

# DIRECT LASER FABRICATION METHOD FOR A BINARY DIFFRACTIVE OPTICAL ELEMENT

Y.G. Kim<sup>1</sup>, H.G. Rhee<sup>1</sup>, Y.S. Ghim<sup>1</sup>, S.Y. Lee<sup>2</sup> and J.H. Lee<sup>2</sup>

<sup>1</sup>Department of Science of Measurement, University of Science and Technology, Daejeon 305-350, South Korea.

<sup>2</sup>Department of Optical Engineering, Kongju National University, Kongju 31080, South Korea.

Corresponding Author's Email: [1hrhee@kriss.re.kr](mailto:1hrhee@kriss.re.kr)

**Article History:** Received 11 April 2017; Revised 7 September 2017; Accepted 15 December 2017

**ABSTRACT:** Binary-type diffractive optics elements (DOEs) are essential components when measuring flow fields. In this paper, a fabrication process for binary-type DOEs was proposed based on direct laser lithography. Two important points must be considered while fabricating DOE. The first was the blurring effect of the lithographic source beam, and the second was the internal spacing issue of the DOE. An effective means of reducing the blurring effect by adjusting the lithography exposure time was suggested. In addition, a method to check the internal spacing was also presented in this paper. A binary-type DOE was successfully fabricated using the proposed process and its optical performance was verified in comparison with the simulation results.

**KEYWORDS:** *Binary Diffractive Optical Elements; Direct Laser Lithograph; Laser Writer; Schlieren Imaging Technique*

## 1.0 INTRODUCTION

Diffractive Optical Elements (DOEs) are widely used in many areas. A computer generated hologram lens is indispensable for aspheric surface measurements [1-2]. Holographic optical elements are key components of heads-up displays. DOEs are also used in mobile phone cameras to spread multi-point IR beam spots or patterns onto an object. These spots due to DOEs are used for the 3-D measuring of objects [3-4] and in the autofocusing function of the phone camera lenses [5-6]. Some DOEs can be used to enhance the contrast of a display by blocking outside light from coming into the display. Moreover, a binary type DOE has been applied to the Schlieren imaging technique [7-8] which is known to be an effective means of observation in a homogeneous medium with density variations in optical devices. Figure 1 shows the basic experimental setup of Schlieren imaging.

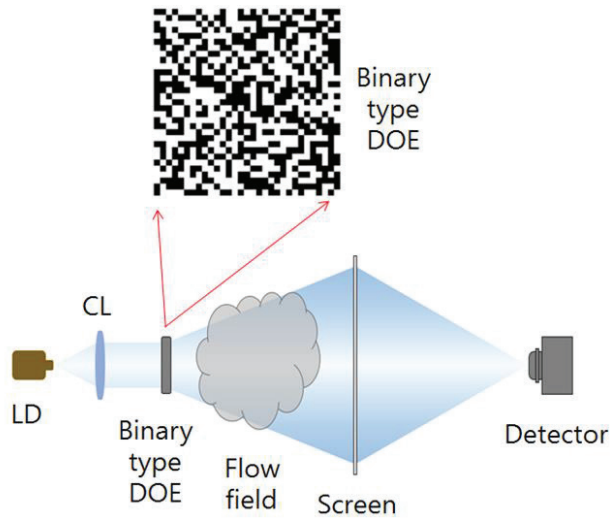


Figure 1: Typical configuration of Schlieren imaging, laser diode (LD) and collimator lens (CL)

In this figure, a DOE converts a point of light into a structured light that visualizes the density change of a flow field. A binary-type DOE, as shown in Figure 1, is designed using an iterative Fourier transform algorithm [9-10]. In this paper, an effective fabrication method for the DOE involving the use of a direct laser lithographic technique is proposed [11-16].

## 2.0 CONFIGURATION OF THE DIRECT LASER LITHOGRAPHIC SYSTEM

Our direct laser lithographic system consists of three major parts. The intensity of the laser light is stabilized at a level of 0.03% through the control of the laser power controller at the front part of the system [16]. The second part is composed of a device which functions as an autofocus system while automatically controlling the focal length of the objective lens by receiving a signal from a quadrant detector (QD) reflected from the surface of the specimen using a laser diode (LD). Third, the specimen is fixed and aligned on a precision stage and a tilt stage driven by an air-bearing linear motor on the X and Y axes. In addition, a shutter is inserted to control the exposure of laser beam from 0 V to 5 V transistor-transistor logic (TTL) signals shown in Figure 2.

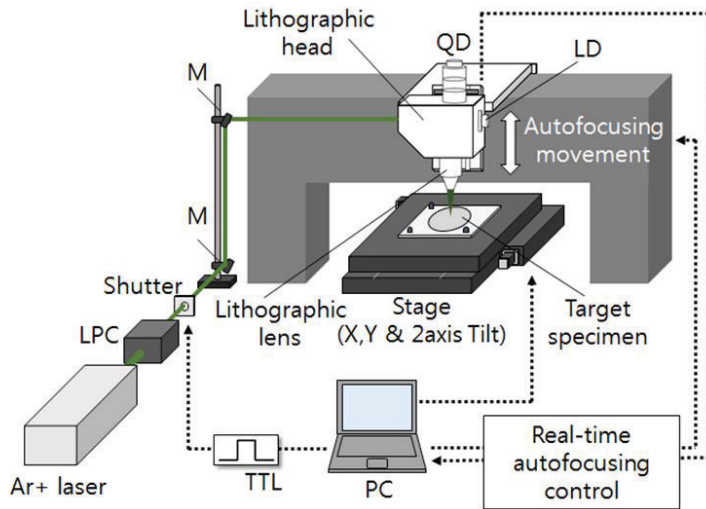


Figure 2: Schematic configuration of the proposed direct laser lithographic system, laser power controller (LPC), mirror (M), quadrant detector (QD) and LD

### 3.0 FABRICATION PROCESS

Most types of direct laser lithography are suitable for fabricating in a line-by-line manner. Fortunately, most DOEs consist of narrow lines. The binary diffractive optical elements, however, requires a rectangular pattern. To address this requirement, fabrication procedure is suggested as illustrated in Figure 3. Each patch of rectangular patterns is written by the raster motion of the XY-stage with the shutter open at the beginning position (the green circle in Figure 3) and closed at the end position (the red circle in Figure 3). The laser source beam passes through the objective lens while the shutter is opening. Otherwise, the beam is blocked. After finishing a rectangular patch, the stage moves to the next pattern.

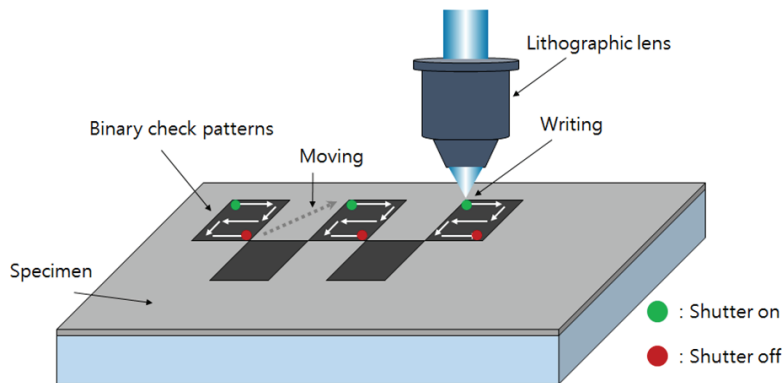


Figure 3: Fabrication mechanism for the binary-type check pattern

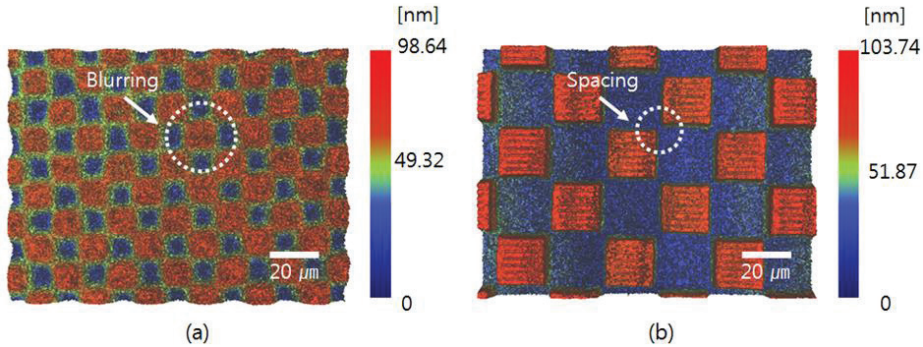


Figure 4: Three-dimensional measuring results of the (a) blurring effect and (b) the spacing between each pattern

There are two important points of view when creating a binary pattern. First, as shown in Figure 4 (a), the laser source beam often has a blurring effect because the beam exposure time increases at the corners of a rectangular patch. The stage should move more slowly at the corner than in other areas. These results are obtained using a commercial scanning type White-Light Interferometer (WLI) [17-18]. The second, as shown in Figure 4 (b), it is important to control the spaces between the patterns [19]. In this paper, the corners of the pattern blurred with various exposure times were tested and a process experiment to control the spaces between the patterns precisely was conducted. The lithographic beam had a line width and therefore, the writing position considering this width for a precise fitting of the size of the rectangular pattern was determined. The blurring effect of the pattern was also tested with various exposure times which were controlled by the shutter operation with a 0 V to 5 V external TTL signals, as shown in Figure 5. The blurring effect was gradually reduced as the exposure time of the laser source beam decreased from 20 s to 0.02 s. The shutter used was a Thorlab SC10 model with a resolution of 1 ms and accuracy of 0.2 ms.

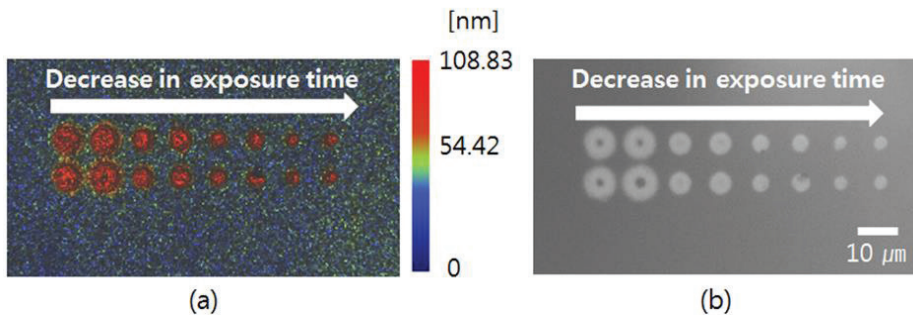


Figure 5: Experimental result of the blurring effect according to the exposure time; (a) 3D image of the fabrication result obtained by a scanning-type WLI, and (b) its photographic view

Figure 6 shows a series of rectangular patterns with different exposure times of 20, 2, and 0.02 s. As a result, it was possible to produce a fine rectangular pattern that minimized the blurring effect. As noted above, it is important to ensure accuracy of the spaces between the patterns. The experimental setup devised here is shown in Figure 7 to verify whether the distances among the patterns were acceptable or not considering the DOE. Figures 7 (a') and (b') demonstrate that the pattern was formed while exposing check patterns in a side-by-side arrangement. The fabricated DOE was irradiated with a He-Ne laser to confirm the diffracted pattern on the screen. Figure 7 (b) shows that unwanted diffraction lines are formed on the screen due to the incorrect spacing of the DOE patterns, as shown in Figure 7 (b'). However, these unwanted diffraction lines disappear when the DOE has the proper spacing, as shown in Figures. 7 (a) and (a'). In order to fabricate the DOE used in the Schlieren image, rectangular patches were fabricated with a 5  $\mu\text{m}$  linewidth using direct laser lithography method. A 25% of the linewidth was overlapped to determine the spacing of each rectangular patch. Based on this experiment, the process conditions to use when fabricating the binary-type DOE were determined.

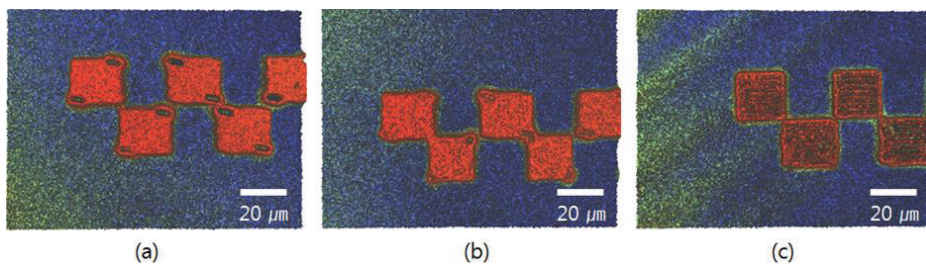


Figure 6: Fabrication results of binary patterns with different exposure times of (a) 20 s, (b) 2 s and (c) 0.02 s

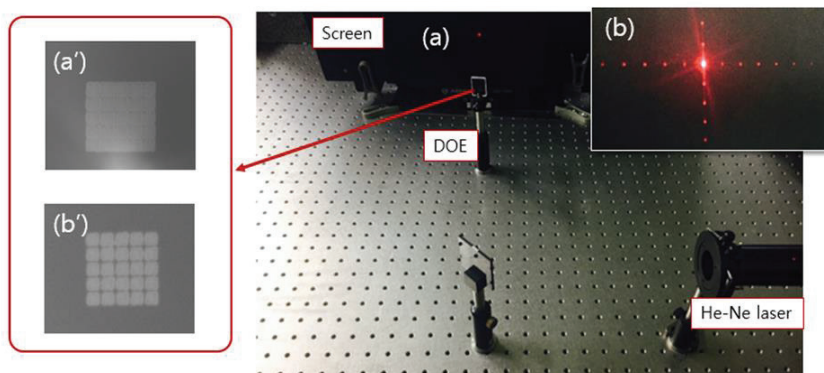


Figure 7: Experimental setup to verify the spaces between the patterns; (a) Diffractional image is formed on the screen due to (a') the proper spacing of the DOE patterns, (b) unwanted diffraction image due to (b') the incorrect spacing of the DOE patterns



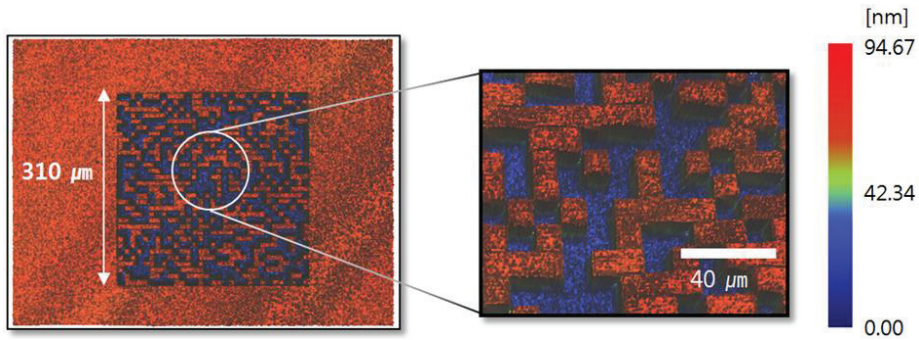


Figure 8: Measurement result of the binary-type DOE as required by Schlieren imaging

#### 4.0 BINARY-TYPE DOE FABRICATION AND VERIFICATION

Using the process conditions described above, the binary diffractive optical element required in the Schlieren image was fabricated. Figure 8 shows the result of the fabrication process. Each rectangular patch had a size of  $10\ \mu\text{m} \times 10\ \mu\text{m}$ , and the total size of the DOE was  $310\ \mu\text{m} \times 310\ \mu\text{m}$ . In order to verify the fabrication results, the image diffracted by the DOE was obtained in the experimental setup shown in Figure 7. Figure 9 (c) shows a diffracted image formed on the screen by irradiating the He-Ne laser onto the DOE. It should be noted that there were no unwanted diffractive lines or pattern blurring. This result appears similar to the simulated image (desired image), as displayed in Figure 9 (b).

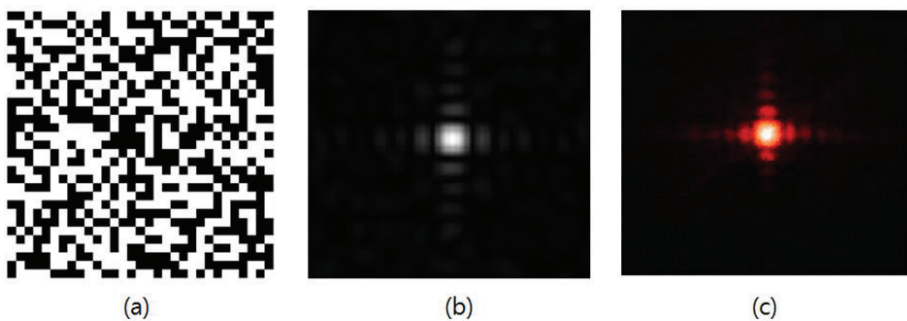


Figure 9: Comparison between the simulation and experimental results; (a) the binary-type DOEs fabricate here, (b) its simulated diffraction image estimated using the Fast Fourier Transform and (c) the experimentally obtained diffraction image

## 5.0 CONCLUSION

In conclusion, an effective means of fabricating a binary-type DOEs is through a direct laser lithographic system. The DOE is used to measure a flow field by the Schlieren imaging technique. To fabricate the DOE, two key parameters are tested; the exposure time and the internal spacing of the DOE. By adjusting the exposure time according to the position of each rectangular patch, the blurring effect is successfully removed. In addition, the internal space also disappears. Overall, the binary diffractive optical element is fabricated using the proposed process and its optical performance is verified through a comparison with simulation results.

## REFERENCES

- [1] H. J. Tiziani, S. Reichelt, C. Pruss, M. Rocktaeschel and U. Hofbauer, "Testing of aspheric surfaces," in *Proceeding of SPIE*, vol. 4440, pp. 109-119, 2001.
- [2] J. M. Asfour and A. G. Poleshchuk, "Asphere testing with a Fizeau interferometer based on a combined computer-generated hologram," *Journal of Optical Society of America A*, vol. 23, no.1, pp. 172-178, 2006.
- [3] A. Shpunt and B. Pesach, "Optical pattern projection," US Patent, US 2010/0284082 A1, 2010.
- [4] B. Pesach and Z. Mor, "Projectors of structured light," US Patent, US 8,749,796 B2, 2014.
- [5] D. K. Cohen, W. H. Gee, M. Ludeke and J. Lewkowicz, "Automatic focus control: the astigmatic lens approach," *Applied Optics*, vol. 23, no. 4, pp. 565-570, 1984.
- [6] H. G. Rhee, D. I. Kim and Y. W. Lee, "Realization and performance evaluation of high speed autofocusing for direct laser lithography," *Review of Scientific Instrumentals*, vol. 80, no. 7, pp. 073103/1-073103/5, 2009.
- [7] M. Bruchhausen, F. Guillard and F. Lemoine, "Instantaneous measurement of two-dimensional temperature distributions by means of two-color planar laser induced fluorescence." *Experiments in Fluids*, vol. 38, no. 1, pp.123-131, 2005.
- [8] J. J. Kim and D. Y. Kim, "Implementation of Image-based Virtual Fence for Surveillance Area Setup", *Journal of the Korea Institute of Information and Communication Engineering*, vol. 19, no. 9, pp. 2145-2152, 2015.
- [9] V. V. Kotlyar, P. G. Seraphimovich and V. A. Soifer, "An iterative algorithm for designing diffractive optical elements with regularization", *Optics Lasers in Engineering*, vol. 29, no. 4, pp. 261-268, 1998.

- [10] H. Kim, B. Yang, J. Park and B. Lee, "A study on the Convergence of Iterative Fourier Transform Algorithm for Optimal Design of Diffractive Optical Elements," *Journal of the Institute of Electronics Engineers of Korea SD*, vol. 40, no.5, pp.298-311, 2003.
- [11] M. Haruna, M. Takahashi, K. Wakahayashi and H. Nishihara, "Laser beam lithographed micro-Fresnel lenses," *Applied Optics*, vol. 29, no. 34 pp. 5120-5126, 1990.
- [12] M. T. Gale, M. Rossi, J. Pedersen and H. Schutz, "Fabrication of continuous-relief micro-optical elements by direct laser writing in photoresists," *Optical Engineering*, vol. 33, no. 11, pp. 3556-3567, 1994.
- [13] A. G. Poleshchuk, E. G. Churin, V. P. Koronkevich, V. P. Korolkov, A. A. Kharussov, V. V. Cherkashin, V. P. Kiryanov, A. V. Kiryanov, S. A. Kokarev and A. G. Verhoglyad, "Polar coordinate laser pattern generator for fabrication of diffractive optical elements with arbitrary structure," *Applied Optics*, vol. 38, no. 8, pp. 1295-1301, 1999.
- [14] H.G. Rhee and Y.W. Lee, "Improvement of linewidth in laser beam lithographed computer generated hologram," *Optics Express*, vol. 18, no. 2, pp. 1734-1740, 2010.
- [15] L. Deck and P. de Groot, "High-speed noncontact profiler based on scanning white-light interferometer," *Applied Optics*, vol. 33, no. 31, pp. 7334-7338, 1994.
- [16] Y. Xie, Z. Lu and F. Li, "Lithographic fabrication of large curved hologram by laser writer," *Optics Express*, vol. 12, no. 9, pp. 1810-1814, 2004.
- [17] A. Harasaki, J. Schmit and J. C. Wyant, "Improved vertical-scanning interferometry," *Applied Optics*, vol. 39, no. 13, pp. 2107-2115, 2000.