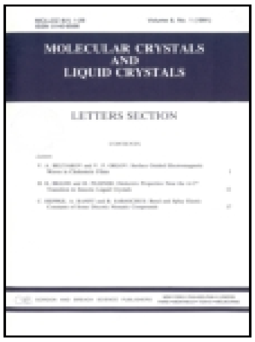

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Control of Laser Speckle Noise by Using Polymer-Dispersed LC

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Laser speckle noise occurs owing to the strong interference that originates in the high coherency of laser light and the surface topography of screen. The suppression of the speckle noise is necessary for laser displays such as an image projection system. To reduce the speckle noise, we have tried to control the speckle pattern by using liquid crystals (LCs). In this paper, we offer an idea for suppressing the speckle noise using a polymer-dispersed LC (PDLC) cell in which the speckle pattern can be varied in addition to the optical diffusive effect.

Keywords: Laser; speckle noise; polymer-dispersed liquid crystal; optical diffusion

1. Introduction

A laser is an attractive light source because of its high efficiency and brightness with low power consumption and long lifetime, pure color and extremely wide color expression that can be realized by choosing the wavelength of laser light, and high directivity and small etendue of light which contribute to downsizing. These characteristics are strong merits, especially for a projection display system. However, there is a serious problem in utilizing a laser as a light source. Strong interference occurs originating in the high coherency of laser light and the surface topography of objects such as a screen, as shown in Fig. 1. The dazzling illumination causes an unpleasant feeling in people. This is well known as “speckle noise” [1–3]. Therefore, the suppression of speckle noise is necessary for laser displays such as an image projection system. In order to suppress speckle noise, the use of diffusers has been reported [4,5]. Furthermore, in addition to the application of a diffuser, the technique of a moving screen or moving diffuser has been investigated [6-8], and it can reduce speckle noise to less than 1/3 [8]. In the technique using a diffuser, the noise reduction originates in lowering the interference of laser light with high coherency. Thus, the strongly diffusive effect also suppresses or degrades numerous merits of laser light mentioned above. In our work, we have tried to formulate an idea for suppressing the speckle noise using liquid

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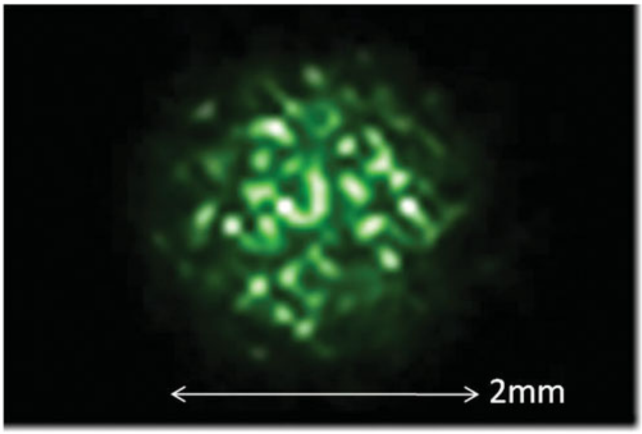

Figure 1. Photograph of speckle pattern.

crystal (LC) devices that have electrically controllable optical characteristics. Recently, we reported a technique using a conventional homogeneous LC cell for reducing the speckle noise [9]. The idea for suppressing speckle noise is to modulate speedily the interference or speckle pattern and average their patterns without lowering the interference or the merits of laser light. In this paper, in order to further reduce the speckle noise, we offer an idea of using a polymer-dispersed LC (PDLC) cell in which the speckle pattern can be varied in addition to the optical diffusive effect.

2. Experimental Procedure

The following materials were used in this research: the nematic LC was E7 (LCC) and the photocurable monomer was NOA-65 (Norland). The E7 LC medium doped with 20 wt% NOA-65 was injected in the isotropic phase into an empty cell fabricated using a pair of glass substrates coated with indium-tin-oxide without alignment films. The cell gap was set 10 μm. Then, the photocure of the monomer was carried out with UV light (365 nm, 20 mW/cm^2) at the isotropic phase temperature (90°C).

The laser spot onto screen was observed using the optical measuring system shown in Fig. 2. The wavelength of laser light used was $\lambda = 532$ nm. Common white paper was used as the screen. For the quantification of speckle noise, the digital photograph of the

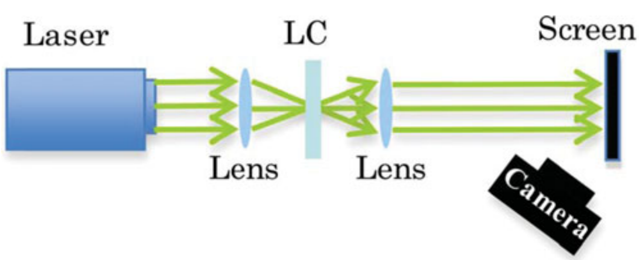

Figure 2. Optical measuring system used in this research.

laser spot was analyzed by using Adobe Photoshop Element 10, and the average value and the standard deviation of the optical power in the speckle pattern were calculated as $I_{ave} = (\sum_{n=1}^{N} I_n)/N$ and $\sigma = \{(\sum_{n=1}^{N} |I_{ave} - I_n|^2)/N\}^{1/2}$, respectively, where N is the total pixel number of the digital image and n is the number of pixels. The contrast is defined as $C = \sigma/I_{ave}$ and extensively used as the value of speckle noise [10]. The contrast ratio and the reduction ratio of speckle noise are shown as C/C_0 and $1-C/C_0$, respectively, where C_0 is a contrast measured without the LC cell.

3. Results and Discussion

Figure 3 shows the UV irradiation time dependence of the microscopic texture observed with a polarized microscope. It is found that the domain size decreases in the initial process

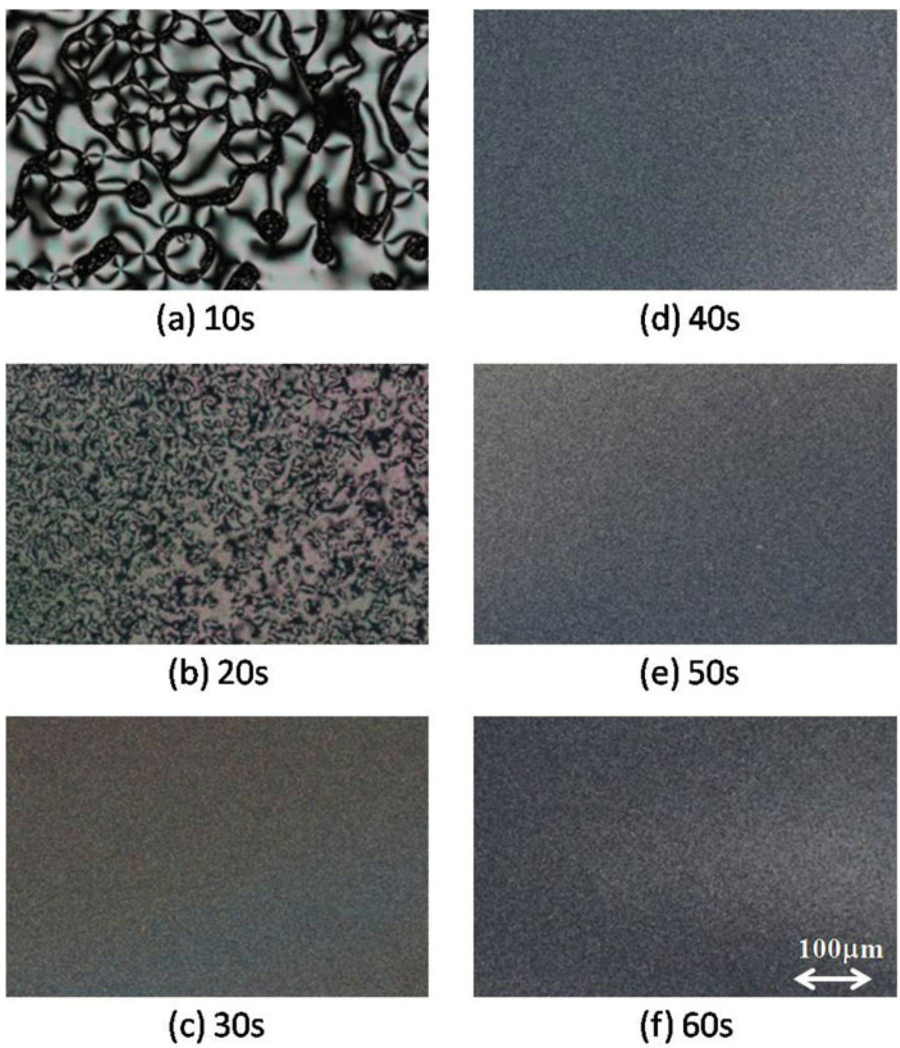

Figure 3. UV irradiation time dependence of microscopic texture in PDLC.

Table 1. UV irradiation time dependence of optical transmittance for PDLC cells fabricated in this research: the transmittance is normalized as the ratio to the transmittance of only laser light without the PDLC cell

UV irradiation time (s)	Transmittance
10	0.85
20	0.61
30	0.55
40	0.58
50	0.58
60	0.56

of photocuring as the UV irradiation time increases, because the number and volume of polymer networks increase. After that, the texture does not almost vary over 30s UV irradiation. Table 1 shows the UV irradiation time dependence of the optical transmittance for the cells shown in Fig. 3, where the transmittance is normalized as the ratio to the transmittance of only laser light without the PDLC cell. It is found that the effect value of optical diffusion in the PDLC cell fabricated in this research is saturated at about 30s UV irradiation.

Table 2 shows the UV irradiation time dependence of the reduction ratio of the laser speckle noise for the PDLC cells fabricated in this research. It is found that about 10% reduction of the speckle noise can be obtained by the optical diffusive effect in the PDLC cells, which were irradiated over 30s UV, under the quiescent condition. Furthermore, in the case of PDLC cell fabricated by 30s UV irradiation, about 25% reduction of the speckle noise can be obtained by adding the spot pattern, which is observed under the application of a square-formed AC electric field (20Vpp (±10V), 100Hz), to the pattern observed under the quiescent condition. This further reduction is originates in the modulation of the laser spot pattern due to the switching of LC molecular orientation. As a result, this fact means that about 15% of the reduction can be obtained by the spot pattern variation. On the other

Table 2. UV irradiation time dependence of reduction ratio of laser speckle noise for PDLC cells fabricated in this research: *A* is the reduction ratio under the quiescent condition (0V) and *B* is that obtained from a composite photograph of the laser spots under the application of 0V and ±10V. The value of *B-A* means the effect of laser spot pattern variation originated in the reorientation of LC molecules under the application of electric field.

	Reduction ratio of speckle noise (%)		
UV irradiation time (s)	*A*: 0V	*B*: composite	*B-A*
10	0.0	0.0	0.0
20	0.0	0.0	0.0
30	11.2	25.7	14.5
40	10.0	10.6	0.6
50	12.1	13.4	1.3
60	7.6	7.6	0.0

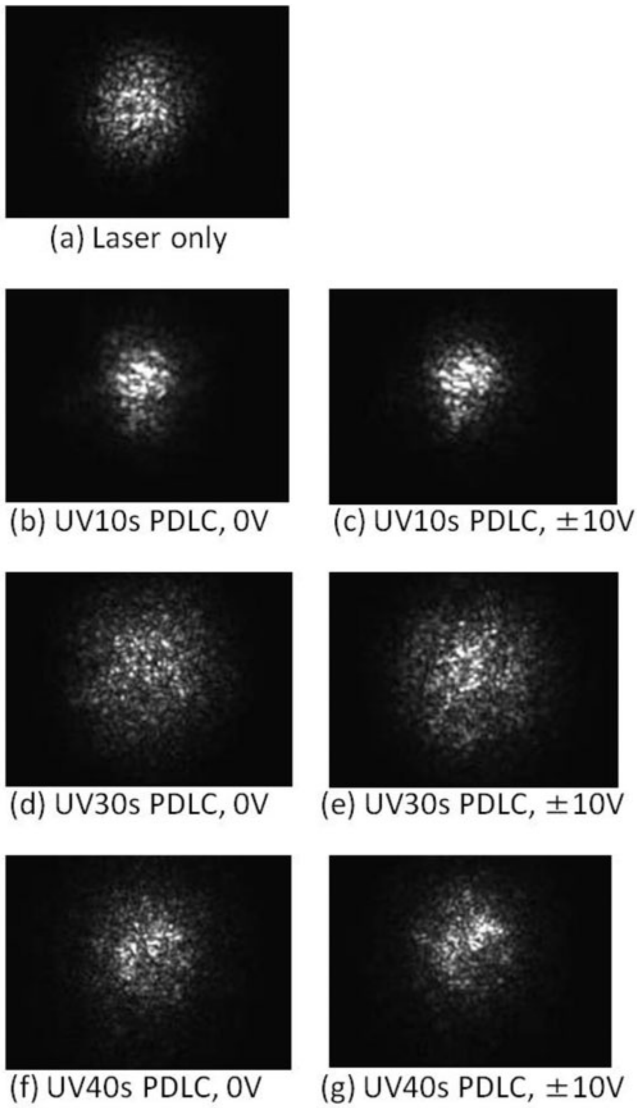

Figure 4. UV irradiation time dependence of laser spot pattern.

hand, the large noise reduction cannot be obtained for the cells photocured by less than 20s and more than 40s UV irradiation. Figure 4 shows the photographs of the laser spot patterns. It is found that the spot pattern changes by the application of the electric field in the case of PDLC photocured by 30s UV irradiation. On the other hand, the large variation of the spot pattern is not observed in the cases of PDLCs photocured by less than 20s and more than 40s UV irradiation. In the case of less than 20s UV, the threshold voltage is less than 10V and the threshold characteristics of the molecular switching is very sharp due to insufficient polymerization, and thus, the optically isotropic situation does not almost change for laser beam because the homeotropic molecular alignment is maintained under the application of the square-formed AC electric field. As a result, the large variation of the laser spot pattern is not observed. In the case of more than 40s UV, it is guessed that the polymerization progresses even over 30s UV irradiation, and then, the strength of the polymer stabilization effect increases. As a result, for excessive UV irradiation, the LC molecules cannot almost reorient under the application of 10V due to the strong polymer anchoring. Therefore, the laser spot pattern does not almost change. However, in the case of 30s UV, the threshold voltage of the PDLC molecular switching is equivalent to the applied voltage of 10V, and thus, the director of the molecules can reorient but is not perfectly homeotropic under the application of the electric field. As a result, the laser spot pattern can be varied by the anisotropy of LC medium for laser beam and the larger reduction of laser speckle noise can be achieved.

4. Conclusions

We have formulated an idea for suppressing laser speckle noise using LC devices which have electrically controllable optical characteristics. In this paper, we focused on PDLC cells, and researched the UV irradiation time dependence of the characteristics of PDLC cells for the effect on the speckle noise reduction. As a result, More than 25% reduction ratio of the laser speckle noise can be obtained. This large reduction originates in not only lowering the interference of laser light due to optical diffusion but also the variation of speckle pattern due to the reorientation of LC molecules under the application of electric field.

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