Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 680-681

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High Resolution Periodical Structure Fabricated by Laser Machining in Photosensitive Polymers

Shinya Shibata[a]*, Yanlong Che[b] Okihiro Sugihara[c] Naomichi Okamoto[a] and Toshikuni Kaino[c]

[a] Graduate School of Electronic Science and Technology, Shizuoka Univ.
3-5-1 Johoku, Hamamatsu, Shizuoka 432-8561, Japan
Tel&Fax: +81-53-478-1121 E-mail: ss-bata@mail.tagen.tohoku.ac.jp
[b] Shizuoka University, NEDO Technical Fellow, Central of Joint Research,
3-5-1 Johoku, Hamamatsu, Shizuoka 432-8561, Japan
[c] Institute of Multidisciplinary Research for Advanced Materials, Tohoku Univ.
2-1-1 Katahira, Aoba-ku, Sendai, Miyagi 980-8577, Japan
Tel: +81-22-217-5672 Fax: +81-22-217-5671

1. Introduction

There has been great interest in optical communication devices for the application in the area of access network and/or fiber to the home (FTTH) systems. Especially, polymer-based devices are advantageous over glass-based devices because of several advantages such as low cost, high processability and so on. Gratings, one of the most effective optical elements, are involved in various waveguide-type optical devices. Consequently, the high efficiency and high performance gratings have been fabricated by using many different approaches such as dry etching processes [1], electron-beam lithography [2.3], and laser interference [4]. For example Bragg reflector in telecommunication wavelength requires gratings with a period of ~500nm. Recently nanometer sized gratings ware fabricated in a polymer by simple interference method using an Nd:YAG (355nm)[4]. In this study, the fabrication of gratings in several photosensitive functional polymer films with the period less than 500nm by optical interferometric system using a single pulse UV laser is proposed and demonstrated.

2. Grating fabrication

The relief grating was fabricated by the two-beam interference technique using a third-harmonic generation of Nd:YAG laser (355nm). A vibration isolation table is not necessary in this system, and the quality of grating by single pulse formation is better than that by multiple pulses. In order to improve the modulation profile of high resolution gratings, the laser was spatially collimated and the interferometric system was accurately and closely set up to avoid the excessive spatial and temporal deviation of two beams. We prepared several kinds of polymer materials, such as polyimides (fluorinated polyimide and photosensitive polyimide), electrooptic polymers (urethane-urea copolymer and 3RDCVXY), and a photoresist (OFPR-800). Some of them are often used as a core material of optical waveguide, and some act as photoresist, therefore they can be developed after exposure.

Polyimides

We used a photosensitive polyimide and fluorinated polyimides with a fluoride content of 23% and 28%, and the grating on each polyimide film was fabricated by the laser ablation technique. Initially, the polyimide films with 3μm thickness were prepared by spin-coating and heat-treatment. The gratings were formed by the single-pulse laser irradiation with an energy density (one side in two-beams) of 200 ~ 400mJ/cm^2. Fig.1 shows AFM photograph of the relief grating on the fluorinated polyimide film (23%) with a period of 400nm and a depth of 100 nm. Here the energy density is 200 mJ/cm^2, and the almost similar grating was obtained on the photosensitive polyimide film by the same energy. On the other hand, when the fluorinated polyimide (28%) was used, higher energy density of 400mJ/cm^2 was required due to the decrease in absorption coefficient at 355nm. By increasing the energy density deeper relief grating was, but the grating profile became worse with the energy over 400 mJ/cm^2.

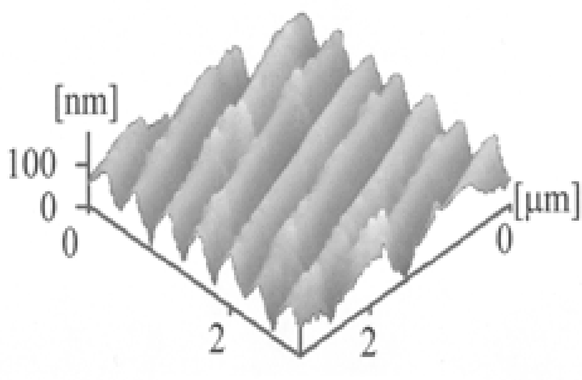

Fig. 1 AFM photograph of grating on fluorinated polyimide (fluoride content 23%) with 400nm period and 100nm depth.

*Author S. Shibata is now with Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, 21-1, Katahira, Aoba-ku, Sendai, 980-8577, Japan

Electrooptic Polymers

In this report, we also demonstrated the fabrication of high resolution nonlinear gratings by using electrooptic polymers based on the present method. The polymer we investigated is a kind of azobenzene-contained urethane-urea copolymer. To induce the second-order nonolinearity, the film was corona-poled beforehand. Then the single-pulse UV laser was irradiated. Figure 2 shows the AFM photograph of the grating with a period of 400nm and a depth of 80nm. The exposure energy density of UV laser was set at 255mJ/cm^2. By inserting a fundamental beam (1064nm) into the grating, second-harmonic output was observed suggesting that the nonlinear grating was realized. We tried the nonlinear gratings using diazo-dye-substituted methylmethacrylate (3RDCVXY) accompanied with wet development.

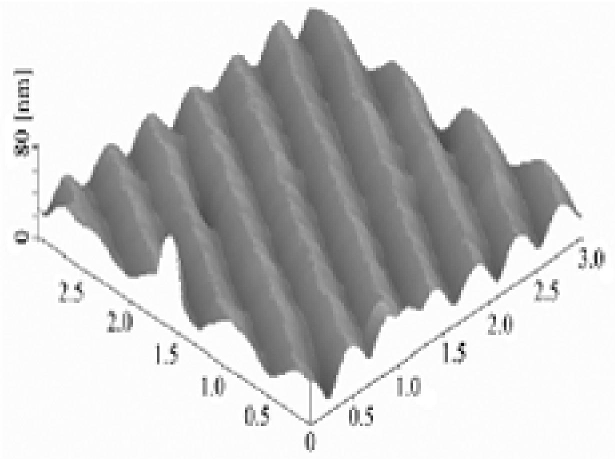

Fig.2 AFM photograph of nonlinear grating on electrooptic polymer film with 400nm period and 80nm depth.

Photoresist

Progress of a deeper and shorter period grating fabrication was achieved by simple UV irradiation method together with wet development using the photoresists. OFPR-800, which is one of the high-resolution positive photoresists, was spin-coated onto the glass substrate and pre-baked at 85 °C in the oven. Single-pulse was irradiated to the films with the energy density of 25 mJ/cm^2, which is less than the ablation threshold (over than 30 mJ/cm^2). Then, the films were developed in the NMD-W solvent for 30 sec, rinsed in water, and finally post-baked in the oven at 145 °C. The grating structure with a period of 400nm and a depth of 340-360 nm was obtained. By wet development process gratings with higher aspect than that of polyimide were fabricated.

We have realized the manufacture of gratings with shorter period. With the setup by changing the incident angle of two beams 200nm period grating (incident angle of 62.5 deg) which was close to the theoretical was fabricated onto the OFPR-800 films. Fig.3 shows an AFM photograph of the actually fabricated relief grating with the period of 200nm and a depth of 80-120 nm. It was found that clear grating without any impurity was observed. This is because we perform the wet development as well as single-pulse irradiation. In the interference method, nano-scale grating successfully can be fabricated using the present simple technique.

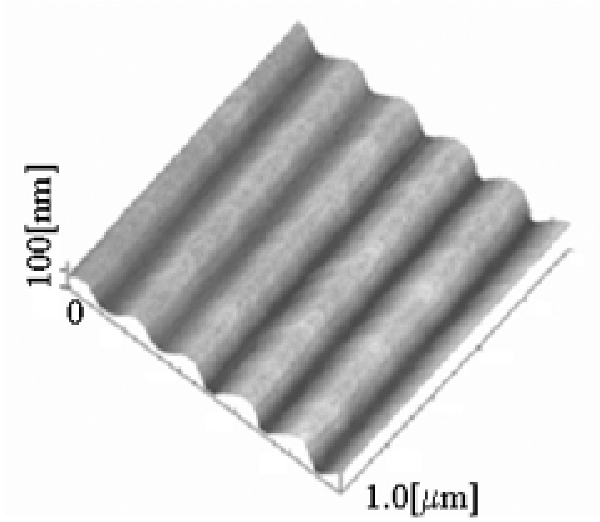

Fig. 3 AFM photograph of grating on OFPR-800 film with 200nm period and 80-120nm depth.

3. Conclusions

Fabrication of the high resolution gratings onto the various photosensitive polymers by the method of the single-pulse two-beam interference using the UV laser has been demonstrated. Relief gratings in polyimide films, nonlinear gratings in electrooptic polymer films and nanometer sized grating in photoresist were successfully realized. This method is useful for highly efficient Bragg gratings and nano-scale structure fabrication for optical applications.

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