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Author(s)	Kawahira, Yuichi; Iwai, Yuji; Fujii, Akihiko et al.
Citation	電気材料技術雑誌. 2005, 14(2), p. 27-30
Version Type	VoR
URL	https://hdl.handle.net/11094/76797
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Fabrication of Tunable Optical Device
with Holographic Polymer Dispersed Liquid Crystal

Yuichi Kawahira[1], Yuji Iwai[1], Akihiko Fujii[1], Katsumi Yoshino[1,2], and Masanori Ozaki[1]

1. Department of Electronic Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamada-Oka,

Suita, Osaka 565-0871, Japan

Tell: +81-6-6879-7759, Fax: +81-6-6879-7774

E-mail: ykawahira@ele.eng.osaka-u.ac.jp

2. Center for University-Industry Cooperation, Shimane University,

Matsue, Shimane 690-0816, Japan

Introduction

Holographic polymer dispersed liquid crystal (HPDLC) is inhomogeneous materials fabricated by holographic recording processes. The result of the writing process is a grating made by a periodic distribution of small liquid crystal droplets embedded in a polymeric solid matrix[1]. Liquid crystals have a large optical anisotropy and are sensitive to an external stress such as an electric field, so the main optical properties derived from this periodic distribution can be easily controlled by an externally applied electric field[2]. HPDLC materials have potential in many tunable optical applications such as display devices[3], optical strain gauges[4], and tunable photonic crystals[5-6].

In this study, we fabricate HPDLC using holographic record process, and try to control diffraction derived from periodic structure of HPDLC by applying an electric field.

Experimental

Materials and Recording Process

The main components used in this study were the pre-polymer NOA65 (Norland Products) mixed with 30 wt.% of the liquid crystal BL005 (Merck). The photoinitiator dye Rose Bengal (Nacalai Tesque) and the co-initiator monomer N-phenylglycine (Nacalai Tesque) were added to the BL005-NOA65 mixture (~5 wt.% respectively). This dye forms free radicals with the presence of the co-initiator in the pre-polymer, and then initiates polymerization of NOA65 with the exposure of the film to green-blue light. The homogeneously mixture were prepared between two indium-tin-oxide (ITO) coated glass slides separated by 9 μm-thick plastic spacers.

Figure 1 shows an experimental setup for the fabrication of the HPDLC. The light source is an Ar^+ laser (Beamlok2060-4S: Spectra Physics) with the wavelength of 514.5 nm. The angle θ between two recording laser beams was kept at $10°$.

The morphology of the HPDLC was observed by the Confocal Laser Scanning Microscopy (CLSM). For morphology observation, the liquid crystal in the HPDLC was removed by soaking it in methanol.
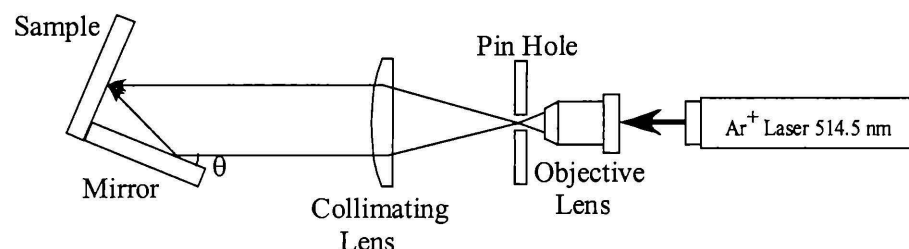
Fig. 1. Experimental setup for the fabrication of HPDLC

Evaluation of Diffraction Efficiency

In order to monitor the formation of the HPDLC in real time, the intensity of a transmitted and diffracted beam of a He-Ne laser light (632.8 nm) was measured by a photodiode and diffraction efficiency was evaluated. A Color filter O-56 (TOSHIBA), which cut off the light with the wavelength shorter than 560 nm, was placed in front of the detector not to detect the writing Ar^+ laser light. The polarization of the probe He-Ne laser light was perpendicular to the grating vector of the HPDLC.

To control the molecular alignment of the liquid crystal, a rectangular wave voltage of 10 kHz was applied between ITO layers of the HPDLC. Then, the diffraction efficiency was evaluated both by parallel and perpendicularly polarized He-Ne laser light.

In order to confirm whether the diffraction efficiency switching was caused by the field-induced molecular reorientation of the liquid crystal or not, the dependence of the response time on applied voltage was measured by oscilloscope. Then, the polarization of the probe He-Ne laser light was perpendicular to the grating vector of the HPDLC.

Results and Discussion

The CLSM morphology of the HPDLC (fabricated at the total power density of laser 250 mW/cm^2, exposure time 230s) is shown in Fig. 2. It was confirmed that holes where liquid crystal droplets had existed were periodically distributed in the polymer with 1.3 μm periodicity.
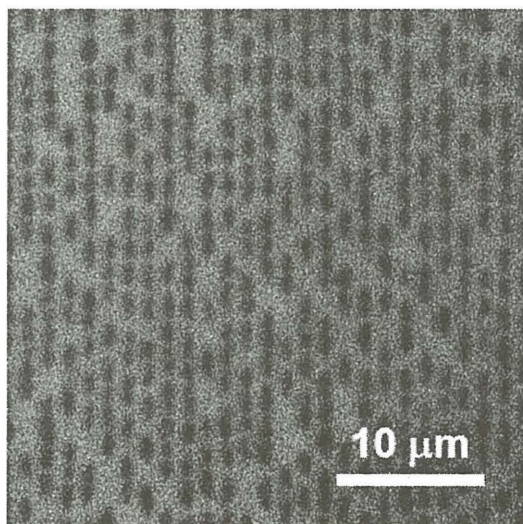

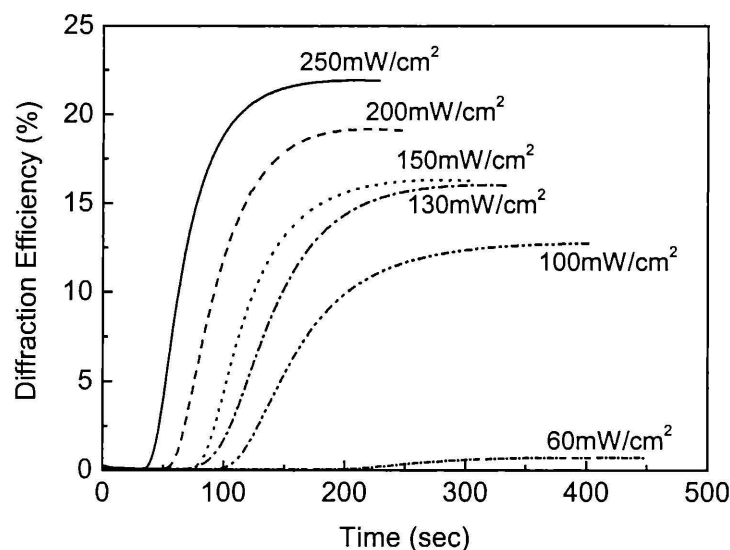Fig. 2. CLSM morphology of the fabricated HPDLC

Fig. 3. Dependence of the diffraction efficiency of the HPDLC on exposure time

The dependence of the diffraction efficiency of the HPDLC on exposure time is shown in Fig. 3. As staring the irradiation of Ar^+ laser beam, periodic structure was fabricated, and the diffraction efficiency gradually increased. From this result, it is found that as the total power density of laser increased, the maximum diffraction efficiency increased.

Figure 4 shows the dependence of the diffraction efficiency of the HPDLC (fabricated at the total power density of laser 250 mW/cm^2, exposure time 230s) on the applied voltage and the polarization of probe He-Ne laser light. When the polarization of probe He-Ne laser light was perpendicular to the grating vector of the HPDLC, the diffraction efficiency decreased as the applied voltage increased. On the other hand, when the polarization was parallel, the diffraction efficiency was nearly constant.

If it is assumed that the director of liquid crystal in droplets is perpendicular to the grating vector of the HPDLC, that phenomenon could be explained as follows. The diffraction efficiency of the HPDLC strongly depends on the difference of the refractive index Δn between the liquid crystal droplets layer and polymer layer. In the case that
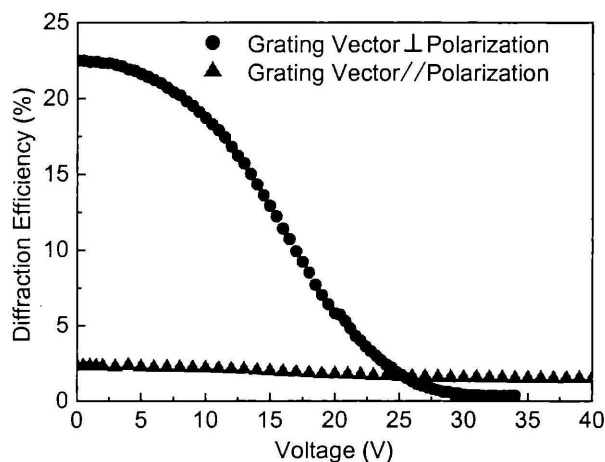

Fig. 4. Dependence of the diffraction efficiency of the HPDLC on the applied voltage
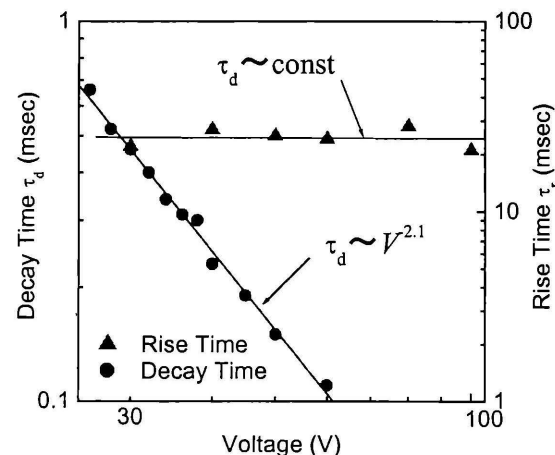

Fig. 5. Dependence of the response time of the diffraction efficiency switching on applied voltage

the polarization of probe He-Ne laser light is perpendicular to the grating vector of the HPDLC, the light feels the difference between n_e (~1.707) of the liquid crystal and the refractive index of the polymer n_{poly} (~1.52) in the initial state (0 V), because the liquid crystal molecules align perpendicular to the grating vector of the HPDLC. However, due to a positive dielectric anisotropy $\Delta\varepsilon$ of the liquid crystal used in this study, the liquid crystal molecules are reoriented along the electric field upon applying voltage. Consequently, at 30 V the light feels n_o (~1.517) of the liquid crystal as the index of the liquid crystal droplets layer, and Δn becomes almost 0. As a result, the diffraction efficiency of the HPDLC decreases upon applying voltage. On the other hand, in the case that the polarization of the probe light is parallel to the grating vector of the HPDLC, whether the voltage is applied to the HPDLC or not, the probe light keeps to feel n_o as the index of the liquid crystal droplets layer, so Δn is not varied. As a result, the diffraction efficiency is constant.

Figure 5 shows the dependence of the response time of the diffraction efficiency switching on applied voltage. The response time in applying voltage (decay time τ_d) was proportional to V^2, and the response time in removing voltage (rise time τ_r) was constant. This result agrees with the response property of Frederiks transition[7-8] induced by an externally applied electric field, so it was confirmed that the diffraction efficiency switching was caused by the field-induced molecular reorientation of the liquid crystal.

Conclusion

In conclusion, we have demonstrated the electrical tuning of the diffraction efficiency of the fabricated HPDLC. The switching of the diffraction efficiency originates from the refractive index modulation caused by the field-induced molecular reorientation of the liquid crystal, which was confirmed by the dependence of the response time of the diffraction efficiency switching on applied voltage.

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