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Short Communication

The Effect of High-Temperature Liquid Crystal on Haze and Voltage Improvements of Dye-Doped Polymer Dispersed Liquid Crystal Film

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Abstract

The current commercial PDLC film and glass products are mainly utilized for internal privacy applications. In this work we studied the effect of process line speed on electro-optical properties of model dye-doped PDLC formulations consisting of high-temperature and standard liquid crystal materials. The results indicated that, in comparison to standard PDLC, the high-temperature PDLC exhibited a significantly lower on-state haze and switching voltage. This study provides a road map for further systematic studies on external applications of PDLC smart glass.

Keywords: High-temperature, Liquid crystal, Dye, Optical transmission, Haze, Applied voltage.

Introduction

The Polymer Dispersed Liquid Crystal (PDLC) technology has been the subject of many studies in the past few decades resulting to rich scientific publications, industrial manufacturing and commercialization of various products worldwide. The published literature on PDLC technology by most academic and some industrial research have included the effect of matrix and liquid crystal [1-10], material composition [11-21], curing parameters [22-36], thickness [37-39], nanoparticles [40-42] and dyes [44-47] on the morphology and electro-optical properties of PDLC films. The correlation between materials and process conditions with electro-optical performances of PDLC are essential on the kinetics of phase separation and dynamics of matrix polymerization and for industrial manufacturing of flexible PDLC products.

In this respect, we have reported a series of studies on the effects of material and process parameters on morphology and electro-optics on industrial-scale flexible PDLC films [8,18-20, 28,30,34,35,38,39]. These studies have shown the effects of material and process parameters on matrix micro-structure; liquid crystal droplet size and number density; optical transmissions; switching voltages and response times in various UV-cured and thermoset PDLC formulations. Although the effect of various chemical and physical parameters on the performances of PDLC have been published extensively, the choice of high-temperature liquid crystal has not yet been published by industrial studies. Namely, by introducing high-temperature in PDLC formulation, it is expected not only to improve the phase separation, polymerization kinetics, morphology and electro-optical performance of PDLC products but also could provide the opportunity to expand their utilization for external application.

In the present work, we studied the effect of high-temperature liquid crystal in a dye-doped PDLC formulation on optical transmissions and switching voltage as a function of UV curing intensity and the process line speed in comparison with those in the same formulation with standard liquid crystal. It should be pointed out that, the main objective of this study is that, in contrast to current PDLC products for internal privacy markets, to provide an alternative road map for industrial development and commercialization of PDLC film and glass products for external applications

Materials, Preparation and Methods

The utilized materials in PDLC formulations of this study include the standard liquid crystal QYPDLC142 (Q142) [T_{ni} = +105°C, T_{in} = -20°C, n_o=1.525, Δn = 0.251] and high-temperature liquid crystal QYPDLC20603 (Q20603) [T_{ni} = +125°C, T_{nc} = -20°C, n_o = 1.518, Δn = 0.205], both procured from Qingdao (CN); pre-polymer N65 (NOA65) [n_p =1.524] obtained from Norland Optical Adhesives (USA); blue dichroic dye DBA purchased from Mitsui Fine Chemicals (JP); photo-initiators Irga-Cure 819 (819) and Irga-Cure 814 (814) obtained from Ciba (CH); UV absorber Tinuvin 400 (TV400) procured from BASF (DE); Acrylic Acid (AA) diluent procured from Kaitai (CN) and 25mm plastic micro-spacer Nano-Micron (NM) obtained from Suzhou Nano-Micro (CN). The utilized material compositions in dye-doped PDLC formulations in weight percent (%W) were as follows: Q142 or Q20603 = 40%; N65 = 51%; DBA = 0.5%; 819 = 0.2%; 184 = 1%; TV400 = 4%; AA = 4%; NM = 0.6%.

All materials were utilized as-such without further purification. The PDLC formulations and curing were carried out by Polymerization Induced Phase Separation (PIPS) technique with UV radiation method. The homogeneous mixtures of materials were placed in a vail and mixed with magnetic stirrers for 3 hours at 45°C. The uncured PDLC formulations were pre-heated at 50°C for 10 minutes and then, as presented in Figure-1, were poured between the vertical gap of two support ITO-PET film rolls on a custom-made coater/laminator system. Under the coating rolls the uncured PDLC sandwich were passed through a pressure roll to insure the uniformity of PDLC film. The thickness homogeneity of PDLC layers were insured by 25mm plastic NM micro-spacers. As presented in Figure-1, The uncured PDLC film samples were then cured on a custom-made UV-IR conveyor belt machine equipped with a high-pressure UV mercury lamp and infrared heater. The curing was accomplished by PIPS phase separation technique at UV intensity of 72 mW/cm^2 and at the line speeds of 0.15, 0.3 and 0.45 meters/minute, respectively.

Each PDLC formulation was carried out on three samples and the reported electro-optical results were the average values of the three samples. Also as presented in Figue-1, the electro-optical properties of PDLC samples were carried out on a specially constructed bench-top photometric system mounted on an optical rail consisting of white light source, sample holder, photometer, amplifier, function-generator and electronic data acquisition network.

The optical transmissions and switching voltage of PDLC films were measured at room temperature through transmission-voltage curves with VAC square-wave at 100 Hz frequency. The total on-state transmission and haze of the PDLC samples were measured by BYK-Gardner Haze-Guard with a white light source.

Figure 1: PDLC film coater/laminator(left), UV-IR curing conveyor (centre) and electro-optical system (right).

Results and Discussion

In Table-1, we tabulated the optical transmissions including the total transmission Ton, and haze Hon; specular transmissions T_{min} and T_{max} and the saturation voltage V90 in standard Q142 and high-temperature Q20603 of dye-doped PDLC films as a function of coating line speed. According to the experimental data of Table-1, the Ton (total transmission) range of Q142-PDLC (52.8 - 51.1%) and Q20603-PDLC (53.6 - 51.4%) are not affected by the line speed. Similar results are observed for Tmax (on-state specular transition), where its range in both Q142-PDLC (56.5 - 53.4%) and

Q20603-PDLC (55.9 - 53.4%) are of the same order of magnitude of Ton as a function of the line speed. Also as provided in Table-1, the line speed does not show noticeable differences on the values of Tmin in both formulations.

Table 1: Effect of line speed on optical transmissions & operating voltage of Q142-PDLC & Q20603-PDLC films.

PDLC Formulation	Speed [m/min]	Ton [%]	Hon [%]	Tmin [%]	Tmax [%]	V90 [volts]
Q142	0.15	52.8	7.3	7.6	56.5	46.1
Q142	0.3	52.6	7.2	6.6	55.5	52.6
Q142	0.45	51.1	6.1	4	53.4	51.1
Q20603	0.15	53.6	2.3	8.1	55.9	31.4
Q20603	0.3	52.7	2.2	7.7	55.7	31.9
Q20603	0.45	51.4	2	5.2	53.4	36.5

However as highlighted in Table-1, the line speed shows substantial differences on Hon (on-state haze) and V90 (saturation voltage) values between Q142-PDLC and Q20603-PDLC films. According to data of Table-1, in Figure -2, we present the behavior of Hon in Q142-PDLC and Q20603-PDLC films as a function of line speed in the two PDLC formulations. The results clearly demonstrate that Hon exhibits a significant decreasing values in Q20603-PDLC (2.3-2.0%) with respect to Q142-PDLC (7.3-6.1%) within the studied line speeds. The reduction of Hon by three times seems to arise from higher crystal-nematic transition and lower no values in Q20603-PDLC with respect to those in Q142-PDLC. In addition, the significant reduction of Hon could be also due to the presence of high polarity fluoro and cyano groups in Q20603 structures, which results to more efficient phase separation in Q20603-PDLC.

Also with reference to Table-1, in Figure-2, we present the V90 (saturation voltage) in Q142-PDLC and Q20603-PDLC as function of line speed. These results also reveal that, within the utilized line speeds, the V90 in Q20603-PDLC (31.4-36.5 volts) are decreased by 10-15 volts with respect to that in the Q142-PDLC (46.1-52.6 volts). Although we did not explore the morphology of PDLC films in the present, but knowing that the switching voltage and morphology have a reciprocal relation, it is clear that the origin of lower V90 values in Q20603-PDLC should be as a result of more efficient phase separation, larger liquid crystal droplet dimensions and number density, in comparison with those in Q142-PDLC films. The 20°C higher nematic-isotropic transition temperature and more functional groups of Q20603 (125°C) results to more favorable phase separation, polymerization kinetics and morphology that provides significant reduction of Hon and V90 in high-temperature Q20603-PDLC films.

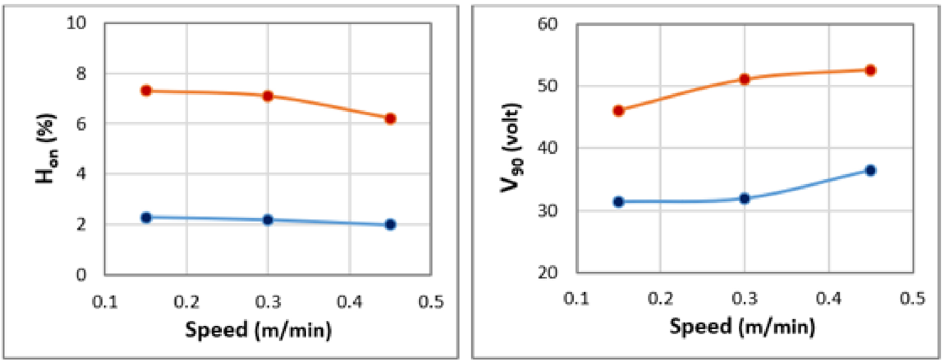

Figure 2: The effect of line speed on Hon and V90 of Q142-PDLC (red) and Q20603-PDLC (blue) films.

Conclusion

The intention of this study was to develop high-temperature PDLC film with improved electro-optical performances for external applications. Accordingly, we utilized a base formulation and prepared dye-doped PDLC films including high-temperature Q20603 and standard Q142 liquid crystals. A comparison of electro-optical properties of model Q20603-PDLC and Q142 PDL films as a function of line speed demonstrated decreasing values and trends of total on-state haze (Hon) and saturation voltage (V90) in Q20603-PDLC films. It should be noticed that, in comparison to Q142-PDLC, the lower Hon and V90 values of Q20603-PDLC is significant for industrial development and manufacturing. Namely, the low Hon is a crucial parameter for visual quality; the low V90 is important energy saving factor and the high-temperature is an essential parameter for external utilization of PDLC products. This work provides a road-map for future systematic studies on other material and process parameters for industrial development of smart glass products for outdoor applications and markets.

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