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Fabrication of large area two-dimensional nonlinear photonic lattices using improved Michelson interferometer

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ABSTRACT

We demonstrate an approach for easy fabrication of large area two-dimensional nonlinear photonic lattices in photorefractive crystal using the laser interference technique with an improved Michelson interferometer. The experimental setup of this method is relatively simple and inexpensive. It can be applied in almost any optical laboratories. Large area (about 28.2 mm^2) two-dimensional square nonlinear photonic lattices have been produced in an iron-doped lithium niobate photorefractive crystal. We analyze the induced nonlinear photonic lattices by plane wave guiding, Brillouin-zone spectroscopy and far field diffraction pattern imaging. The period of the induced photonic lattices can be dominated easily. The induced photonic lattices can exist stably for a long time in the photorefractive crystal.

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]. People find many interesting phenomena and applications in the materials with periodic refractive index modulations, such as discrete solitons and discrete diffraction [3–6]. Photonic lattices are periodic optical microstructures that are designed to affect the motion of photons in a similar way that periodicity of a semiconductor crystal affects the motion of electrons. Photonic lattices offer new possibilities to route, control, and steer light in all-optical information processing and nano-photonics devices. The fabrication of photonic lattices has always been of great interest. Thus far, some sophisticated techniques have been proposed and developed for making periodic optical microstructures, such as colloidal crystallization, two-photon polymerization and holographic lithography [7–10]. However, it has been a challenge to fabricate large-area periodic optical microstructures in bulk media.

The optical induction technique is a more convenient way for fabrication of photonic lattices [3–5]. Photonic lattices can be optically induced in photorefractive crystals utilizing the interference of several monochromatic light beams. The periodicity of the induced lattices can be controlled by the interference angle whereas the modulation depth depends on exposure time and the intensity of the interfering waves. The photonic lattices can be induced optically in photorefractive material at very low power levels employing their anisotropic electro-optic properties. 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 a wealth of nonlinear optical phenomena in discrete lattice systems [3–6,11,12]. Iron-doped lithium niobate ($LiNbO_3$:Fe) crystal is a self-defocusing photorefractive material where the light induces a negative refractive index change with the order of 10^{-4}–10^{-3} [13,14]. This index change is sufficient to create the photonic lattices which can be kept for a few months in the dark room [15–17].

In 2007, Zhu et al. proposed a method to fabricate the two-dimensional nonlinear photonic lattices in photorefractive material [18]. They called it a Fourier-transform method. They generate multi-beam interference by amplitude mask and Fourier transform lens. It is a significative accomplishment. However, in this way, the diameter of interference beams is very small, so the area of induced two-dimensional photonic lattices is very small (about 0.25 mm^2). It limits the application of the nonlinear photonic lattices in integrated optics and micro-/nano-photonics. Therefore, fabrication of large area two-dimensional photonic lattices is still the focus of research. In this paper, we report on experimental fabrication of large area two-dimensional nonlinear photonic lattices in $LiNbO_3$:Fe photorefractive crystal using laser interference with an improved Michelson interferometer device. The experimental setup of this method is relatively simple and inexpensive. It can be applied in almost any optical laboratory. The area of induced two-dimensional nonlinear photonic lattices

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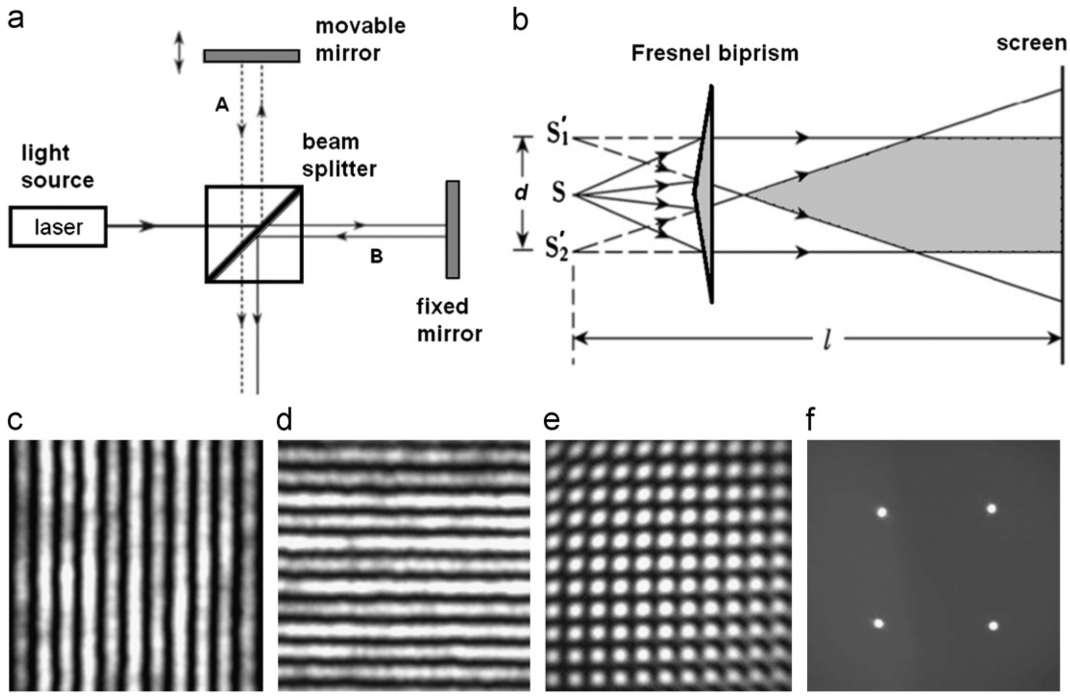

Fig. 1. (a) The schematic drawing of Michelson interferometer. (b) The schematic drawing of Fresnel biprism. S is a point light source and S_1', S_2' are the virtual images. (c) The two-beam interference fringes produced by Fresnel biprism. (d) The two-beam interference fringes produced by Michelson interferometer. (e) The intensity pattern of the two-dimensional square lattice wave which is produced by cascaded Fresnel biprism and Michelson interferometer. (f) Picture is the image of the Fourier spectrum pattern of output optical field.

in the crystal is about 28.2 mm^2. The induced photonic lattices have long dark storage time, so they can exist stably for a long time in $LiNbO_3$:Fe crystal. The period of the induced photonic lattices can be dominated easily. Moreover, the method we employed is not limited to this kind of photorefractive material.

2. Experimental methods

As is known to all, the beam division method in laser interference can be divided into wave-front division and amplitude division. Michelson interferometer is a double-beam amplitude division interference device and Fresnel biprism is a wave-front division interference device, as shown in Fig. 1(a) and (b). Both of them can produce bright and dark stripes alternating with each other and the spacing of stripes can be dominated easily. In our experiment, we improve Michelson interferometer by adding a Fresnel biprism before it. The interference fringes along the vertical direction produced by Fresnel biprism which are perpendicular to the interference fringes of Michelson interferometer are shown in Fig. 1(c) and (d). We can change the spacing of vertical fringes by adjusting the distance of Fresnel biprism and light source. Analogously, adjusting Michelson interferometer can change the spacing of horizontal fringes. Thus, the improved Michelson interferometer can produce a wide diameter two-dimensional square lattice wave with alterable periods, as shown in Fig. 1(e). The lattice wave can induce a large area two-dimensional square photonic lattice in $LiNbO_3$:Fe crystal. Fig. 1(f) is the Fourier spectrum pattern of output optical field of the improved Michelson interferometer.

The schematic diagram of the experimental setup is shown in Fig. 2. Beam path *a*, a linearly polarized beam of a Nd:YAG laser with a radiation wavelength of $\lambda = 532$ nm and power $P = 80$ mW is first expanded and spatially filtered using a microscope objective with subsequent pinhole. Then, the divergent beam incidents to the Fresnel biprism and subsequent Michelson interferometer, giving rise to the required lattice wave, which illuminates the

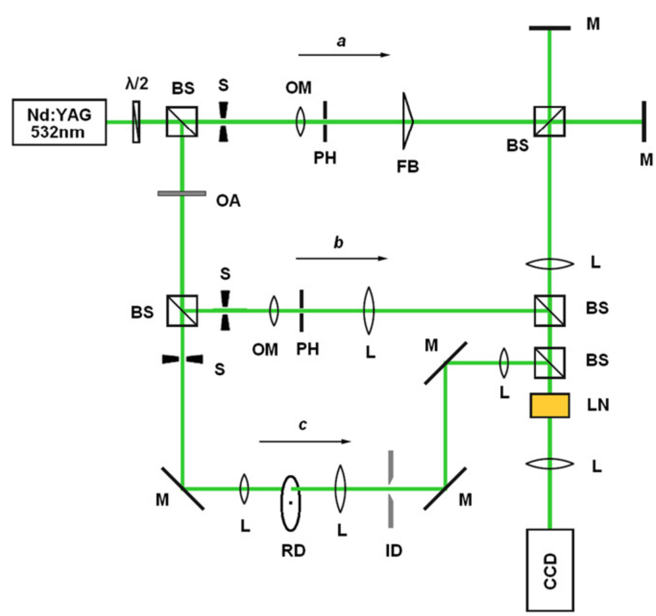

Fig. 2. Schematic representation of experimental scheme for fabricating large area two-dimensional nonlinear photonic lattices in $LiNbO_3$:Fe crystal. **λ/2**, half-wave plate; **BS**, beam splitter; **S**, shutter; **OM**, microscope objective; **PH**, pinhole; **OA**, optical attenuator; **M**, mirror; **FB**, Fresnel biprism; **L**, converging lens; **ID**, iris diaphragm; **RD**, rotating diffuser; **LN**, $LiNbO_3$:Fe crystal.

input face of the photorefractive $LiNbO_3$:Fe crystal (dimensions are 10 mm × 10 mm × 5 mm, doped with 0.03 wt% Fe) through a balsaming lens. The balsaming lens can eliminate the chromatic aberration and reduce spherical aberration, and help to produce a clear unchanged image. The lattice wave is linearly polarized perpendicular to the *c*-axis of the $LiNbO_3$:Fe crystal (*o*-polarized). The intensity of the lattice wave is about 56.5 mW/cm^2 which is measured at the front face of the crystal. Beam path *b* is used for