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Large exponential gain coefficient in polymer assisted asymmetric liquid crystal cells originating from surface effect

Jiayin Fu [a,b], Jingwen Zhang [a,b], Tingyu Xue [a,b], Hua Zhao [a,b,*]

[a] Institute of Modern Optics, Department of Physics, Harbin Institute of Technology, Harbin 150001, China
[b] Key Laboratory of Micro-Optics and Photonics Technology of Heilongjiang Province, Harbin 150001, China

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ABSTRACT

As large as 4607 cm^{-1} gain coefficient in two beam coupling experiment was obtained by introducing PVK:C_{60} film to ZnSe assisted liquid crystal system. As short as 5.0 ms holographic recording time was reached when probing the grating formation process, showing great potential in real time applications. Systematical two beam coupling and grating probing experiments were performed in studying the mechanism behind the high photorefractive (PR) performance. Unusual energy transfer direction change and gain coefficient fluctuation were observed when the voltage polarity and incidence side were altered in the related two wave coupling experiments.

1. Introduction

In recent years, 3D display [1,2] draws growing attentions with rapid development of digital technology. The success of the movie “Avatar” demonstrated vitality and bright prospect of 3D display. Envisioned with great potential for growth, leading technology companies, such as Apple, Inc, Google, Inc, Facebook, Inc. etc. are aggressively investing in 3D display and related technologies. Riding with this trend, research activities on real-time holographic display [3–7], fast electro-optic modulation [8–11] and photonic circuit [12–15] become highlights again lately. Organic materials for these applications have many positive attributes regarding their potential including high figures of merit, large size, flexibility and controllability, and easy processing. For decades, investigations on the photorefractive (PR) nonlinearity of organic materials, arguably the most promising candidate for 3D holographic display, continues to progress [16,17]. Compared to other organic materials, liquid crystals (LCs) share many merits, such as broadband birefringence, large optical nonlinearity, low-voltage tunability etc. [18–22] and hence are intensively studied as favorable ones among PR materials.

In most of previously reported works on PR LCs, the response time ranged mostly in order of minutes to seconds, restricted by LC low charge transport properties. To shorten response times, photoconducting interlayers were introduced into LC cells to improve the charge transportation [23,24]. In 2012, by introducing ZnSe photoconductive layers, Lian et al. [25] shortened the response time to 15.0 ms. When an external electric field voltage is applied on a LC system, the voltage is mostly dropped across the LC layer because of its relatively high resistivity. Therefore, nano or sub-nano interface between LC and adjacent layers is positively or negatively charged. As the result, a series of novel phenomena were observed under external illumination. In order to understand the influence of electric charge accumulation at the interface on the physical processes in LC system and related experimental observation, we made several asymmetric LC cells with different photoconducting interlayers and studied these samples systematically. We report our work as follows.

2. Preparation of samples

The structure of asymmetric LC panel we designed was illustrated in Fig. 2. A PVK:C_{60} polymeric thin film was introduced as one of photoconductive layers, and another ZnSe film deposited on the opposite side served as both charge transportation and homeotropic alignment agents [25]. Photosensitizer C_{60} was slightly doped into 4,4′-n-pentylcyanobiphenyl (5CB) LC to improve photo-charge generation. All the materials used are commercially available, including 5CB (Merck), C_{60} (Aldrich) and the polymer poly[N-vinylcarbazole] (PVK) (Aldrich), except ZnSe.

In preparing the top substrate, measured amounts of PVK and C_{60} (97.0 wt.% PVK, 3.0 wt.% C_{60}) were dissolved in a toluene and cyclohexanone solvent mixture (mixing ratio 3:1), the concentration of the solution was set to 1.0 wt.%. After 24 hours stirring at

* Corresponding author at: Institute of Modern Optics, Department of Physics, Harbin Institute of Technology, Harbin 150001, China.
E-mail address: zhaohuaz@hit.edu.cn (H. Zhao).

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80 °C, the solution was spin-coated onto a clean ITO glass plate and then the top substrate was put into a leveled, covered container for the sake of slowly drying to achieve a smooth film surface. After air drying, the top substrate was placed in a vacuum oven for 12 hours at 80 °C to remove all remaining solvent. The thickness of the PVK:C_{60} thin film was characterized with a stylus profilometer (Ambios Technology, Inc. Model XP-100). The average thickness of the film measured was 150 nm and the roughness of the film was within 2.0 nm. In preparing a bottom substrate, a 500 nm-thick ZnSe thin film was deposited onto another clean ITO glass plate using e-beam evaporation methodology (LJ-550E, LJ-UHV Technology Co.). The cavity temperature of e-beam evaporator was heated up to 100 °C for the sake of good adhesion performance. The substrate rotation speed was 20 rpm during deposition and the deposition rate was set at 3 Å/s to ensure good film quality. After substrates being prepared, an empty cell was made by placing two pieces of spacers (polyester wrap with specific thickness) or fiber powders (Merck) with specific diameter between the two substrates with the PVK and ZnSe covered sides face each other. The thickness of LC layer was determined by spacers or fiber powders (powder for 3.5 μm cell and polyester wrap for 6.4 μm, 12.7 μm, 31.0 μm cells) placing in between the two substrates. And then 5CB doped with 0.05 wt.% C_{60} was filled into the cell with capillary effect. The operating temperature was set above the clear point and then gradually cooling to room temperature after filling to ensure good molecular alignment. The cell fabrication process is illustrated in Fig. 1 and the schematic structure of a fabricated LC cell is illustrated in Fig. 2.

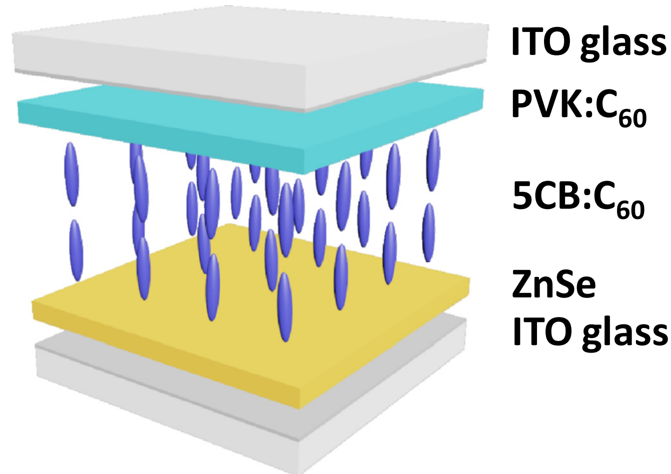

Fig. 2. Schematic of LC cell with PVK:C_{60} and ZnSe layers on the opposite sides.

3. Two beam coupling experiments

With typical slanted geometry (illustrated in Fig. 3), the two beam coupling experiments was performed with a semiconductor diode pumped laser centered at 561.0 nm as a coherent light source. The LC cell was tilted at an angle $\beta=45°$ to the bisector of the two p-polarized recording beams 1 and 2, with a crossing angle at $2\theta=0.67°$ in the air and corresponding grating spacing $\Lambda=29.6$ μm calculated according to $\Lambda=\lambda/[2n\sin(\theta/2)]$, where λ is the wavelength of the writing beams in vacuum and $n=1.63$ is the refractive index of LC in the incident direction, which was calculated using index ellipsoid equation ($n_e=1.54$, $n_o=1.72$, $\beta=45°$). The two writing beam 1 and 2 were adjusted with equal power at 5.0 mW, and equal diameter, 2.0 mm. To better understand the influence of photoconductive layer on PR process, both applied voltage direction and incident plane were altered (illustrated in Fig. 4). These four configurations were denoted as cases A, B, C, D, which will be stated separately in the following passages.

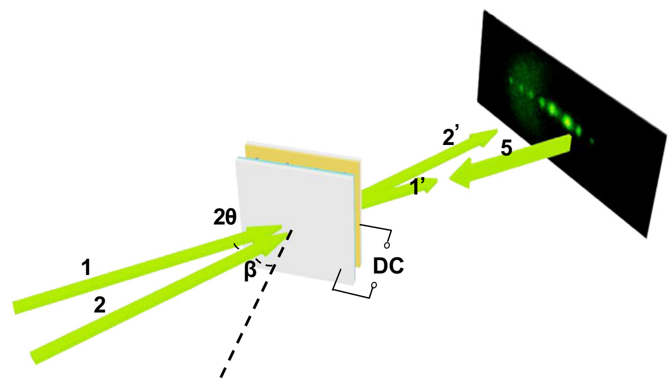

Fig. 3. Scheme of the two beam coupling and grating-probing experiments.

Fig. 5 shows gain coefficients of 12.7 μm-thick specimen varying with voltage under the four cases illustrated above, which were calculated according to $\Gamma=(\cos\theta/d)\ln(\gamma_1\cdot\gamma_0)$, where γ_0 and γ_1 refer to the transmitted intensity ratio of two recording beams

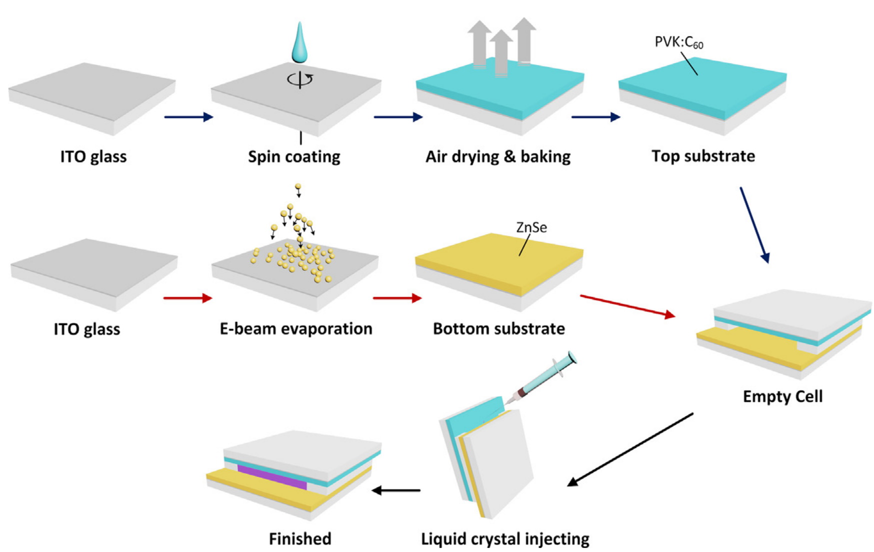

Fig. 1. Schematic diagram shows how a LC cell is prepared.