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Holographic grating formation in PVB doped polymer dispersed liquid crystal based on PUA

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ABSTRACT

Different contents of poly(vinyl butyral) (PVB) have been incorporated into the conventional holographic polymer dispersed liquid crystal (HPDLC) composition based on liquid crystal mixture and polyurethane acrylate (PUA) with a particular composition. As the PVB content is increased, the hardness, elastic modulus and thermal stability of polymer matrix are improved because of the entanglement by PVB, which has a relatively high molecular weight compared with PUA oligomer. Diffraction efficiency is enhanced with the addition of PVB except for HPDLC film with 10 wt.% PVB owing to augmentation of the phase separation between polymer and LC, caused by the increase of elasticity of the polymer matrix. However, the increase in viscosity on adding PVB produces a slow saturation time and coalescence of the LC droplet, showing a lower diffraction efficiency at the PVB content of 10 wt.% than at 0 wt.%.

1. Introduction

Liquid crystal displays (LCDs) are used for many applications such as information displays in technical instruments and in vehicle clocks, navigation, spatial light modulators and very fast light shutters. More importantly, they have come to dominate the display market in portable instruments because of their slim shape, low weight, low voltage operation and low power consumption [1]. Hence, new technique called holographic polymer dispersed liquid crystal (HPDLC) for various displays have recently been researched owing to their advantages, viz., no color filter, no alignment layer, no polarizer, easy fabrication, and so on, compared with conventional LCDs. HPDLCs have extensive potential applications in optical communications, flat panel displays, information storage and integrated optics [2]. In particular, HPDLCs can be used simply in applications involving transparent screens and HUDs (head-up displays), which are used mostly in dashboard and navigation fittings on the windshields of automobiles and aircraft. Therefore, they should have high mechanical and thermal properties to withstand serious environment changes, as well as reasonable electro-optical properties such as high contrast ratio, low driving voltage and fast response time [3]. Poly(vinyl butyral) (PVB) has been widely used as the interlayer in safety glass because of its excellent properties of toughness, tear strength and durability, optical clarity, and so on [4]. Although PVB has these many advantages, relatively few studies have been undertaken in the display field. Therefore, in this work, PVB was incorporated into a conventional HPDLC system to fabricate film having good mechanical properties (high strength, hardness and thermal stability) and high electro-optical properties as functions of the content of PVB and LC at a chosen composition.

2. Experimental details

2.1. Materials and polyurethane acrylate (PUA) oligomer synthesis

PUA oligomer was synthesized from poly(propylene glycol) (PPG, $M_n = 300$) and a molar excess of hexamethylene diisocyanate (HDI) to form isocyanate-terminated prepolymers, followed by capping with hydroxyethyl methacrylate (HEMA). (PPG, HDI and HEMA were all supplied by Sigma-Aldrich Korea, Yongin, Korea). Detailed synthetic procedures are described in previous papers [5,6]. The HPDLC composite films were prepared from a homogeneous pre-polymer mixture consisting of the PUA oligomer, and a reactive diluent, viz., in which *N*-vinylpyrrolidone (NVP, Sigma-Aldrich Korea, Yongin, Korea) was used to control the viscosity and the E7 was used as the LC at three loadings, viz., 40, 45, and 50%. Rose Bengal (RB, Junsei chemical, Tokyo, Japan) and *N*-phenylglycine (NPG, TCI, Tokyo, Japan) were used as a photoinitiator and a coinitiator, respectively, for holographic recording with an Ar-ion laser. Synthetic procedure of PUA oligomer and fabrication of HPDLC film doped by PVB is presented in Scheme 1. Basic formulations and experimental ranges to fabricate the holographic

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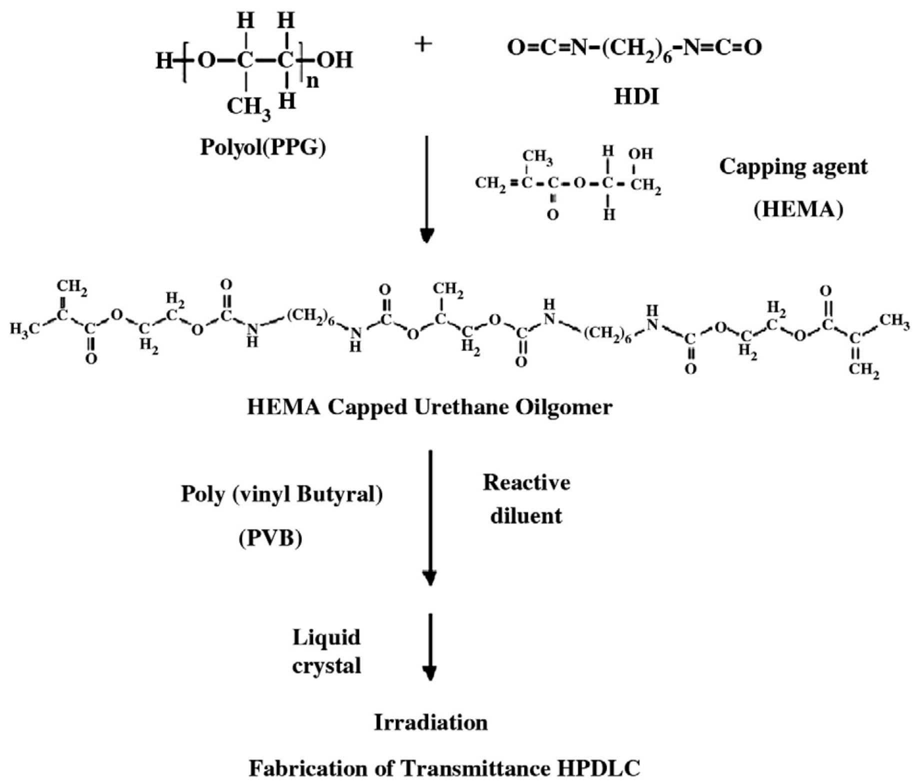

Scheme 1. Fabrication scheme of transmittance HPDLC based on PUA.

grating are indicated in Table 1. Various contents of PVB (M_w = 40,000, Sigma-Aldrich Korea, Yongin, Korea) were incorporated as a dopant.

2.2. Preparation of film and grating

All polymer films for mechanical thermal analyzer were cured by UV (1.5 mW cm^{-2}, 365 nm) for 3 min with 0.1 wt.% Darocur 1173 (Ciba in Korea, Seoul, Korea) as an initiator [7]. For holographic recording two Ar-ion lasers (514 nm, 100 mW cm^{-2} and 3 min) were impinged at 23° on the cell which was constructed by sandwiching the reactive mixture (PUA oligomer, NVP, PVB, and LC), RB and NPG between two indium tin-oxide (ITO) coated glass plates with a gap of 10 μm [8,9]. The interference of the two beams established the periodic interference pattern.

2.3. Characterization

Viscosity behaviors of pre-polymer/PVB were investigated with Brookfield viscometer (Brookfield DV-II+, Brookfield Engineering Laboratories, Inc., Middleboro, USA). The nanoindentation tests and thermal stability of the polymer were performed using a Nanoindenter (MTS Nanoindenter XP, MTS Korea, Seongnam, Korea) using a continuous stiffness measurement technique and thermogravimetric analyzer (TGA Q50, TA Instruments Korea, Seoul, Korea), respectively. Morphologies of the HPDLC films were observed by a field-emission scanning electron microscopy (FE-SEM, JEOL Model JSM-5610, Japan).

Reading was accomplished using a probe beam, positioned at the Bragg angle. Diffraction efficiency was determined by dividing the

Table 1
Formulation and various results of films prepared at various conditions.

Oligomer/NVP[a]	PVB content (%)	SP[b] ((Jcm^{-3})$^{1/2}$)	Functionality	Cell gap (μm)	LC content (%)	Diffraction efficiency (%)	Saturation time (s)	Rising time[c] (ms)	Decay time[c] (ms)
3/1	0	24.46	1.75	10	40	60	3	–	–
				10	45	48	–	–	–
				10	50	30	–	–	–
	1	24.44	1.73	10	40	76	6	0.71	2.9
				10	45	52	–	–	–
				10	50	37	–	–	–
	3	24.41	1.70	10	40	72	–	0.54	4.35
				10	45	56	–	–	–
				10	50	40	–	–	–
	5	24.38	1.66	10	40	68	–	0.45	6.64
				10	45	48	–	–	–
				10	50	34	–	–	–
	10	24.31	1.57	10	40	56	9	–	–
				10	45	44	–	–	–
				10	50	22	–	–	–

[a] HEMA-capped urethane acrylate oligomer with PPC 400 is abbreviated as PUA oligomer. A 0.3% of RB and 1.8% of NPG have been included in all formulations.
[b] Solubility parameters (SP) of LC and PVB are 20 and 23 (J cm^{-3})$^{1/2}$, respectively.
[c] Rising time and decay time are measured at film of 40 wt.% LC under 50 Hz and 30 V.