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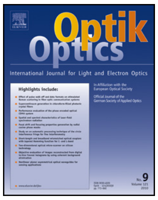

Original research article

Experimental study for size-controllable self-imaging of grating

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ABSTRACT

Size-controllable Talbot images are generated using a proposed optical system combining a lens and a curved grating. A practical experiment is performed and magnified, identified and compressed images of grating are measured. Theoretical analysis explains the mechanisms of size-controllable Talbot imaging and simulation calculations confirm the corresponding predictions. This study is helpful for the wide applications of Talbot imaging of grating.

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1. Introduction

The Talbot effect is a well-known self-imaging phenomenon of grating in optic science [1,2]. It becomes a popular research topic and attracts the attention in many fields including X-ray diffraction [3], quantum revival [4,5], electron imaging [6] and nonlinear effects [7,8]. Furthermore, the Talbot effect has been applied in many aspects, such as optical metrology [9], Talbot array illuminator [10,11], multiplying-pulse repetition rates [12,13] and quantum lithography [14,15]. We know that when a grating with period d is illuminated by a monochromatic light with wavelength λ, exact image of grating generate at integral Talbot distances $z_N = z_t$ with N an integer and $z_t = 2d^2/\lambda$, and compressed images form at fractional Talbot distances $z_N = mz_t/n$ with m and n co-prime numbers [16–18]. Yet, magnified images appear under specific settings using divergent source [9,19,20] or curved grating [21]. According to our knowledge, the magnified and compressed images of a grating have never been simultaneously observed in one experimentally optical system.

In our formal work [22], we study theoretically Fresnel diffraction of curved fractal grating and predict that the self-image of grating is size-controllable. In this paper, we concentrate on the experimental study about size-controllable self-imaging of grating. In practical experiment, we bend the soft grating along one direction to form the curved grating and obtain simultaneously the magnified and compressed images with the help of the lens. Theoretical analysis for Talbot imaging of grating gives the explanation and the simulation calculations show the variation of the Talbot image with the curvature of the grating and focal length of the lens as well as the propagation distance. The work of this paper verifies the comprehensive controllability of the size of the Talbot image, and this significant advantage must be benefit to the flexible applications of Talbot effect of grating in optical connections and optical integration.

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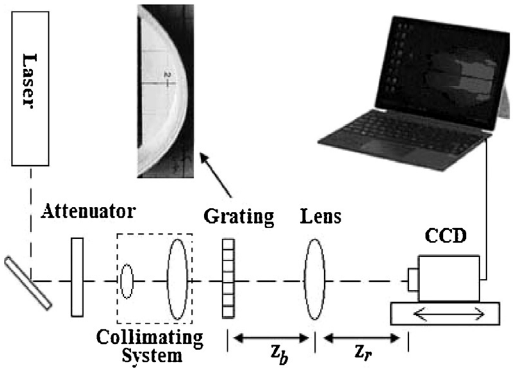

Fig. 1. Schematic diagram of the experimental setup for measuring size-controllable images of grating.

2. Experiment measurement

The flexible acquirement of size-controllable imaging of periodic grating is necessary in the information processing. Here, we perform the experimental verification to obtain the size-controllable images of grating using a simple optical system consisting of a curved grating and a lens. Fig. 1 shows the schematic diagram of the experimental setup. A light beam from the laser source at $\lambda = 0.532\ \mu$m passes through two collimating lenses and turns in to parallel light, and then impinges onto a grating. A lens at $f = 60$ mm is placed at distance z_b behind the grating, and a charge-coupled device (CCD) camera with No. DU888 receives the diffraction intensity at distance z_r behind the lens. The CCD camera is set on a moving platform with an accuracy of 1 nm so as to shift flexibly. An attenuator is used to control the intensity. The curved grating is implemented by inserting a straight grating into the groove of the parabolic cylinder with focal length $p = 50$ mm, where a periodic copper net with the period $d = 100\ \mu$m is selected as a straight grating and it is bent along one periodic direction of grating.

For convenience comparison, the first step of the experiment is to place a straight grating in the optical path without the lens to record the Talbot image of the grating, as shown in Fig. 2(a), and the exact image of grating is recorded by the CCD camera at second Talbot distance $z_2 = 2d^2/\lambda = 75.2$ mm. The period of the measured diffraction distribution just equals to the grating period of 100 μm.The second step is to place the lens at $z_b = 55$ mm behind the grating, and Fig. 2(b) and (c) show the intensity distributions recorded by CCD camera placed at $z_r = 15.1$ mm and 29.4 mm, respectively. The periods of the measured diffraction distributions are 74.5 μm and 50.8 μm and they are smaller than the period of grating. These results show that the period of diffraction distribution decreases with the increase of the propagation distance and only the compressed Talbot images of the grating can be obtained using the lens.

Fig. 2(d) shows the diffraction pattern when the grating is bended along the parabolic cylinder with focal length $p = 50$ mm and the cylinder axis is long vertical direction, where the lens is still set at $z_b = 55$ mm and the CCD is also at $z_r = 29.4$ mm. With comparison with Fig. 2(c), the period and the duty ratio of the fringes in Fig. 2(d) are unchangeable along the horizontal direction but increase along the vertical direction though the positions of the lens and the CCD are the same as that of Fig. 2(c). The compressed image of the grating appear along the horizontal diffraction, but the unequal duty ratio along the vertical diffraction means the diffraction intensity distribution is not an image of the grating because of different duty ratio. Fig. 2(e) shows the recorded diffraction pattern at $z_r = 37.0$ mm. At this distance, the duty ratios of the fringes in two directions are the same as that of the grating. Comparing with Fig. 2(a), we can see that this is the image of grating, and the horizontal distribution shown in Fig. 4(e) is a compressed Talbot image of the grating and the vertical distribution is a magnified Talbot image of the grating. Shifting the CCD, Fig. 2(f) shows the diffraction pattern recorded at $z_r = 84.9$ mm. It can be seen that the duty ratio of the fringes in the vertical direction is the same as that of the grating, and this distribution is the compressed image of the grating. In contrast, the duty ratio of the fringes is different from that of the grating, and the fringe structure in the horizontal direction is not a grating image. The reason for the results of Fig. 2(e) and (f) is that the grating sample is bent only in one direction. For explanation of these experiment results, we provide the theoretical analysis in the following content.

3. Theoretical analysis

The experiment setup shown in Fig. 1 can be simplified by a schematic diagram of the optical system shown in Fig.3. This optical system includes three components, namely, a curved grating, a lens, and a monitor screen.

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