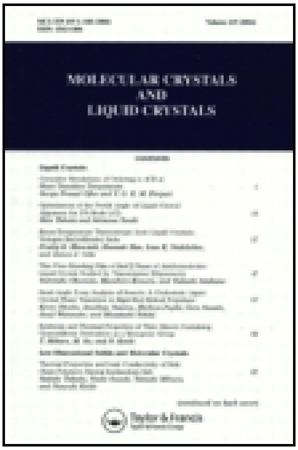

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The Electro-Optic Effects of Smectic Liquid Crystals

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THE ELECTRO-OPTIC EFFECTS OF SMECTIC LIQUID CRYSTALS

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The effects of dielectric anisotropy, the electric conductivity and the molecular orientation on the glass plate were studied on the electro-optical characteristics so as to make clear the mechanisms of the electro-optic effects observed in the smectic liquid crystals. As a result, three types of the electro-optic effects were observed, which depended upon the molecular orientation induced by the dielectric anisotropy and by the conductivity anisotropy.

Tani[1] reported the electro-optical storage effect in a certain smectic liquid crystal with positive dielectric anisotropy, in which optical scattering was induced by being subjected to a voltage and sustained after removing the voltage. However, the details and mechanism of this effect have not been made clear in his report.

In this paper, the authors made studies on the scattering phenomena in smectic-A liquid crystals by using sandwich-type cells varied in orientation on the wall, dielectric anisotropy or electrical conductivity, in an attempt to clarify the scattering mechanism.

In measuring the electro-optical properties, three types of smectic-A liquid crystals shown in Table 1 were used. Table 1 also shows the temperature range of the smectic-A phase and ionic materials added to smectic-A liquid crystals to change their conductivity. The sample was sandwiched between two Nesa-coated glass plates 25μm in thickness.

Table 2 describes that scattering depends on the initial molecular orientation on the glass plates, the dielectric anisotropy and electrical conductivity. The initial molecular orientations are parallel one by rubbing or diphenylchlorosilane treatment,[2] and the vertical one by lecithin coating

TABLE 1 Liquid crystals used in this experiment and ionic materials added into them.

Liquid crystals	Dielectric anisotropy	Temperature range of smectic-A phase	Ionic materials
DBAB	positive (+7.9)	63 - 96°C	CTAC
HBBA	nearly zero (-0.32)	58 - 69°C	TBAB
DBBA(65mol%) CEHE(35mol%)	negative (-2.0)	38 - 61°C	TBAB

DBAB: p-decyloxybenzylidene-p'-aminobenzonitrile
HBBA: p-hexyloxybenzylidene-p'-butylaniline
DBAB: p-decyloxybenzylidene-p'-butylaniline
CEHE: 1-cyano-1-(p-ethoxyphenyl)-2-(p-hexyloxyphenyl)-ethylene
CTAC: cetyltrimetylammonium chloride
TBAB: tetrabutylammonium bromide

TABLE 2 Scattering phenomena in smectic-A liquid crystals

Dielectric anisotropy	Conductivity	Initial orientation	
		Parallel(∥)	Vertical(⊥)
positive	low	S_1---(a)	—
	high	S_1 , S_2	S_2---(b)
zero	low	—	—
	high	—	S_3
negative	low	—	S_3---(c)
	high	—	S_3

S_1 : Scattering phenomena (1)
S_2 : Scattering phenomena (2)
S_3 : Scattering phenomena (3)
— : not scatterd

or acid-treatment. The low and high conductivities given in Table 2 mean $10^{-11} \sim 10^{-12}$ ℧/cm and $10^{-9} \sim 10^{-10}$ ℧/cm, respectively, when the vertical-aligned cells are subjected to the dc voltage of 2.5V.

The scattering phenomenon (1) is observable in the parallel-aligned cell with positive dielectric anisotropy. The voltage dependence of transmittance is typically shown in Figure 1. The scattering is observed above the threshold voltage V_1 but disappears again at still higher voltages. The voltage dependence shows that the state with low dielectric constant changes into that with high dielectric constant at the threshold voltage V_1.

It is made clear from this change of the dielectric constant and microscopic observations that the parallel orientation changes into a vertical orientation at the threshold voltage V_1. This scattering phenomenon (1) seems to be induced by formation of scattering centers during the transformation process from the parallel orientation into the vertical one.

The scattering phenomenon (2) is observable in the cell with the positive dielectric anisotropy and the high conductivity. The voltage dependence of transmittance is shown in Figure 2. The microscopic observation showed that the

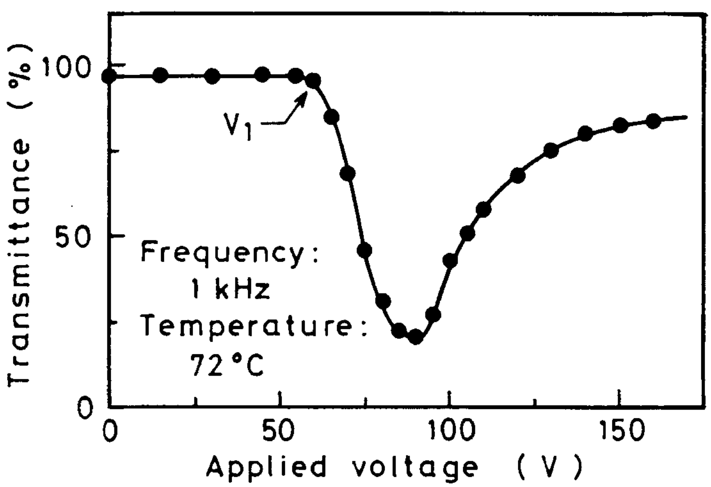

FIGURE 1 Characteristic of scattering phenomenon(1) (corresponding to Table 2 (a)).

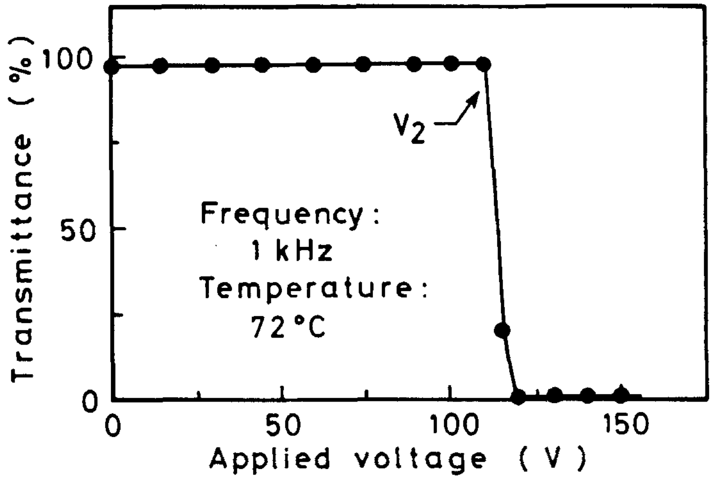

FIGURE 2 Characteristic of scattering phenomenon(2) (corresponding to Table 2 (b)).

disturbance mode in the cells was similar to the dynamic scattering mode in nematic liquid crystals.[3]

It is seen from these results that this disturbance mode seems to depend upon superposition of the orientation effect by dielectric anisotropy and the one by conductivity anisotropy in a similar manner as in the dynamic scattering mode. The direction of the molecular orientation produced by these effects is in contrast to that in nematic liquid crystals. The dielectric anisotropy forces the molecules to align parallel to the electric field and the conductivity anisotropy ($\sigma_\perp > \sigma_\parallel$) forces the molecules to align perpendicular to the electric field.

The scattering phenomenon (3) is observable in the liquid crystal cells, that is, the vertical-aligned, high conductivity cells with small dielectric anisotropic liquid crystal or the vertically aligned cells with negative dielectric anisotropic liquid crystals. The voltage dependence of transmittance is shown in Figure 3. At the threshold voltage V_3, the low conductivity changes into the high conductivity and the vertical orientation of molecules also changes into the parallel orientation. This transformation of molecular orientations is considered to depend upon the dielectric and/or the conductivity anisotropy.

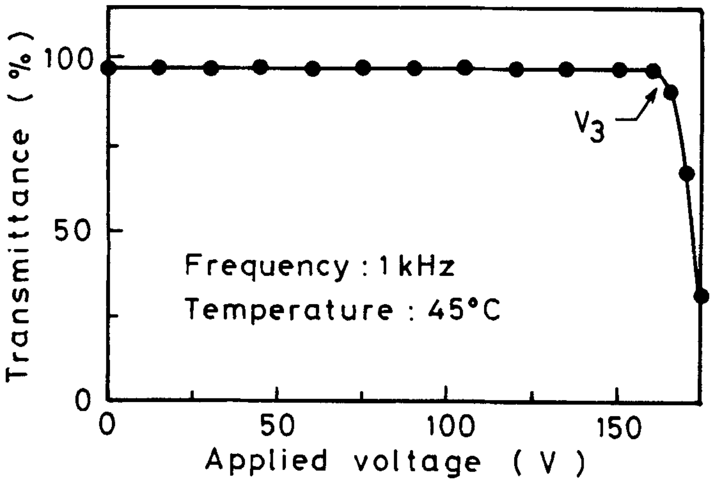

FIGURE 3 Characteristic of scattering phenomenon(3) (corresponding to Table 2 (c)).

The optical scattering seems to be induced by the formation of scattering centers during the process of directional change of orientation.

In Table 3 are summarized the conditions for generation of the scattering phenomena in smectic-A liquid crystals and related effects of orientation of their molecules. Further studies will be reported later.

Acknowledgement

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TABLE 3 The condition for generation of the scattering phenomena in smectic-A liquid crystals and related effects of orientation of their molecules.

Types of scattering	Liquid crystal		Initial orientation	Change of orientation	Factors contributing to change of orientation
	Dielectric anisotropy	Conductivity			
Scattering phenomenon(1)	positive	high, low	$\parallel$	$\parallel \rightarrow \perp$	E
Scattering phenomenon(2)	positive	hige	$\parallel$, $\perp$	$\parallel$ / $\perp$ $\rightarrow$ random	E , I
Scattering phenomenon(3)	zero	high	$\perp$	$\perp \rightarrow \parallel$	I
	negative	low	$\perp$	$\perp \rightarrow \parallel$	E
	negative	high	$\perp$	$\perp \rightarrow \parallel$	E , I

$\parallel$: parallel orientation
$\perp$: vertical orientation
E : orientation by electric field (by dielectric anisotropy)
I : orientation by electric current (by conductivity anisotropy)