Fabrication of Polymer Laser Device by Two-Photon Induced Photopolymerization Technique

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Introduction

Minute structures fabricated in polymer and organic materials are considered to be promising because of their flexible features for a variety of applications. By precise fabrication technique using these materials, several two- and three-dimensional structures have been demonstrated in the optical applications such as waveguide, microchannel, and photonic band gap structures. Specifically, laser lithography through a multiphoton absorption of the energy from a hundred femtosecond pulse laser results in a capable of very high spatial resolution with the highest precision, i.e., in the range of hundred nanometers. Because the simultaneous absorption rate of two photons has a highly nonlinear dependence on laser power density, the process cross-section is confined to the smaller area around the focus of a Gaussian laser beam. This property can process the polymer devices within the space smaller than the diffraction limit.

In this study, we fabricated a polymer sub-microstructure for optical device application by two-photon-induced laser lithography technique. Polymer pattern could be minimized as small as ~100 nm. The photopolymerization resin contains laser-dye, thus promising a high level of the optical gain. We utilized the lithography technique to the photonic crystal application, where the template of the two-dimensional photonic crystal was modified by polymer gain medium as defect-shape and line-shape orientations. Photonic band gap effect from polymer-doped photonic crystals is expected to exploit the application such as organic solid-state laser device.

EXPERIMENTS

The two-photon-induced polymerization was performed in a photonic crystal filled with a photocurable resin containing radical photoinitiator and laser-dye. The laser-dye used was DCM, which was encapsulated in the dendrimer. A beam from a mode-locked Ti: sapphire laser (710 nm, <130 fsec, 80 MHz) was directed at an objective lens (NA=0.95) and then focused on the photonic crystal. The average beam power in the resin was less than 5 mW. The photonic crystal was placed on x, y, and z-stage scanners to make a desired polymer structure. The confocal optical microscope was used to locate a photonic crystal at the precise position, and take optical images of the fabricated structure after photopolymerization.

RESULTS AND DISCUSSION

Precise control of the two-photon-induced polymerization in our experimental setup could make possible to fabricate a polymer modified photonic crystal. Since two-photon absorption is carried out within a volume of ~100nm scale, one could focus the laser excitation within a hole of the photonic crystal. Fig. 1a shows the evidence that the laser beam was tightly focused at the center of the hole of the photonic crystal. When the photonic crystal was filled with the photocurable resin, polymerization could start at each hole. Fig. 1b shows the polymer bits fabricated in the photonic crystal. The optical image was measured after washing the unpolymerizaed resin. Since we used the photonic crystal with a lattice constant of 500 nm and hole diameter of 100 nm, we could achieve the precise control of polymer-bits fabrication in point of size and position with a hundred-nanometer accuracy (optical resolution of the images in Fig.1 looks larger because of the measurement limitation). Optical contrast of the fluorescent bits shown in Figure 1c is enough high to predict our achievement of polymer process for optically active photonic crystal application. In Figures 1d and e, polymer bits-lines were demonstrated by scanning the excitation laser beam along the hole-orientation of the photonic crystal. The single lines of the polymer-bits were fabricated in the photonic crystal along the Γ-X direction. In this structure, polymer bits were formed within the holes of the photonic crystal. Thus, the surface of the photonic crystal appeared flat in the reflection image, while fluorescence of each bit appeared clearly under optical excitation. Our results indicated that the polymer lithography technique through the two-photon absorption could be extended to the photonic crystal applications such as band gap effect and defected-mode of the light propagation.

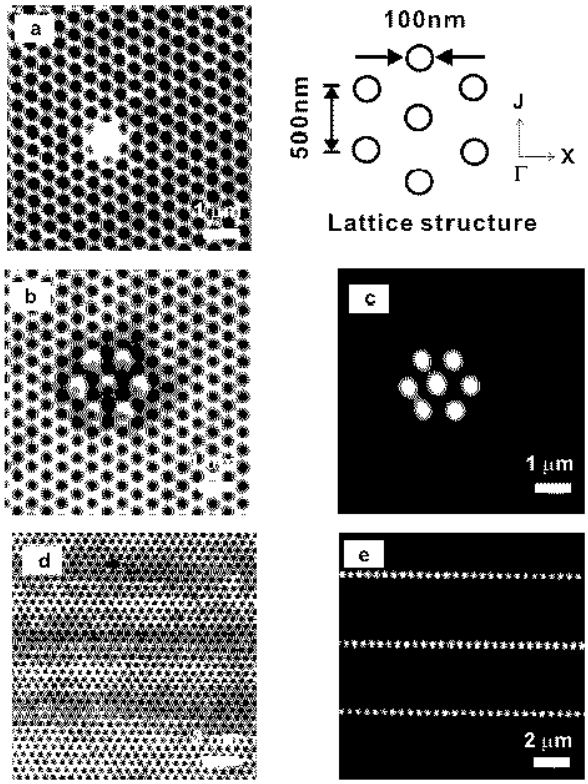

Figure 1. Optical images of the photonic crystal having a lattice constant of 500 nm and hole diameter of 100nm. (a) Femtosecond laser beam was focused on the surface of the photonic crystal. (b) Reflection image of the polymer-bits in the photonic crystal. (c) Fluorescence image of the polymer-bits in the photonic crystal. (d) Reflection image of the polymer bits-line in the photonic crystal. The bits were unclear because they were formed inside the photonic crystal. (e) Fluorescence image of the polymer bits-line in the photonic crystal.

CONCLUSION

We have fabricated polymer-doped photonic crystal for optical device application. To do so, we used a femtosecond pulse laser to cause two-photon induced photopolymerization, where the precise control of the lithography was demonstrated in the small space such as the photonic crystal. Since we can introduce organic chromophore in the photonic crystal, our technique exploits the optically active photonic crystal for the wide variety of applications.

REFERENCS

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