Self-Recovery Mechanical/Optical Characteristics of Gel-state Liquid Crystal Mixtures for Stretchable Displays

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ABSTRACT

In this paper, we present our recent studies on liquid crystal gel films as the light modulation layer for stretchable liquid crystal displays. The liquid crystal gel with self-assembly dendrimer showed light modulation based on electro-optical effect, durability to elongation and structural recovery by thermal treatment. Reversible reaction of self-assembled network will be useful for reliable stretchable liquid crystal display.

1 Introduction

Flexible liquid crystal displays using plastic substrate as the next-generation display have been developed because their advantages are expected to lead innovation to current information-driven society. In these flexible displays, stretchability is powerful feature for attachment on three-dimensionally curved surface and stretchy place. For this reason, realization of stretchable display is desirable for attachment on human skin, clothing and robot as the wearable or Internet of Things devices.

Stretchable liquid crystal display using patterned ultraviolet light irradiation has been reported in recent years[1]. This stretchable display is composed of nematic-phase liquid crystal, gelator and azo-based dye. The photoisomerization of azo-based dye which is induced by ultraviolet irradiation enables display of pictogram. Besides, the structural durability to biaxial stretching was achieved by formation of elastic gel-state liquid crystal. However, visual information in this method is limited to the display of static image. The development of liquid crystal gel showing electro-optical characteristics is required for display function of various dynamic images. Also, there is the trade-off relation between flexibility and robustness of display device[2]. To ensure the stretchability, softness of display components become key technology. A balance between stretchability and reliability is one of difficult challenges in the development of stretchable displays.

To overcome these issues on liquid crystal layer, we proposed dichroic dye-doped liquid crystal gel, as shown in Fig.1. The brightness can be controlled by voltage

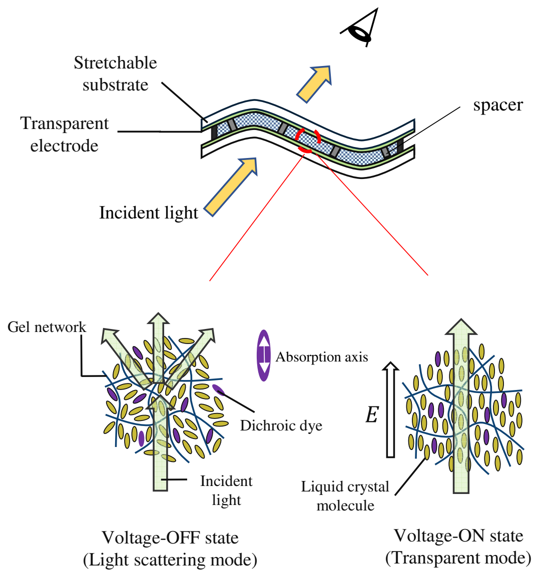

Fig. 1 Proposed device structure for stretchable liquid crystal devices.

switching (molecular alignment of dichroic dye), using guest-host effect. The gel network structure is expected to suppress because both molecular alignment and optical characteristics are changed by flow effect. Also, gel-state material can be usually classified as physical and chemical gel. If formation of physical liquid crystal gel is possible, structural recovery is expected by thixiotropy of gel material. This unique property will be useful for lifetime-free stretchable liquid crystal devices and we will be able to overcome the balance issue between flexibility and reliability as the display device.

In this paper, we present liquid crystal gel films composed of self-assembly dendrimers with lysine groups and nematic-phase liquid crystal for stretchable displays. We discuss the evaluated electro-optical property[3] and mechanical stability of liquid crystal gel[4]. Note that we aimed to achieve stretchable display assuming the maximum stretching rate of human knee, about 1.5-fold elongation.

2 Self-assembly Dendrimer Based on Hydrogen Bonding

G. Tang et al. has already reported self-assembly dendrimer with lysine groups (POSS-Lys)[5]. This dendrimer molecule forms columnar stacking structure by hydrogen bonding, as shown in Fig.2 (a). This bonding shows reversible reaction to thermal treatment (Sol-gel transition temperature: 120°C). We focused on this material as the gelator. The reasons are follows. One is that this material is categorized as physical gel and has self-assembly characteristics. This feature is expected to structural recovery of destroyed LC layer by unintentional force. Another is that mechanical strength of gel network is expected to be strong due to many lysine groups. This gelator was synthesized by Nard Corp. To confirm the formation of liquid crystal gel, we attempted some kinds of nematic-phase liquid crystal. As the results, terminally-modified liquid crystal with cyano group, such as 4-Cyano-4'-pentylbiphenyl (5CB, purchased from LCC) exhibited suppression of fluid behavior even if the bottle stands inversely (see Fig. 2(b)). This behavior means formation of gel-state liquid crystal. Also, appearance of this liquid crystal gel exhibited opaque state. The light scattering behavior is attributed to difference of refractive index between randomly-aligned liquid crystal domains in gel network.

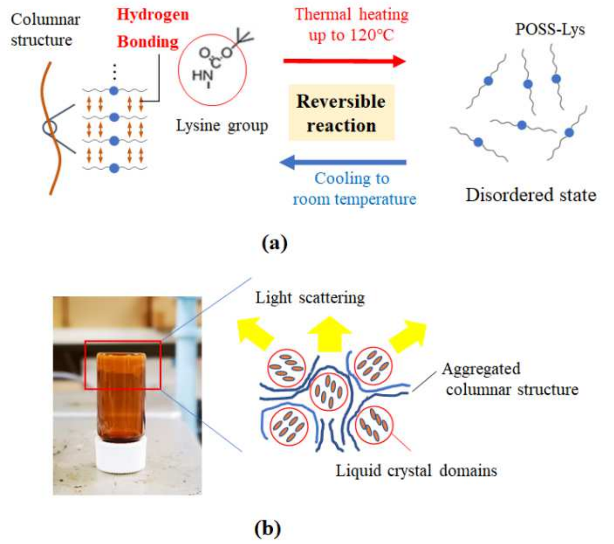

Fig. 2 (a) Reversible bonding reaction among POSS-Lys dendrimer molecules (b) formation of liquid crystal gel by mixture of 5CB and POSS-Lys of 0.5wt% concentration.

3 Results and Discussion

We investigated electro-optical characteristics of dye-doped liquid crystal gel and durability to tensile stress. As the dichroic dye, we used G-241 synthesized by Hayashibara Corp.

3.1 Electro-optical Characteristics

Fig. 3 shows the dependence of voltage transmittance characteristics on kinds of cyano-based liquid crystal. The nematic 5CB and E7 were purchased from LCC. The TD-1018XX and TD-1019XX were JNC Corp. The difference of refractive indexes and nematic-isotropic (NI) transition temperatures were summarized in Table 1. Voltage transmittance characteristics depends on each liquid crystal material. The maximum contrast ratio was obtained by liquid crystal E7, 1: 6.9. The readily visible level of pictogram was reported as 1: 5 at least. Obtained contrast ratio is applicable to display devices. Here, we discuss the minimum and maximum transmittance. Fig. 2(b) means liquid crystal gel during voltage off state has light scattering behavior. This light scattering is attributed to the difference of the refractive indexes of liquid crystal domains. The difference of refractive index of E7 is larger than that of other liquid crystal materials. As the results of increasing of haze, transmittance at voltage-off state in E7 liquid crystal gel is low. In contrast, maximum transmittance in E7 is higher than that of other liquid crystal. These results are closely related to the nematic-isotropic phase (N-I) transition temperature. When the N-I transition temperature is higher, molecular order is better generally. The relation between the N-I temperature and maximum transmittance is reasonable.

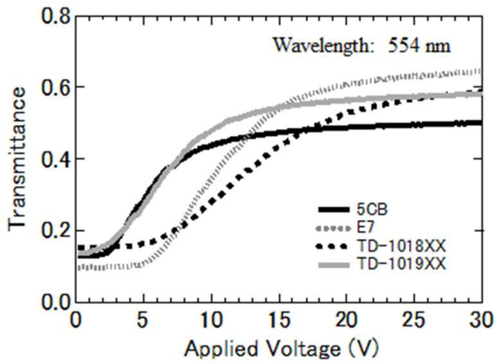

Fig. 3 Voltage-transmittance characteristics of dye-doped liquid crystal gel films. Thickness of LC gel films was 10 μm.

Table 1. Optical and thermal data of Liquid Crystal Materials with Cyano groups

Liquid crystal material	Δn value	N-I transition temperature (°C)
5CB	0.18	35.0
E7	0.24	60.0
TD-1018XX	0.12	49.8
TD-1019XX	0.18	35.1

3.2 Elongation Test to Liquid Crystal Gel

The structural durability to elongation is necessary for application of stretchable display. We examined elongation test to liquid crystal gel films on stretchable substrate, as shown in Fig. 4. We used transparent polydimethylsiloxane (PDMS) single substrate as the stretchable substrate because fabrication of stretchable liquid crystal cell was difficult. As the reference, we prepared liquid crystal/polymer composite films based on covalent bonding. Compared with the liquid crystal gel films, the cracking can be seen in liquid crystal/polymer composite films. In contrast, liquid crystal gel films exhibited 1.5-fold elongation durability. This is attributed to movable cross-linking point among columnar structure.

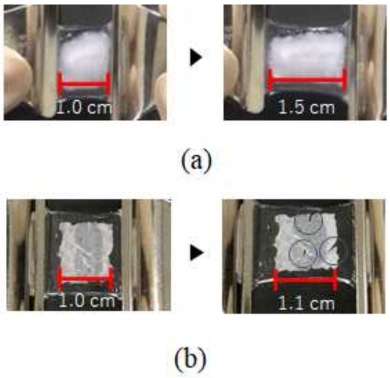

Fig. 4. Uniaxially-Elongated test to the films on PDMS substrate (a) liquid crystal and POSS-Lys mixture films (b) liquid crystal and photo-polymerized monomer based on covalent bonding.

3.3 Demonstration of recovery characteristics

Finally, we investigated the structural recovery of structurally-destroyed liquid crystal gel films. Fig. 5(a) was pristine state of liquid crystal gel films into the cell structure without dichroic dye. The evaluated haze value was 87.0%. After that, compressive force was applied to this film and gel-state structure was broken intentionally, as shown in Fig. 5(b). The haze value of this film was decreased to 67.3%. On the microscope image, colored contrast which caused by birefringence of liquid crystal can be seen. This is attributed to phase segregation between single liquid crystal phase and gel-state phase. Unfortunately, the destroyed film structure was not recovered at room temperature. Fig. 5(c) shows the image after thermal treatment at 150℃ for 2min (above sol-gel transition temperature). Interestingly, both the film structure and the haze value were recovered to those of the original state even through liquid crystal layer had been destroyed once, as shown in Fig. 5(d). This unique characteristic shows a possibility of breakthrough to solve a trade-off relation between flexibility and reliability for display devices

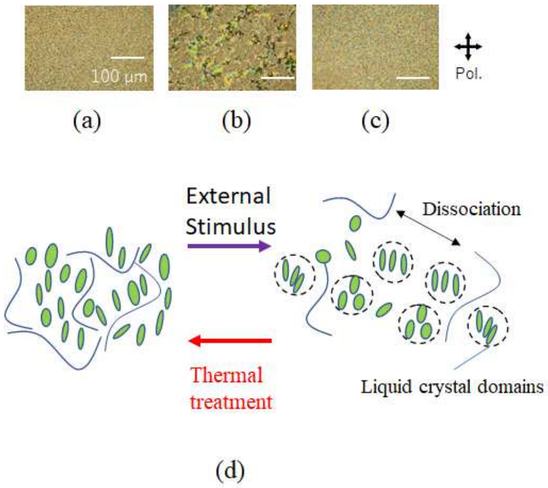

Fig. 5. (a-c) Crossed-Nicols polarizer microscope images of Liquid crystal gel using POSS-Lys of 1.5 wt%. (d) schematic illustration of structural recovery. The haze values of (a), (b) and (c) were 87.0%, 67.3% and 88.0% respectively.

because the easy recovery leads to the concept of lifetime-free display.

4 Conclusions

For stretchable liquid crystal display, we demonstrated liquid crystal gel films which showed the electro-optical characteristics achieving visually discernible level and structural recovery of destroyed liquid crystal gel. As a reference to show the stretchability, polymer network based on covalent bonding in liquid crystal readily destroyed to slight elongation. The issues of both lowering the self-assemble temperature with using proper gelator molecules and the alignment control of liquid crystal gel are still open for the development of lifetime-free display devices.

Acknowledgements

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