Fabrication method for inductive mesh film on spherical substrates

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Abstract: To fabricate an inductive mesh film with a micron grade line width on a concave spherical substrate, we put forward a laser direct writing method of concentric optical scan, and it means that the intersecting point of three kinematic axes and an optical axis is the curvature centre of concavity. The specific scanning way is separated into four steps. Firstly, a concave spherical substrate of coating photoresist is installed erectly on a horizontal shafting, and a laser beam is focused on the edge of photoresist surface. Afterward, the substrate and horizontal shafting rotate as a whole with the rotary of an erect shafting, a line is written on the photoresist surface while a rotation period is accomplished. Then, the laser beam is turned an angle at the pitching direction, and the substrate is rotated again a cycle, so another line is written. Repeating this way, we get a set of latitude lines. Finally, the substrate makes a quarter turn around the horizontal axis, and repeating preceding processes, we get a mesh figure of intersecting latitude lines. In the experiment part, we fabricate an inductive mesh film with a period 600 μm and a line width 7 μm on a concave spherical substrate.

Keywords: microstructure fabrication; photolithography; transparent conductive film; inductive mesh; spherical substrate.

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Biographical notes: Xiaoguo Feng received his BS in Mechatronic Engineering from Jilin University in 1998, MS in Optical Engineering from University of Chinese Academy of Sciences in 2003, and PhD in Optics from University of Chinese Academy of Sciences in 2006. He worked as a Researcher in Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Science in 1998. He has been a Research Professor in Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Science in 2014. His research interests include opto-mechanical systems design, microstructure fabrication technology and metamaterial.

1 Introduction

An inductive mesh film is often applied to an infrared window for shielding the electromagnetic interference, and its performance is evaluated by optical properties and electrical characteristics [1]. Generally, the optical properties of mesh only relate to the duty ratio, but its electrical characteristics are related to the conductivity of material and line width and duty ratio [2,3]. While the duty ratio is determined, under perfect electrical conductivity (PEC) assumptions, the narrower line width of inductive mesh is, the better performance of inductive mesh is. Thus, narrowing the line width is of crucial importance for fabricating an inductive mesh film [4,5]. In practice, to keep the low resistance, it is best to fabricate an inductive mesh with several microns line width [6].

To generate a figure with a micron grade line width on a thick photoresist or a curved substrate, an advanced maskless photolithography technique of laser direct writing should be selected [7,8]. However, writing a fine figure on a curved substrate is often very complex and difficult, so few papers introduce this kind of subject [9,10]. This paper puts forward an idea that latitude lines intersect latitude lines to form an isometric mesh on a concave spherical substrate, and a laser direct writing way called concentric optical scan, and a set of technological process for a specific experiment. To highlight the key, the writing method of concentric optical scan is emphatically discussed.

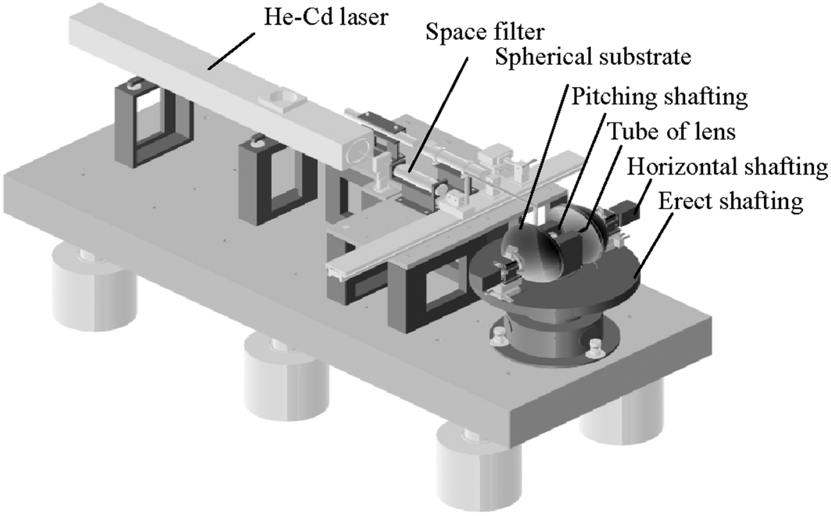
2 Method of concentric optical scan

It is well known that a hexagonal grid is the most suitable for a spherical substrate, and the writing method of concentric optical scan can also generate a hexagonal grid on the concave of a spherical substrate. But in practice this is very difficult, so we put forward that latitude lines intersect latitude lines to form a quadrangled mesh on a spherical substrate.

As shown in Figure 1, the overall structure of concentric optical scanning equipment. The equipment mainly composes of laser, laser power controller (LPC), space filter, high-speed shutter, concentric scanning system, alignment system and so on. The concentric scanning system is the core part of equipment, and has a structural feature that the intersecting point of three kinematic axes and an optical axis is the curvature centre of concave. The concentric scanning system contains an erect, a horizontal and a pitching shafting. The erect shafting is set on a base and hollow inside, and its bush can rotate around the erect axis. The horizontal shafting is used to hold a spherical substrate, and fastened with the bush of erect shafting. The pitching shafting is also set on the base, and can rotate along the pitching direction. The laser beam is led by several optical mirrors, and finally reflected by a reflecting mirror in the centre of pitching shafting, and focused at the position of concave spherical radius by a lens that is fixed on the pitching shafting.

The specific scanning way is separated into four steps. Firstly, a concave spherical substrate of coating photoresist is set erectly on a horizontal shafting, and the centre of sphere is adjusted to overlap with the horizontal axis, and the photoresist surface is adjusted to overlap with the laser focal spot. A laser beam is focused on the edge of photoresist surface. Afterward, the substrate and horizontal shafting rotate as a whole with the rotary of an erect shafting, while a rotation period is accomplished, a line is written on the photoresist surface. Then, the laser beam is turned an angle at the pitching direction by the reflecting mirror in the centre of pitching shafting, and the substrate is rotated again a cycle, so another line is written. Repeating this motion way, a set of latitude lines is gained. Finally, the substrate makes a quarter turn around the horizontal axis, and repeating preceding processes, so another orientation lines are also written. After development, we get an isometric mesh figure of latitude lines intersection.

Figure 1 Sketch of concentric optical scan machine



3 Error analysis of concentric optical scan

It must be pointed out that axes of three mechanical spindles and one optical axis must intersect at the curvature centre of concave, and the homocentric error between these axes will induce the period and line width variation of mesh.

As shown in Figure 2, C is the curvature centre of concave surface without the homocentric error, C′ is the curvature centre of concave when the homocentric error exists, OC is an axis of shafting without the homocentric error, OC′ is the axis of shafting when the homocentric error exists, OA is the position of concave without the homocentric error, and OA′ is the position of concave when the homocentric error exists. The distance of C′ and C is described by Δc, the curvature radius of concave is described by R, the central angle corresponding with a half of aperture is described by θ, the defocus is described by Δz, and the period error of mesh is described by Δl.

From Figure 2, the below relationship may be obtained

$$\Delta\beta \approx \frac{\Delta_C}{\mathrm{R}} \tag{1}$$

$$\beta = \frac{\pi - \theta}{2} \tag{2}$$

So

$$\mathrm{OA} = \frac{R\sin\theta}{\sin\beta} = 2\cdot R\cdot\sin\frac{\theta}{2} \tag{3}$$

and

$$\Delta_Z \approx \mathrm{OA}\cdot\Delta\beta \tag{4}$$

From equations (1), (3) and (4), there is

$$\Delta_Z \approx 2\cdot\Delta_C\cdot\sin\frac{\theta}{2} \tag{5}$$

and

$$\mathrm{OA}' \approx \mathrm{OA} \tag{6}$$

$$\mathrm{A'B} = \mathrm{OA}'\cdot\sin(\beta-\Delta\beta) \tag{7}$$

$$\Delta\theta = \mathrm{arc}tg\frac{\mathrm{A'B}}{\mathrm{R}-\mathrm{OA}'\cdot\cos(\beta-\Delta\beta)} - \theta \tag{8}$$

$$\Delta_l \approx R\cdot\Delta\theta \tag{9}$$

From equations (1)–(3), (6)–(9), there is

$$\Delta_l \approx R\cdot\left[\mathrm{arc}tg\frac{2\sin\frac{\theta}{2}\cdot\cos\left(\frac{\theta}{2}+\frac{\Delta_C}{R}\right)}{1-2\sin\frac{\theta}{2}\cdot\sin\left(\frac{\theta}{2}+\frac{\Delta_C}{R}\right)} - \theta\right] \tag{10}$$

So the relationship of Δc, Δz and Δl may be expressed by formula (10). Provided that R = 150 mm and θ = 40°, we can obtain the relationship curve of Δc, Δz and Δl, see Figure 3.

Figure 2 Relationship sketch of homocentric error

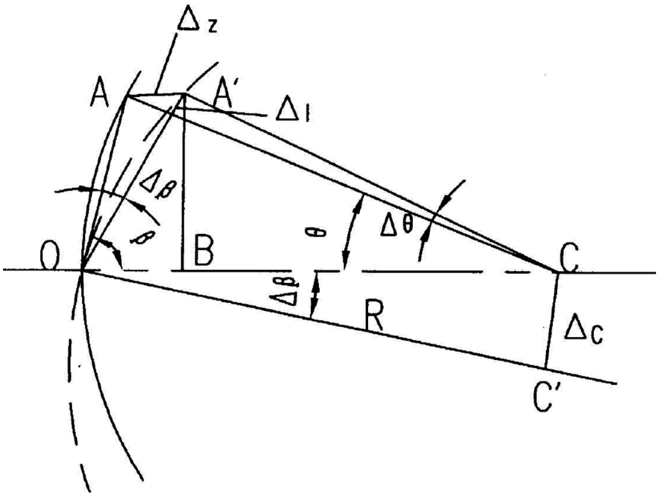
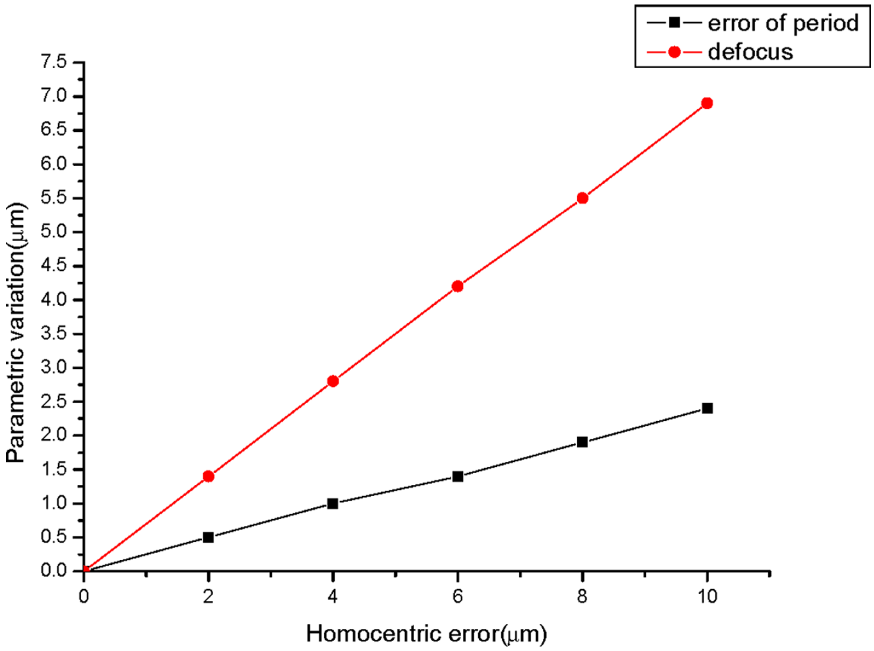


Figure 3 Relationship curve of Δc, Δz and Δl (see online version for colours)



Obviously, the homocentric error has a great effect on the defocus, and the defocus will induce the line width variation of mesh or cannot generate the figure. To fabricate an inductive mesh with a micron grade line width, the focal depth of writing lens is also several microns, so the homocentric error of writing equipment must be controlled.

4 Process flow and experiment

He-Cd laser is selected as the writing light source, and its wavelength is 441.6 nm, and the writing power of optical system is controlled by a LPC. The laser beam is filtered and enlarged by a space filter, and is deflected by several reflecting mirrors and focused by an object lens NA = 0.27. He-Ne laser is selected as the alignment light source, and its wavelength is 632.8 nm. The input power of optical system is also controlled by a LPC, and the laser beam is also filtered and enlarged by a space filter. The optical path is deflected by two prisms to form a common-path with the writing system before the object lens, and a quarter-wave plate is set between two prisms to deflect the alignment beam (see Figure 1).

The process flow of Figure 4 is selected. Firstly, a spherical substrate is cleaned by purificant, and spin-coated positive photoresist on the concave of substrate by a special device. And then, the substrate is set on the horizontal shafting of writing equipment, and the photoresist is exposed along with the running equipment. After developing by developer, a mesh figure on the concave is obtained, (see Figure 5(a), the slot width is 5.4 μm, the photoresist thickness is 0.35 μm). Afterwards, the chromium and copper are evaporated on the concave by a coating machine, and the surplus photoresist is dissolved by the acetone, so a thin metallic mesh is obtained (see Figure 5(b), the line width is

5.6 μm, the metal thickness is 0.09 μm). Finally, the thickness of metallic mesh is grown by plating, the plating solution is the solution of 2% $CuSO_4$ and the current flow is 10 mA (see Figure 5(c), the line width is 7 μm, the metal thickness is 0.5 μm).

Figure 4 Fabrication process flow of inductive mesh

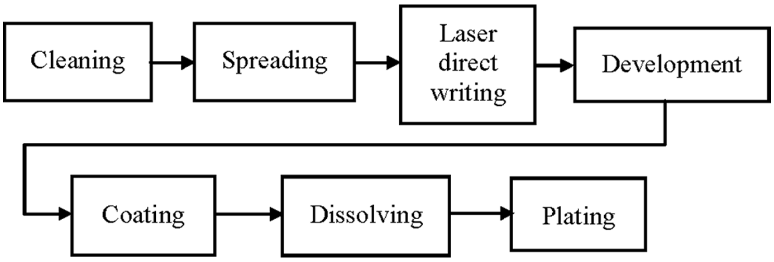


Figure 5 AFM photographs of fabrication process for an inductive mesh: (a) after development; (b) after photoresist dissolved and (c) after plating

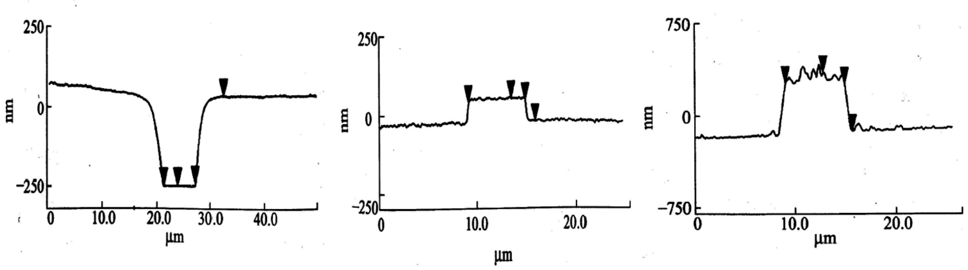


Figure 6 Regional amplified picture of inductive mesh on the concave of spherical substrate (see online version for colours)

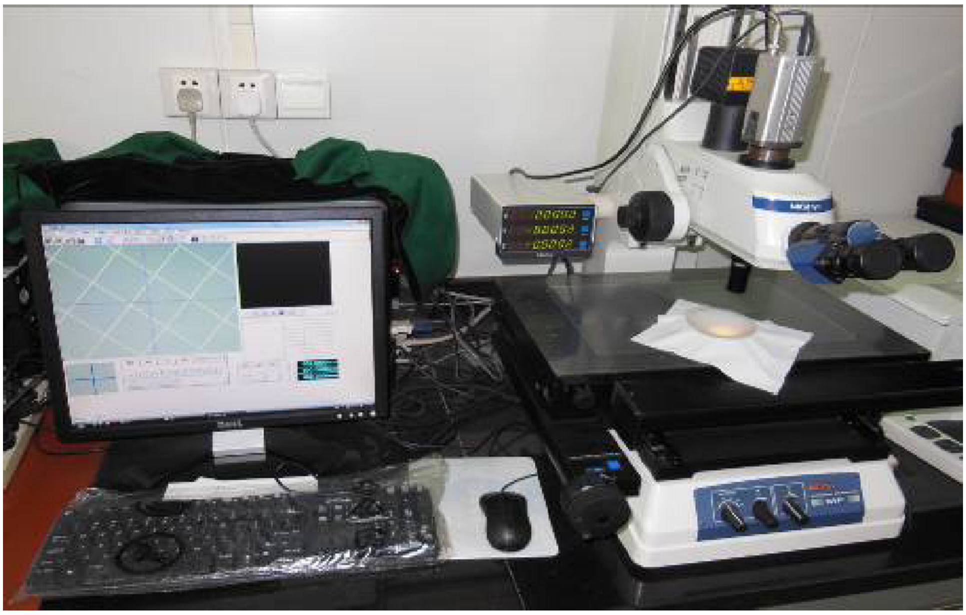


Figure 6 shows a regional amplified picture of an inductive mesh on the concave of spherical substrate. At last, we fabricated an inductive mesh of a period 600 μm and a line width 7 μm on the concave surface of an MgF_2 substrate. The curvature radius of concavity is 200 mm, and its aperture is 150 mm.

5 Conclusions

To generate a mesh figure with a micron grade line width on a concave spherical substrate, we present a laser direct writing method of concentric optical scan, and analyse effects of homocentric error between three mechanical axes and an optical axis. Furthermore, we also introduce the process flow of fabricating an inductive mesh film on an optical substrate. The experiment result shows that an inductive mesh film with a period 600 μm and a line width 7 μm is fabricated on an MgF_2 spherical substrate.

From our experience, at the present time, the fabrication accuracy of writing method is superior to soft lithography' or duplication' on a curved substrate, and the process flow is also appropriate in fabricating a metallic mesh film on an MgF_2 or ZnS substrate. Furthermore, the method of concentric optical scan may also be transplanted to fabricate other fine figures on a regular curved substrate. Of course, at some aspects, as the detection method of photoresist thickness on a curved substrate and improvement of focusing servo-control accuracy, we need further study yet.

Acknowledgements

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