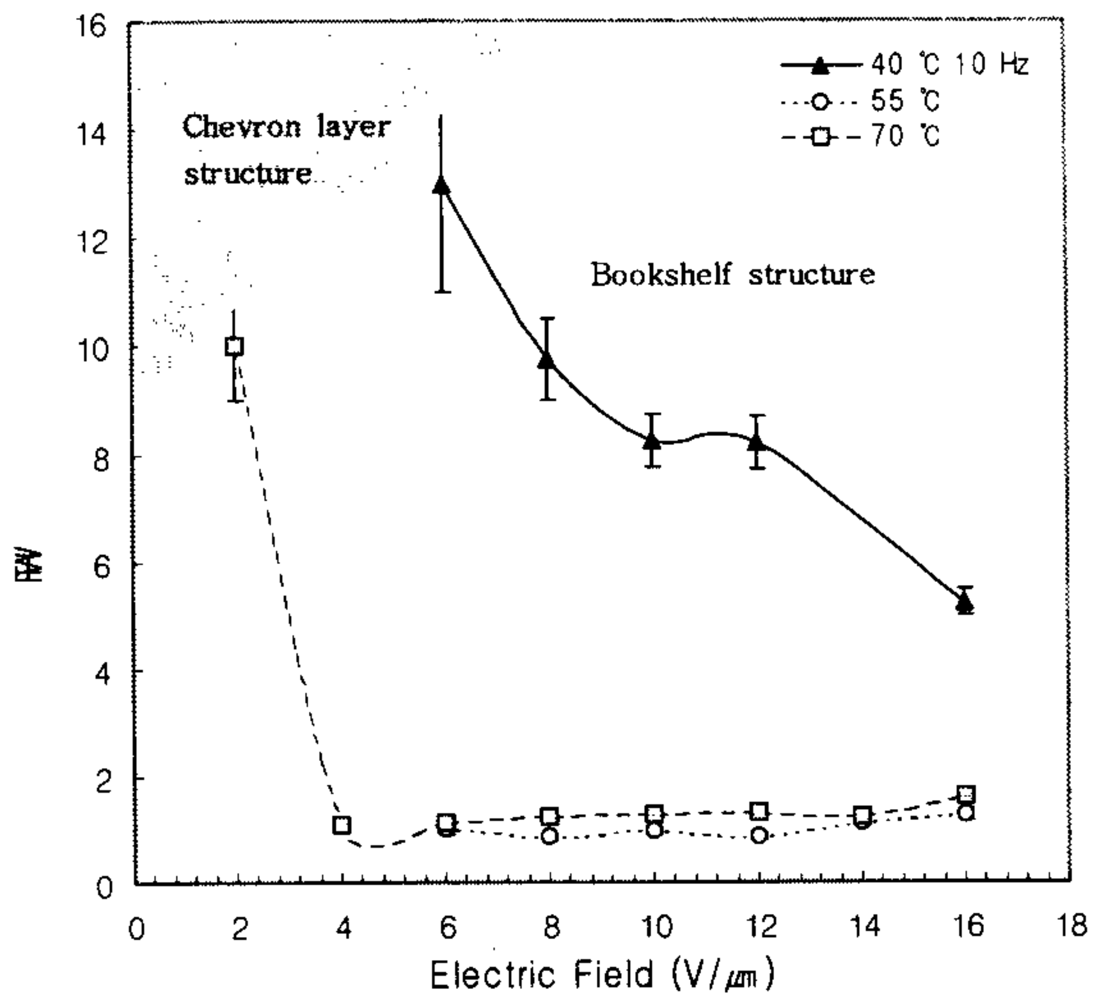


Fig.5 : Full width at half maximum (FWHM) of the reoriented bookshelf layer structure depending on the electric fields as a function of temperature at 10 Hz frequency.

However, the critical threshold electric fields and the FWHM of the bookshelf rocking curves could be defined depending on temperatures when the electric fields were applied with higher than 500 Hz from Fig. 6. And the FWHM of the bookshelf rocking curves showed the tendency of merge with the increase of the applied electric fields.

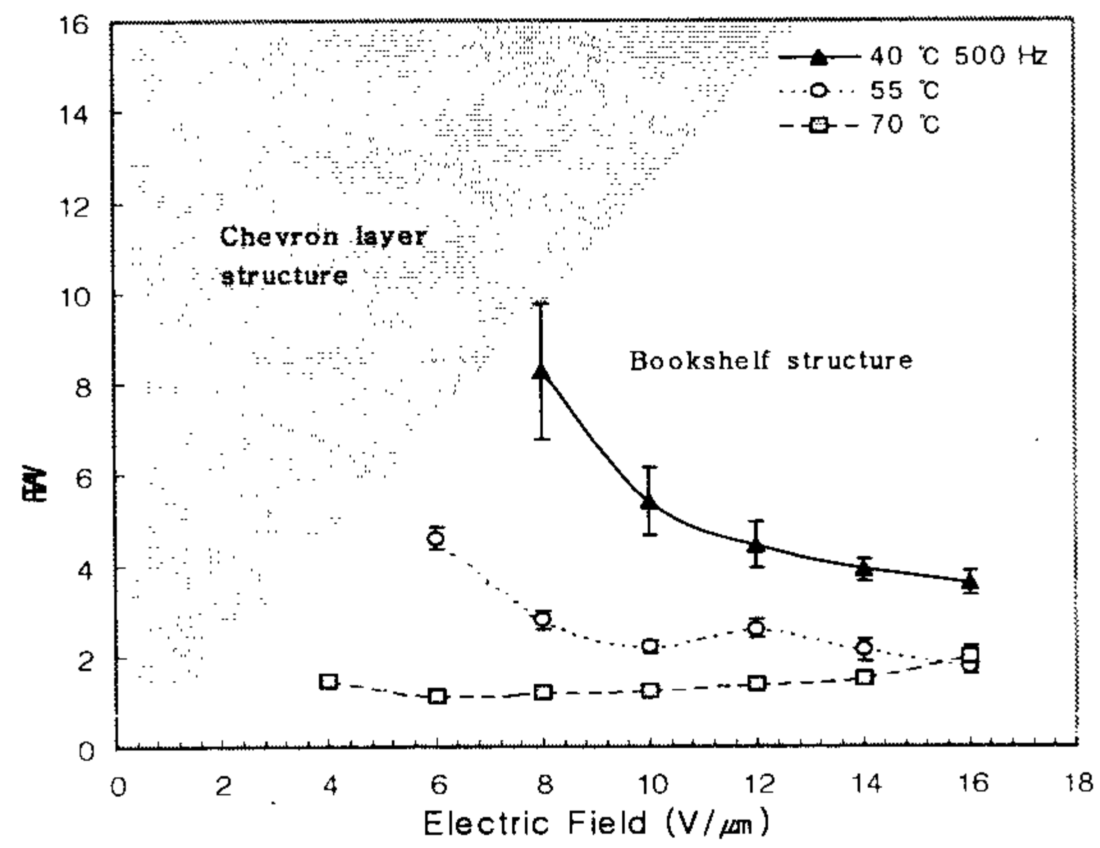


Fig. 6. Full width at half maximum (FWHM) of the reoriented bookshelf layer structure depending on the electric fields as a function of temperature at 500 Hz frequency.

As a result of analyzing the FWHM of the bookshelf rocking curves, 1) the threshold electric field and the FWHM of degree is almost independent of frequencies in SmC* phase, but very dependent upon frequencies in SmC_A phase. 2) Below 100 Hz, the FWHM of the rocking curves is following the phase difference dependence, not the temperature, which can be related to the viscosity of the material, above 500 Hz.

Fig.7 shows the proposed model for the layer structure in the smectic A and C* & C_A phases, and the electric field induced layer reorientation motion. In SmA phase, tilted bookshelf layer structure, pseudo bookshelf layer structure and even low layer tilt chevron structure can be obtained depending on the cell gap thickness and surface condition. The chevron structure in SmC* and SmCA phases, which have almost symmetric angles but different intensity distribution, is independent of the cell thickness and surface condition. The intermediate layer bend of chevron and bookshelf coexists at the threshold condition. The bookshelf or pseudo-bookshelf structure can be obtained during by applying sufficient electric field, and the pseudo-bookshelf structure is maintained after turning off the electric field. We confirmed that this observation is explained the layer reorientation model in detail and it depends on frequencies.

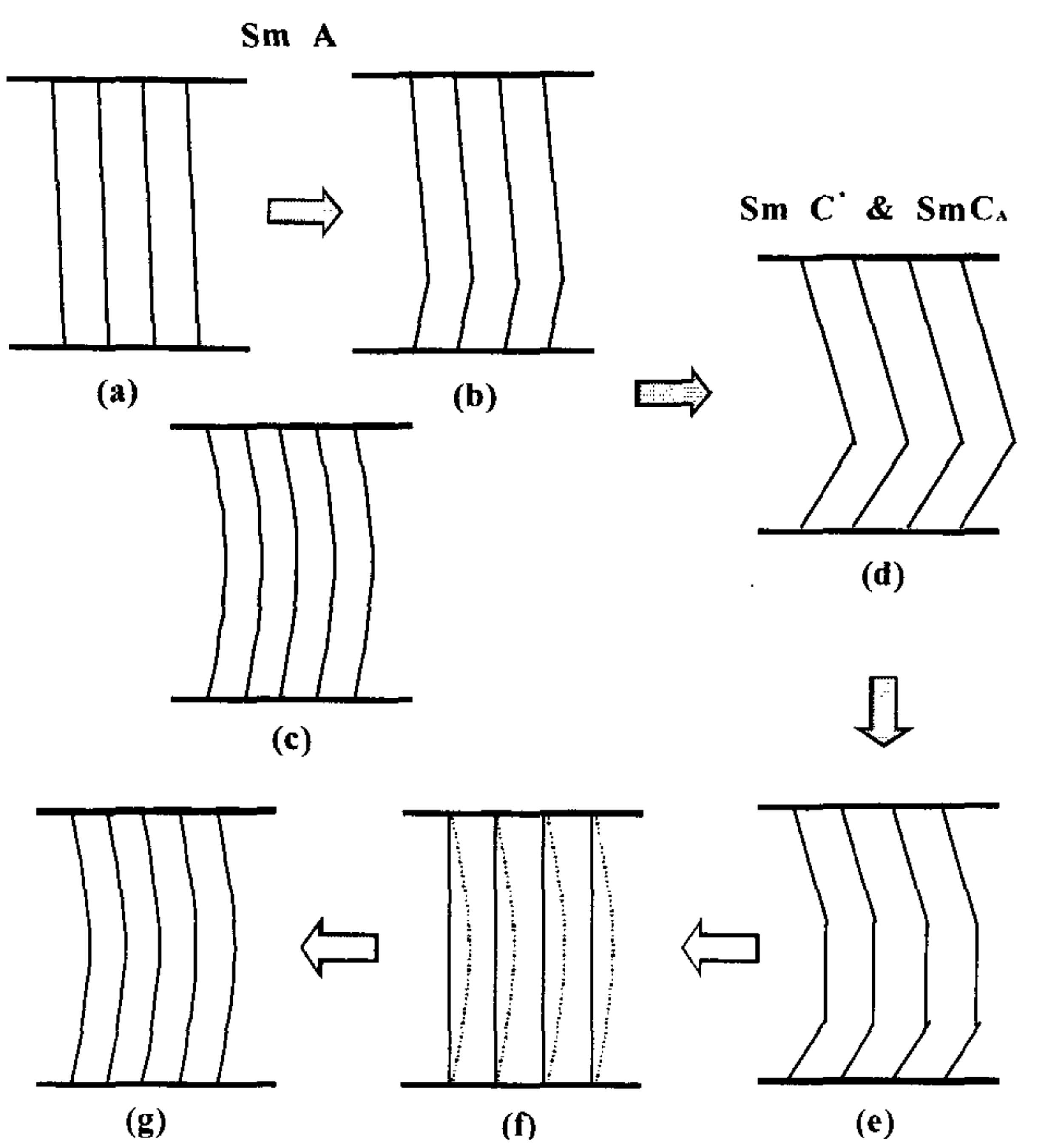


Fig. 7. Proposed model for the layer structure in the smectic A and C^* & C_A phases, and the electric field induced layer reorientation motion.

4. Conclusions

The layer of bookshelf structure from chevron structure as a function of electric field, frequency and temperature is studied. It was found that the chevron to bookshelf transition has a threshold with frequency and the optimizing condition of electric field with a critical frequency. The deformed layer was maintained for a while after the electric field turned off. We also proposed a model for the layer reorientation in smectic A, C and C_A phases.

Acknowledgement

This work was performed Advanced Backbone IT technology development project supported by Ministry of Information & Communication in republic of Korea.

References

[1] F. Reinitzer, *Monatsch Chem.*, **9**, 421 (1888).

[2] M. Terada, S. Yamada, K. Katagiri, S. Yoshihara, J. Kanbe, Ferroelectrics **149**, 283 (1993).

[3] Y. Hanyu, K. Nakamura, Y. Hotta, S. Yoshihara, J. Kanbe, 1993 SID XXIV, 364 (1993).

[4] T. P. Reiker, N. A. Clark, G. S. Smith, D. S. Parmar, E.B. Sirota, and C. R. Safinya, Phy. Rev. Lett. **59**, 2658 (1987).

[5] Yukio Ouchi, Ji Lee, Hideo Takezoe, Atsuo Fukuda, Kasumi Kondo, Teruo Kitamura and Akio Mukoh, Jpn. J. Appl. Phys. **27**, L-1993 (1988).

[6] P. Cluzeau, P. Barois, H. T. Nguyen and C. Destrade, Eur. Phys. J. B, **3**, 73 (1998).

[7] Masahiro Johno, A. D. L. Chandani, Yukio Ouchi, Hideo Takezoe, Atsuo Fukuda, Mitsuyoshi Ichihashi and Kenji Furukawa, Jpn. J. Appl. Phys. **28**, L-119 (1989).

[8] Li Chen and Satyendra Kumar, Appl. Phys. Lett. 71 (2), 664 (1992).

[9] K. H. Kim, K. Ishikawa, H. Takezoe, and A. Fukuda, *Phys. Rev. E*, **51**, 2166 (1995).

[10] K. Miyachi, J. Matsushima, Y. Takanishi, K. Ishikawa, H. Takezoe, and A. Fukuda, *Phys. Rev. E*, **52**, 2153 (1995).