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Optical properties and optimized conditions for polymer dispersed liquid crystal containing UV curable polymer and nematic liquid crystal

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Polymer dispersed liquid crystal was synthesized by combining a UV curable polymer and a nematic liquid crystal. Optimized conditions for the optical properties of the PDLC were found to be the concentration ratio of LC and polymer at 7:3, UV curing time of 18 min, and the thickness less than 25 μm. In the case of the high LC concentration ($\geq$70%) sample, the amount of liquid crystal segregated in the polymerization process was enough to form a spherical shape of droplet, and the threshold driving voltage was reduced. The response time for the turn-on process was nearly independent of the concentration, while the turn-off process was almost proportional to the concentration. From microscopic image and UV–visible spectrum analysis, the relation between LC droplet morphology and optical properties were explained.

1. Introduction

These days, saving energy is one of the most important issues related with global warming, and windows are often regarded as a less energy efficient component. A new class of windows, the so-called ‘smart window’, is expected to be a solution for buildings and transportation vehicles to reduce heating and cooling energy [1]. Among the various candidates of smart window materials, polymer-dispersed liquid crystal (PDLC) [2] is the most commercialized in daily life. PDLC can be used not only for smart windows, but also for displays and tunable optical modulators [3]. In general, the size of an LC droplet embedded in polymer matrix is in the range of 1–20 μm, but there are exceptions having nanosized droplets. The on/off ratio of transmittance is determined by the matching and mismatching of the refractive indexes between the liquid crystal (LC) droplets and the polymer matrix.

When no electric field is applied, the orientations of LC molecules in droplets are disordered depending on the anchoring force against the wall surface of the droplets. As LC has birefringence, it has two different refractive indexes n_o (ordinary) and n_e (extraordinary), and the average refractive index is given by $\langle n \rangle = (n_e + 2n_o)/3$. The index mismatch between the LC and the polymer (n_p) causes the light-scattering to make it hazy (off state). When a certain amount of electric field is applied, the LC molecules are oriented along the electric field direction. If the ordinary refractive indexes of LC (n_o) and polymer (n_p) are matched for the incident light parallel to the electric field, it becomes transparent (on state). As a result, in order to have a high contrast ratio between the on and off states, the LC should have a high birefringence ($\Delta n = n_e - n_o$) and good index matching ($n_o \approx n_p$).

Norland optical adhesive 65 (NOA65) has been used for PDLC widely, as a fast photocurable polymer matrix [4–14]. NOA65 can be polymerized by ultraviolet (UV) irradiation, and LC is segregated from polymer forming micro-sized droplets. Lovinger et al. [15] claimed that a variety of morphologies ranging from two-phase LC droplets and single-phase nematic spherulites were found depending on composition and irradiation temperature up to 65 °C for 60% LC. According to them, the LC droplets were not spherical, but have bimodal size distributions in the range of 0.2–8 μm. On the other hand, real-time Fourier transform infrared spectroscopy has been used to observe and quantify the curing reaction process of NOA65 and nematic liquid crystal (E7) [16]. In this paper, we studied the optical properties of PDLCs with NOA65 matrix with different LC concentrations, thicknesses, and curing times, comprehensively.

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Table 1
Summary of synthesis conditions and optical properties for PDLC samples.

Sample number	d (μm)	LC: polymer	UV curing time (min)	V_{th} (V_{rms})	V_{sat} (V_{rms})	T_{on} (%)	T_{off} (%)	Response time τ_{on} (ms)	Response time τ_{off} (ms)
1	26	7: 3	15	15.3	35.4	81.87	23.87	2.1	27.8
2	31	7: 3	15	24.6	42.4	77.77	17.17	1.2	29.3
3	51	6: 4	15	48.4	70.7	40.40	12.90	8.5	11.3
4	54	6: 4	18	45.5	63.6	45.19	13.63	9.5	8.8
5	56	7: 3	15	23.5	63.6	60.46	14.78	4.3	71.1
6	56	7: 3	18	16.2	56.6	65.89	18.52	2.9	53
7	55	8: 2	15	15.9	42.4	71.11	23.34	1	110.1
8	50	8: 2	18	13.8	49.5	77.27	26.21	1.2	171.2
9	42	6: 4	15	36.9	63.6	67.08	16.50	31.7	25.4
10	47	6: 4	18	43.8	63.6	54.31	14.31	13.3	5.2
11	44	7: 3	15	14.9	49.5	72.51	18.94	8.8	42.3
12	41	7: 3	18	9.2	49.5	73.16	23.62	6.5	51.2
13	45	8: 2	15	7.6	28.3	78.20	33.32	6.1	79.7
14	46	8: 2	18	9.2	35.4	77.61	30.83	3.3	78.6

2. Experimental details

As a prepolymer, UV curable adhesive NOA65 with refractive index $n_p = 1.524$ was used, and nematic liquid crystal (C7, Qingdao

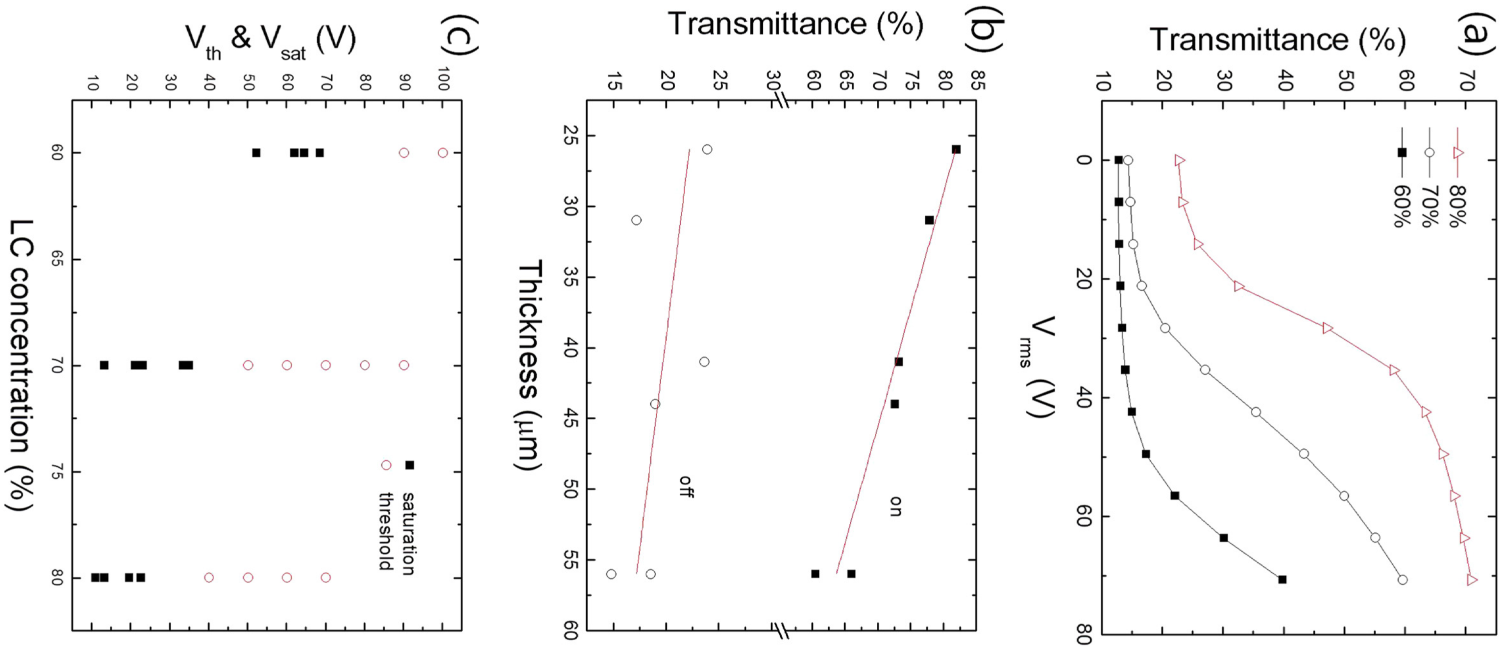

Fig. 1. (a) Representative data of transmission changes as functions of driving voltage for the samples with different concentrations of LC. (b) The transmittances were measured as a function on thickness for the samples with the same LC concentration, 70%. Upper (lower) data indicate transmissions in on (off) state. (c) The threshold and saturation voltages were plotted as functions of LC concentrations.