The fabrication and characterization of asymmetric gratings using the optical Talbot effect

T Photia[1], M Medhisuwakul[2], W Temnuch[1], S Srisuphaphon[3], and S Deachapunya[3,*]

[1]Department of Physics, Faculty of Science, Kasetsart University, Bangkok Province, 10900, Thailand

[2]Kamnoetvidya Science Academy, Rayong Province, 21210, Thailand

[3]Department of Physics, Faculty of Science, Burapha University, ChonBuri Province, 20131, Thailand

[*]E-mail: sarayut@buu.ac.th

Abstract. We fabricate asymmetric gratings, which have the ratio between the opening window and period or the opening fraction, f<0.5. The gratings were fabricated by using CNC milling machine to engrave a pattern on transparent acrylic sheets. The characterization of the gratings was performed with the optical Talbot effect. The results of the Talbot pattern, as well as the intensity along the longitudinal distance, can apparently identify the opening window and grating period. The grating with the opening window of 23 μm, period of 100 μm, and thus the opening fraction of 0.23 can be obtained with our method. This type of grating can be used in many practical applications such as optical spectroscopy.

1. Introduction

A binary grating is frequently used in diffraction experiments. In optics, the grating is divided into two regimes, i.e. the transmission and reflection to be used in a variety of experiments. For example, the design of binary gratings with high efficiencies can be done with coupled-wave analysis [1]. An analysis of a complete snapshot polarimeter based on a polarization diffraction grating (PDGr) is presented [2]. The binary grating is used with various experiments for several fields, such as ultrasonic wave [3], electrons [4, 5, 6] and molecules [7, 8].

The Talbot effect is a near-field diffraction effect. It was observed by Henry Fox Talbot in 1836 [9, 10]. The effect can be observed when a plane wave propagates through a periodic diffraction grating. The so-called self-imaging can be appeared at regular distance away from the grating plane. This distance is called the Talbot length. The Talbot effect is not complicated to perform and can be set by a small amount of optical elements. Therefore it is used in many researches in light diffractions such as for generating 1-D and 2-D optical lattices [11], study the transverse shift inside a double-grating Talbot interferometer [12], realization of the optical carpets [13]. The sum of intensity of the Talbot as well as fractional Talbot patterns along the longitudinal distance has been measured for locating the Talbot length precisely [14]. Among all these studies, the binary gratings have been used in their experiments. However, asymmetric gratings, which have the ratio between the opening window and period or the opening fraction, f<0.5 provide higher visibility of the Talbot pattern than the one with the binary grating. In this paper, we present the fabrication of asymmetric gratings using CNC milling machine and the characterization using the optical Talbot effect.

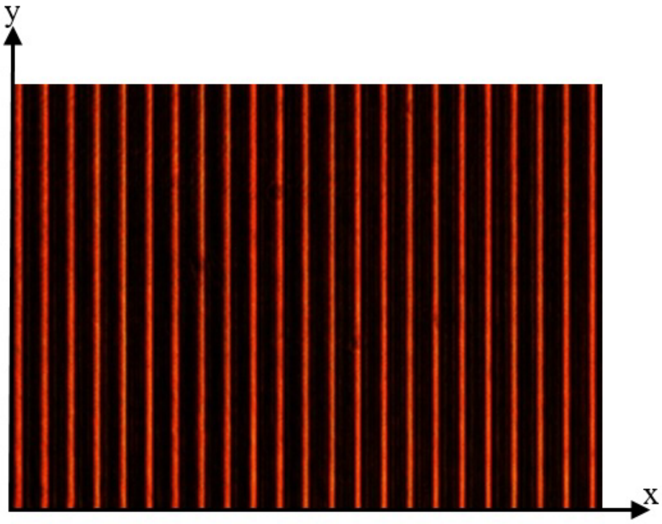

Figure 1. Interference pattern at $z = 8L_T$. The pattern shows that our grating has the opening window of 23 μm (the width of the bright stripes), period of 100 μm (the period of the pattern), and thus the opening fraction of 0.23.

2. Method and experiment

Our gratings were fabricated by making engraving patterns on the surface of clear acrylic sheets. SCM440 high-carbon steel was machined to a 3-mm diameter with its tip sharpened. It was then attached to a home-made spring loaded holder for the HAAS TM1P CNC milling machine. The patterns were designed by using Solidwork&Solidcam software. For our typical Talbot experiment, a home-made tunable diode laser (λ =780nm) is used as a coherent source for generating the interference pattern when the beam is passing through the grating. The laser source is normally expanded by an optical telescope (GBE15-B, Thorlabs) to a diameter of about 45 mm in order to cover the whole grating. The grating is placed on a motorized translation stage (MTS50/M-Z8, Thorlabs) for the longitudinal scan. In our present setup, we use a CCD (DCU223C, Thorlabs) for the detection of the interference patterns, and subsequently the intensity is integrated along the longitudinal direction (z) with four pixels in the center of the CCD camera to be able to start within the center of a bright fringe. The interference images were recorded for the overall distance (z) of 16.50 mm with the step of 0.05 mm. After that we can calculate the opening window and period of grating from the interference image at multiples of the Talbot length which can also be located by considering from the intensity scan [14]. This method to identify the Talbot length as well as the multiples of it with the intensity scan along the longitudinal distance (z) is described elsewhere [14]. We conclude here that the intensity along z direction at the center of the screen ($x = x_1$) is given by

$$I(x = x_1, z) = \sum_{n,m} A_n A_m \exp(i\frac{2\pi(n-m)}{d}x_1 - i\frac{(n^2-m^2)\pi}{L_T}z), \tag{1}$$

where n and m are an integer number, $A_n = \sin(n\pi f)/n\pi$ and $A_m = \sin(m\pi f)/m\pi$ are the components of the Fourier decomposition along the transverse x axis for the diffraction element with an opening fraction f, $L_T = \frac{d^2}{\lambda}$ is the Talbot length, and d is the grating period [10].

3. Results and discussions

Figure 1 is the interfernce pattern at $z = 8L_T = 102.6$ mm of one of our gratings. The pattern shows the self-imaging which is corresponded to the opening window of 23 μm, period of 100 μm, and thus the opening fraction of $f = 0.23$. This pattern is used to confirm the location of the Talbot length, opening window and period of the grating. Figure 2 represents the result of the grating as shown in Fig. 1. It shows the intensity scan as a function of the longitudinal distance (z) behind the grating. The arrows indicate two successive talbot distances, $z = 8L_T$, and $9L_T$. Theoretical simulation of wavelength λ =780 nm according to Eq.(1) is presented with the truncated sum at $n, m = \pm 25$ for the grating with the period $d = 100$ μm, and with the opening fraction, $f = 0.23$. The slight mismatch between the experiment and theory is possibly due to the imperfect alignment between the grating and CCD camera and noises from the images as well as the vibration of the motorized translation stage motion. Nevertheless, the information can adequately provide to extract the Talbot length.

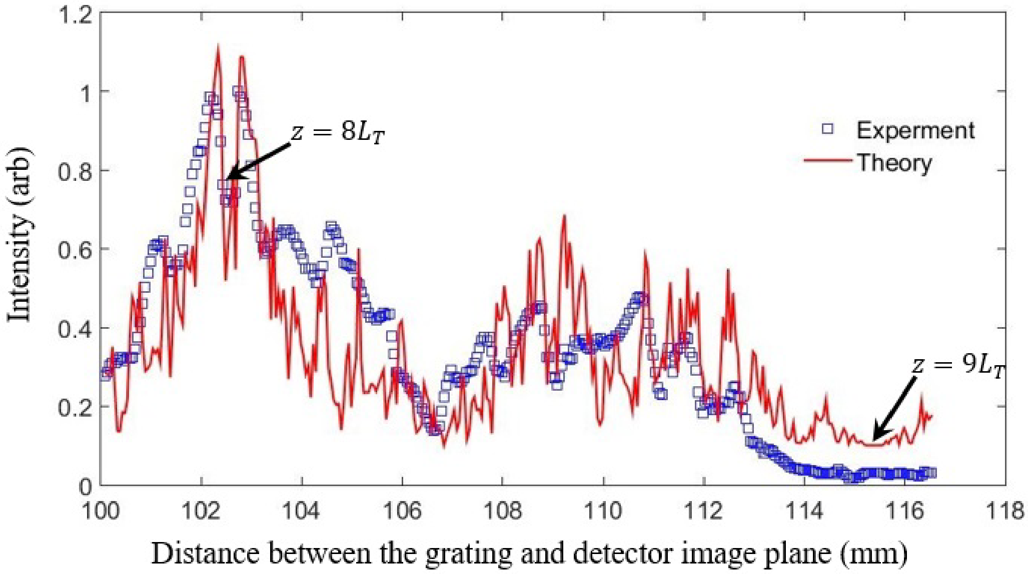

Figure 2. Intensity scan as a function of the longitudinal distance (z) behind the grating. The arrows indicate two successive talbot distances, $z = 8L_T$, and $9L_T$. Theoretical simulation of light wavelength λ =780 nm according to Eq.(1) for the grating with the period $d = 100$ μm, and with the opening fraction, $f = 0.23$ at the center of the screen or a bright fringe ($x = x_1 = 0$).

4. Conclusions

We introduce a simple method to produce and characterize asymmetric gratings. The fabrication can be done in a machine workshop. The characterization of the opening fraction of gratings is possible only with the Talbot effect since it provides the self-imaging of the grating itself. This type of grating can be used in many practical applications such as optical spectroscopy [15].

Acknowledgments

SD gratefully acknowledges the support from National Research Council of Thailand (224/2561) and Faculty of Science, Burapha University (21/2560), and the technical supports of the laser with Dr. Waranont Anukool. MM acknowledges the great work of grating fabrication with Mr. Sarun Nounjeen.

References

[1] Farn M W 1992 *Appl. Opt.* **31** 4453

[2] Cofré A, Vargas A, Torres-Ruiz F A, Campos J, Lizana A, Sánchez-López M and Moreno I 2017 *Opt. Laser. Technol.* **96** 219

[3] Greenwood M S 2018 *Ultrasonics* **84** 134

[4] Kawata Y, Aoki K, Inada Y, Yamao T and Hotta S 2018 *Jpn. J. Appl. Phys.* **57** 03EH11

[5] Liu W, Lu Y, Wang L and Jia Q 2017 *Phys. Plasmas.* **24** 023109

[6] Kumar P, Bhasin L, Tripathi V K, Kumar A and Kumar M 2016 *Phys. Plasmas.* **23** 093301

[7] Deachapunya S, Stefanov A, Berninger M, Ulbricht H, Reiger E, Doltsinis N L and Arndt M 2007 *J. Chem. Phys.* **126** 164304

[8] Juffmann T, Truppe S, Geyer P, Major A G, Deachapunya S, Ulbricht H and Arndt M 2009 *Phys. Rev. Lett.* **103** 263601

[9] Talbot H F 1836 *Phi. Mag. Ser.* **9** 401

[10] Case W B, Tomandl M, Deachapunya S and Arndt M 2009 *Opt. Express* **17** 20966.

[11] Deachapunya S and Srisuphaphon S 2014 *Chin. Opt. Lett.* **12** 031101

[12] Deachapunya S and Srisuphaphon S 2014 *Measurement* **58** 1

[13] Berry M, Marzoli I and Schleich W 2001 *Phys. World* **14** 1

[14] Photia T, Panthong P, Srisuphaphon S, Chiangga S and Deachapunya S 2016 The 5th Burapha University International Conference 126

[15] Sutham W, Srisuphaphon S, Wongrach K and Deachapunya S 2017 *J. Phys.: Conf. Ser.* **901** 012103