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Fast Switchable Grating Based on Ferroelectric Liquid Crystal

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Abstract

In this article, a method for the fabrication of Ferroelectric liquid crystal switchable grating based on photo-alignment technique has been proposed. The first order diffraction efficiency is 86% and response time is 69 μ s, which is 10 times faster than the existing switchable gratings. Maximum performance can be achieved at the electric field of 7V/ μ m.

1. Introduction

Liquid crystal (LC) gratings has been widely used in flat-panel display, projection display, backlight for display, optical interconnects and numerous electro-optical applications [1, 2, 8, 10]. Various types of LC gratings [12-14] have already been studied but they suffer through slow switching speed, high power consumption, and low diffraction efficiency [1, 3-4]. For liquid crystal polarization grating [5, 6] which can achieve binary LC grating, also show slow switching speed. Therefore, Ferroelectric liquid crystal (FLC) with ultra-fast response time can be a good alternative [7]. In this article, we propose a method to fabricate the FLC grating which can modulate the diffraction profile with fast speed and at a cost of very small power consumption. Ultimately, this can be integrated into a diffraction projection display and Pico-projector. The Photo alignment technique [11] by sulfonic azo dye SD1 has been used to create the two-alignment domains having mutually orthogonal alignment direction.

2. Results and Discussion

The schematic diagram for the fabrication procedure of the FLC grating cell is shown in Fig.1, which include two-step UV exposure of sulfonic azo dye layer. Only one substrate has been coated with the SD1 afterwards, this layer has been exposed through the UV light in two-step to create the two different alignment domains. The re-writability of the alignment direction is the unique property of SD1 dye that makes the fabrication procedure simpler. Thus to create the two alignment domains, First, the substrate has been exposed through UV to get unidirectional alignment, then after in second step, the same substrate has been exposed with mask of desired pitch in a manner such that the alignment direction in two alignment domains are mutually perpendicular. Afterwards, the cell has been assembled and cell thickness was maintained at 1.5 μ m. The FLC FD 4004N (from Dai-ippou Ink and Chemicals, Japan) has been injected in to the cell by the capillary action.

First exposure step

Second exposure step

Assembling

Fig.1. Schematic diagram of FLC Grating Cell Fabrication Procedure. This procedure includes two-step exposure to ultimately generate two alignment domains which are mutually perpendicular.

Fig.2. The setup used in our experiment. FLC cell placed between two crossed polarizers. And screen is used to observe the diffraction profile.

Fig.2 illustrates the schematic diagram of our experimental setup. The FLC cell is placed between the cross polarizers. A screen has been placed at distance to observe the diffraction profile.

The square wave electric field has been applied to the FLC grating cell to modulate the diffraction profile. The mechanism for FLC grating lies on the transmittance difference in two alignment domains. With one polarity of the applied field, the transmittances of two domains are the same and light does not show any grating effect. While for other polarity, the transmittance difference between two domains appears which results in the diffraction pattern. Thus, the diffraction is limited to only one of the polarity while no diffraction exists in other polarity of the electric field. The on-state and off-state represent states with or without diffraction respectively.

Fig.3. First order diffraction efficiency vs. the applied voltage. Insertions (b) and (c) represent the photographs for on-state and off-state. Insertion figure (a) shows the intensity profile for on-state with 7V/μm applied electric field.

Fig.3. illustrates the dependency of the diffraction efficiency on the applied electric field. The diffraction efficiency (DE) is defined as:

$$DE_m = I_m / I_0, \quad (1)$$

where I_m stands for the m order intensity in on-state and I_0 stands for the zero order intensity in on-state. The photographs of on-state and off-state of the diffraction profile are shown in the insertions (b) and (c) in Fig.3. The intensity profile in on-state has also been measured along the diffraction pattern and presented in the insertion (a) of Fig.3. The intensity profile represents that the first order intensity is much larger than other orders (excluding main beam) which gives us high diffraction efficiency.

The contrast ratio defined as:

$$CR = \max(\sum I_{\pm m}) / \min(\sum I_{\pm m}), \quad (2)$$

is measured. The contrast ratio for the $\pm 1^{st}$ orders diffractive beam is 352:1 at 7V/μm of electric field.

Fig.4. Electric field dependency of Response time of main and first order diffraction beam.

The plot of response time vs. voltage for both main beam and the first order is shown in Fig.4. The response time here is defined as time to change transmittance from 10% to 90% in rising period and 90% to 10% in falling period. Response time of the FLC can be calculated as:

$$\tau_{on} = \tau_{off} \sim \frac{\gamma\phi}{P_s E}, \quad (3)$$

where γ represents rotational viscosity coefficient, P_s stands for spontaneous polarization and E is applied electric field.

Proposed grating reveals a very fast response time even at small electric field. When apply 1.33V/μm of electric field, 135μs is response time for the main beam and for the first order it is 239μs. Response times decrease with increasing the electric field and at 7V/μm it decreases to 69μs for both main beam and first order. This response time is at least 10 times faster than the fastest existing grating technologies and can be further improved by the proper selection of material.

3. Conclusion

In this project, we have experimentally demonstrated the switchable grating structure based on ferroelectric liquid crystals with ultra-fast switching speed and high diffraction efficiency at small electric field. In the experiment, the response time of 69μs at 7V/μm has been achieved. High efficiency for the first order up to 86% has been observed with 352:1 contrast ratio. The fabrication process is relatively simple, fast and easy for repeating. We believe this method shows great promise as element for projection display and Pico-projectors.

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