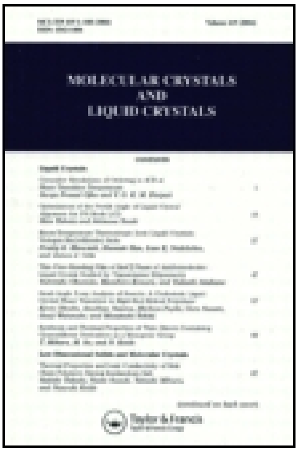

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Submicron Channel Fabrication in Photoresist Film Using Continuous Wave Laser

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Submicron Channel Fabrication in Photoresist Film Using Continuous Wave Laser

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Laser fabrication of submicron hollow channel using a continuous wave (CW) light source is investigated. In conventional laser fabrication, CW laser beam affects the immediate vicinity of a beam exposure area because the fabrication employs a heat mode process. Our method proposed, however, three-dimensionally localizes the exposure area in a focal plane by controlling the reaction time constant of a photoresist film. As a result, we have fabricated a submicron hollow channel in the photoresist film using the CW laser source.

Keywords CW laser; laser fabrication; nonlinear optics; photoresist; reaction time constant

1. Introduction

The major method of submicron structure fabrication for photoresist employs photolithography with femtosecond lasers [1,2]. The method can localize the exposure area in a focal plane by multiphoton absorption induced. However, the laser oscillator is unstable and very expensive for mass production. Therefor, we propose submicron CW laser fabrication by a nonlinear optical effect.

We exposed a submicron hollow channel in a positive type photoresist film, which is spin-coated on a slide glass. The exposed area is removed after a development process. In general, the CW laser fabrication becomes a heat mood process, which decreases fabrication accuracy [3]. However, our method can fabricate submicron structures in a photon mode process by controlling the reaction time constant of the photoresist.

2. Experimental and Theorical Backgrounds

First, we indicate a reaction-time-constant control approach of photoresist. Figure 1 shows an energy diagram of photoresist. $\emptyset_{1B}$ and $\emptyset_{2B}$ are quantum yields for stimulated transition between Ground state (S_0) and excited state (S_1). $\emptyset_{3B}$ is a quantum yield for stimulated transition for Triplet excited state (T_1) to some upper states. $\emptyset_{2A}$ is a quantum yield for spontaneous transition from S_1 to S_0. Q is a triplet yield for S_1 to T_1. σ_1 and σ_3 are absorption cross-sections for S_1 and T_1, which may be defined as an absorption coefficient per unit

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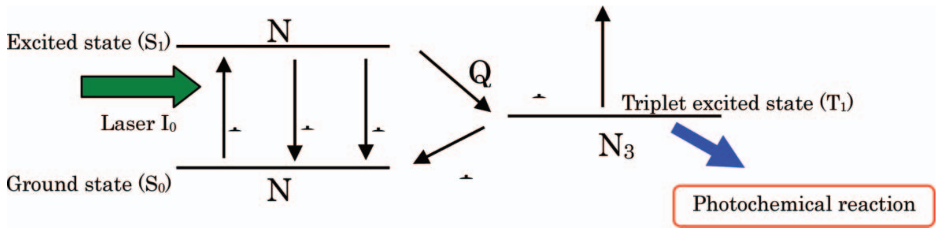

Figure 1. An energy diagram of photoresist Oir-907-17

inversion per unit volume. σ_2 is a stimulated emission cross-section for Excited state. I_0 is an incident light intensity.

We assume that the lifetime in T_1 is relatively long. In this case, the rate equation of photoresist can be formulated by following equation;

$$\frac{dN_1}{dt} = \sigma_2\phi_2\frac{I_0}{\hbar\omega}N_2 + \phi_{2A}N_2 + \phi_{3A}N_3 - \sigma_1\phi_{1B}\frac{I_0}{\hbar\omega}N_1, \tag{1}$$

$$\frac{dN_2}{dt} = \sigma_1\phi_{1B}\frac{I_0}{\hbar\omega}N_1 - \sigma_2\phi_{2B}\frac{I_0}{\hbar\omega}N_2 - \phi_{2A}N_2 + N_2Q, \tag{2}$$

$$\frac{dN_3}{dt} = N_2Q - \phi_{3A}N_3 - \sigma_3\phi_{3B}\frac{I_0}{\hbar\omega}N_0. \tag{3}$$

From these relations, reaction time constant τ is estimated

$$\tau = \left(\frac{\sigma_1\phi_{1B}}{\sigma_3\phi_{3B}}Q + \sigma_2\phi_{2B}\frac{I_0}{\hbar\omega} + \phi_{2A} + Q\right)^{-1}. \tag{4}$$

Under these conditions of general exposure using incoherent light sources, τ is approximately constant. This is because the second term including I_0 is smaller than other terms. However, if a laser is used as an exposure light source, I_0 becomes very large. In contrast, if the wavelength of the laser is sufficiently shifted from the resonance center of an absorption spectrum, σ_1 and ϕ_{1B} become very small. For that reason, we use photoresist Oir-907-17, Fujifilm Arch product. The absorbance at wavelength of 532 nm is sufficiently low (0.09). In this case, the transient photochemical reaction depends on the second term including

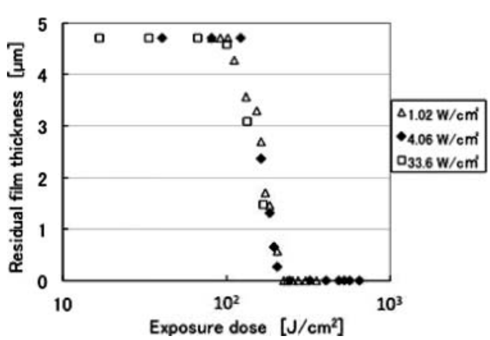

Figure 2. Sensitometric curve of photoresist OiR 907-17.

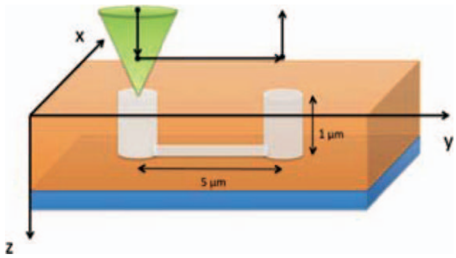

Figure 3. A schematic image of hollow channel exposure at z = 1 μm in depth.

I_0. Then the reaction time constant depends on beam intensity I_0. Figure 2 shows a sensitometric curve of a 4.7 μm thickness photoresist OiR 907-17 film. The figure indicates that a dose dependence of residual film thickness exposed over a 1.02–33.6 W/cm^2 beam intensity range. In this figure, the photosensitive characteristic nonlinearly depends on the exposure dose. The experiment determined the exposure beam intensity at 107 W/cm^2, which is considered as loss of reflectance and film absorption. Then the beam intensity is sufficient to modulate the reaction time constant nonlinearly [4].

3. Experiment

Figure 3 shows a schematic image of hollow channel exposure. We exposed the hollow channel in the photoresist film with a focused SHG-YAG laser beam (λ = 532 nm). The Airy disk size at a focal plane is about 721 nm and the focal depth is about 906 nm. We prepared a 9-μm thickness photoresist film with spin coating process. The film was attached on a x-y-z stage, which can control travel distances and travel speeds in x-y-z axis. One vertical hollow was exposed at a travel speed of 8 μm/s and with a travel distance of z = 1 μm. The consecutive horizontal channel was exposed at a travel speed of 8μm/s and with a travel distance of 5μm. Also, the other vertical one was exposed again.

4. Results and Discussion

Figure 4 shows an optical micrograph at a surface of the exposed area. The two vertical holes appear as black dots. The photo quenching of the vertical holes is down to a moth eye effect; the vertical hole becomes quantum well, which trap incident photons. In contrast, horizontal channel appear as a collard line. The color is provoked by reflected light from boundary of photoresist and air at the hollow channel. Hence, the color indicates a difference of refractive index is large at the boundary area.

Figure 5 (a) shows an AFM image of the exposure area. The AFM image proving the flat film surface was not affected by the beam exposure. Figure 5 (b) shows a tomographic image of the exposed area at z = 1.2 μm with a four-wave-mixing confocal microscope

Figure 4. An optical micrograph of hollow channel exposed

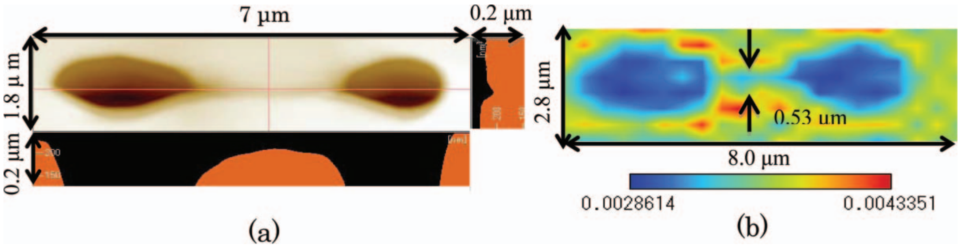

Figure 5. The measurement of hollow channel exposure. (a) AFM image at the exposed area. (b) Four-wave-mixing confocal microscopic image at $Z = 1.2\ \mu$m.

proposed in Reference 5. The microscope can increase the image contrast of submicron objects. The microscope has tomographically imaged the submicron structure inside the film. The hollow channel width measured about 0.53 μm.

5. Conclusion

Controlling the reaction time constant of the photoresist can make the submicron hollow channel inside the photoresist film. 3D submicron laser fabrication can be made with the cost effective CW laser.

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