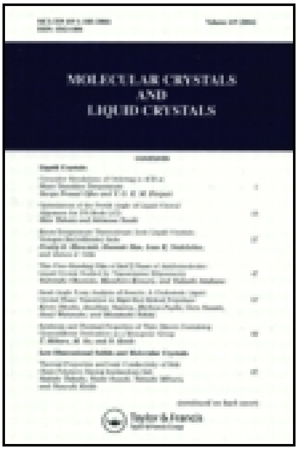

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Photon-Induced Micro/Nano Fabrication, Manipulation, and Imaging with Unconventional Photo-Active Systems

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Photon-Induced Micro/Nano Fabrication, Manipulation, and Imaging with Unconventional Photo-Active Systems

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We describe about the optical technologies of fabrication, control and imaging of micro/nano structures using unconventional photo-active systems. A focused beam of a near-infrared pulsed laser with a peak power of some ten kilowatts scans in three dimensions to form three-dimensional micro-structures such as micro-tubes and micro-coils with photo-polymerizable material, based on two-photon excitation/absorption process. Three-dimensional optical data-storage which contains data in a volumetric medium is also realized with two-photon process in a photorefractive crystal or with a photochromic molecule for recording and with confocal microscopic optics for phase-reading. We will also show our experimental result of self-growing of micro-fiber in photopolymer by the exposure of a stationary focused laser beam. These technologies can be coupled with the currently progressing near-filed optical technology for observation, fabrication and control of nanometric structures.

Keywords photo-fabrication; optical data-storage; near-field optics; confocal microscopy; two-photon process; photopolymer; photorefractive crystals; self-assembly

INTRODUCTION

Optical technology has been successfully used in modern high-tech industries such as communication industry with optical fiber and microwave communication, audio/visual and computer industry with optical mass data-storage, semiconductor industry with photo-lithographic machines, mechanical engineering with laser machinery, and even clinical medical field with laser surgery.

In this paper, we describe the future optical technologies of fabrication, control and imaging of micro/nano structures, which we have developed using unconventional photo-active systems. The paper includes our recent experimental results obtained with high-power pulsed laser and micro/nanometric mechanical controller. A near-infrared pulse laser with a peak power of some ten kilowatts locally excites photo-active material at the focused position, where photon density is extremely high and two coherent photons simultaneously absorbed by the material. This two-photon process generates desirable micro-structures as a laser beam scans in UV-sensitive material.

TWO-PHOTON PROCESS FOR THREE-DIMENSIONAL MICRO-FABRICATION

Figure 1 shows a set of micro-structures fabricated with an near-infrared pulse laser[1,2]. They were fabricated as three-dimensional structures with a resolution of 0.5μm in ultra-violet (UV) sensitive photo-polymerizable resin. As a focused beam of near-infrared Titanium Sapphire laser moves three-dimensionally under computer-control in the UV-sensitive resin, the resin is locally photopolymerized (solidified) to form a three-dimensional micro-structure. The mechanism of polymerization of UV sensitive resin by a near-infrared laser is based on the two-photon excitation/absorption process. If the photon density is extremely high, two photons coherent each other are absorbed simultaneously by the resin which is sensitive to the frequency twice higher than the frequency of a near-infrared single photon. This could occur only at focus of laser beam of high power. Although the power of the Titanium Sapphire laser is not high enough in average, it is compressed into a short-pulse train, increasing the peak power up to several kilo-watts with the duration of ~100 femto-second at the repetition rate of 80MHz.

Three-dimensional optical data-storage as a promising high-density optical memory is also realized with two-photon technique with a photorefractive crystal or with a photochromic molecule[3-5]. The method is also applied to nondestructive three-dimensional observation of microscopic structure[6].

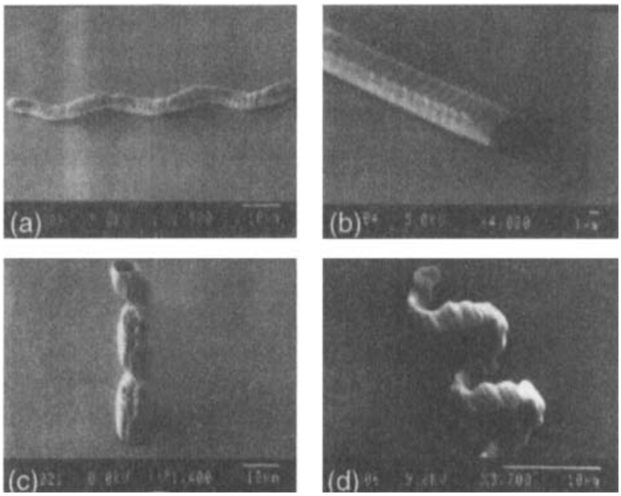

FIGURE 1 Three-dimensional micro-structure fabricated in ultra-violet sensitive photopolymerizable resin with a scanning laser beam spot of near-infrared high-power pulsed laser.

SELF-GROWN FABRICATION WITH A FOCUSED LASER BEAM

We found that a very thin needle with a diameter of a few micron is gradually grown in the resin with the stationary focused laser beam incident on the boundary of the photopolymerizable resin at the glass substrate. Figure 2 shows a photo of this experiment[2]. A micro-fiber of polymer grows in resin. This phenomenon is explained as follows: A focus laser spot locally photopolymerizes the resin, changing the refractive index locally. A small lens with the size of laser spot is hence formed, which focus the laser beam in front of it, resulting the another photopolymerization in front of the small lens, forming a small rod along the optical axis. The laser beam travel in this thin rod (fiber) with wave guide propagation mode, giving the spot in front of itself. AS a result even a one-millimeter long fiber of a few micron diameter is self-grow by some ten seconds.

We also found that a multiple needles are fabricated at once radially from the beam focused point in a certain condition of the laser beam power and the numerical aperture of objective lens. It is shown in Fig. 3.

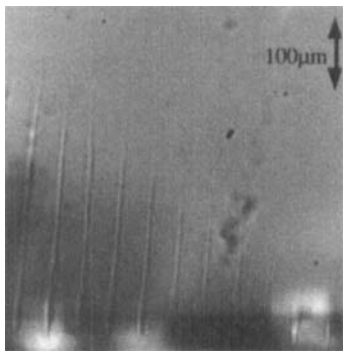

FIGURE 2 A micro-needle grows with a stationary focused laser beam.

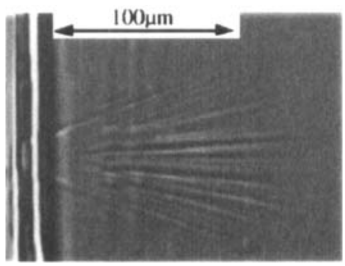

FIGURE 3 Many needles can be also self-grow radially from the focused point of laser.

COMBINATION WITH NEAR-FIELD OPTICS

Two-photon and self-assembly physics (mathematical) can be coupled with the currently progressing technology of near-filed optical for observation, fabrication and control of nanometric structures[7-9]. Figure 4 shows the computer simulation of the movement of two small spheres with the refractive index higher than solution near the aperture on the screen smaller than wavelength of light[10]. The physics of the movement is the spatial distribution of radiation force by the laser beam. The light is incident to the aperture from the other side providing evanescent field locally near the aperture. A sphere is attracted by the aperture and another one moves on the top of the first one.

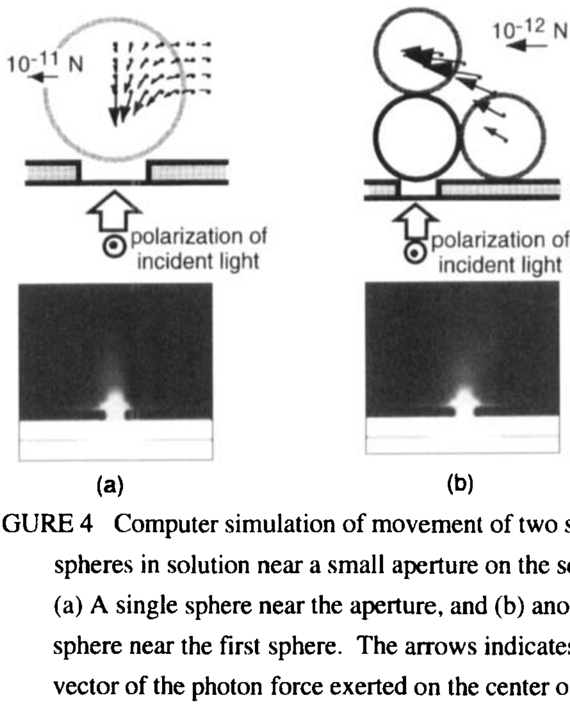

FIGURE 4 Computer simulation of movement of two small spheres in solution near a small aperture on the screen. (a) A single sphere near the aperture, and (b) another sphere near the first sphere. The arrows indicates the vector of the photon force exerted on the center of a sphere, and the gray scale represents the field intensity distribution. The first sphere is trapped at the aperture and the second one is at the top of the first one.

References

[1.] S. Maruo, O. Nakamura, and S. Kawata, Opt. Lett., **22**, 132-134 (1997).

[2.] S. Maruo and S. Kawata, Proc. IEEE MEMS 97, 169-174 (Nagoya, 1997)

[3.] A. Toriumi, J. M. Herrmann, and S. Kawata, Opt. Lett. , **22**, 555-557 (1997)

[4.] H. Ueki, Y. Kawata, and S. Kawata, Appl. Opt., **35**, 2457-2465 (1996).

[5.] Y. Kawata, Ishitobi, and S. Kawata, Appl. Phys. Lett. (submitted)

[6.] O. Nakamura, V. Daria, K. Fujita, Y. Kawata, S. Kawata, Cell Vision, **4**, 163-164 (1997).

[7.] Y. Inouye and S. Kawata, Opt. Commun., **134**, 31-35 (1997).

[8.] H. Furukawa and S. Kawata, Opt. Commun., **132**, 170-178 (1996).

[9.] S. Kawata and T. Tani, Opt Lett., **21**, 1768-1770 (1996).

[10.] K. Okamoto and S. Kawata, Proc. JNFO6, 38-43 (Osaka, 1997).