DESIGN AND FABRICATION WITH ELECTRON BEAM LITHOGRAPHY OF A DIFFRACTIVE OPTICAL ELEMENT

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În această lucrare sunt prezentate rezultate în premieră la scară națională privind proiectarea şi fabricarea prin litografie cu fascicul de electroni a unui element optic difractiv. Acest element optic difractiv funcționează în reflexie şi are două nivele. Elementul optic difractiv a fost proiectat să reproducă logo-ul „IMT" la infinit. Metodele de proiectare şi caracterizare prezentate aici pot fi utilizate pentru realizarea de elemente optice difractive cu aplicații diverse.

In this work the first results obtained at national level regarding the design and fabrication with electron beam lithography of a diffractive optical element are presented. This diffractive optical element has two levels and it works in reflection. The purpose of the diffractive optical element is the reproduction of „IMT" logo in the far-field. The approach for the design and fabrication presented here can be extended forr the realization of the diffractive optical elements with various application.

Keywords: Electron beam lithography, diffractive optical elements

1. Introduction

Diffractive optical elements (DOEs) are microoptic components that operate by light diffraction. In fact a DOE is a matrix composed of small elements called pixels that modify the amplitude and/or phase of the incoming radiation. The new aquired amplitude/phase distribution of the radiation modifies the way the radiation propagates beyond DOE. Phase based DOE are more efficient than amplitude based DOE.

DOEs can be fabricated using microfabrication techniques (layer deposition, etching, optical lithography, electron beam lithography, etc. [1], [2]), DOEs are more flexible than the classical microoptic components (lens, prisms)

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since DOEs can have more functions. DOEs have also the advantage of batch processing which implies reduction of costs and increasing of the fiability. Due to the fact that DOEs presents usually small surface height contrast ranging from hundreds of nanometers to few microns (depending of the radiation wavelength), DOEs can be replicated more easily than their classical counterparts.

There are many application domains for DOEs including optical communications, optical interconections, sensors, beam shaping, material processing, advertisment, etc.

Up to now, some DOEs have been fabricated in IMT-Bucharest working in transmission as a beam splitter [3] and in reflection as generator of a logo [4] or as Fresnel reflective lenses [5]. All these DOEs have been fabricated using optical lithography which cannot offer a resolution better than a few microns. DOEs fabricated in IMT-Bucharest have two levels and even four levels [5]. Also, there are results regarding the theoretical studies of DOEs at national level [6], [7].

In this paper the results regarding design, fabrication with electron beam lithography and characterization of a diffractive optical element which allows the reproduction of „IMT" logo in the far-field are presented.

2. Design

Regardind their nature, the DOEs can be theoretically studied with analytical methods (Fresnel lenses, diffraction grating) or numerical methods if the DOEs have complex functions. The DOE studied here cannot be designed with analytical methods. In order to design this DOE with numerical methods we have used a specialised software 3Lith [8] available in the National Institute of Research and Development for Microtechnologies (IMT – Bucharest). In the following, we will presents some features of this software.

3Lith software works by introducing the image which is desired to be reconstructed at a certain distance or at infinite as the input file. After an iterative process one can obtain the DOE configuration. This software also allows the image reconstruction. The files with DOEs configurations are converted to a compatible format to electron beam lithographic equipment, so that after applying some corrections, the XY phase distribution of the designed DOE is transferred into XY electron resist height distribution of the fabricated DOE. The height distribution of the electron resists is obtained by varying the electron beam intensity. 3Lith software allows to design a DOEs with 2, 4, 8, 16,...256 levels. Since this procedure for the fabrication of multilevel DOEs is rather difficult because a strict control of the process parameters (temperature, humidity, developing solution quality, irradiation dose, developing time) is needed, we have chosen to design a two level DOEs, as long as it is much easier to introduce in the electron beam lithography equipment a „black-white" file which do not raise problems related to electron beam dose or developing conditions like a „gray-tone" file does. So, we have introduced in the associated script the option „N_phase = 2" which means that the phase distribution of the designed DOE will have only two levels.

We have designed a DOE with 1024 μm × 1024 μm size and the pixel dimension of 1 μm. The radiation wavelength is 0.635 μm. The image which contains the "IMT" logo used for generation of the DOE is represented in Fig. 1. The image is asymmetric since the two-levels DOEs generates both the object image and its inversed image.

The DOE configuration is produced by 3Lith software as a image in tiff format. This image is composed from black and dark-gray zones. The image is converted into a "black-white" image in order to obtain the input file for electron beam lithography equipment. The white zones represent the zones impressed by the electron beam. In the case of the two-levels DOEs it is not important which zone corresponds to "hill" and which zone corresponds to "valley" since the phase difference between the two zones is π. The DOE image is represented in Fig. 2.

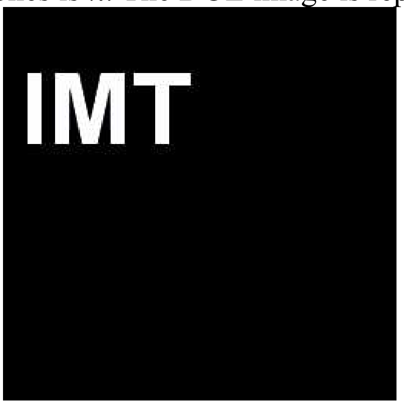

Fig. 1. The image with "IMT" logo used for generation of the DOE.

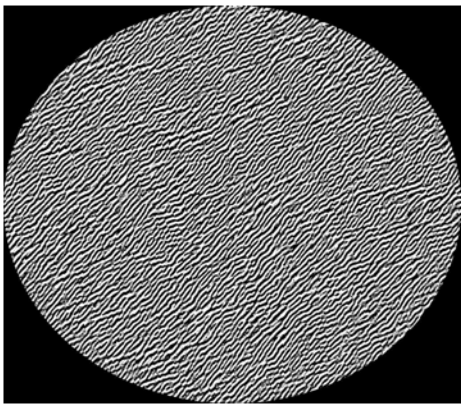

Fig. 2. Diffractive optical element image

The far-field image has been reconstructed using the same software. The image is represented in Fig. 3. One can notice that both the direct image and the reversed image are generated.

The designed DOE has been tested with the help of an configurable DOE based on liquid crystals formed of 1024 × 1024 pixels with 8 μm pixel size. This configurable DOE belongs to INFLPR Bucharest. The DOE file generated for this test resembles the initial DOE file presented in Fig. 2, the only change is the pixel size, which is 8 μm now. One can notice the practical generation of the reversed image in conjunction with the direct image. The far-field image obtained with the configurable DOE is represented in Fig. 4.

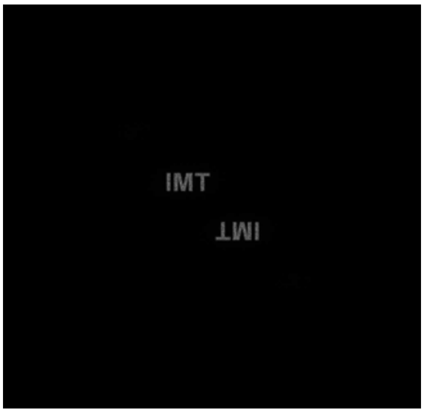

Fig. 3. The far-field image obtained by the reconstruction

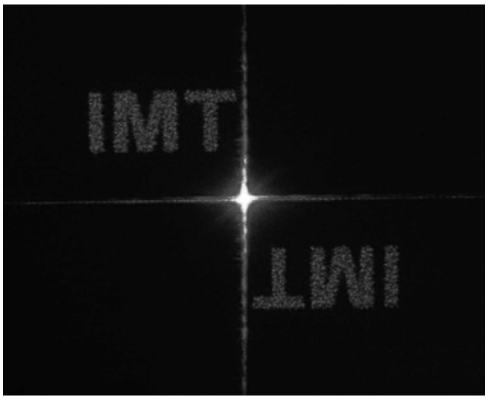

Fig. 4. The far-field image obtained with the configurable DOE

3.Fabrication

DOE has been fabricated using the electron beam lithography equipment Raith e-line. DOE has been obtained by direct writing in PMMA with the electron beam. The technological process is structured as follows: the first stage consists in

PMMA deposition by spinning. PMMA is a polymer with properties of positive electronresist (the irradiated zone are removed at the developing process). Further, PMMA layer is exposed to electron beam with distribution given by the DOE input file. After developing process one can obtain a height distribution. The fabricated DOE works in reflection so that it is necessary to have deposited a reflective layer (in this case we have deposited a thin layer of gold by sputtering). The fabrication process is represented in Fig. 5.

The PMMA layer thickness should be chosen so that the phase difference between “hills” and “valleys” is equal to π. In the case of the DOE working in reflection the height difference between “hills” and “valleys” is derived from the condition

$$\frac{2\pi}{\lambda}2d = \pi \tag{1}$$

where d represents the height difference between “hills” and “valleys” (in our case d is the PMMA layer thickness). From the above relation one can obtain that

$$d = \frac{\lambda}{4} \tag{2}$$

The PMMA layer thickness is almost 160 nm. The layer thickness is adjusted by modifying the spinning rotation speed (if the rotation speed increases, the thickness of the deposited layer by spinning decreases)..

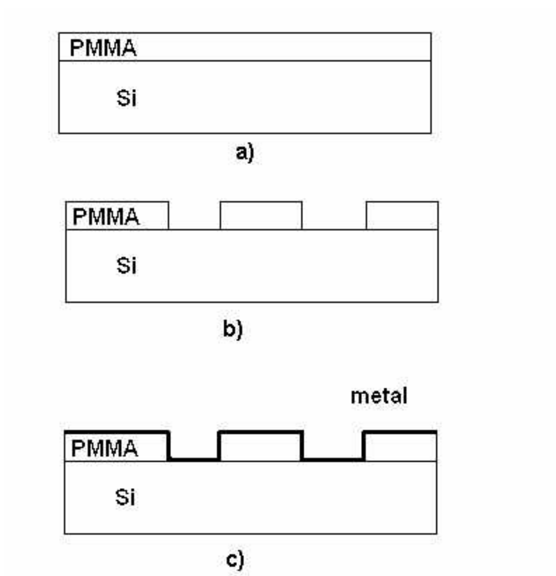

Fig. 5. Fabrication stages for DOE

a) Deposition of a thin layer of PMMA by spinning

b) Configuration of PMMA layer by electron beam lithography

c) Deposition of a thin layer of gold with as a reflective layer

4. Characterization

The fabricated DOE has been characterized. The set-up for characterization is represented in Fig. 6. Since DOE works in reflection mode, the far-field image is mirrored. That is why it is necessary to mount a mirrror in order to obtain the desired image. The mirror has also the role to remove the inversed image by an adequate positioning of the mirror. The central spot appears due to the transversal dimension of the laser beam which is larger than the DOE dimension. The far-field image is represented in Fig. 7.

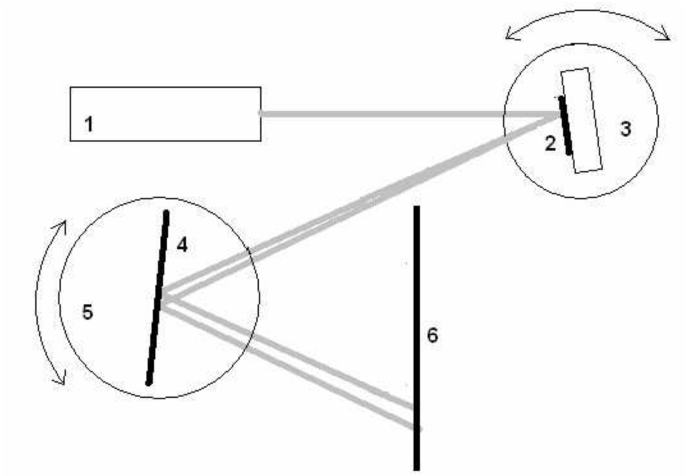

Fig. 6. The characterization set-up. 1) laser diode;
2) DOE; 3) rotative support for DOE; 4) mirror; 5) rotative support for mirror; 6) screen

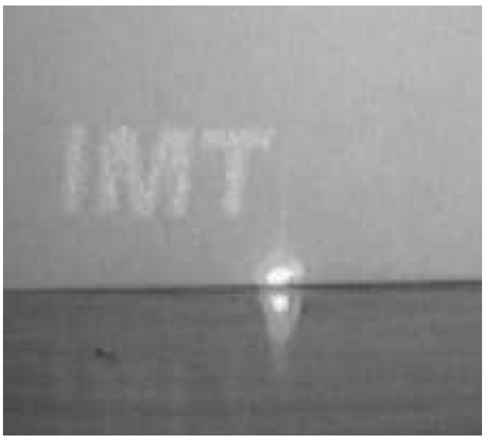

Fig. 7. The far-field image obtained with the fabricated DOE

Images of the fabricated DOE are represented in Fig. 8 and 9, respectively. In Fig. 8 is represented a general view of the fabricated DOE. This image has been obtained with an optical microscope. In Fig. 9 is represented a detailed image of DOE obtained with SEM. The pixels were designed with a high degree accuracy. The dark zones represent PMMA.

Fig. 8. Image of DOE obtained with an optical microscope

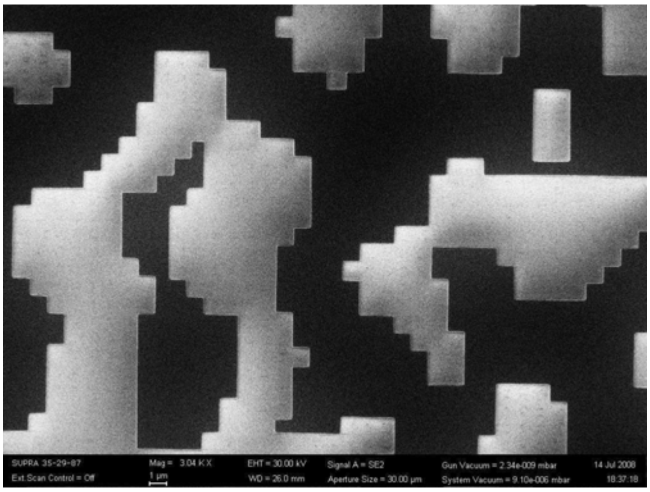

Fig. 9. Image of DOE obtained with SEM

5. Conclusions

In this paper we report realization at of a DOE with two levels, working in reflection which is able to reproduce in far-field the logo “IMT”, obtained with electron beam lithography. The fabrication of DOE using this technique represents a priority at the national level.

In order to design this complex DOE we have used the 3Lith software. Although this software allows the fabrication of the complex 3D structures, we have adapted the software capabilities for designing two-levels DOE which are more suitable for fabrication.

Even if the fabrication process for DOE using the electron beam lithography is time-consuming, the fabrication accuracy is much better than in the case of the optical lithography based processes. The use of the replication techniques reduces the production costs.

The results regarding DOE design and fabrication with electron beam lithography open the way for realization of DOEs with applications in various domains.

Acknowledgments

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