Laser writing system for fabrication of diffractive optics elements

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We report a laser writing system for fabrication of diffractive optical elements with He-Cd laser. The wavelength of the light source is 441.6 nm. The output beam is collimated into parallel light with uniform intensity distribution after passing through the spatial filter with a pinhole of 25 μm and the collimating device. A microscopy objective lens with numerical aperture (NA) of 0.65 is used to focus the beam into a small diffraction spot. Any pattern can be written with this system. Experimental results are presented. The written gratings and the phase patterns were verified with a conventional optical microscopy and the Taylor Hobson equipment.

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Direct laser writing technique is a very important and flexible fabrication technology in the micro-optic and micro-electronic fields. This technology combines laser technology, lithographic technology and computer technology for fabrication of diffractive optical elements. Compared with the other fabrication methods, laser writing technology has many advantages such as low cost, stable performance, simple configuration and high fabrication precision. This technology is well suited to realize any desired phase pattern, using raster scanning of the resist-coated substrate under a focused laser beam[1]. Microoptical elements are fabricated as surface-relief structures by the programmable exposure of a photoresist film and the subsequent reactive-ion or wet-chemical etching technology. Large size microoptical components can be fabricated precisely by the laser writing method. The optical elements processed by the laser writing system are widely used in optical communication, optical signal processing, optical interconnection and optical storage, etc.. Laser writing technology has received much attention and is developed rapidly. Although an expensive, high-precision laser writing system has been reported[1,2], there is a strong need of a simple, cheap and effective laser writing system for practical applications.

Here, we report the experimental work of establishing a He-Cd laser writing system for fabricating diffractive optics elements. He-Cd laser is a common light source in laser writing for its short wavelength and low price. The experimental setup is shown in Fig. 1. The light source of the laser writing system is the He-Cd laser with a wavelength of 441.6 nm. The output beam is collimated and has uniform intensity distribution after passing through the spatial filter with a pinhole of 25 μm and the collimating lens. In the experiment, a microscopy objective lens with numerical aperture (NA) of 0.65 is used to focus the beam into a small diffraction spot. The photoresist-coated sample is fixed onto a computer-controlled $X-Y$ folded stage (MM-3M-F-1.5-GR256; NA. Inc.) that provides the minimum step length of 31 nm. The sample is the glass substrate coated with AZ1805 type photoresist with a thickness of 570 nm.

The spatial resolution and the minimum feature size of the fabricated component are determined by the focused laser spot size. The size of the diffraction-limited spot is given by the following equations[2]

$$D_0 = \lambda/(2\mathrm{NA}),$$
$$D = \sqrt{2}D_0, \qquad (1)$$

where λ is the laser wavelength; NA is the numerical aperture of the microscope objective which is used to produce the diffraction spot; D_0 is the diameter of light spot where the intensity is $1/e^2$ of the maximum intensity; D is the diameter of light spot where the intensity is $1/e$ of the maximum intensity. The theoretical size of the focal spot with NA of 0.65 is about 0.48 μm.

To obtain the required exposure pattern, we control the light exposure by choosing a proper speed of the stage and the intensity of the light source. The basic procedure of fabrication of the optical elements with laser writing technology is described as follows: developing the exposure pattern; etching the substrate; removing the residual photoresist. In the experiments, the exposure samples

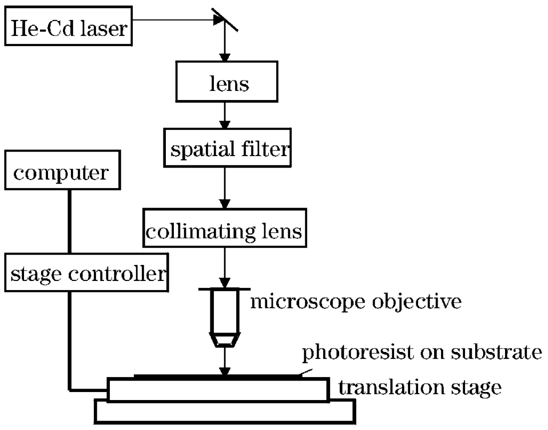

Fig. 1. Schematic illustration of the experiment setup.

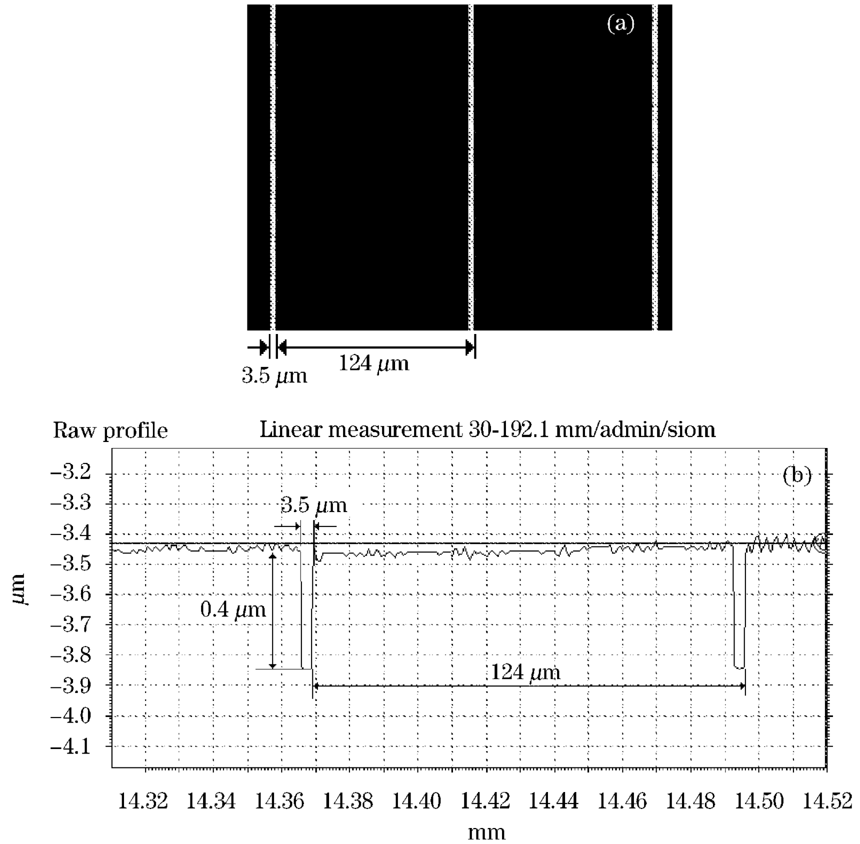

Fig. 2. (a) The written grating with a period of 124 μm and a feature size of 3.5 μm; (b) The etched surface-relief phase grating measured with Taylor Hobson equipment.

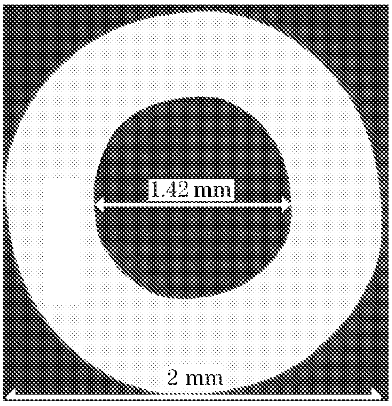

Fig. 3. Optical microscopy photograph of the fabricated circular phase plate.

were developed in Shipley Microposit Developer and the photoresist patterns were transferred into the substrate by wet chemical etching[3] in a dilute solution of hydrofluoric acid. At the same time, the chromium photomask can also be fabricated at low cost with this method.

With the scanning speed of 18.6 mm/min, we fabricated various gratings. Diffraction efficiency is an important parameter to characterize the grating performance. It is largely determined by the groove properties of the grating. High grating efficiency can be obtained through controlling the groove shape. Here we emphasized the edge quality and the processing linewidth of the grating. Figure 2(a) shows the developed photoresist pattern of the grating we fabricated. The period and the linewidth are 124 and 3.5 μm, respectively. Figure 2(b) shows the surface profile of the grating measured by Taylor Hobson equipment after etching the substrate and removing the photoresist. The etched depth is about 0.4 μm.

In addition, various circular binary phase plates have been fabricated by an overlap writing manner with the same writing speed as above. Figure 3 shows the microscopy photograph of a circular phase plate with the inner diameter of 1.42 mm and the outer diameter of 2 mm. The obtained phase plates can be used in optical signal processing for optical superresolution technique[4]. At the same time, this system can also produce other microoptical elements, such as the hexagonal phase grating[5] and the circular Dammann grating[6].

Due to the focusing and positioning errors, the theoretical precision 0.48 μm of this laser writing system has not been reached. With adoption of auto-focusing system, the smaller linewidth close to the theoretical value will be obtained. We believe that the precision of this system could be enhanced with further improvement.

In summary, the direct laser writing system for fabrication of microoptical components was described. Various gratings and circular binary phase plates were fabricated. The obtained optical elements were checked with a conventional optical microscopy and the Taylor Hobson equipment. From the experimental results, we can see this smart He-Cd laser writing system is capable of fabricating the diffractive optics gratings, microoptical elements and photomasks with low cost. With the corresponding computer programs various complicated structures can be fabricated. It is clear that the fine-linewidth pattern should be written with the expensive high-precision laser writing system, while some practical microoptical elements with large linewidths need to be fabricated with low cost. The system reported in this paper is simple, cost-effective and useful. It is capable of yielding satisfactory experimental results that are described above. Therefore, we believe that the reported laser writing system is a useful tool for fabrication of novel optical elements for practical applications.

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