Preliminary Experiment on Fast Response Liquid Crystal Drive by Photo-Induced Flexoelectric Effect

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ABSTRACT

Aiming for realizing ultrafast response by rotating the long axis of the liquid crystal molecule, novel driving scheme based on photo-induced flexoelectric effect are investigated. As a fundamental experiment, response time of nematic liquid crystal mixed with p-dimethylamino-azobenzene are measured with using sandwiched cell whose inner bottom surface has groove structure.

1 Introduction

Liquid crystal displays (LCDs), which are classified as non-light emitting displays, have disadvantage as such that the optical response speed is slower than light emitting displays such as organic electro-luminescence and micro light-emitting diode. Generally, response speed of LCDs is about several milliseconds. In order to further improve the performance of optical devices including LCDs that use liquid crystals (LCs), it is necessary to improve the response speed. According to Hada et al.,[1] UV irradiation of azobenzene derivative molecules doped in SmB LC results in a light transmittance change of $\Delta T/T = 5 \times 10^{-3}$. Electron diffraction intensity measurements show intensity variation of $\Delta T/T$ = 0.13, its response speed is as fast as 180 ps. Cattaneo et al. [2] reported that femtosecond laser irradiation to a homogeneously aligned LC cell filled with 4-pentyl-4'- cyanobiphenyl (5CB) resulted in picosecond order response observed by the pump-probe method. As another approach to improve the response speed of LCDs, flexoelectric effect [3, 4] attracted the researchers interests. Flexoelectric effect is a phenomenon in which the dipole moment of LC molecules is not offset when the spray and/or the bend deformation occur in the LC alignment field, and resultant macroscopic polarization exhibits. Flexoelectric response is regarded to be faster than the dielectric response [5-8].

In this study, an attempt to cause a photo-induced bend deformation driven by photo-isomerization is investigated, where flexoelectric polarization switching is detected by using nematic LC doped with p-dimethylamino-azobenzene (DAB). Our goal is to demonstrate an ultrafast response of molecular rotation around the long molecular axis induced by flexoelectric effect stimulated with femtosecond light pulses.

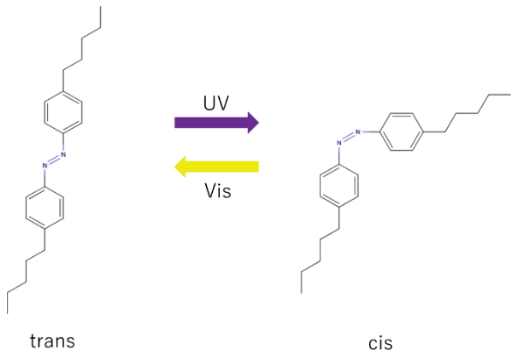

Fig. 1 Trans-to-cis photoisomerization of DAB

2 Concept

The fascination of ferroelectric liquid crystals (FLCs), which was eagerly researched in the 1980s, was high-speed response caused by molecular motion around the long molecular axis (i.e. Nambu-Goldstone mode and soft mode). FLCs had not widely used as display materials because they possess smectic phase, which was difficult to be controlled the molecular alignment unlike nematic LCs. Therefore, we invented a novel concept of ultra-fast switching by photo-induced flexoelectric polarization in the direction perpendicular to the long molecular axis with a nematic LCs that is easy to control the orientation and switching by rotating around the long molecular axis. DAB, as a photoisomerization reaction agent shown in Fig.1, is doped with 5wt% into host nematic LCs. DAB has an absorption band of π-π* electrons near 360 nm and leading to trans-to-cis photoisomerization by irradiation with UV light. The transformed cis-DAB is a dogleg shaped molecule, and surrounding NLC molecules may follow this bend deformation. By arranging molecules of LC mixture onto a groove structured whose surface is covered by vertical alignment agent, bend deformation can be

controlled simply by molecular rotation around the long axis of the molecule. Figure 2 shows the schematic illustration of this novel LC driving concept. The molecules in the leftmost column of Fig. 2 represent before UV irradiation, where the shape of all molecules is straight and vertically aligned against

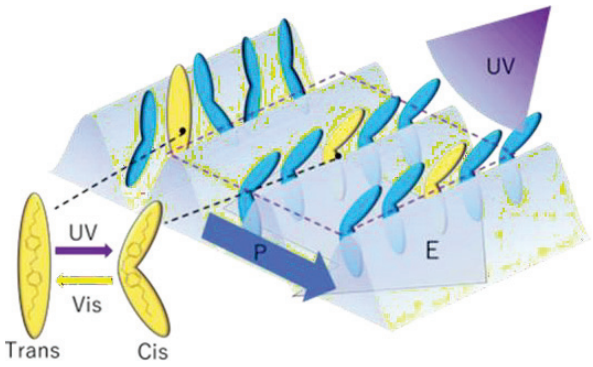

Fig. 2 Concept illustration of ultrafast response nematic liquid crystal

the groove structured surface. Right after UV irradiation, DAB bends in a dogleg shape. LC Molecules around the DAB are bend-oriented according to the dogleg shape of the DAB, then bend-orientation induces the flexoelectric polarization. At this moment, the direction of flexoelectric polarization is horizontal random and not aligned. Therefore, the flexoelectric polarization can be switched by applying an in-plane electric field as shown in right column in Fig. 2. The director profile seems to be similar to zenithal bistable device (ZBD) [9].

3 Experiment

To fabricate a sandwich type LCD cell, glass substrate was processed with surface cleaning using a plasma ashing instrument. The hydrophilicity was improved by performing for 30 minutes. Fig. 4 shows a cross-sectional illustration of a cell structure in which flexoelectric polarization is expected to occur due to orientational deformation. The groove structure on the bottom substrate surface was formed using a two-luminous flux interference exposure system. The laser beam with a wavelength of 355 nm is divided into two beams, and they superimpose at 10° angle of incidence to interfere with each other. Interfered Laser beams are incident to the photoresist-coated glass substrate. The nominal pitch and height of the groove structure shown in Fig. 3 are 1 μm each. The top substrate is common flat surface with electrodes for in-plane electric field. A vertical alignment layer was spin-coated (1st: 800 rpm, 2nd: 2200 rpm) on each glass substrate, then prebaked at 100 °C, and post-baked at 180 °C. LC mixture is filled at isotropic phase temperature into the cell which was composed of top (flat surface) and bottom (groove structured surface) substrates with using an adhesive and a spacer. As a liquid crystal mixture, fluorine based nematic LC and DAB was used. It was heated at 120 °C. and stirred at a rotation speed of 800 rpm. A homogeneously aligned sandwich type cell whose nominal cell gap was 15.2 μm was also prepared to confirm the nematic phase of this mixture.

Fig. 3 Laser microscope image of groove structure

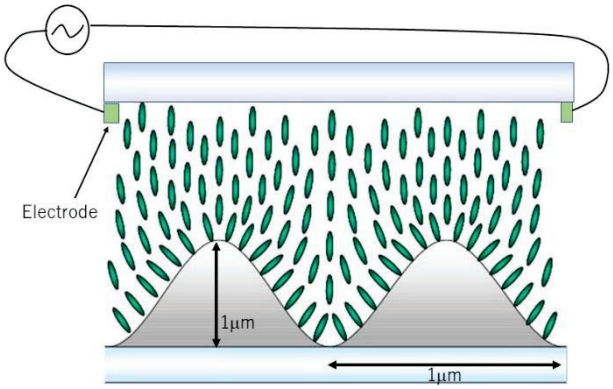

Fig. 4 Schematic sideview of the LCD sample

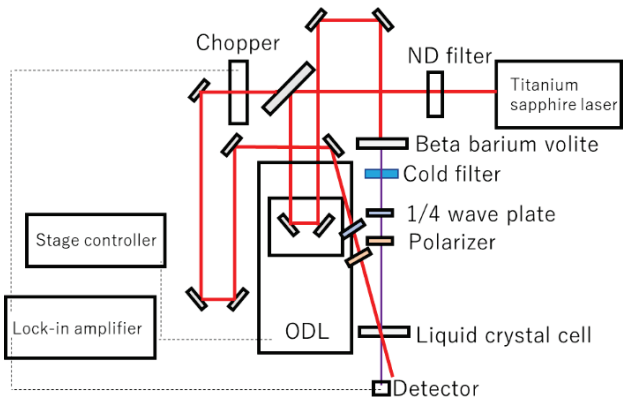

Fig. 5 Pump-probe optical system

Figure 5 shows a typical pump-probe method optical system constructed in our experiment. A titanium sapphire laser light (XF-1 Spectra-Physics, pulse width δ = 103 fs) is split into two beams by a beam splitter. One is for probe light and the other is for pump light. Based on second harmonics generation technique, the pump light was converted to 390 nm by β-BaB_2O_4 (BBO) from 780 nm light. The state of polarization of laser beams was converted by 1/4 wave plates and polarizers to *p*- or *s*- polarization, and the two laser beams were irradiated so as to overlap on the sample LC cell. It is possible to perform time-resolved measurements of picoseconds and femtoseconds.

4 Results

To confirm a response of photoisomerization, laser beam (390 nm, 0.49 W/cm^2) was irradiated onto the homogeneously aligned sandwich type cell. As shown in Fig.6, it was found that in the entire yellow cell by the trans-type DAB, only a part irradiated with the laser is orange, which implies the trans-to-cis photoisomerization.

To verify our pump-probe optical system, Fig. 7(a) represent the spectrum intensity obtained with using spectrometer (BLUE-Wave, StellarNet). The probe light (780nm) that excites BBO also serves as the probe light for the LCD sample, however it is too strong to illuminate the LCD sample, therefore 780 nm light is attenuated by attenuator, resulting in a broadened spectrum. Fig. 7(b) represent the spectrum intensity, where the sample LCD was inserted. It is clearly found that the 390 nm light as excitation light of the LCD sample cell was completely absorbed by the LC substance regardless of DAB doping. This result implies that the photoisomerization of DAB does not cause sufficient orientational deformation to induce flexoelectric polarization in the case of homogeneously aligned sandwich type cell. Soon we will carry out pump-probe method measurement with four polarization combination of probe light of 780 nm and pump light of 390 nm with using the sample with groove structured surface.

5 Summary

It is expected that the dynamic molecular motion is occurred only by molecular rotation around the long molecular axis. Since it can be driven without other molecular rotation or translational motion, ultrafast response is expected. Elemental technologies to realize this drive method are currently under developing.

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Fig.6 Trans-to-cis photoisomerization by LASER irradiation with 390 nm

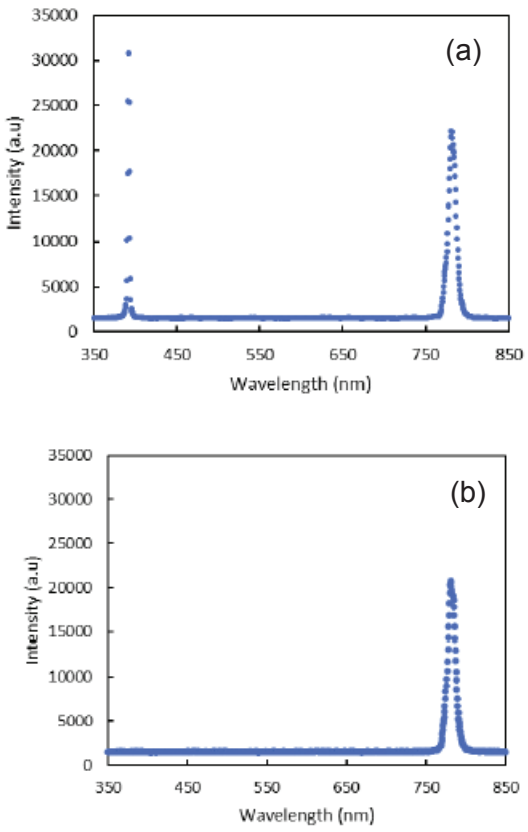

Fig. 7 Spectrum intensity. (a) without inserting LCD sample, (b) LCD sample was inserted

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