Lithographic fabrication of large curved hologram by laser writer

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Abstract: We fabricated a large curved computer-generated hologram pattern on the concave substrate with diameter of 110mm and radius of curvature of 504mm. The line width of the hologram varied form 39um to 810um. We adopt the single pass and the screw-lines to fabricate this curved hologram precisely and efficiently. 80% of the fabrication time is saved by this method. This work will be useful to the measurement of large convex secondary mirrors that is also hardness at present.

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

References and links

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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

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diamond milling, soft lithography, and direct writing [2–5]. Limited resolution restricts applications of diamond milling to relatively smooth, slowly varying relief structures [2]. 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, we have experimentally demonstrated the lithography technique for fabricating a large grating pattern on a concave lens surface with precise alignment by using a laser direct writer [6,7,8]. In this letter, we experimentally demonstrate the fabrication of large curved computer-generated hologram precisely and efficiently. This large curved hologram has greatly varied line width. This technique is useful for the measurement of large convex secondary mirrors that is also hardness at present.

2. Fabrication and characterization

We fabricated a large curved hologram on the concave substrate with diameter of 110mm and radius of curvature of 504mm. The line width of the hologram varied form 39um to 810um. It is very important to take proper writing strategy because the great variation of the line width of the hologram. The fabrication efficiency will be very low if there is no proper writing strategy.

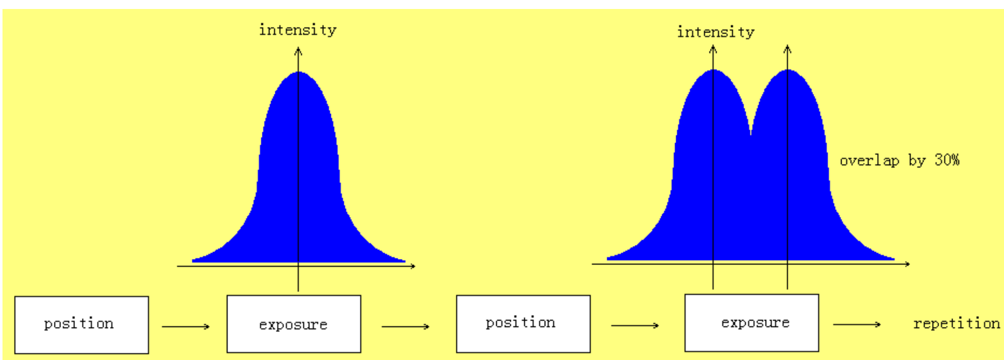

Fig. 1. The overlap writing method of laser writer.

For the precise line width of this large pattern, the general adopted writing method is overlap by 30%(Fig.1). For instance, to get a zone with width of 80um by a single laser beam of 10um, the detailed description of the writing process will be: firstly, precisely move the beam to the radial position to write; then, increase the beam intensity to expose the photoresist and a circle with width of 10um will be formed (the substrate is rotating); thirdly, decrease the beam intensity not to expose the photoresist and precisely move the laser beam to the next radial position (the distance is 7 um to the previous position) to write; fourthly, increase the beam intensity again to expose the photoresist and the circle will be 17um in line width; such-and-such, a zone with width of 80um will be formed after 11 times of repetition. It should be noticed that to precisely position the laser beam needs 80% of each repetition time because the complicated position system. By this method, we fabricated the large curved hologram and it spent about 24 hours to complete the writing. It is obviously that this method is not appropriate to fabricate such kind of diffractive patterns.

In order to fabricate the large curved hologram efficiently, we adopt the combination of single pass and screw line (Fig.2). For instance, to write the same zone with width of 80um by a single laser beam of 10um, the detailed description of the writing process will be: firstly, precisely move the beam to the radial position to write a circle with width of 10um by single pass (Fig. 2(a)); then control the laser beam to move at a invariable velocity in the radial direction, at the same time, modulate the laser beam intensity from zero to the value which can expose a line with width of 10um in one circumference (Fig. 2(b)); thirdly, let the laser beam moving at the same velocity in the radial direction with proper laser intensity and the laser beam will write screw line(Fig. 2(c)); fourthly, let the laser beam moving at the same velocity in the radial direction with proper laser intensity until it reach the position when the zone width is about 70 um, modulate the laser beam intensity from the value which can expose a line with width of 10um to zero in one circumference(Fig. 2(d)); fifthly, precisely position the beam to write a circle with width of 10um by single pass again(Fig. 2(e)); sixthly, put the substrate in resist developer, and a zone with precise width of 80um is formed (Fig. 2(f)). It should be noticed that the substrate is rotating all through the process.

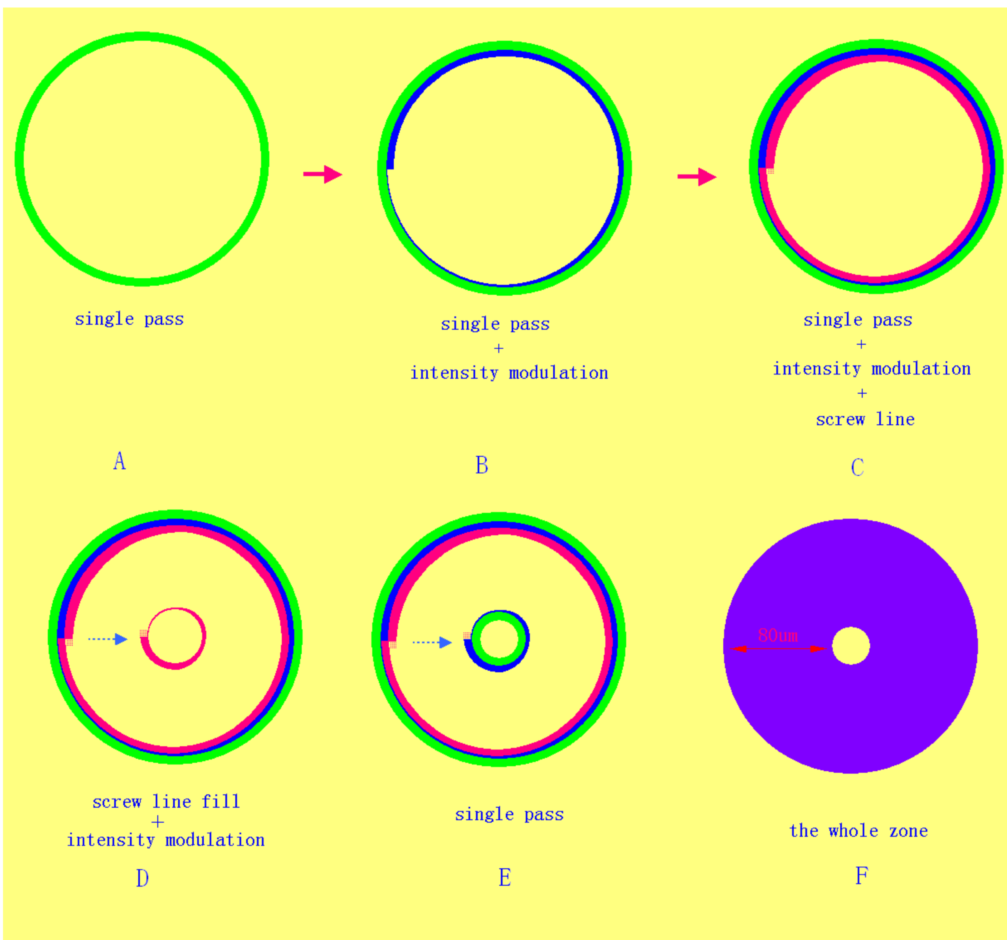

Fig. 2 The combination of single pass and screw line to precisely write large zone.

It is obviously that there are only two precise positions in the combination of single pass and screw line to write a zone comparatively with 11 times of precise positions by overlap. The time spent to write the pattern will be saved greatly by reducing the times of position. On the other hand, the precise single passes at two edge of the zone cause the zone a precise width. By this combination, we fabricated the large curved hologram again and it spent about 5 hours to complete the writing comparatively with about 24 hours, therefore, 80% of the fabrication time is saved.

The joint error of the single pass can be corrected by optimization of the intensity data of the beam at the joint [8]. We obtained photoresist film with uniform thickness on the large concave lens surface by selecting proper spin-coating parameters and the method of double exposure [6,7]. Before UV exposure, we prebaked the sample in a 90-centigrade oven for 30 minute to remove the excess solvent and to improve the adhesion of film to substrate.

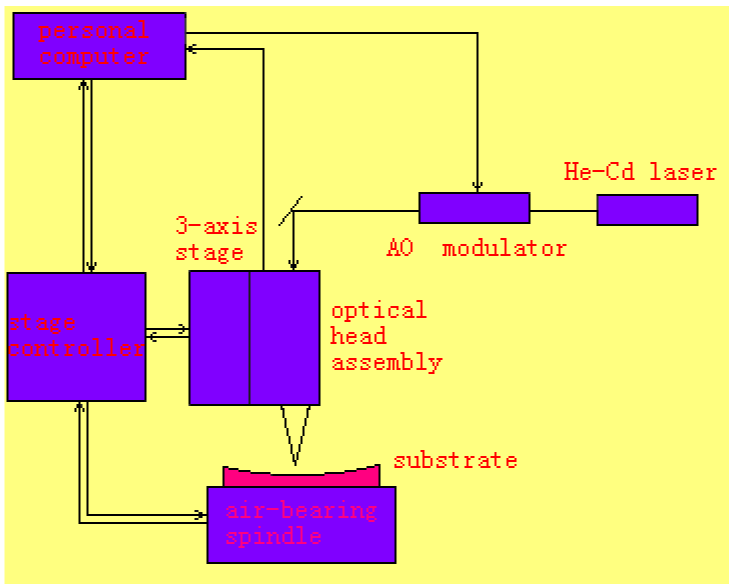

Fig. 3. Schematic of the laser writer system.

A schematic diagram of our laser direct writing system is shown in Fig. 3. 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 um 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 [9]. We aligned the axis of the optical head assembly with theair-bearing spindle's center of rotation by means of spinning a diffraction grating [10].

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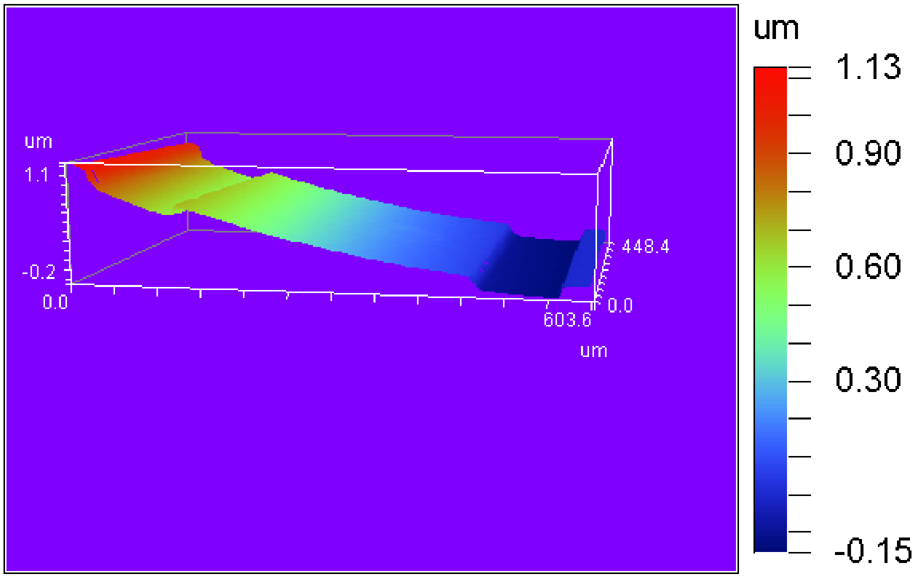

Fig. 4 Part three-dimensional plot of the large curved hologram.

Part three-dimensional plot of the curved hologram fabricated by our laser writer is shown in Fig. 4. The left line width of the fabricated pattern is 95.81um and the right line is 88.73um. Comparatively with the line width of 96.03um and 89.05um fabricated by overlap, there is no inferior quality of pattern considering the testing error of the apparatus. By the way, this curved hologram with line width from varied form 39um to 810um will be used to get a non-spherical wave surface as the standard surface to testing the convex non-spherical surface of the optical mirrors.

3.Conclusion

We fabricated a large curved computer-generated hologram pattern on the concave substrate with diameter of 110mm and radius of curvature of 504mm. It is very important to take proper writing strategy because the great variation of the line width of the hologram. By the combination of single pass and screw line, 80% of the fabrication time is saved. Part three-dimensional plot with high quality of the large curved hologram fabricated by lithography is given. This work will be useful for the measurement of large convex secondary mirrors that is also hardness at present.

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