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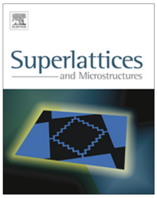

Optical induction of non-diffracting discrete photonic lattice

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ABSTRACT

The triangle lattices was optically induced in an externally biased cerium doped strontium barium niobate (SBN) photorefractive crystal using a mask with three holes or six holes, respectively. Numerically, the transmittance function of the amplitude mask and its Fourier-transform function were given out instead of treating each hole as a simple point source. Experimentally, the differences between the two lattices were analyze by phase distribution, far-field diffraction pattern, Brillouin-zone spectroscopy. And the three-dimensional (3D) images by computer simulation are also used to study their differences. In addition, the anisotropy lattices are presented by designing the amplitude mask properly.

1. Introduction

Nonlinear periodic structures have recently become an active area of research due to many exciting possibilities of controlling wave propagation, manipulating and trapping [1,2]. Many interesting phenomena and applications in the materials with periodic refractive index modulations, such as discrete solitons and discrete diffraction, have been found [2–9].

The fabrication of photonic lattices is also of great interests. Thus far, some techniques have been proposed and developed for making periodic optical microstructures, such as self-assembly, two-photon absorption, colloidal crystallization and holographic lithography [10–15]. Recent years, the optical induction technology [3–6], was reported and has drawn much attention. The technique relies

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on the interference of several monochromatic light beams, whereby the resulting intensity pattern is translated into a periodic change in the refractive index of a photorefractive material. Although the refractive index modulation in photorefractive material is low (10^{-4}–10^{-3}), the existence of photonic spatial band gaps in these materials has been demonstrated which enables to realize the nonlinear optical phenomena in discrete lattice systems [2–9]. Conventional multiple beams interference is implemented by a complicated optical setup. In [15], Matoba et al. fabricated 2D waveguide arrays using the Mach–Zehnder configuration with piezoelectric translator. In [6], Zhang et al. fabricated 3D photonic lattices using superposition of a pair of 2D photonic lattices by two amplitude masks. The optical setups of their experiments are very complex. In 2001, Kondo et al. proposed a method to generate multi-beam interference with a single setup based on a diffractive beam splitter (DBS) [12]. It is a significative accomplishment. However, in this way, multi-beam interference must rely on a special and more expensive device. We proposed a simple experimental method to generate multi-beam interference using an amplitude mask with holes [16–21] instead of DBS. This method is inexpensive. But in all those letters, each little hole on the amplitude mask is seen as a point light source. We know the hole diameter should be much smaller than the wavelength, in order for the point source model to be valid. So the point light source is not valid for the actual value of the diameter of each hole (0.8 mm). In this letter, we use the circle function to describe light distribution of the hole, and give out the precise express of the light distributions after the amplitude mask and its Fourier-transform express. In addition, we optically induced the triangle lattices in an externally biased cerium doped strontium barium niobate (SBN) photorefractive crystal use a mask with three holes or six holes, separately. And analyze their differences by far-field diffraction pattern, Brillouin-zone spectroscopy, phase distribution and a three-dimensional (3D) image distribution. In addition, this method can be easily extended to generate more complex photonic lattices microstructures, such as anisotropy lattices, by designing the amplitude mask properly.

2. Theory

The schematic of optical Fourier transformation method is given in Fig. 1(a). An amplitude mask with six holes is placed in the front focal plane of the Fourier transform lens. When a broad plane wave illuminates onto the mask, the transmittance function of each hole in the amplitude mask can be seen as circle function. The distance between adjacent holes is 'a'. As such, the light field distribution (U_1) after these six holes in the x'–y' plane can be described by the convolution of the following six combined δ functions with a circle function:

$$\begin{aligned}U_1(x',y') = \Big[&\delta(x'-a/2,y'-\sqrt{3}a/2)+\delta(x'-a,y')+\delta(x'-a/2,y'+\sqrt{3}a/2)+\delta(x'+a/2,y'+\sqrt{3}a/2)\\&+\delta(x'+a,y')+\delta(x'+a/2,y'-\sqrt{3}a/2)\Big]\otimes \mathrm{circ}\left(\sqrt{x'^2+y'^2}/\omega\right)\end{aligned} \tag{1}$$

where ω is the radius of little holes, $\otimes$ is the symbol of convolution and circ is circle function. After passing through a Fourier-transform lens, the resulting field distribution (ψ_1) in the focal plane (x–y plane) behind the lens is described by

$$\psi_1(x,y) = \left[2\cos(2\pi ay/\lambda f)+4\cos(\pi ax/\lambda f)\cos(\sqrt{3}\pi ay/\lambda f)\right] \times \left[\lambda f\omega J_1(2\pi\omega\sqrt{x^2+y^2}/\lambda f)/\sqrt{x^2+y^2}\right] \tag{2}$$

In this equation, J_1 is the first-order Bessel function and f is the focal length of the Fourier-transform lens.

We block three holes of the six holes, as shown in the insets of Fig. 1(b) and (f). Due to the distance between adjacent holes of the six holes is 'a', the distance between adjacent holes of the three holes (see inset of Fig. 1(f)) is '$\sqrt{3}a$'. As such, the light field distribution (U_2) after these three holes in the x'–y' plane can be described by the convolution of the following three combined δ functions with a circle function:

$$U_2(x',y') = \left[\delta(x'-a/2,y'-\sqrt{3}a/2)+\delta(x'-a/2,y'+\sqrt{3}a/2)+\delta(x'+a,y')\right]\otimes \mathrm{circ}(\sqrt{x'^2+y'^2}/\omega) \tag{3}$$