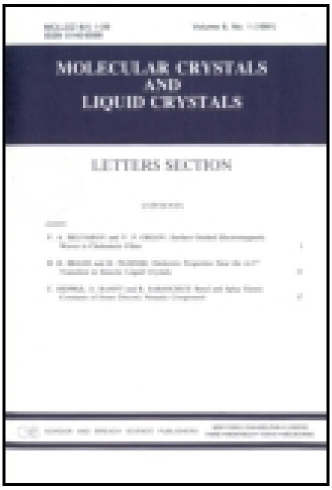

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Control of Laser Speckle Noise Using Liquid Crystals

Kazuhiro Iwami[a], Shunsuke II[a], Yukio Koizumi[b], Masatoshi Ono[b] & Hirokazu Furue[a]

[a] Department of Materials Science and Technology, Tokyo University of Science, Katsushika, Tokyo, Japan

[b] Funai Electric Advanced Technology Research Institute, Tsukuba, Ibaraki, Japan

Published online: 30 Sep 2014.

To cite this article: Kazuhiro Iwami, Shunsuke II, Yukio Koizumi, Masatoshi Ono & Hirokazu Furue (2014) Control of Laser Speckle Noise Using Liquid Crystals, Molecular Crystals and Liquid Crystals, 595:1, 144-148, DOI: 10.1080/15421406.2014.918237

To link to this article: http://dx.doi.org/10.1080/15421406.2014.918237

Mol. Cryst. Liq. Cryst., Vol. 595: pp. 144–148, 2014

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2014.918237

Control of Laser Speckle Noise Using Liquid Crystals

KAZUHIRO IWAMI,[1,*] SHUNSUKE II,[1] YUKIO KOIZUMI,[2] MASATOSHI ONO,[2] AND HIROKAZU FURUE[1]

[1]Department of Materials Science and Technology, Tokyo University of Science, Katsushika, Tokyo, Japan
[2]Funai Electric Advanced Technology Research Institute, Tsukuba, Ibaraki, Japan

Laser speckle noise occurs owing to the strong interference that originates in the high coherency of laser light and the surface topography of the screen. The suppression of the speckle noise is necessary for laser displays such as in an image projection system. In order to reduce speckle noise, we try to control the speckle pattern by using liquid crystals (LCs) that have electrically controllable optical characteristics. In this paper, we formulate an idea for suppressing speckle noise using a voltage-gradient LC cell and a polymer-dispersed LC cell.

Keywords laser; speckle noise; liquid crystal; voltage-gradient cell; polymer-dispersed liquid crystal

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 the screen. 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 these in 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. Therefore, the diffuser also suppresses or degrades numerous merits of laser light mentioned above, i.e., destroys the laser light. In our work, we have tried to formulate an idea for suppressing speckle noise using liquid

*Address correspondence to Kazuhiro Iwami, Department of Materials Science and Technology, Tokyo University of Science, 2-1-6 Niijuku, Katsushika, Tokyo 125-8585, Japan. Tel.: +81-3-5876-1717 Fax: +81-3-5876-1614; E-mail: hfurue@rs.noda.tus.ac.jp

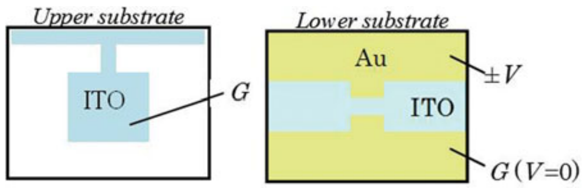

Figure 1. Substrates in a voltage-gradient cell.

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 two ideas: one is a voltage-gradient LC cell in which the retardation of LC can be controlled and distributed non-uniformly in the laser spot area, and another is a polymer-dispersed LC 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 E8 (LCC), the photocurable LC monomer was UCL-001 (DIC) for the polymer-dispersed LC, and the LC alignment film was polyimide RN1199 (Nissan Chemical Industries) for the voltage-gradient cell. In the fabrication of the voltage-gradient cell, a solution of polyimide was spun onto glass substrates shown in Fig. 1, and then baked. After the thermal treatment, the substrates were rubbed. Then, the LC medium was injected in the isotropic phase via capillary action into an empty cell fabricated using a pair of the substrates in which the rubbing directions and the cell gap were set parallel and 6 μm, respectively. On the other hand, in the fabrication of the polymer-dispersed LC cell, the E8 LC medium doped with 50 wt% UCL-001 was injected in the isotropic phase into on empty cell fabricated using a pair of glass substrates coated with indium-tin-oxide (ITO) without alignment films. The cell gap was set 10 μm. Then, the photocure of the LC monomer was carried out with UV light (365 nm, 2 μW/cm^2) at the isotropic phase temperature.

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 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

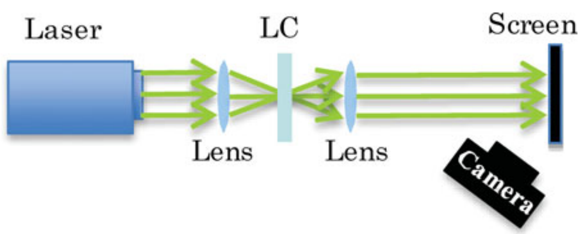

Figure 2. Optical measuring system used in this research.

Table 1. Contrast ratio and reduction ratio of speckle noise measured in the case using a voltage-gradient LC cell.

	Off state (V=0)	On state (Vpp=2.0−3.5V)
Contrast ratio	1	0.53
Reduction ratio (%)	0	47

$I_{ave} = (\sum_{n=1}^{N} I_n)/N$ and $\sigma = \{(\sum_{n=1}^{N} |I_{ave} - I_n|^2)/N\}^{\frac{1}{2}}$, 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 $(C_0 - C)/C_0$, respectively, where C_0 is a contrast measured without the LC cell.

3. Results and Discussion

3.1 Voltage-gradient LC cell

Figure 3 shows photographs of the speckle patterns observed before and after using the voltage-gradient LC cell. Figure 3(b) was obtained by synthesizing the speckle patterns under the application of voltages from 2.0 to 3.5 Vpp at 0.1 Vpp step. It can be seen that bright spots (speckle noise) are reduced by using the voltage-gradient cell. Table 1 shows the measurement results of the contrast ratio and the reduction ratio of speckle noise. It is found that the reduction ratio of speckle noise reaches more than 40% for the common white-paper screen used in this research by modulating the applied voltage. The reduction ratio of speckle noise is measured as 29% for the same screen in the case using a conventional homogeneous LC cell [9]. Therefore, this large reduction originates in not only the temporal variation of the situation of polarized light due to the modulation of applied voltage but also the spatial variation of that due to the voltage gradiation inside the cell.

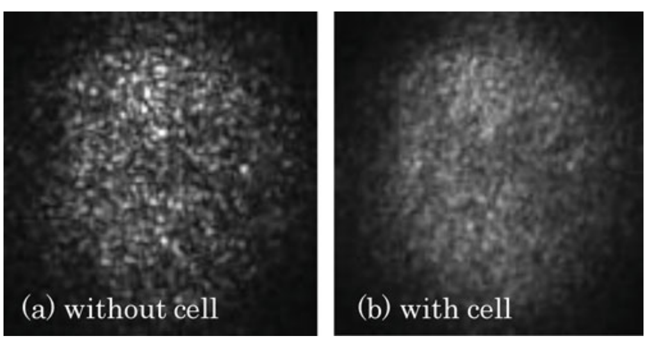

Figure 3. Photographs of speckle patterns in the situation with and without a voltage-gradient LC cell.

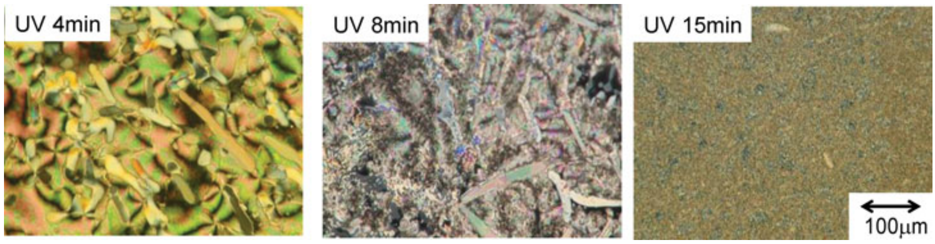

Figure 4. UV irradiation time dependence of microscopic textures in E8 LCs doped with UCL-001 monomer.

3.2 Polymer-dispersed LC cell

Figure 4 shows the UV irradiation time dependence of the microscopic textures observed with a polarized microscope in E8 LCs doped with UCL-001 monomer. It is found that the domain size decreases in the process of photocuring as the UV irradiation time increases, because the number and volume of polymer networks increase. As a result, the longer the UV irradiation time is, the stronger the optical scattering is. Furthermore, the threshold voltage of LC molecule switching increases due to the effect of polymer stabilization as the increase of the UV irradiation time. Figure 5 shows the measurement results of the contrast ratio in the use of the polymer-dispersed LC cells photocured by 4, 8 and 15 min UV irradiation. The contrast ratio was measured by synthesizing the spot patterns under the application of voltage from 1 to 20 Vpp at 1 Vpp step. It is found that from the results in the case of the number of synthetic spot pattern = 1, the reduction of speckle noise can not be almost obtained only by introducing the polymer-dispersed LC cell without the spot pattern variation. Therefore, the cells fabricated in this research does not almost diffuse the light. Table 2 shows the reduction ratio of speckle noise in the case of the number of synthetic spot pattern = 21. It is found that the effect of the spot pattern variation on the reduction of speckle noise is strongest in the use of the cell photocured by 8 min UV irradiation. In the case of shorter UV irradiation time such as 4min, since the domain size of LC is large, the variation of speckle pattern is small. On the other hand, in the case of longer UV irradiation time such as 15 min, since the threshold voltage is high and thus the reorientation of LC molecules is small under the voltages used in this research, the variation of speckle pattern is small. Therefore, it is guessed that the 8 min UV irradiated cell can show the best performance for the reduction of speckle noise.

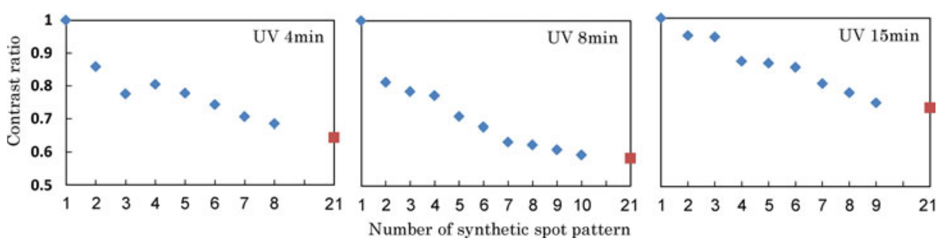

Figure 5. Contrast ratio measured in the use of polymer-dispersed LC cells photocured by 4, 8 and 15 min UV irradiation.

Table 2. Reduction ratio of speckle noise measured in the use of polymer-dispersed LC cells.

	Reduction ratio (%)	
UV irradiation time(min)	Total effect	Effect of spot pattern variation
4	36	36
8	43	42
15	28	27

4. Conclusions

We formulated an idea for suppressing laser speckle noise using LC devises that have electrically controllable optical characteristics. The reduction ratio of speckle noise more than 40% was obtained by using a voltage-gradient LC cell. This large reduction originates in not only the temporal variation of the situation of polarized light due to the modulation of applied voltage but also the spatial variation of that due to the voltage gradiation inside the cell. Furthermore, >40% reduction ration of speckle noise can be obtained by the use of a polymer-dispersed LC cell. This large reduction originates not in lowering the interference of laser light due to light scattering but in the variation of speckle pattern due to the reorientation of LC molecules under the application of electric field. Further reduction of speckle noise will be expected by utilizing the combination of those two type of LC cells.

Acknowledgments

The authors thank Dr. H. Fukuro and Mr. H. Endoh of Nissan Chemical Industries for supplying polyimide materials. We also thank Dr. H. Takatsu, Dr. H. Hasebe, Dr. K. Maruyama, and Dr. I. Nishiyama of DIC for supplying photocurablemesogenic monomer materials.

References

[1] Goodman, J. W., & Dainty, J. C. (1975). *Laser Speckle and Related Phenomena.*, Springer: Heidelberg, 9.
[2] Dainty, J. C. (1976). *Progress in Optics.*, *14*, 1.
[3] Okamoto, T., & Asakura, T. (1995). *Progress in Optics.*, *34*, 183.
[4] Burckhard, C. B. (1970). *Appl. Opt.*, *9*, 695.
[5] Nakayama, Y., & Kato, M. (1979). *J. Opt. Soc. Am.*, *69*, 1367.
[6] Lowenthal, S., & Arsenault, H. (1971). *J. Opt. Soc. Am.*, *61*, 847.
[7] Rawson, E. G., Nafarrate, A. B., Norton, R. E., & Goodman, J. W. (1976). *J. Opt. Soc. Am.*, *66*, 1290.
[8] Kasazumi, K., Kitaoka, Y., Mizuuchi, K., & Yamamoto, K. (2004). *Jpn. J. Appl. Phys.*, *43*, 5904.
[9] Furue, H., Terashima, A., Shirao, M., Koizumi, Y., & Ono, M. (2011).*Jpn. J. Appl. Phys.*, *50*, 09NE14.
[10] Mitamura, T., Kitajima, H., Shirakawa, T., & Ogawa, Y. (1993). *Hokkaido DaigakuKogakubuKenkyuHokoku[in Japanese]*, *164*, 49.