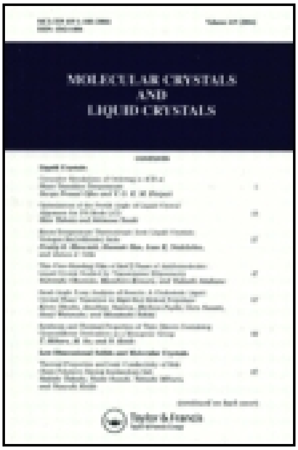

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Simple Fabrication of Nonlinear Gratings in Polymer Film Using Simultaneous Process of Emboss Heating and Thermal Poling

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We introduce a simple fabrication technique of nonlinear polymeric optical waveguide patterns based on the simultaneous process of emboss heating and poling. The polyimide film on the nickel plate was used as master grating. The condition of the fabricated pattern depends on removal temperature and the stability of the master grating is investigated. The submicron surface relief grating with $\chi^{(2)}$ is realized in the NLO polymer film.

Keywords: second-order nonlinearity; embossing heating; thermal poling; surface relief grating; $\chi^{(2)}$ grating

INTRODUCTION

Recently, various kinds of optical devices, including electrooptic (EO) modulators and frequency conversion devices, have been demonstrated. It is necessary to fabricate the nonlinear grating in the nonlinear optical (NLO) polymer waveguide for these optical devices. Many studies of fabrication for nonlinear grating have been reported such as UV-photobleaching[1], direct electron-beam irradiation [2], reactive ion etching[3], holographic method[4]. However, these techniques require a multi process of fabricating pattern and thermal poling. We introduce a novel fabrication technique of nonlinear surface relief grating (SRG) in polymeric optical waveguide by emboss heating[5] together with poling using a master grating. The present technique enables us to shorten the process time and to realize a mass of production. In the master grating, the dielectric polyimide was used instead of metal. The advantages of master grating using polyimide film over that using metal are low cost, low dielectric constant and high mechanical strength. We realize the fabrication of nonlinear SRG based on the simultaneous process of emboss heating and thermal poling.

MASTER GRATING

In our study, a polyimide was selected in the grating region of master because of high thermal stability (Tg~420 ℃), low dielectric constant (ε_s=3.6) close to that of NLO polymer (ε_s=4.1) and high mechanical strength. The nickel plate was used as an electric plate. After the polyimide film (5×5 mm^2 size) was prepared onto the nickel plate, the grating division on the polyimide film was fabricated by a holographic method using a single pulse UV (355 nm) laser. This technique has some advantages that no vibration isolation table is necessary and the grating period over wide range can be realized. The thickness of polyimide film was 2.0 μm, and the period of fabricated grating was 0.67 μm ~ 5.0 μm. For example, when the energy density of 500 mJ/cm^2 with a period of 5.0 μm was exposed on the polyimide film, the depth of grating was about 400 nm.

EXPERIMENTAL RESULTS

Embossing and Poling

We prepared polymethylmethacrylate (PMMA) doped with Disperse Red 1 (DR1) as an NLO material. Fig.1 shows the simultaneous process of emboss heating and thermal poling for the fabrication of SRG with $\chi^{(2)}$. This process was done at 100 ℃ by stamping the master under pressure (~2 kg) into the DR1/PMMA film and applying a high voltage (0.8 kV) between the nickel plate and the ground. The poled film was cooled down to 27 ℃ ~ 90 ℃, maintaining the electric field and pressure, and then it was removed. The condition to form the pattern into NLO polymer depends on the removal temperature of master grating. When the master was removed at room temperature, the grating of replica was damaged

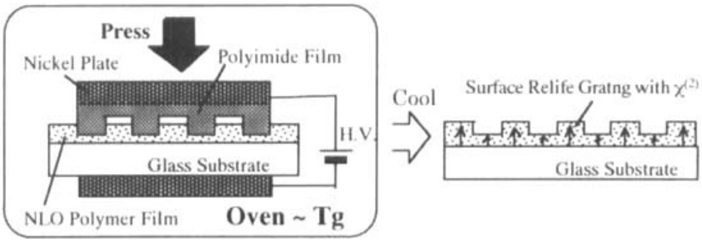

FIGURE 1 Simultaneous process of embossing and poling.

or roughened. A fine pattern was formed at removal temperature of 50 ℃, 80 ℃, and 90 ℃. Fig.2 shows the AFM photographs of the grating pattern (Λ=1.0 μm) of replica when the removal temperature was 27 ℃ (a) and 50 ℃ (b). These results show that the removal temperature of master grating is important for the pattern quality of replica. We succeeded in fabricating the SRG having the depth of 171 nm ~ 568 nm into the DR1/PMMA film with the period of 0.67 μm ~ 5.0 μm.

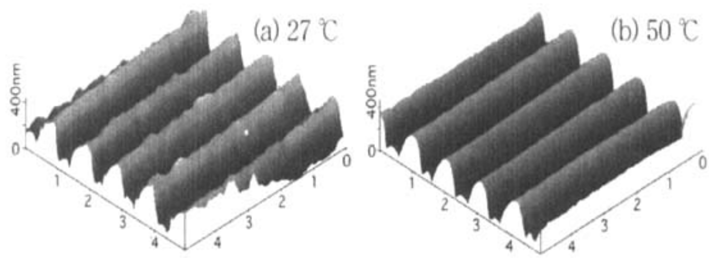

FIGURE 2 AFM photograph of SRG depend on removal temperature.

Stability of Master Grating

We measured the mechanical and thermal stability of master grating. A He-Ne laser was illuminated to the grating area of master grating (Λ=0.67 μm) and the first-order Bragg diffraction efficiency was observed for each stamping. This process was repeated 35 times. The efficiency increased rapidly during the first stamping and remained constant throughout the rest of the process. Moreover, the first-order Bragg diffraction efficiency showed no further decay at 300 °C for at least 200 hours. These observations satisfy the excellent mechanical and thermal stability.

Nonlinear SRG

A fundamental wave of Nd:YAG laser at 1064 nm was used to confirm the presence of $\chi^{(2)}$ in the SRG film with the period of 0.67 μm. When the fundamental wave was exposed on the nonlinear SRG region, the diffraction of SHG was observed. When the measured grating-coupling efficiency was 18.3 %, the SHG conversion efficiency was estimated to be 7.08×10^{-6} % at a guided fundamental peak power of 549 W. Finally, the submicron SRG with $\chi^{(2)}$ into the NLO polymer film was successfully realized by very simple method.

CONCLUSION

Simple fabrication technique of surface relief grating with $\chi^{(2)}$ in an NLO polymer by the simultaneous process of embossing and thermal poling was realized. This technique has several advantages over other techniques because of the reduced process time, the cost-efficiency available for mass-production, and the applicability to most of NLO polymers. The master grating of polyimide showed excellent mechanical and thermal stability. This technique can be applied not only to the formation of SRG with $\chi^{(2)}$ but also the formation of various $\chi^{(2)}$ patterns by selected pattern of master.

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