Fabrication of large diffractive optical elements in thick film on a concave lens surface

Yongjun Xie, Zhenwu Lu, and Fengyou Li

State Key Laboratory of Applied Optics, Changchun Institute of Optics and Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun 130022, China
luzw@sklao.ac.cn

Abstract: We demonstrate experimentally the technique of fabricating large diffractive optical elements (DOEs) in thick film on a concave lens surface (mirrors) with precise alignment by using the strategy of double exposure. We adopt the method of double exposure to overcome the difficulty of processing thick photoresist on a large curved substrate. A uniform thick film with arbitrary thickness on a concave lens can be obtained with this technique. We fabricate a large concentric circular grating with a 10-μm period on a concave lens surface in film with a thickness of 2.0 μm after development. It is believed that this technique can also be used to fabricate larger DOEs in thicker film on the concave or convex lens surface with precise alignment. There are other potential applications of this technique, such as fabrication of micro-optoelectromechanical systems (MOEMS) or microelectromechanical systems (MEMS) and fabrication of microlens arrays on a large concave lens surface or convex lens surface with precise alignment.

OCIS codes: (220.3740) Lithography, (050.1970) Diffractive optics

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1. Introduction

There are many applications for fabricating large computer-generated diffractive optical elements (DOEs) on curved surfaces such as convex and concave lenses (mirrors) for use in the measurement of convex secondary mirrors [1] and ultraviolet spectroscopic instruments [2]. At present, approaches to the fabrication of DOEs with continuous surface relief include diamond milling, soft lithography, and direct writing [2–5]. Limited resolution restricts applications of diamond milling to relatively smooth, slowly varying relief structures [3].

Digitization of the desired surface figure, or binary optics as it has been called, would not work well for the fabrication of DOEs on a curved surface because it is generated by integrated-circuit microfabrication technology. Soft lithography technology would not work well when the pattern needs precise alignment with a curved substrate. Direct writing by a focused laser beam, in which accurate control of the process parameters enables a complex continuous-relief microstructure to be fabricated in a single-exposure scan and development step, has significant advantages (writing area and scanning speed) over the electron-beam direct-writing technology for the fabrication of large DOEs on a curved surface with precise alignment. To overcome the difficulty of processing photoresist on a large curved substrate, one can use the nonlithography technique that was developed at the University of Arizona Optical Sciences Center [5]. The technique involves thermally selective oxidization to transfer a large DOE pattern onto a metallic film on a curved substrate. However, the linear profile produced with this nonlithography technique is of inferior quality in comparison with that produced by use of lithography.

Recently, Xie *et al.* have experimentally demonstrated the lithography technique for fabricating a large computer-generated DOE pattern on a concave lens surface with precise alignment by using a laser direct writer [6]. In this paper, we extend lithographic fabrication of large DOEs on the concave lens surface to the photoresist film with arbitrary thickness from the thin film. It will be possible to fabricate DOEs with continuous surface relief by this extension. [3] To our knowledge this is the first time that a laser direct writer has been used to transfer with precise alignment a large DOE pattern onto a concave lens surface in thick photoresist film by means of lithography.

2. Fabrication and characterization

Fabrication begins with spin coating a photoresist onto the concave substrate surface. The substrate is 110 mm in diameter and has a radius of curvature of 504 mm. We can learn by experiment that the thickness of the photoresist in the radial direction will increase significantly by spin coating with thick film. There may be other approaches to coating uniform thick film on the lens surface. However, the surface quality of the photoresist film may be not suitable for the laser direct writer. There is also the additional investment.

In our experiment we adopt the method of double exposure to overcome the difficulty of processing thick photoresist film on a large curved substrate. The preexposure setup is shown in Fig. 1. An object lens is used to obtain the focused laser beam from the laser. A special spherical diaphragm with a designed pattern is introduced in the setup to modulate the exposure area on the photoresist film. In this exposure process the substrate needs to be rotated at constant angular velocity.

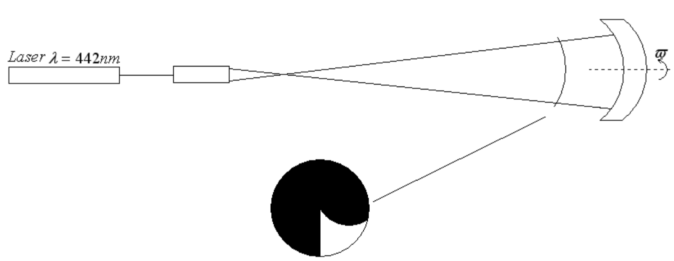

Fig. 1. Schematic of the setup for preexposure.

For our experiment we used the Shipley S1813 Microposit photoresist, which we diluted with Shipley Type P Microposit thinner in a volume ratio of 1:0.5 ml (photoresist:thinner). The photoresist was dispensed in liquid form onto a concave substrate with a 504-mm radius of curvature. The spin rate was controlled to reach 1000 rpm within 15 s. A thick substrate was obtained after it was subjected to a spin rate of 1000 rpm for 30 s. The photoresist film was approximately 2.3 μm thick. Before the first exposure, we prebaked the sample in a 90 °C oven for 30 min to remove the excess solvent and to improve the adhesion of film to substrate. Then the substrate was exposed by the setup shown in Fig. 1. After the first exposure, we developed the substrate in the Microposit developer for 20 s and then baked the sample in a 90 °C oven for 15 min to remove the excess solvent and to again improve the adhesion of film to substrate. The thickness of the photoresist will be in the range of 100 nm in the radial direction after the first exposure process. It should be noted that these operations should be performed in a clean room.

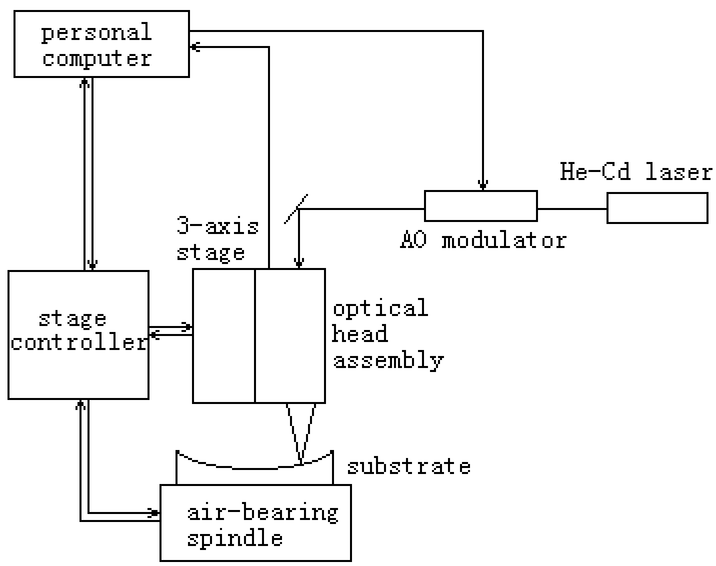

Fig. 2. Schematic of our laser direct writer.

A schematic diagram of our laser direct-writing system is shown in Fig. 2. It should be noted that we used a 150-mW He–Cd laser at a wavelength of 442 nm. Stage (or focal spot) movement was controlled to a precision of 0.1 μm in three Cartesian axes by use of feedback from distance measurements with linear encoders from Heidenhain GmbH. The concave substrate coated by photoresist film is aligned with the air-bearing spindle by means of a high-precision alignment apparatus. [7] We aligned the axis of the optical head assembly with the air-bearing spindle's center of rotation by means of spinning a diffraction grating [8].

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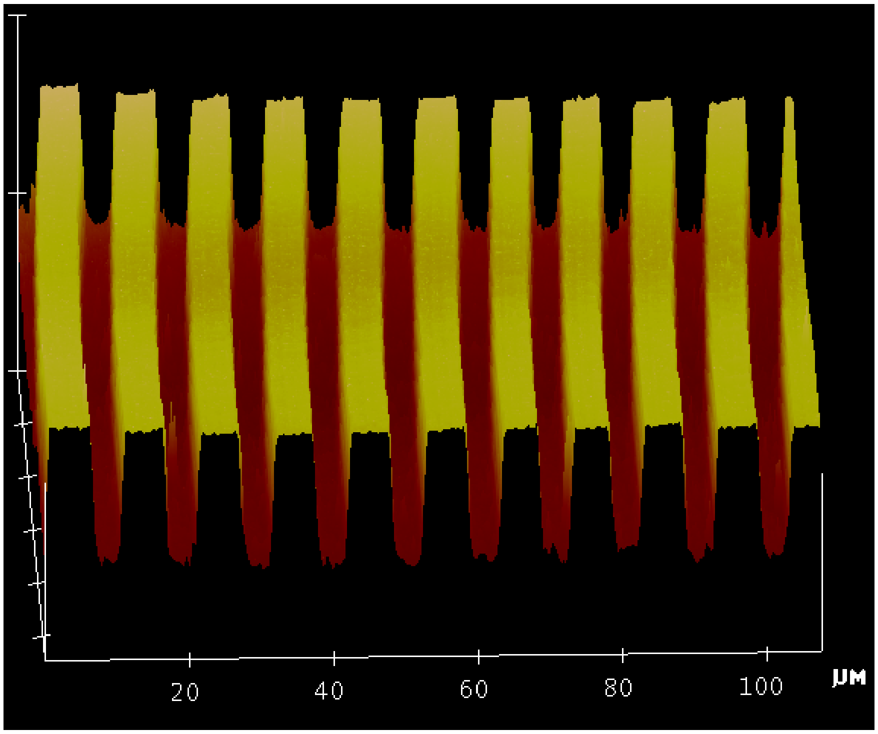

Fig. 3. Three-dimensional plot of the grating profile.

Using an atomic-force microscope, we evaluated the linear profiles of the grating with a 10-µm period produced by this technique. The film thickness is ~2.0 µm after development, and the thickness variation in the radial coordinate direction is ~0.093 µm.

3. Conclusions

We have fabricated a concentric circular grating in photoresist film with thickness of 2.0 µm on a concave lens surface with precise alignment by using the strategy of double exposure. It is believed that this technique can also be used to fabricate larger DOEs in thicker film on a concave or convex lens surface (mirrors) with precise alignment. For our laser direct-writing system, the DOEs can be fabricated at a maximum diameter of ϕ400 mm and at a maximum area of 200 mm × 200 mm. It should be possible to fabricate DOEs with continuous surface relief by use of this technique, and there are other potential applications, such as fabrication of MOEMS or MEMS on a large concave lens surface and fabrication of microlens arrays on a large concave lens surface.

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