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Contour offset algorithm for precise patterning in two-photon polymerization

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Abstract

A contour offset algorithm (COA) has been developed to fabricate precise patterns easily in the range of several microns using a nano-replication printing (nRP) process, which employs two-photon polymerization. In this process, microscale patterns are fabricated by a voxel matrix scanning method that uses raster graphic data transformed from the two-tone (black and white) bitmap figure file. The raster data consist of two kinds of entities to control laser on/off; '1' for laser-on and '0' for laser-off. However, the replicated patterns did not precisely coincide with an initial design due to an intrinsic shortage of the nRP process: the fabricated patterns become generally larger than the designed shape. To solve the point at issue, the COA was proposed in this work: an outer-contour matrix of an initial design was reconstructed then, it was modified by the amounts of offset-ratio that can be calculated using the relation of a pattern size, a designed figure size, and a voxel size. The effectiveness of the proposed algorithm was evaluated through several examples with 200 nm resolution.

1. Introduction

Two-photon polymerization (TPP) has been recognized as one of the most promising technologies for producing more integrated and more diversified nano- and microdevices, because it has the virtue of allowing the direct fabrication of nano-detailed 2D patterns or true 3D structures without any additional process. In TPP, a highly localized area around the center of a focused beam can be solidified by controlling the threshold energy for polymerization. It has been recently reported that femtosecond laser pulses can be tightly focused onto liquid-state monomers and initiate a chemical process by TPP with the resolu-

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tion close to 100 nm in size [1,2]. Many works [2–13] related to the TPP have reported that it has various potential applications such as a 3D optical memory, photonic crystals, highly integrated optical devices, direct patterning, etc. These devices evidently require high structural complexity, while the conventional photolithography has limitations for the fabrication of complex 3D structures.

In this work, a nano-replication printing (nRP) process has been newly developed to pattern complicated 2D shapes directly on a glass plate. In the process, a raster scanning method, called as a voxel matrix scanning (VMS) method, was introduced to fabricate patterns. A two-tone (black and white) bitmap figure was employed to be transformed as a voxel matrix that consisted of two codes: ‘1’ for a black-color-pixel and ‘0’ for a white-color-pixel. The voxels were generated at the center position of an outer contour in a voxel matrix. Therefore, a fabricated pattern was generally larger than a designed shape: it had undesirable shape-error terms, which come from an intrinsic shortage of the VMS method. In this work, we propose a contour offset algorithm (COA) to improve the precision of the nRP process. The offset-amounts, required in the COA, can be calculated easily using the relations of a pattern size, an initial design size, and a voxel size. The outer contour of the initial pattern is then reconstructed by considering the offset-amounts. Through some examples, it is confirmed that the patterns fabricated with the COA had considerably higher precision in comparison to those fabricated without the COA.

2. Nano replication printing process

2.1. nRP system and voxel matrix scanning method

Fig. 1 illustrates that the developed nRP system consisted of a laser system, some beam controlling device, and some optics. A mode-locked Ti:Sapphire laser beam, with wavelength of 780 nm, repetition of 80 MHz, and pulse-width of less than 100 fs, is projected onto a Galvano-mirror type scanner. An isolator and a shutter are located between the femtosecond Ti:Sapphire laser and the scanner; the former is applied to prevent the back-

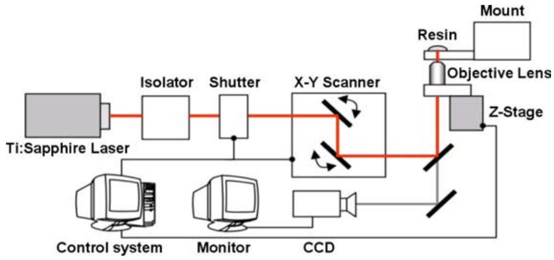

Fig. 1. Schematic diagram of an optical system for nRP process with two-photon absorption. A laser source is Ti:Sapphire laser. A focus of the laser beam is controlled by X–Y scanner and Z-stage, and the exposure time of the laser beam is controlled by an optical shutter.

ward beam reflecting to the laser oscillator and the latter is employed to control the beam on/off. The shutter can be operated up to 5 kHz, but below 500 Hz is preferred for stable operation. A focused beam is scanned on x- and y-axis plane by the scanner with the resolution of approximately 24 nm a step, and the focal plane is moved along the vertical axis using a piezoelectric stage. The laser beam is tightly focused with an objective lens (NA 1.25×100, immersion oil used) on a photocurable resin, which is dropped on a cover-glass plate. The shutter, the scanner, and the piezoelectric stage are controlled precisely using a developed control program. And a high magnifying CCD camera is useful for adjusting the position of a beam spot and for monitoring the status of a fabrication process in real-time.

In the nRP process, a raster graphics type of a voxel matrix, as shown in Fig. 2(a), has been employed to fabricate patterns on a plate. Micropatterns were fabricated directly using a voxel matrix scanning (VMS) method as illustrated in part (b) of Fig. 2, which is proposed to easily produce micropatterns according to the entities of a voxel matrix; in the case of ‘1’ elements in the voxel matrix, the shutter is open to generate voxels; in contrast, the shutter is closed to prevent the generation of voxels. When the solidification is finished by TPP, the remaining extra liquid-state monomer can be eliminated easily after dropping several ethanol droplets on the patterns. The two-photon photocurable resin used in the work was a mixture of urethane acrylate monomer,