Wavelength-Selective Reflection of Cholesteric Liquid Crystals Depending on Temperature and Dopant Concentration

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ABSTRACT

We report temperature-dependent color variation in cholesteric liquid crystals with different concentrations of chiral dopant. The reflected color, corresponding to the chiral pitch, is governed by both molecular thermodynamics and dopant solubility. The color tuning range is extended with increasing the dopant concentration.

1. INTRODUCTION

Cholesteric liquid crystals (CLCs) have attracted great interest for color flexible displays since the optical components such as polarizer, color filter, and backlight unit are not required in the reflective CLC displays [1-4]. The CLCs show self-formed photonic crystals through arranging themselves in a helical structure by a chiral dopant [5]. The helical structure of CLCs gives rise to wavelength-selective reflection of the incident light. The color of the reflected light is directly governed by a chiral pitch of the CLCs. In general, the helical pitch of the CLC was varied by the concentration of the chiral dopant and the thermodynamic properties of the CLC molecules. With increasing temperature, the pitch is gradually decreased due to molecular thermodynamic properties of the CLCs [6,7]. In a confined structure such as a sandwiched cell, the pitch of the CLCs goes down stepwise due to the competition between thermodynamic twisting power and boundary condition. Recently, it was also reported that the dopant solubility, depending on the temperature, controlled the helical pitch of the CLCs [8]. When temperature increases, the helical pitch decreases in the CLCs because the effective amount of the solved dopant, contributing the twisting power, increases.

In this work, we report a temperature-dependent color variation of the CLC depending on the dopant concentration. In a CLC sample with low concentration of the chiral dopant, the wavelength of the selective reflection in the CLC, directly corresponding to the helical pitch, was decreased stepwise as reported previously [6,7]. In a high concentration, the corresponding wavelength was rapidly decreased up to a certain critical temperature and gently decreased showing steps with increasing temperature. Below the critical temperature, the rapid decrease of the helical pitch was mainly originated from the dopant solubility contributing the twisting power. Above the critical temperature, on the other hand, the helical pitch was gently decreased due to the thermodynamic properties of the CLC molecules. In this regime, the steps of the selective wavelengths, originated from the boundary conditions of the rubbed surfaces, were obviously observed. In addition, the thermal tuning rate of the wavelength was extended with increasing the concentration of the chiral dopant. The extension of the wavelength tuning range is expected to be applicable to the full color CLC display applications.

2. EXPERIMENT

The helical structure of the CLC was generated by doping R-811 (right handed chiral dopant, Merck) to the nematic LC of E7 (Merck). The LC mixture was stirred in an isotropic phase for 10 hours to make the composite uniformly and homogeneously. The polyimide alignment layer was spin-coated on the indium-tin-oxide (ITO) glasses and cured them on a hotplate. After rubbing the alignment layer, two rubbed substrates were assembled in anti-parallel direction. The cell thickness was maintained by the use of 6 μm glass spacers. The CLC was injected into the assembled cells by capillary action in the isotropic phase. Finally, the sample cells were cooled down slowly to achieve a planar texture.

The variation of the reflected color depending on temperature was observed using a microscope mounting a microfurnace. The reflectance spectra of the CLC samples with different concentrations of the chiral dopant were measured varying temperature from 25 °C to a phase transition temperature of them.

3. RESULT AND DISCUSSION

Figure 1 shows the reflected color of the CLC samples with 30 wt.% and 40 wt.% chiral dopant. In the 30 wt.% CLC sample, the cholesteric phase was maintained under a condition of temperature from 26 °C to 41 °C. However, the reflected colors were slightly shifted near red color under whole temperature range showing the cholestric phase (see Fig. 1(a)). In the 40 wt.% sample, on the other hand, the color shift from red to green was clearly observed (Fig. 1(b)). In this sample, the cholesteric phase was observed from 27 °C to 38 °C.

To observe quantitatively the color variation depending on temperature, we measured the reflectance spectra of the CLC samples with different concentrations of the chiral dopant. Figure 2 shows the central wavelengths as a function of the temperature of the CLC samples with the chiral dopant of 30 wt.% and 40 wt.%. In a low concentration of the dopant, the corresponding wavelength to the selective reflection was gradually decreased with finite steps when temperature was increased. Under an assumption that the helical twisting power of the chiral dopant is constant within the cholestric phase, the pitch variation just depends on the thermodynamic properties of the CLC molecules, that is, thermal vibrations [6]. With increasing temperature, the thermal vibration strength was increased and thus the twisting angle variation between nearest neighboring molecules was increased. The

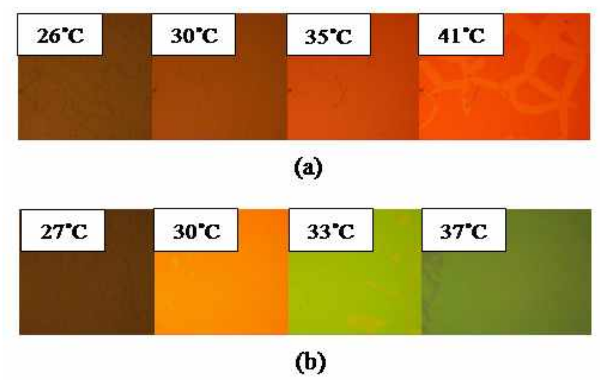

Figure 1 Microscopic textures of the change in reflected colors at different temperatures of the CLC samples mixed with (a) 30 wt% and (b) 40 wt.% chiral dopant.

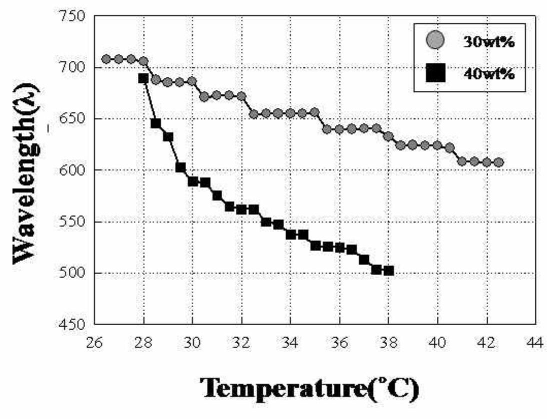

Figure 2 Measured results of the central wavelength of the CLC samples with the different concentrations of the chiral dopant: 30 wt.% and 40 wt.%.

increase of the angle variation resulted in reducing the helical pitch of the CLC. In the sandwiched samples with the rubbed alignment layers, the surface anchoring effect produces degeneracy of the stable pitches due to the competition between the twisting power and the boundary condition. The wavelength steps were observed at every increment of the half pitch. In this case, the chiral dopant was fully dissolved in the nematic LCs in the whole temperature range of the cholestric phase.

As the concentration of the chiral dopant was increased, the corresponding wavelength was rapidly decreased up to a certain critical temperature (about 30 °C). After the critical temperature, the pitch variation is similar to that in the low concentration, that is, the wavelength gradually goes down stepwise with increasing temperature. In the regime of the upper critical temperature, the molecular thermodynamic properties previously mentioned directly affected the pitch variation. In the regime of the lower critical temperature, however, the step variation of the corresponding wavelength did not observed clearly due to the rapid variation. In addition, the decay behavior of the corresponding wavelength shows the steeper slope than the thermodynamic behavior. In this regime, the solubility of the chiral dopant in the nematic LCs mainly affects the pitch variation [8]. The amount of the chiral dopant contributing the twisting power strongly depends on temperature. The only dissolved dopant produces the helical twisting power but the undissolved remainder does not contribute the

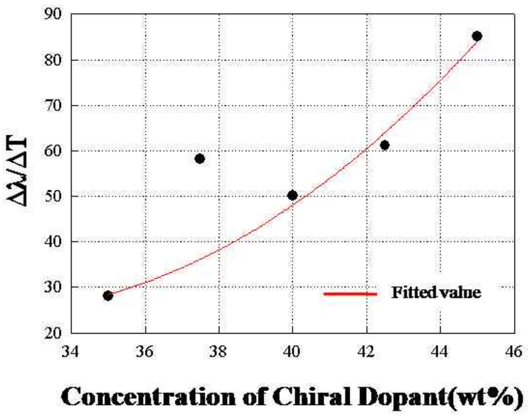

Figure 3 The measured color tuning range divided by temperature (figure-of-merit) of the CLC samples with the different dopant concentrations.

twisting power. With increasing temperature, the undissolved dopant is gradually dissolved in the LCs and thus enhances the twisting power. In addition, the thermodynamic behavior still affects the pitch variation in this regime. As a result, the corresponding wavelength rapidly goes down due to both contribution of the thermodynamic behavior and the dopant solubility. The critical temperature corresponding to the dopant solubility was gradually increased with increasing the concentration of the chiral dopant. This means that the critical solubility (fully dissolved concentration) gradually increases.

We investigated the high concentrated CLC samples observing the critical temperature within the cholestric phase to measure the wavelength-tuning range. Figure 3 shows the *figure-of-merit* in the wavelength tunability per temperature as a function of the dopant concentrations. With increasing the concentration, the figure-of-merit gradually increases due to the extension of the temperature range related to the dopant solubility, where the pitch variation shows the steep slope. The high concentrated CLC was useful to apply a full color CLC display because the wide wavelength tunability from red to blue is required. However, increasing the dopant concentration, the temperature range showing the cholestric phase was reduced.

4. SUMMARY

In summary, we demonstrated the color variation in the CLCs depending on temperature and the dopant concentration. In the low concentrated CLCs, the wavelength corresponding to the helical pitch of the CLC was decreased stepwise originated from the competition between the helical twisting power controlled by the chiral dopant and the confined boundary condition governed by the rubbed alignment layers. In the high concentration, however, the wavelength variation was divided by two regimes: the thermodynamic regime and the solubility regime. In the thermodynamic regime, the thermal vibration depending on the temperature mainly decreases the helical pitch. In the solubility regime, on the other hand, the undissolved dopant contributes the pitch variation together with the thermal vibration. Therefore, the helical pitch rapidly decreases with increasing temperature. In addition, the figure-of-merit in the wavelength tunability was enhanced with increasing the dopant concentration. Our work is expected to be applicable to the full color CLC display applications.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] S. H. Xianyu, T.-H. Lin, and S.-T. Wu, "Rollable multicolor display using electrically induced blueshift of a cholesteric reactive mesogen mixture", Appl.Phys.Lett., 091124, Vol. 89 (2006).

[2] G. D. Filpo, F. P. Nicoletta, and G. Chidichimo, "Cholesteric Emulsion for Colored Displays," Adv. Mater., pp. 1150-1152, Vol. 17, (2005).

[3] J. Chen, S. M. Morris, T. D. Wikinson, and H. J. Coles, " Reversible color switching from blue to red in a polymer stabilized chiral nematic liquid crystals," Appl. Phys. Lett., 121118, Vol. 91 (2007).

[4] A. Bobrovsky, and V. Shibaev, "Novel type of combined photopatternable and electro -switchable polymer-stabilized cholesteric materials," Jour. of Mater. Chem., pp. 366-372, Vol. 19, (2009).

[5] N. Tamaoki, "cholesteric Liquid Crystals for Color Information Technology," Adv. Mater., pp. 1135-1147, Vol. 13, (2001).

[6] P. N. Keating, "A Theory of the Cholesteric Mesophase," Mol. Cryst. Liq. Cryst., pp. 315-326, Vol. 8, (1969).

[7] J. V. Gandhi, X.-D. Mi, and D.-K. Yang, “Effect of surface layers on the configurational transitions in cholesteric liquid crystals,” Phys. Rev. E, pp. 6761-6766, Vol. 57, (1998).
[8] Y. Huang, Y. Zhou, C. Doyle, and S.-T. Wu, “Tuning the photonic band gap in cholesteric liquid crystals by temperature-dependent dopant solubility”, Opt. Express, pp. 1236-1242, Vol. 14, (2006).