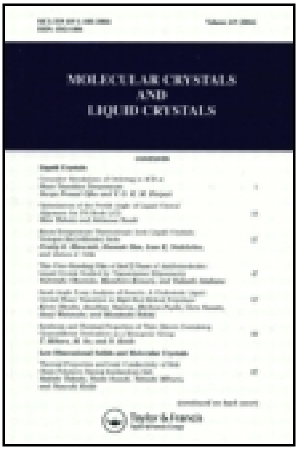

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Fabrication of $x^{(2)}$ Grating in Poled Polymer Film by Single Pulse UV Laser Irradiation Using Holographic Method

Makoto Nakanishi [a], Okihiro Sugihara [a], Hisashi Fujimura [a], Chikara Egami [a] & Naomichi Okamoto [a]

[a] The Graduate School of Electronic Science and Technology, Shizuoka University, 3-5-1 Johoku, Hamamatsu, 432, Japan

Version of record first published: 24 Sep 2006

Mol. Cryst. Liq. Cryst., Vol. 322, pp. 43–48
Reprints available directly from the publisher
Photocopying permitted by license only

Fabrication of $\chi^{(2)}$ grating in poled polymer film by single pulse UV laser irradiation using holographic method

MAKOTO NAKANISHI, OKIHIRO SUGIHARA, HISASHI FUJIMURA, CHIKARA EGAMI, and NAOMICHI OKAMOTO
The Graduate School of Electronic Science and Technology, Shizuoka University, 3-5-1 Johoku, Hamamatsu 432 Japan

Received 6 April 1998; accepted 26 April 1998

We introduce a simple fabrication technique of nonlinear polymeric optical waveguide patterns based on the holographic method. It is found that the second-order nonlinearity of a poled polymer film is erased by single pulse UV laser irradiation. In order to form the periodical structure in the optical polymer waveguide, the optical system of two-beam interference is arranged and a single pulse of UV laser is exposed directly onto the poled film. We prove that this method can simply fabricate the $\chi^{(2)}$ grating with the period from submicron to submillimeter.

Keywords: second-order nonlinearity; holographic method; $\chi^{(2)}$ grating; poled polymer; single-pulse of UV laser

INTRODUCTION

The periodical structure for electrooptic (EO) tunable grating and quasi-phase matching (QPM) in the poled polymer waveguide is important to realize highly efficient operation of EO modulation and frequency conversion. There are several methods to fabricate the $\chi^{(2)}$ grating using several techniques such as periodical poling[1], UV-photobleaching[2], direct electron beam irradiation[3] and reactive ion etching[4]. On the other hand, it is possible to fabricate the diffraction grating by holographic method consisting of two coherent beams. This method has already been realized to fabricate the diffraction grating[5][6] as a practical technique. However, as far as we know, there has been no report on the fabrication of the $\chi^{(2)}$ grating for frequency conversion and linear EO applications using NLO materials by the holographic method using single pulse UV laser irradiation. In comparison with other techniques, this method has several advantages: (1) no masking nor etching is necessary, (2) No vibration isolation table is necessary, (3) Grating period over wide range can be realized. In this paper, the fabrication of $\chi^{(2)}$ gratings from ~100 μm to ~0.7 μm using two optical systems is proved.

EXPERIMENTAL SETUP

We prepared T-AP polymer[2] doped with Disperse Red 1 (DR1) as a NLO material. This polymeric system has lager nonlinearity and greater thermal stability than other dye-doped polymer films. A single pulse of third-harmonic wave of Nd:YAG laser operating at 355 nm with a pulse duration of 5 nsec was used. Therefore a vibration isolation table is not necessary in this system because the period of mechanical vibration is on the order of microsecond. The fringe period by the interferometer is theoretically given $\Lambda=\lambda/2\sin\theta$, where θ is the incident angle of two beams. For example, in order to obtain a first-order QPM-SHG and EO modulation using the DR1/T-AP film, respective period of $\chi^{(2)}$ grating of ~ 5 μm and ~100 μm is required. Considering these applications, we prepared two types of optical system as shown in Fig.1 (a) and (b). The optical system of Fig.1 (a) make it possible to fabricate the $\chi^{(2)}$ grating with the period from submicron to tens of micron. That of Fig.1(b) is

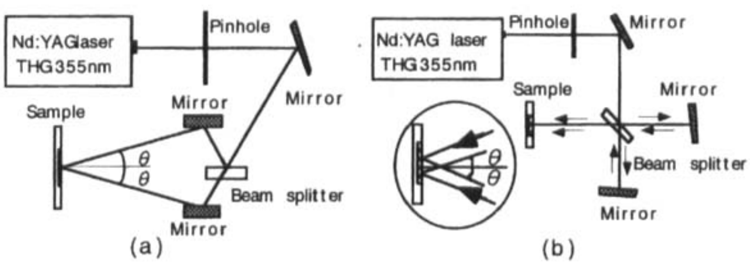

FIGURE 1 Two types of schematic diagram of the experimental setup.

suitable for forming the $\chi^{(2)}$ grating with the period more than tens of micron. Thus by selecting the appropriate interferometric arrangement, the required period can be realized over a wide range.

EXPERIMENTAL RESULTS

UV Irradiation and Its Effect

We tried to erase the second-order nonlinearity of poled polymer films by exposing the UV laser. The UV beam was directly exposed onto the ϕ=5 mm area of poled films. In order to investigate the decay of second-order nonlinearity of poled polymer films by UV irradiation, the Maker Fringe technique using a Q-switched Nd:YAG laser operating at 1064 nm with 90 ns pulse width and 3-kW peak power was used. Fig.2 shows the decay of SH intensity of the poled polymer film as a function of energy density of UV

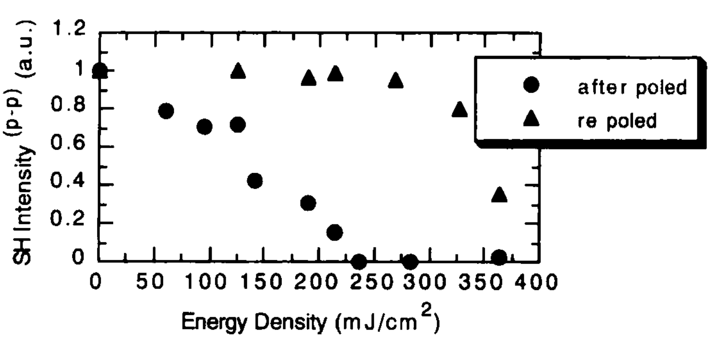

FIGURE 2 Second-order nonlinearity versus the incident energy density.

laser. It was found that the second-order nonlinearity was completely erased over 250 mJ/cm^2. We have investigated the effect of the decay of nonlinearity of poled films by measuring the absorption spectrum change as shown in Fig.3. No decay of peak absorption is observed by UV irradiation below 200 mJ/cm^2. By increasing the UV laser intensity, the peak absorbance was increased. Moreover, re-poling was performed on the UV exposed film as shown in Fig.1. The nonlinearity was recovered to the same level before

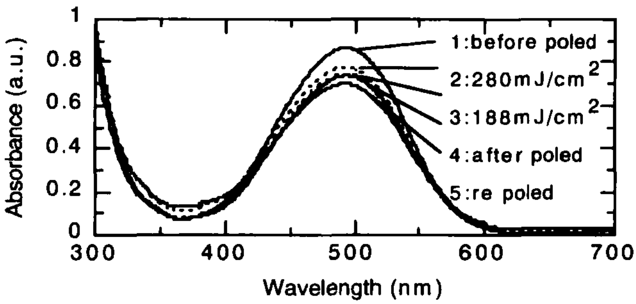

FIGURE 3 Absorption spectrum change under various conditions.

irradiation for the film exposed below 300 mJ/cm^2. However, the nonlinearity of the film after more than 300 mJ/cm^2 irradiation was lower than that of the nonexposed film. A refractive index change of less than 0.2 % was actually obtained in the DR1/T-AP system by single pulse UV irradiation at 250 mJ/cm^2. It is well known that the azo dye such as a DR1 molecule can be photobleached by UV irradiation. According to the energy of N=N bond in DR1 molecule, we can estimate that the photon energy of the bond breakdown must be higher than 4.3 eV, which means that the required irradiation wavelength should be less than 285 nm. Therefore, it was considered that the mechanism of the erasure of $\chi^{(2)}$ with 250 mJ/cm^2 was thermal effect which is caused by the absorption of a laser beam at the absorption range of the dye doped poled film rather than the breakdown.

Moreover, such a high energy density (more than 300 mJ/cm^2) could give an etching onto film. Fig.4 shows a AFM photograph of the actually

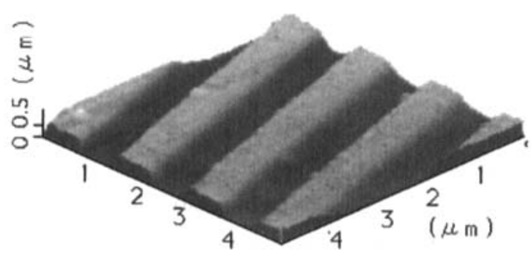

FIGURE 4 AFM photograph of the $\chi^{(2)}$grating of 1.5 μm period.

fabricated grating in DR1/T-AP film with the 1.5 μm period using the UV energy density of 400 mJ/cm^2. The fabrication of the grating with a period up to 0.7 μm was succeeded using this technique. We suggest that the ridge $\chi^{(2)}$ grating can be fabricated by performing the poling forming the relief grating.

Fabrication of $\chi^{(2)}$ Grating

It was found that the fabrication of the buried $\chi^{(2)}$ grating and the ridge $\chi^{(2)}$ grating can be realized by combing the UV irradiation and the poling process. At first, we fabricated the buried type $\chi^{(2)}$ grating. After the corona-poling was performed, single pulse UV laser was exposed onto the dye doped polymer film. Fig.5 shows the typical fringe pattern of SH intensity of $\chi^{(2)}$ grating fabricated by exposure of the energy density of 250 mJ/cm^2 using the setup of Fig.1(b). In this measurement, the $\chi^{(2)}$ grating of 70 μm with period was used to facilitate with a modified Maker fringe method because the spot size

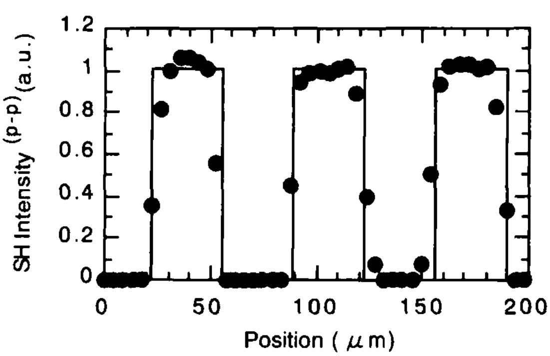

FIGURE 5 SH intensity versus lateral position of $\chi^{(2)}$ grating film.

of the beam diameter was 11 μm. From this figure the clear fringe pattern of $\chi^{(2)}$ grating with the period of 70 μm was obtained. A similar result was also obtained with other poled polymer films.

In the next place, we tried to fabricate the ridge type $\chi^{(2)}$ grating by the latter process. After a single pulse UV laser (400 mJ/cm^2) was exposed onto poled polymer film, the corona poling was performed. The $\chi^{(2)}$ grating with the period of 0.7 μm was fabricated on the poled polymer films. A fundamental wave of Nd:YAG laser at 1064 nm was used to investigate the presence of SH intensity distribution. When the fundamental wave was exposed on the grating region with 0.7 μm period, the diffraction of SHG of the zeroth-order and the first-order with the DR1/T-AP system was observed. As a result of this experiment, we succeeded in fabricating the ridge type $\chi^{(2)}$ grating with the period up to 0.7 μm.

CONCLUSION

In summary, we have proposed and demonstrated a simple method for the fabrication of the $\chi^{(2)}$ grating in poled polymer films by exposing single pulse UV laser using the holographic method. We proved that UV irradiation of 250 mJ/cm^2 was erased the second-order nonlinearity of the poled film. The mechanism of the decay of nonlinearity was suggested to be the thermal effect. The buried type $\chi^{(2)}$ grating of 70 μm was fabricated by the exposure of the lower energy density. Moreover, the ridge-type $\chi^{(2)}$ grating with submicron period was fabricated by the exposure of the higher energy density with corona-poling process. The several advantages of this technique, easy and maskless way, make it useful for several NLO polymers (not only the DR1/T-AP film) for waveguide devices by use of EO modulation and frequency conversion.

References :

[1.] G.Khanarian, R.Norwood, D.Haas, B.Feuer, and D.Karim, Appl.Phys. Lett., **57**,977 (1990).

[2.] M.Nakanishi, O.Sugihara, N.Okamoto, and K.Hirota, Appl.Opt., **37**, 1068 (1998).

[3.] H.Nakayama, O.Sugihara, N.Okamoto, Opt.Lett., 22, 1541 (1997).

[4.] S.Tomaru, T.Watanabe, M.Hikita, M.Amano, and Y.Shuto, Appl.phys. Lett., **68**, 176 (1996).

[5.] Y.Aoyagi, K.Sano and S.Namaba, Opt.Commun., **29**, 253 (1979)

[6.] C.J.Barrett and A.L.Natansphn, and P.L.Rochon, J.Phys.Chem., 8836 (1996)