Direct writing of diffractive optical elements in polymer materials

Wataru Watanabe and Hiroyuki Mochizuki

Femtosecond-laser filamentation can generate useful refractive-index changes while thermal treatment helps improve the diffraction efficiency.

Polymer materials are widely used to fabricate micro-optical elements because of numerous advantageous characteristics, including low cost, ease of manufacture, and high transmission in the visible spectral region. Diffractive optical elements (DOEs) are attractive examples of such materials because of their compactness and high optical potential. They are commonly applied in areas such as beam shaping, material processing, sensing, optical metrology, and lighting, and their design and fabrication can be tailored to the specific application need. Integration of DOEs in monolithic bulk materials provides good mechanical stability and high integration density.

When an ultrashort laser pulse is focused inside the bulk of transparent materials, filamentation occurs as a consequence of the dynamical balance between Kerr self-focusing and defocusing in the electron plasma generated by the ionization process. Clamping of the peak intensity inside the filaments can cause nonlinear absorption, which results in localized modifications in the filamentary volume. Femtosecond-laser processing using filamentation is a versatile technique that is useful for fabrication of volumetric photonic devices in transparent materials.

The filaments can induce regions—up to hundreds of micrometers long—in polymer materials displaying refractive-index changes (see Figure 1). To increase the diffraction efficiency of DOEs embedded in polymer substrates, various factors must be considered, including laser parameters, material types, and focusing conditions.

We fabricated DOEs using filaments embedded in polymers. Figure 2 shows an optical schematic of the process. Femtosecond-laser pulses with a wavelength of 800nm were focused using a microscope objective lens. We generated structures with a period of 10µm in the polymers by scanning a filament along a direction perpendicular to the optical axis. The length of the filamentary refractive-index change was approximately 300µm. Figure 3 portrays top views of the DOEs fabricated in

Continued on next page
The first-order Bragg-diffraction efficiency in PMP was 45.1%, approximately an order of magnitude higher than the characteristic values for the other polymers, which were 0.3–4.6% (see Figure 4).

In addition to material selection, the diffraction efficiency of DOEs can be increased through thermal treatment after femtosecond-laser irradiation. The efficiency of gratings in poly(methyl methacrylate) was increased by more than an order of magnitude by subsequent heating below the glass transition temperature. It increased from 1.9 to 72% when heated for 500h at 70°C. Possible mechanisms for the refractive-index change induced by femtosecond lasers in polymers are mainly related to a change in density, the complete and partial separation of the side chain from the polymer molecule, and/or tensile stress.

We are currently working to improve the fabrication of volume gratings of various types within polymers. Direct micromachining using femtosecond-laser filamentation opens the door to 3D integration of high-efficiency DOEs in polymers.

The authors acknowledge discussions and collaboration with Satoshi Hirono, Makoto Kasuya, and Katsumi Matsuda at Omron Corporation (Japan) and Kazuyoshi Itoh and Yasuyuki Ozeki at Osaka University (Japan).

Author Information

Wataru Watanabe and Hiroyuki Mochizuki
Photonics Research Institute
National Institute of Advanced Industrial Science and Technology
Ikeda, Japan

References

© 2009 SPIE