Impact of Thickness of Liquid Crystal Cell on Holographic Properties with the Assistant of Photoconductive ZnSe Film

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Abstract: As short as response time (5.4 ms) and as large as exponential gain coefficient (1795.0 cm^{-1}) were obtained in C_{60} doped 5CB liquid crystal cells sealed between two ITO glass plates coated with ZnSe film.

OCIS codes: (090.0090) Holography; (090.5694) Real-time holography.

1. Introduction

For decades, the exploration of novel photorefractive (PR) material and the optimization of existed ones never stop drawing the great interest of researchers [1]. Compared to inorganic material such as $LiNbO_3$, organic materials including polymers and liquid crystal occupy a more important niche in holographic display owing to their high figures of merit, easy processing and flexibility [2]. Also, low dc field applied on liquid crystal are very promising in both experimental and commercial use [3]. However, there is still much room for the improvement of response rate. Since the discovery of PR effect in LCs [1], most reported PR-like effect in nematic liquid crystals still maintains slow response rates and the holograms is transient in most reported works [4], which hinder the applications of LCs on real-time holography. With endeavors on seeking photorefractive substrates to accelerate PR process and interlayers [2] to optimize specimen structure, response as short as several tens of ms have been achieved. For instance, near real-time response of 17.1 ms has been realized in our group by introducing photoconductive ZnSe film [5]. Intrigued by this work, a further improved response time of 5.4 ms and exponential gain coefficient 1795.0 cm^{-1} were recently obtained in our work. Compared to 17.1 ms in which pictures are displayed discontinuously, the advantage of 5.4 ms is that it provides a frequency of 200 Hz, which has satisfied the real-time display where display is continuous. In spite of this, it can therefore be inferred from both works that photoconductive material ZnSe plays a significant role in accelerating PR process.

2. Specimen preparation and experimental setup

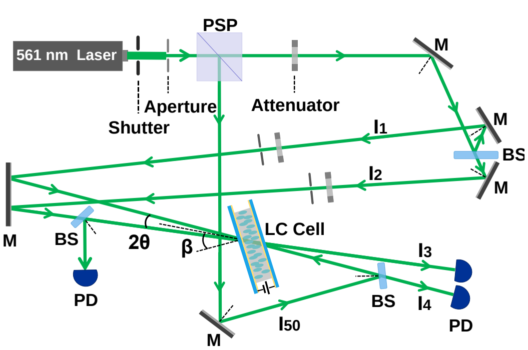

Fig. 1 Experimental configuration for measuring 2BC parameters and response dynamic. PSP: Polarization Splitting Prism; M: Mirror; BS: Beam Splitting; PD: Photodetector.

In our specimen, (a) ZnSe was chosen to be a photoconductive agent, which is responsible mainly for the transporting of charge carriers and partially for their generating and trapping functionalities; (b) 4,4'-n-pentylcyanobiphenyl (5CB) was employed for its excellent nonlinearity such as birefringence and photoelectric effect; (c) fullerene C_{60} was added to serve as an efficient charge generator. Photoconductive ZnSe was directly deposited on the top of two ITO glass with e-beam evaporation deposition methodology (LJ-550E, LJ-UHV Technology Co., Ltd.). C_{60} were mixed with 5CB at weight ratio of 0.05 wt. %. We mainly studied the holographic properties of LC cells with different LC layer thickness ranging from 6.4 μm to 62.0 μm. It should be noted that

ZnSe not only plays the role in serving as an agent for charge-carrier transporting, but also act as an aligning layer. With a typical slanted geometry shown in Fig. 1, the cell was tilted at an angle $\beta = 45°$ to the bisector of two recording beams, whose crossing angle was $2\theta = 1.0°$ corresponding to a grating spacing $\Lambda = 18.9$ μm. Two p-polarized recording beams (λ=561.0 nm) were tuned into identical intensities (14.2 $mW \cdot cm^{-1}$) to illuminate LC cell at an intersection of 0.07 cm^2.

3. Experimental results and discussion

3.1 2BC experiments

Seven kinds of specimens with different thickness of LC layer were fabricated and exponential gain coefficients (EGCs) versus applied voltage were measured. As shown in Fig. 2(a), the seemingly irregular result indicated a complicated process of space-charge field formation in the specimens. In the range from 12.7 to 62.0 μm, EGC was quite low from -41 cm^{-1} up to 161 cm^{-1}. As the thickness decreased further, the sign of EGC became more complex. In LC cell with 5.1 μm thick LC layer, for instance, EGC first increased to the maximum of 670.3 cm^{-1} at 2.0 V applied and then decreased to its negative values with a peak of -1031.5 cm^{-1} at 6.5 V. The situation observed in 3.5 μm was just the opposite. EGC gradually decline to 474.6 cm^{-1} at 2.0 V and then increased to the largest value of 1795.0 cm^{-1} at 6.5 V. Here, the change of energy transferring direction probably stemmed from the space charge redistribution, which led to the phase shift between the total index refraction modulation and the interference pattern change. It is also noticed that standard deviation of EGC became very large during 5.5 V~6.5 V. As the voltage increased further, the scattering of two transmitted beams intensified and led to weaker energy coupling.

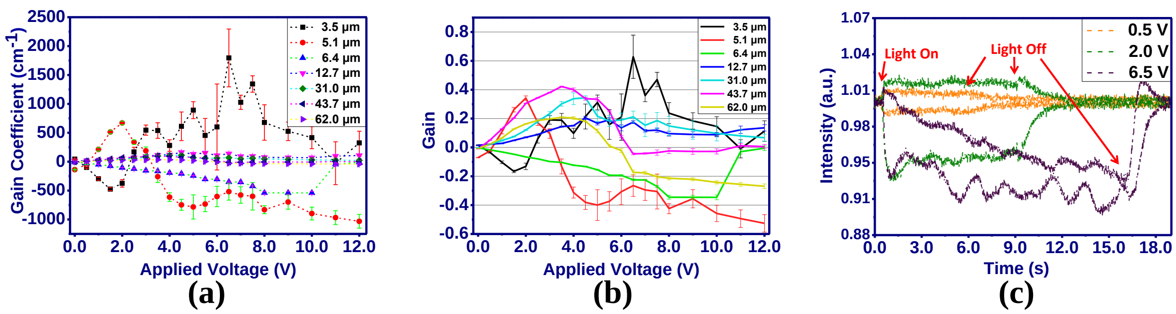

Fig. 2 (a) EGCs versus applied voltage with different thickness of LC layer; (b) gain versus applied voltage with different thickness of LC layer; (c) 2BC dynamic obtained at 0.5 V, 2.0 V and 6.5 V in LC cell with 3.5 μm thick LC layer.

As described above, thinner specimen corresponds to larger absolute value of EGC. We tentatively attributed this trend to the surface-mediated PR effect [6]. When calculating gain according to $\gamma = \cos(\beta)\ \ln(\gamma_0 \cdot \gamma_1)$. It is found that there was no so big difference (Fig. 2(b)) on the gain for LC cells with different thickness of LC layer, neglecting their signs. The thinner the LC layer was, the higher the EGC became, which implied that surface-mediated PR effect played a critical role on EGC. In addition, there was a phenomenon as shown in Fig. 2(c) that was very similar with that as described in Ref [6], a sharp temporary increase appeared when switching off the dc field, which was mainly attributed to surface-mediated PR effect. This similar phenomenon was seen in our cases as shown in Fig. 2(c). The 2BC dynamic curve measured at 6.5 V indeed jumped to a higher value before returning to the final level upon switching off the dc field.

Fig. 2(c) also shows that considerable asymmetrical energy transferred from one beam to another at 2.0 V. That is, which indicated that the grating here was PR-like. Particularly, as voltage raised to 6.5 V, intense energy competition between two recording beams appeared. Moreover, the attenuation of both beams was observed at 6.5 V instead of amplification of one beam and attenuation of the other, which is due to scattering and diffraction to higher orders in both sides. This also helped explain why the standard deviations of EGC were very large at 5.5 ~6.5 V shown in Fig. 2(a).

3.2 Grating-probing experiments

Both p-polarized and s-polarized probing beams were employed to readout PR grating, respectively, by propagating precisely against one of two recording beams as shown in Fig.1. All gratings in our cases fall into Raman-Nath regime, in which many high diffraction orders are expected. It can be seen form Fig. 3(a) that response time measured with s-polarized reading beam was generally 20 ms faster than that by p-polarized one. It is because that p-polarized probing beam could interact with two writing beams of p-polarization and thus partially smeared out the grating while s-polarization not, whose polarized direction was perpendicular to writing beams and could transmit

LC cell without any disturbance to the written grating. In addition, with an increase in the thickness of LC layer, response time decreased rapidly and then reached its minimum 5.4 ms in 6.4 μm and finally tend to be stable in thicker LC layer. Minimum response time of two kinds of polarization probing was both located in 6.4 μm as presented in Fig. 3(b). However, low diffraction efficiency (2.69 %) and EGC (-466.3 cm^{-1}) at 11.0 V in 6.4 μm sample were not very high and still needed to be further improved. This result is promising in real-time holographic display. By comparison, no grating forms in LC cell without depositing ZnSe film even high electric field was applied. This difference suggests that fast response rate are most probably attributed to photoconductive ZnSe film. The key to boost response performance lies in the fast excitation and transportation of charge carriers within interference pattern by virtue of ZnSe film. Owing to faster shift speed of electrons than that of holes, electrons would be ahead of holes to shift rapidly to the dark area along film transverse as shown in Fig. 3(c) and then recorded grating in a very short time.

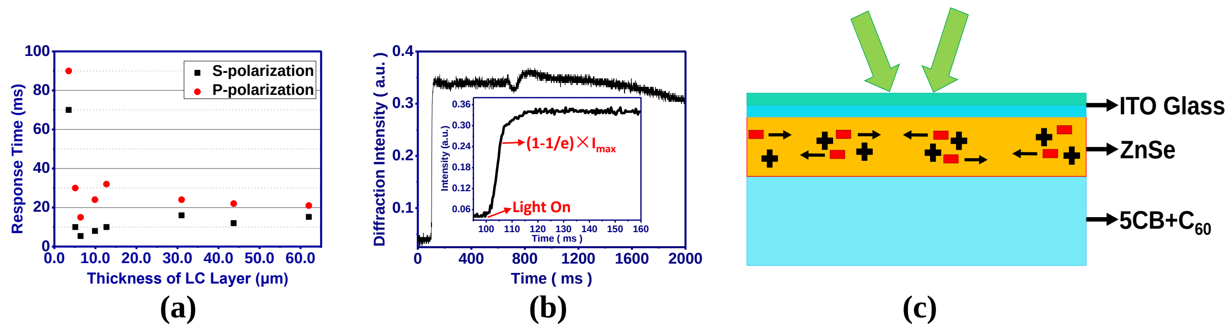

Fig. 3 (a) Response time versus thickness of LC layers under s- and p-polarization probe at applied voltage of 11.0 V; (b) response dynamic of specimen of 6.4 μm thick LC layer with s-polarization probe at 11.0 V, detailed response was indicated in the inset; (c) tentative mechanism of grating formation.

4. Conclusion

In conclusion, the holographic performance was investigated in C_{60} doped 5CB liquid crystal cells sandwiched between two ITO glass plates coated with ZnSe film. A large EGC as high as 1795.0 cm^{-1} was measured in the specimen with 3.5 μm LC layer. Surface-mediated PR effect was tentatively regarded to contribute to the large EGC. More importantly, real-time Response of 5.4 ms has been realized in specimen with 6.4 μm thick LC layer. The excellent capability of ZnSe to accelerate charge carriers generation and transportation was the main reason to the fast response. Both results indicated a further step towards real-time holography display. Moreover, low activation energy of ZnSe makes it possible to operate the specimens in our work in IR waveband.

5. References

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