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Effect of DNA Doping on Liquid Crystal

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We focus on deoxyribonucleic acid (DNA)-doped liquid crystals and investigate the effect of DNA doping on the molecular alignment structure and electrooptical characteristics for several kinds of DNA molecules such as single and double strands formed by adenine, thymine, guanine and/or cytosine bases. Double strand-DNAs can produce a twist deformation of liquid crystal alignment, while single strand-DNAs cannot. Furthermore, the twisting power is different between the adenine-thymine and guanine-cytosine DNA. As a result of the electrooptical measurement, it has been found that the DNA doping may influence the characteristics such as the response time and threshold voltage.

Keywords Alignment structure; DNA; electrooptical characteristics; response time; threshold voltage; twist deformation

1. Introduction

All matters are formed by atoms and molecules without any distinction of their kinds. However, biological organisms are entirely different from other matters in terms of the self-assembling nano-structure of living tissue and the high responsiveness. On the other hand, distinctive features of liquid crystal system [1–5] are also the easy self-assembly and the high responsiveness. Therefore, we can easily understand their close connection which inspires us with biological systems being not able to exist without liquid crystal systems [6]. It is a well known fact that the study of the liquid crystal started from its discovery during the research of the biological matter in 1888 [1,2]. Therefore, we expect bio-applications such as bio-sensors and medical supplies utilizing liquid crystals and liquid crystal devices with bio-materials which have super-high functionalities. In this research, we focus on deoxyribonucleic acid (DNA) as the biological molecule. It is well known that DNA can show liquid crystalline states [7–10]. We study on the DNA-doped liquid crystals and investigate the effect of DNA doping on the molecular alignment structure and

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the electrooptical characteristics of liquid crystal for several kinds of DNA molecules such as single and double strands (ss and ds) formed by adenine (A), thymine (T), guanine (G) and/or cytosine (C) bases.

2. Experimentals

The materials used in this research were as follows: the liquid crystal was 5CB (Kanto Chem.); the DNAs were ss-DNAs of 10-base A, T, G and C and ds-DNAs of 40-base A-T and G-C (Invitrogen); and the LC alignment film was polyimide SE-150 (Nissan Chem. Ind.). The phase sequence of 5CB is: crystal (25°C) nematic liquid crystal (35°C) isotropic liquid.

A solution of polyimide was spun on glass substrates coated with indium-tin oxide and then baked. After the thermal treatment, the substrates were rubbed. Then, the liquid crystal medium, which was doped with the DNA molecules, was injected in the isotropic phase via capillary action into an empty cell, in which the rubbing directions were set anti-parallel and the cell gap 4 and 25μm for the electrooptical effect and the circular dichroism (CD) measurements, respectively. Next, the cell was cooled gradually to the temperature where the LC medium was in the nematic (N) phase.

The microscopic texture observation and the electrooptical effect measurement were done using a conventional measuring system with a polarizing microscope. We define the response time as follows: the rise and fall times are time for 90% transmittance variation at the on and off states of electric field, respectively, as shown in Figure 1. The response time was measured applying a pulse waveform voltage in which

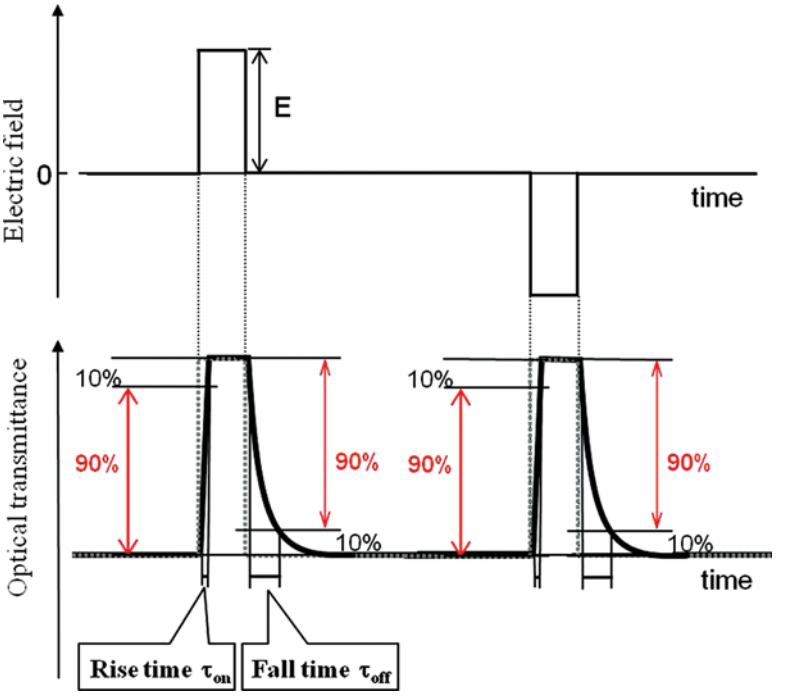

Figure 1. Definition of response time. (Figure appears in color online.)

the pulse width and amplitude were 50 ms and 10 V, respectively. The threshold voltage was measured using a triangular waveform voltage in which the frequency and amplitude were 0.25 Hz and 10 V, respectively. In order to research the twist deformation due to DNA molecules, the CD measurement was carried out using a spectropolarimeter J-720WI (JASCO) with a wavelength range of 300–900 nm.

3. Results and Discussion

Tables 1 and 2 show the clearing temperature of liquid crystal media doped with ss- and ds-DNA, respectively. It is found that the clearing point is not almost changed

Table 1. Clearing temperature of ss-DNA doped 5CB

	Clearing temperature [°C]			
Concentration [μM]	Adenine (A)	Thymine (T)	Guanine (G)	Cytosine (C)
0	34.8 (pure 5CB)			
25	35.4	34.7	35.3	35.4
100	35.2	35.1	34.7	35.0

Table 2. Clearing temperature of ds-DNA doped 5CB

	Clearing temperature [°C]	
Concentration [μM]	Adenine-thymine (A-T)	Guanine-cytosine (G-C)
0	34.8 (pure 5CB)	
25	35.1	34.8
100	34.6	35.0

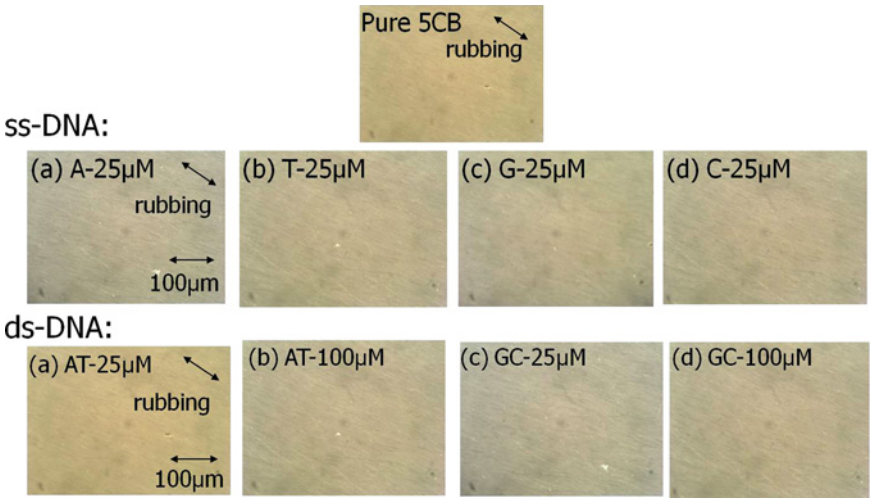

Figure 2. Microscopic textures of DNA-doped liquid crystals. (Figure appears in color online.)

even by DNA doping of 25 and 100 μM concentration. Therefore, the DNA doping does not strongly influence the thermodynamics of liquid crystal molecules.

Figure 2 shows the microscopic textures of DNA-doped liquid crystals. It is found that the microscopic textures of DNA-doped liquid crystals are not different from that of pure 5CB with a uniform alignment. Thus, DNA molecules do not condense in liquid crystal system and not macroscopically vary the molecular alignment of liquid crystal.

Figure 3 shows the CD spectra in DNA-doped liquid crystals, in which a chiral dopant (0.1 wt% CM-33: Chisso) was doped in all media because 5CB used was 99.9% purity and the CD peak was observed even in a conventional cell of 5CB without DNA. It is found that although the DNA doping cannot change the macroscopic molecular alignment of liquid crystal in the homogeneously rubbing cell, ds-DNA

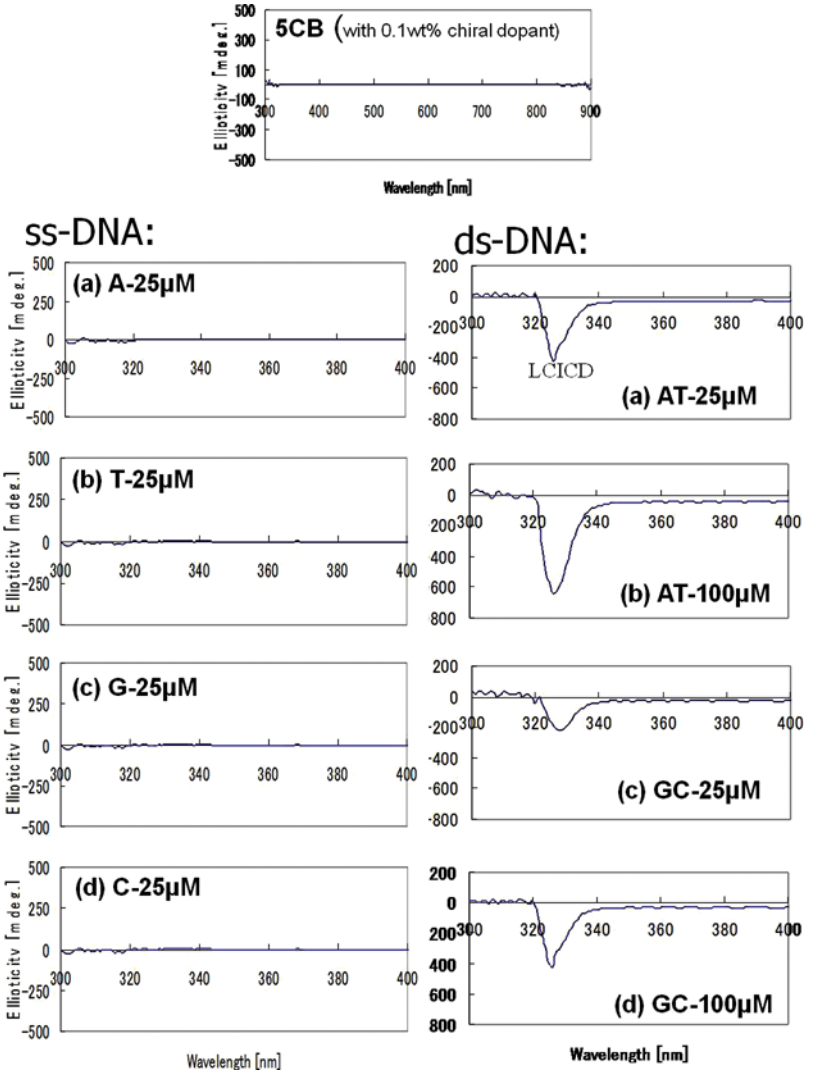

Figure 3. CD spectra in DNA-doped liquid crystals. (Figure appears in color online.)

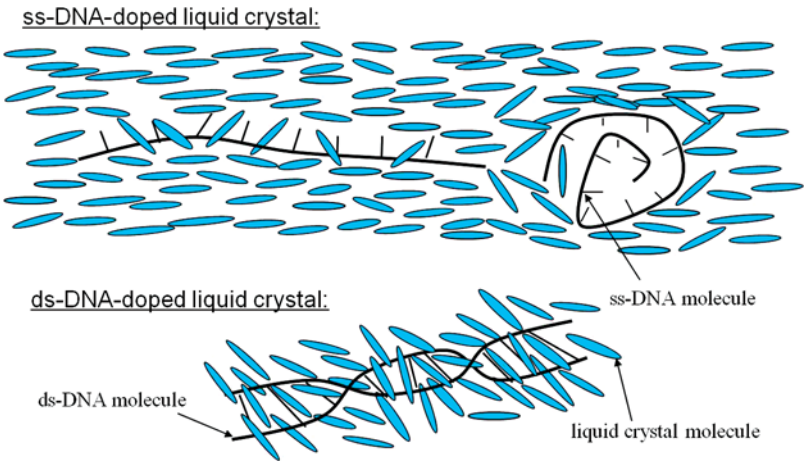

Figure 4. Molecular alignment structure models of DNA-doped liquid crystals. (Figure appears in color online.)

can produce microscopically a twist deformation of liquid crystal system accompanying with the liquid crystal induced CD (LCICD) [11–13], while ss-DNA cannot. It is inferred that this twist deformation originates from the molecular twist conformation of ds-DNA, as illustrated in Figure 4. Furthermore, it attracts our attention that the twisting power is different between the A-T and G-C DNA molecules. The high-speed DNA sequencing would be able to realize by utilizing the liquid crystal system.

Tables 3 and 4 show the electrooptical characteristics in terms of the response time and the threshold voltage. It is found that the DNA doping does not strongly influence the response time, but may give a tendency of the fall time; (pure liquid crystal) < (ss-DNA-doped liquid crystal) < (ds-DNA-doped liquid crystal), though

Table 3. Response time of DNA doped 5CB

	Rise time τ_{on} (μs)	Fall time τ_{off} (ms)
pure 5CB	965	38
100 μM-A doped	795	43
10 μM-AT doped	940	58
10 μM-GC doped	760	58

Table 4. Threshold voltage of DNA doped 5CB

	Threshold voltage (V)
pure 5CB	0.19
100 μM-A doped	1.25
10 μM-AT doped	0.25
10 μM-GC doped	0.23

not of the rise time for the measurement accuracy in this work. The DNA doping would not strongly influence the rise response because the rise response at on-state originates in the coupling effect of electric field and dielectric polarization. On the other hand, since the fall response at off-state originates in the elastic effect, the DNA doping may influence the fall time. Moreover, it is found that the threshold of ss-DNA-doped liquid crystal is much higher than that of pure and ds-DNA-doped 5CB. It is guessed that the threshold increasing originates in the depolarizing field due to the ionic behavior of ss-DNA molecules.

4. Conclusions

We researched the effect of DNA doping on the molecular alignment structure and electrooptical characteristics of liquid crystal. The ds-DNAs can produce a twist deformation of liquid crystal alignment, while ss-DNA cannot. It is inferred that this twist deformation originates from the molecular twist conformation of ds-DNA. Furthermore, the twisting power is different between the A-T and G-C DNA molecules. In the electrooptical characteristics, the DNA doping may influence the fall response time of liquid crystal and the ss-DNA doping strongly influences the threshold electric field by the occurrence of the depolarizing field due to the ionic behavior of ss-DNA molecules.

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