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Taper array in silica glass for beam splitting

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ABSTRACT

We proposed taper array in silica glass for beam splitting which was fabricated by water-assisted femtosecond laser direct writing technology and the subsequent heat treatment. We divided the array into many fabricating cells which were executed automatically in sequences as specified by the program that contained the information for the three-dimensional stage movements. Each cell could fabricated a rectangular cylinder. The size and distribution of the rectangular cylinder could be controlled by adjusting the position of the fabricating cells. Then the heat treatment should be used to reshape the rectangular cylinders into taper array. The experimental results show that the taper periodic microstructures in silica glass are uniform and smooth, and the tapers can divide the incident light into beam array. The results demonstrated that the combination of the water-assisted femtosecond laser direct writing technology and the heat treatment is accessible and practical for the high quality micro-optical elements. These micro-optical elements will have potential applications in fluorescence detection and beam splitter.

1. Introduction

In recent years, integrated optical devices have attracted numerous researchers' attention. The devices like beam splitters [1], couplers [2], and modulators [3] as well as the active devices like lasers based on waveguides structures [1,4]. At present, the laser direct writing technology is practical and flexible compared with the other fabrication methods, and this technology could realize three-dimensional microstructures in most materials [5,6]. In silica glass, the three-dimensional hollow microstructures also can be fabricated by femtosecond laser direct writing technology and followed chemical etching [5,7,8]. The fabrication of hollow microstructures is relevant to chemical and biological analysis [9]. The typical fabrication methods of hollow microstructures like microchannels are soft lithography [10], wet etching [11] and the bonding technology [12]. Generally, it is difficult to realized uniform diameter at the opening and middle area [8]. It is more difficult to fabricate uniform periodic microstructures in microchannel by femtosecond laser direct writing technology followed chemical etching. As the 3D microchip can be realized by water-assisted femtosecond laser direct writing technology [13]. Using this method, the hollow and periodic microstructures in silica glass can be fabricated directly.

In this paper, we present a method for fabricating periodic microstructures in silica glass using water-assisted femtosecond laser direct writing technology as the beam splitter. Using this method, the periodic microstructures could be located in any place, without limitation of space structure and fabricating length. The distribution of the rectangular cylinders should be designed and fabricated automatically by three-dimensional stage (Prior Scientific Inc.), cell by cell. After subsequent heat treatment, the internal surface of fabricating area could be much smoother which was crucial for optical elements. Finally, the rectangular cylinders array could be reshaped and the taper array was realized in silica glass. The experimental results confirmed that taper microstructures have beam splitting capacity. This taper beam splitter has potential application in various fields, such as biomedicine, fluorescence detection, and beam splitters.

2. Fabrication of taper array

In the experiments, Ti: sapphire regenerative amplified laser system (Coherent Inc.) was used as the femtosecond laser source. The repetition rate, central wavelength and pulse width of the femtosecond laser are 1 kHz, 800 nm, and 120 fs, respectively. For selecting the high quality laser beam a circular aperture was employed with the diameter of 5 mm. The periodic microstructures were fabricated automatically, so a mechanical shutter with 100 ms response time should be used to select the laser direct

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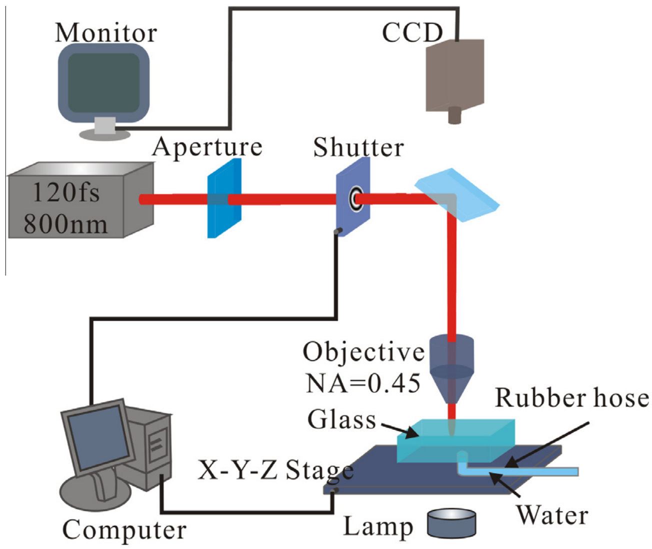

Fig. 1. The experimental setup for fabrication of the microchannels.

writing area. The experiments were carried out by using water-assisted femtosecond laser direct writing technology and the laser beam was focused into the distilled water by an optical microscope (20×/0.45, Nikon). The used base material of sample was commercially available silica glass. A computer controlled three-dimensional stage (Prior Scientific Inc.) with the resolution 100 nm was used to move the glass sample. The whole experimental process was monitored by a charge coupled device (CCD) in real time. The experimental setup is shown in Fig. 1 [13].

The silica glass was fasten on the three-dimensional stage and a rubber hose was fixed under the silica glass. The laser beam was focused in the rubber hose for inducing the breakdown in the distilled water [14]. We first drilled a hole from the bottom of the silica glass, then started the programme for fabricating the periodic microstructures automatically. When the laser beam ablated the silica glass, the silica material could be etched into debris which dispersed into the distilled water. Therefore, the hollow microstructure could be fabricated. With the length increasing of the hollow structure, the distilled water was pumped into the ablated area for cleaning the high level debris through the rubber hose. Therefore the effects of blocking and redeposition generated by the ablated debris are greatly reduced. The use of the rubber hose ensured the effectively cleaning and the continuously pumping fresh water into the ablating area. Therefore, the fabricating scale could be increased and the periodic microstructures could be fabricated in one step.

In order to ablate the silica glass into debris as much as possible and improve the fabricating efficiency, the repetition rate of the femtosecond laser was set 1 kHz and the scanning speed was set 260 μm/s. The femtosecond laser was focused in the distilled water by a 20X objective (NA = 0.45) for fabricating the periodic microstructures. Two patterns of the array were designed as shown in Fig. 2(a), square pattern in the left and triangle pattern in the right. From Fig. 2(a), it can be seen that, the interval of adjacent rectangular cylinders is 50 μm, both horizontally and vertically.

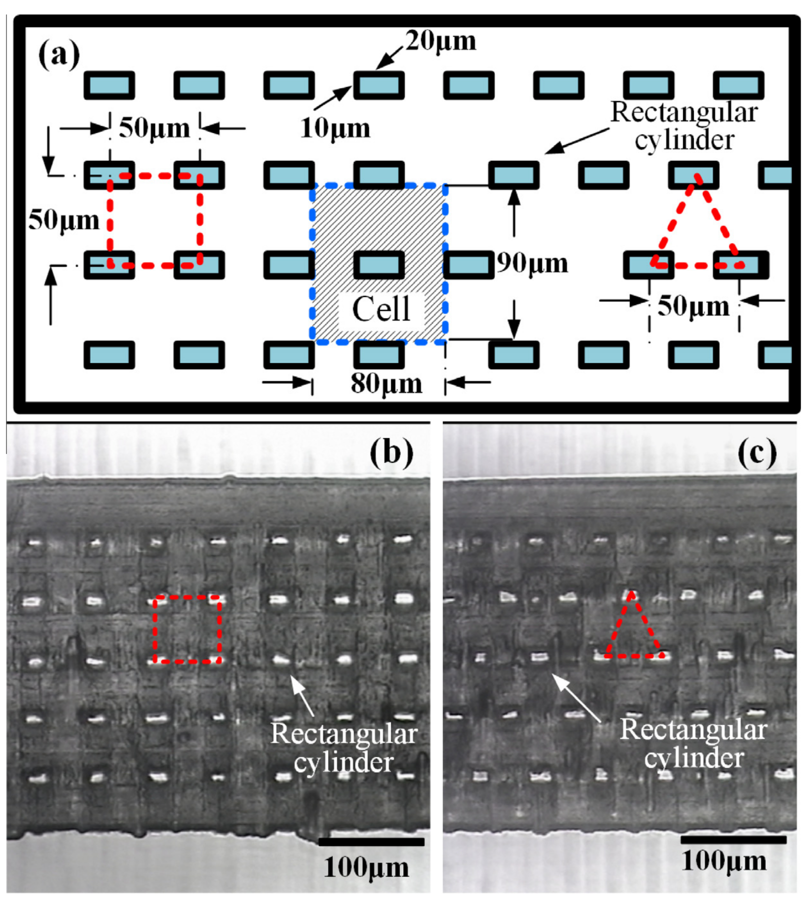

Fig. 2. (a) The schematic of the designed pattern, (b) the fabricated array with square distribution and (c) the fabricated array with triangle distribution.