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| Author(s)    | Ohoka, Hiroshi; Ozaki, Masanori; Ganzke, Dirk et al.                                |
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## Dielectric Properties in Ferroelectric Liquid Crystal Mixtures with Short Pitch

Hiroshi Ohoka<sup>1</sup>, Masanori Ozaki<sup>1</sup>, Dirk Ganzke<sup>2</sup>, Wolfgang Haase<sup>2</sup> and Katsumi Yoshino<sup>1</sup>

<sup>1</sup>Department of Electronic Engineering, Graduate School of Engineering, Osaka University.

2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

Tel: +81-6-6879-7759, Fax: +81-6-6879-7774

E-mail: ozaki@ele.eng.osaka-u.ac.jp

<sup>2</sup>Institute of Physical Chemistry, Darmstadt University of Technology

Petersenstr.20, 64287 Darmstadt Germany

### Introduction

Ferroelectric liquid crystal has attracted much fundamental interest and many studies have been reported since its first discovery of ferroelectricity in smectic C\* phase by Meyer *et al* [1]. Because it was the first non-solid ferroelectrics and also various types of fast electro-optic effects have been proposed utilizing ferroelectric liquid crystals [2-4], it has also stimulated extensive studies for practical use [5-7].

The materials for display device are mainly nematic liquid crystals at present. However, the response time of nematic liquid crystal is slow as order of *ms*. It is not enough to display the animation. In this reason, ferroelectric liquid crystals which response as fast as the order of  $\mu$ s have been expected in terms of display application. Generally, helical structure in ferroelectric liquid crystal is undesirable to electro-optical application. However, the possibility of the application has been studied and some electro-optical effects (such as DHS [2], TSM [4], DHF [8] and so on) has been proposed. Moreover, the ferroelectric liquid crystals are also expected for non-display application due to its characteristic electro-optical behavior. For example, when the helical pitch is short and interactions between molecules are strong, it needs high electric field to unwind the helical structure, so fast response is possible by DHF effect. In the case of ferroelectric liquid crystal having the helical pitch which is as short as the order of visible light wavelength, the characteristic selective reflection appears in visible region.

In this study, the temperature dependence of the dielectric constant is investigated in short pitch ferroelectric liquid crystals whose helical pitch is systematically controlled.

### Experimental

All mixtures were prepared with the same achiral matrix (65 weight % of the phenylpyrim-

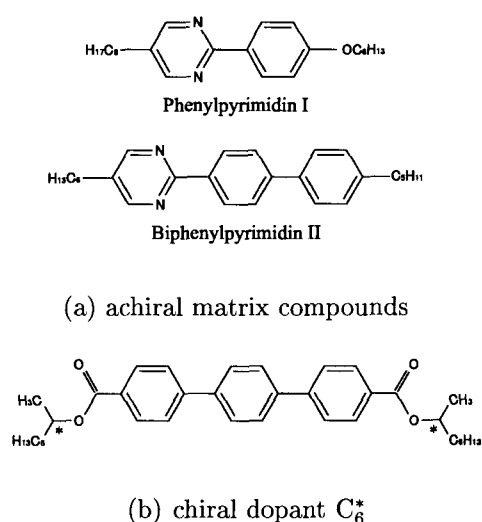


Fig. 1. Chemical structure of the matrix compounds.

idin(I) and 35 weight % of the biphenylpyrimidin(II), Fig.1). This matrix exhibits smectic C phase at a room temperature. The pyrimidins (I+II) were chosen due to their small rotational viscosities compared with their phenyl homologues. This results in faster switching times.

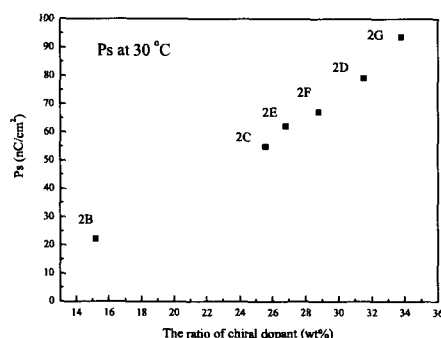


Fig. 2. Spontaneous polarizations of each mixture with different concentration of chiral dopant at 30 °C.

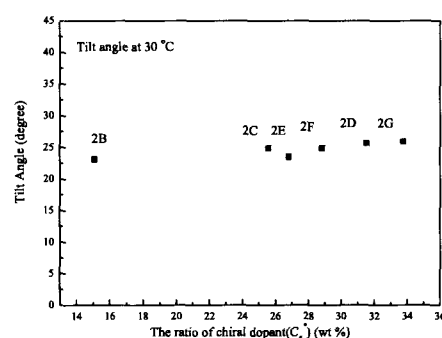


Fig. 3. Tilt angle of each mixture with different concentration of chiral dopant at 30 °C.

As a chiral dopant the R-configuration of  $C_6^*$  (see Fig.1) was chosen due to its strong twisting power. This dopant was solved in the achiral matrix with the desired proportion. The dependence of the liquid crystalline parameters on the concentration of  $C_6^*$  is shown in Figs. 2 and 3. The tilt angle  $\theta$  shows little dependence on chiral dopant ratio. The spontaneous polarization  $P_s$  is a chiral property and increases exponentially with the concentration of chiral dopant  $C_6^*$ .

The samples were sandwiched between two glass plates with indium tin oxide (ITO) transparent electrodes and polyimide layers (JSR Corporation, AL-1254) which is spin-coated and unidirectionally rubbed to obtain planar orientation. The cell-thickness was set with the polyethylene terephthalate sheet.

The dielectric constant was measured with an impedance analyzer (HP 4192A). In the measurements of temperature dependence of dielectric constant, the cooling rate was about 0.02 °C/min.

## Results and Discussion

The temperature dependence of the dielectric constant measured for each sample in the cell of 10  $\mu\text{m}$  in thickness is shown in Fig.4. It is evidently dependent on the length of helical pitch. The temperature dependence of dielectric constant in the sample which has long helical pitch (2B) is the same as that in common ferroelectric liquid crystal.

Under phase transition temperature between smectic A and smectic C\*, the temperature

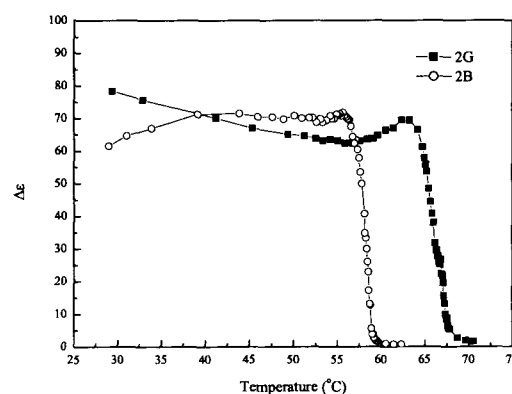


Fig. 4. The temperature dependences of dielectric constant in 2B and 2G.

dependence of dielectric constant showed a sharp peak, and decreased monotonously after that. On the other hand, the temperature dependence of dielectric constant in the short helical pitch sample (2G) shows a sharp peak at smectic A - smectic C\* phase transition and then increases again in the region of low temperature after instant decrease [6,9].

There exist two relaxation mechanisms of the dielectric constant in smectic C\* phase. One is the fluctuation of the azimuthal angle of the molecular long axis around the helical axis, which is denoted as the Goldstone mode. The other is the fluctuation of the tilt angle and is denoted as the soft mode. The temperature dependence of the dielectric constant was measured for cells in various thickness, 2  $\mu\text{m}$ , 10  $\mu\text{m}$ , 100  $\mu\text{m}$  and 250  $\mu\text{m}$ , using sample (2F) which also exhibits unusual behavior of the dielectric constant. Figure 5 indicates evident difference in the variety of cell thickness. In the thick cells ( $> 10 \mu\text{m}$ ),

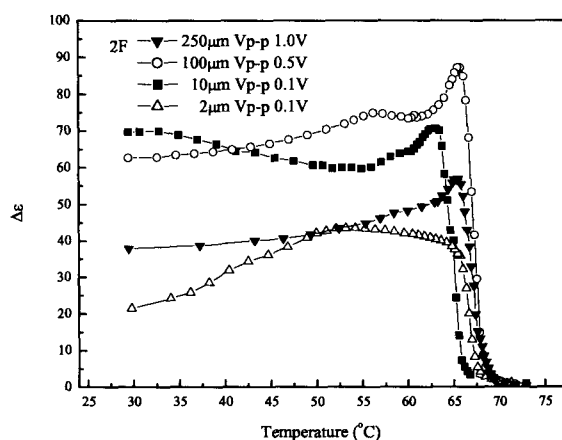


Fig. 5. The temperature dependence of dielectric constant with cell thickness 2 $\mu\text{m}$ , 10 $\mu\text{m}$ , 100 $\mu\text{m}$  and 250 $\mu\text{m}$ .

the sharp peaks were seen under the smectic A - smectic C\* phase transition. To clarify the origin of this sharp peak, the temperature dependence of the dielectric constant in 10- $\mu\text{m}$  cell at various frequencies were measured, as shown in Fig. 6. First, the sharp peak appears at low frequency ( $< 3 \text{ kHz}$ ). With increasing temperature, once the peak disappeared and then appears again at high frequency. However, the profiles of two peaks, one is at low frequency and the other is at high frequency, seemed to originate from different contributions. Figure 7 shows the temperature dependence of the dielectric constant in 2G under D.C. bias field 20 V for the cell of 10  $\mu\text{m}$  in thickness. As known well, under high electric field, the Goldstone mode should be suppressed [10] and the dielectric constant in the smectic C\* phase is decreased just as equal level to that in the smectic A phase. In the Fig. 7, the narrow peak which was considered to originate from the soft mode was observed at the phase transition. This narrow peak is associated with the peak seen in Fig. 6 at high frequency. Therefore, the sharp peak at high frequency shown in Fig. 6 was considered to originate from the soft mode due to the suppression of the Goldstone mode at high frequency. In other words, the peak at low frequency in Fig. 6 which is broader than that at low frequency, is considered to originate from Goldstone mode.

In the thin cell of 2  $\mu\text{m}$ , the temperature dependence of the dielectric constant is much different from the others. It may originate from the large surface effect comparing to the other thicker cells or an unusual behavior of the temperature dependence of the helical pitch because

of the thinness of cell. In the thickest cell of  $250\ \mu\text{m}$ , the temperature dependence of the dielectric constant indicates similar behavior to that of conventional ferroelectric liquid crystals. However, in  $100\ \mu\text{m}$  cell, the slight peak appears after first peak and in  $10\ \mu\text{m}$  cell, the dielectric constant increases again at low temperature. That is to say, the temperature dependence of the dielectric constant indicates different behavior from that of conventional ferroelectric liquid crystals as the thickness of the cell becomes thinner. It is known that the temperature dependence of the helical pitch is greatly influenced by surface [11]. The temperature dependences of spontaneous polarization [12] and tilt angle may also be influenced by surface, but the profiles are not so much different. Therefore these unusual behaviors of dielectric constant at low temperature are considered to be resulted from the unusual temperature dependence of the helical pitch by surface effect.

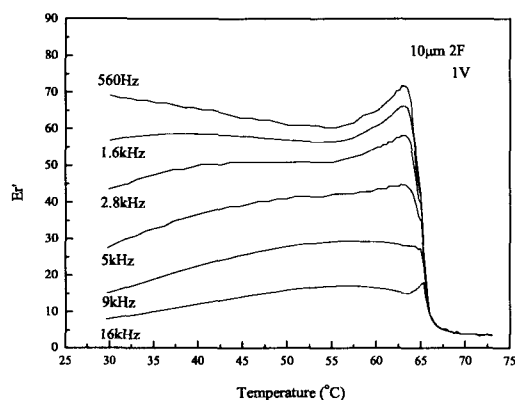


Fig. 6. The temperature dependence of the dielectric constant in 2F at various frequencies for the cell of  $10\ \mu\text{m}$  in thickness.

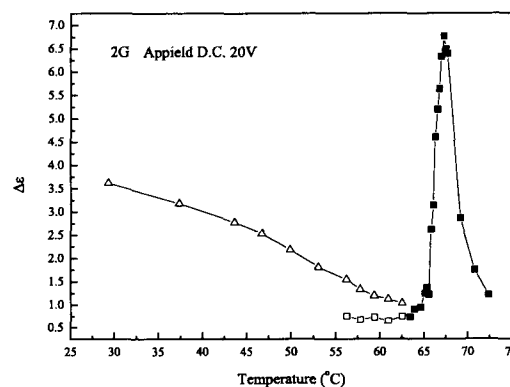


Fig. 7. The temperature dependence of the dielectric constant in 2G under D.C. bias voltage of 20 V for the cell of  $10\ \mu\text{m}$  in thickness.

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