Fabrication Technology of the Centrosymmetric Continuous Relief Diffractive Optical Elements

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Abstract

Diffractive Optical Element (DOE) can be used to simplify optical systems such as lightening its mass, reducing elements numbers and so on. In the paper, Laser Direct Writing Method was used to fabricate centrosymmetric continuous relief Diffractive Optical Element’s mask and ion beam reaction etching method was used to realize transferring micro structures from photoresist layer to substrate. Before the mask’s fabrication, we used polar coordinate pattern Laser Direct writing system to study the response rule of photoresist layer to the laser exposure, and then the mask were fabricated successfully. During transferring process, the speed ratio of etching between photoresist layer and substrate was measured and the measuring experiment for flux of the gas which was used to produce ion beam was done. In the end, we combined the Laser Direct Writing Method with ion beam reaction etching method to realize the fabrication of a plane diffractive focusing lens with continuous relief micro structure successfully. The technology can also be used to fabricate other Centrosymmetric Continuous Relief Diffractive Optical Elements

Keywords: Laser Direct Writing, Diffractive Optical Element, micro structure, ion beam reaction etching

1. Introduction

DOE often have micro continuous relief structures on its diffractive surface. But in past long period of time, the structure could not be fabricated effectively because of absence of fit technology, so the elements could not be used in optical systems widely. In order to use this kind of optical elements, researchers tried to fabricate the structures with semiconductor technology, they succeeded and Binary Optical Element (BOE) technology appeared. In the technology, binary steps were fabricated to replace continuous relief structures approximatively. But the diffractive efficiency of BOE was decided by the step numbers, so if you want to get high diffractive efficiency the step numbers must be added. This will lead to a fact that technology became more complicated and element cost added also. The high cost limited application of BOEs.
With the development of laser technology, Laser Direct Writing method came out. In the method, the substrate was spread with photoresist on the surface firstly, and then the photoresist layer was exposed under laser beam. Laser power was controlled by computer to change continuously, so the microstructures in photoresist layer were continuous after development. After that, ion beam reaction etching method could be used to transfer microstructures from photoresist layer to substrate.

In the paper, we realized the fabrication of DOE by means of combining Laser Direct Writing method with ion beam reaction etching method.

2. Principle of the polar coordinate Laser Direct Writing method

Polar Laser Direct Writing system is composed of controlling computer, Ar+ laser, optical collimating lenses, laser writing head, amplifiers, radial coordinate controller and angular coordinates controller, figure 1. Laser beam from Ar+ laser is collimated by optical lenses firstly and then collimated beam arrives to laser writing head. Laser beam can be auto-focused to a spot on the photoresist layer at the surface of substrate fixed on the revolving stage. According to the design result of Centrosymmetric CR-DOE mask, laser power can be adjusted continuously by computer via controlling acoustic optic modulator. At the same time, the position of laser beam spot can also be controlled by computer via radial coordinate controller and angular coordinate controller. Thus, the photoresist layer on mask plate can be exposed by laser beam with anticipated power at exact position. After development, exposed photoresist can be dissolved and continuous relief micro structure appears in the photoresist layer.

3. Experiments and results

3.1 DOE mask fabrication

Two experiments were done to study the relations between microstructure depth and laser power, exposing position radius and laser power. During experiment 1, exposing position radius was fixed at 1000μm, 3200μm, 10000μm and 15000μm, a same form micro structure was fabricated with different laser power. After development, the depths of these micro structures in photoresist layer were measured. During experiment 2, same depth micro structures were fabricated at different radius with different laser power and each laser power value was measured.

During the two experiments, photoresist plate rotation speed 10rad/s, photoresist S1830, developer Microposit351, photoresist layer thickness about 2.2μm and development time 60seconds.

Measurement results of laser power and microstructure depth in experiment 1 were shown in table 1. In table 1, R exposing position radius, P laser power, d micro structure depth.
Table 1. Measurement results of laser power and microstructure depth

| R(μm) | P1/ d1(mw/μm) | P2/ d2(mw/μm) | P3/ d3(mw/μm) | P4/ d4(mw/μm) | P5/ d5(mw/μm) | P6/ d6(mw/μm) | P7/ d7(mw/μm) |
|-------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| 15000 | 150/0.684     | 180/0.972     | 220/1.103     | 280/1.395     | 300/1.587     | 350/1.753     | 400/2.053     |
| 10000 | 100/0.548     | 125/0.687     | 150/0.966     | 180/1.155     | 220/1.389     | 260/1.784     | 300/2.053     |
| 3200  | 25/0.344      | 40/0.508      | 50/0.652      | 60/0.953      | 75/1.176      | 90/1.405      | 100/1.600     |
| 1000  | 20/0.246      | 30/0.502      | 45/0.688      | 60/0.863      | 75/1.102      | 90/1.364      | 100/1.547     |

Datum in table 1 was analyzed with Microsoft Excel, in fig.2.

Fig. 2 Relations between microstructure depth and laser power

Fig.2 shows that micro structure depth is about in direct ratio to laser power at different exposing position radius and there is a laser power threshold during exposing. That means if laser power is less than the threshold photoresist can not be exposed effectively.

Measurement results of experiment 2 were shown in table 2. In table 2, R exposing position radius, Dg designed depth of micro structure, Dr measured depth of micro structure, P laser power.

Table 2 Measurement results of laser power and exposing position radius

| R(μm) | 15000 | 14000 | 13000 | 12000 | 11000 | 10000 | 9000 | 8000 | 7000 | 6000 | 5000 | 4000 | 3200 |
|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|
| Dg(μm)| 1.0   | 1.0   | 1.0   | 1.0   | 1.0   | 1.0   | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  |
| Dv(μm)| 1.03  | 1.46  | 1.10  | 0.98  | 0.99  | 1.05  | 1.03 | 1.00 | 1.01 | 0.99 | 0.98 | 1.00 | 1.06 |
| P(nW) | 192.3 | 187.5 | 173.6 | 157.1 | 149.2 | 143.6 | 126.8| 117.9| 109.4| 90.8 | 75.4 | 70.3 | 65.8 |

Measurement datum of experiment 2 was analyzed with Microsoft Excel, fig.3.
Fig. 3 shows that exposing position radius is about in direct ratio to laser power while same depth micro structure were fabricated at different exposing position radius and there is also laser power threshold.

From two experiments result, micro structure depth will add while laser power add and laser power must be changed as the same tendency to the change of exposing position radius. For a single continuous relief micro structure, we used such a method to get laser power. In the method, we measured laser power values at the radius position of beginning and end of the structure according to result in experiment 2, then the laser power values between the two radius positions were gotten via calculation according to the result of two experiments. By the method, we succeeded in fabrication of a single continuous relief micro structure. For a designed mask of a kind of centrosymmetric continuous relief diffractive focus lens, diffractive micro structures were shown in fig. 4, we used the method to get laser power. For every single structure, laser power values were gotten as before. So as long as we measure several laser power values at several separate radius position, we can get all laser power in exposing area. With the method, we succeeded in fabrication of the mask. Measurement result of micro structures of the mask was shown in fig. 5. We call this method as laser power characterization method.
3.2 Micro structure transfer

After mask fabrication, we transferred micro structures from mask to substrate (SiO2) with ion beam reaction etching method. We measured the etching speed ratio between photoresist layer and substrate. In the measuring experiment, we prepared 6 masks which were fabricated a circle groove with same depth in photoresist layer with Laser Direct Writing method and roasted these masks in an oven at different temperature (table 3) to dry them at different rigidity firstly, and then we put them in an ion beam reaction etching system to etch the photoresist layer. After that, we got grooves at 6 substrates with different depth. According to the surface quality of these grooves, we got the fit etching speed ratio and roast temperature. The etching speed was about 2:1 and the roast temperature was 120°C. In this case, we prepared a mask of plane diffractive focusing lens mask with continuous relief micro structure. We used ion beam reaction etching method to realize micro structure transferring. During etching process, ion beam gas SF6, flux 30~45sccm/min, RF power 20~40W, air-pressure range in reaction vacuum cavity 2.8~3.5Pa, all these parameters were got according to experiment. At the end, we fabricated a plane diffractive focusing lens with continuous relief micro structure successfully and its diffractive efficiency was more than 92%. We also measured the size of micro structures of the lens at different radius, and the result was shown in table 4 and fig 6.

Table 3. measuring experiment result of etching speed ratio

| Roast temperature, (°C) | 100  | 110  | 120  | 130  | 140  | 150  |
|-------------------------|------|------|------|------|------|------|
| Micro structure depth in photoresist layer, (um) | 1.571 | 1.516 | 1.501 | 1.513 | 1.544 | 1.628 |
| Micro structure depth after etching, (um) | 0.6299 | 0.6146 | 0.7402 | 0.7945 | 0.8407 | 0.8917 |

Table 4. Contrast between designed and measured value of continuous relief microstructure

| radius, (μm) | width, (μm) | depth, (μm) |
|--------------|-------------|-------------|
|              | designed    | measured    | designed | measured |
| 640.5        | 51.0        | 51.0        | 0.633    | 0.632    |
| 978.5        | 34.0        | 34.5        | 0.633    | 0.631    |
| 4359.0       | 7.0         | 7.0         | 0.633    | 0.621    |

4. Conclusions

In the paper, the relations between micro structure depth and laser power, exposing position radius and laser power were studied via experiments. According to the experiment result, micro structure depth is about in direct ratio to laser power at different exposing position radius and laser power must be changed in direct ratio to exposing position radius if you want to get micro structures at different radius with same depth. Ion beam reaction etching method was used to transfer micro structures from photoresist layer to substrate successfully. We fabricated a plane diffractive focus lens with continuous relief micro structure successfully at the end and the diffractive efficiency of the lens was more than 92%.

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