Optics Communications 366 (2016) 291–300

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Invited Paper

Photorefractive and computational holography in the experimental generation of Airy beams

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ARTICLE INFO

Article history:
Received 6 November 2015
Received in revised form
19 December 2015
Accepted 17 January 2016
Available online 21 January 2016

Keywords:
Airy beams
Computational holography
Spatial light modulator
Photorefractive holography

ABSTRACT

In this paper, we present the experimental generation of Airy beams via computational and photorefractive holography. Experimental generation of Airy beams using conventional optical components presents several difficulties and a practically infeasible. Thus, the optical generation of Airy beams has been made from the optical reconstruction of a computer generated hologram implemented by a spatial light modulator. In the photorefractive holography technique, being used for the first time to our knowledge, the hologram of an Airy beam is constructed (recorded) and reconstructed (read) optically in a nonlinear photorefractive medium. The Airy beam experimental realization was made by a setup of computational and photorefractive holography using a photorefractive $Bi_{12}TiO_{20}$ crystal as holographic recording medium. Airy beams and Airy beam arrays were obtained experimentally in accordance with the predicted theory; with excellent prospects for applications in optical trapping and optical communications systems.

1. Introduction

In recent years, the study of Airy beams has attracted great interest in optics and atomic physics due to their unusual features such as the ability to remain diffraction-free over long distances while they tend to freely accelerate during propagation. This was shown theoretically and experimentally by Siviloglou et al. [1,2]. The origin of these strange features, explained by Berry and Balazs in 1979, is due to a non-trivial solution of the Schrodinger equation in quantum mechanics for a free particle and the caustic envelope overlap by the superposition of a plane wave [3]. These self-accelerating Airy beams have also inspired prominent research interests and potential applications such as optical micromanipulation [4–7], plasma physics [8,9], optical microscopy [10], and, recently, the growing interest in the influence of optical vortices on Airy beams [11–13].

On the other hand, the holography, which was proposed by Dennis Gabor in 1948, enables the information of the amplitude and the phase of an object or optical wave to be recorded on a holographic recording medium. Since the development of the laser in the 1960s, there have been several works of conventional holography that used a laser as a source of coherent light and holographic recording materials such as silver halide films, thermoplastics, and photosensitive materials. In addition to the conventional holographic method (classical holography), computational (or numerical) holographic methods were proposed: computer generated holograms, when the recording or construction of the hologram is numerical (CGH) [14,15]; and, digital holography, when holograms are recorded with CCD sensors of high resolution and numerically reconstructed [16–18].

Additionally, the development of computers and electronic devices that are ever faster and are of higher resolution, such as CCD cameras and spatial light modulators (SLMs) based on liquid crystal display (LCD) or micro mirrors (DMDs), new laser sources, optical systems and opto-mechanical devices which are also of excellent quality. This has enabled the experimental implementation of holographic systems of numerical (via computer generated holograms, CGHs), and optical reconstruction (via spatial light modulators, SLMs) of wavefronts of objects and optical beams, including this nondiffracting beams: Airy beams.

Photorefractive holography (PRH) has been presented as a promising technique for dynamic processing of record-holographic reconstruction and holographic interferometry techniques to analyze surfaces and optical wavefronts [19]. This is based on the photorefractive effect, consisting in modulation of the refractive index via photoinduction of charge carriers and linear electro-optic effect in some semiconductor crystals with a particular features, the so-called photorefractive crystals ($LiNbO_3$, SBN, KBT, $BaTiO_3$, $Bi_{12}TiO_{20}$, among others) [19]. Due to the fact that it is a process that occurs at the electronic level of semiconductor crystals with nonlinear optical properties, the holographic networks feature high resolution and short response time, making it

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http://dx.doi.org/10.1016/j.optcom.2016.01.045
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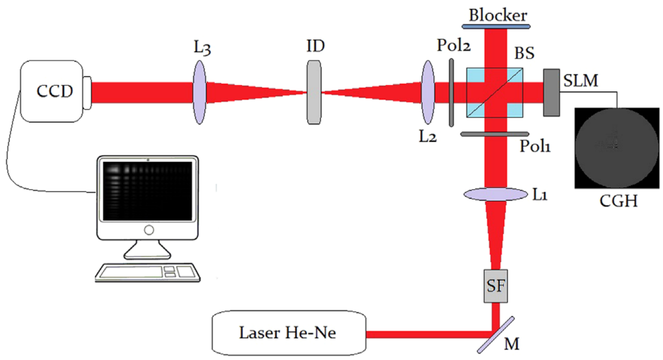

Fig. 1. Experimental holographic setup for Airy beam generation, where Ms are mirrors, BS is a beam splitter, SF is the spatial filter, Ls are lenses, Pol's are polarizers, SLM is spatial light modulator, ID is the mask and CCD camera for image acquisition.

possible to act as a holographic recording medium that does not require chemical or computational processing for reconstruction of the holographic image and presents indefinite reusability in photorefractive holographic interferometry [17,20–23].

Based on all this, we present the experimental generation of Airy beams via computational and photorefractive holography. The Airy beam experimental realization was made by a setup of computational and photorefractive holography using a photorefractive $Bi_{12}TiO_{20}$ crystal as holographic recording medium. The Airy beams and Airy beam arrays obtained experimentally are in accordance with theoretical predictions. This presents excellent prospects for applications in optical trapping [4–7], optical communications systems [8,9], and, the recent works on photorefractive trapping where the accelerating beam could open new perspectives if used in combination such trapping technology [24–27].

2. Airy Beams: theoretical background

The solution for Airy beams propagating with infinite energy can be obtained by solving the normalized paraxial equation of diffraction in (1+1)D [1]

$$i\frac{\partial}{\partial\xi}\phi(s,\xi)+\frac{1}{2}\frac{\partial^2}{\partial s^2}\phi(s,\xi)=0 \tag{1}$$

where ϕ is the complex amplitude of the electric field associated with planar Airy beams; $s=x/x_0$ and $\xi=z/kx_0^2$ are the dimensionless transverse and longitudinal coordinates; x_0 is an arbitrary transverse scale and $k=2\pi n/\lambda_0$ is the wavenumber of an optical wave.

An ideal Airy beam is immune to diffraction effects, but it possesses infinite energy making its experimental generation impossible. However, it is possible to obtain a finite-energy version of

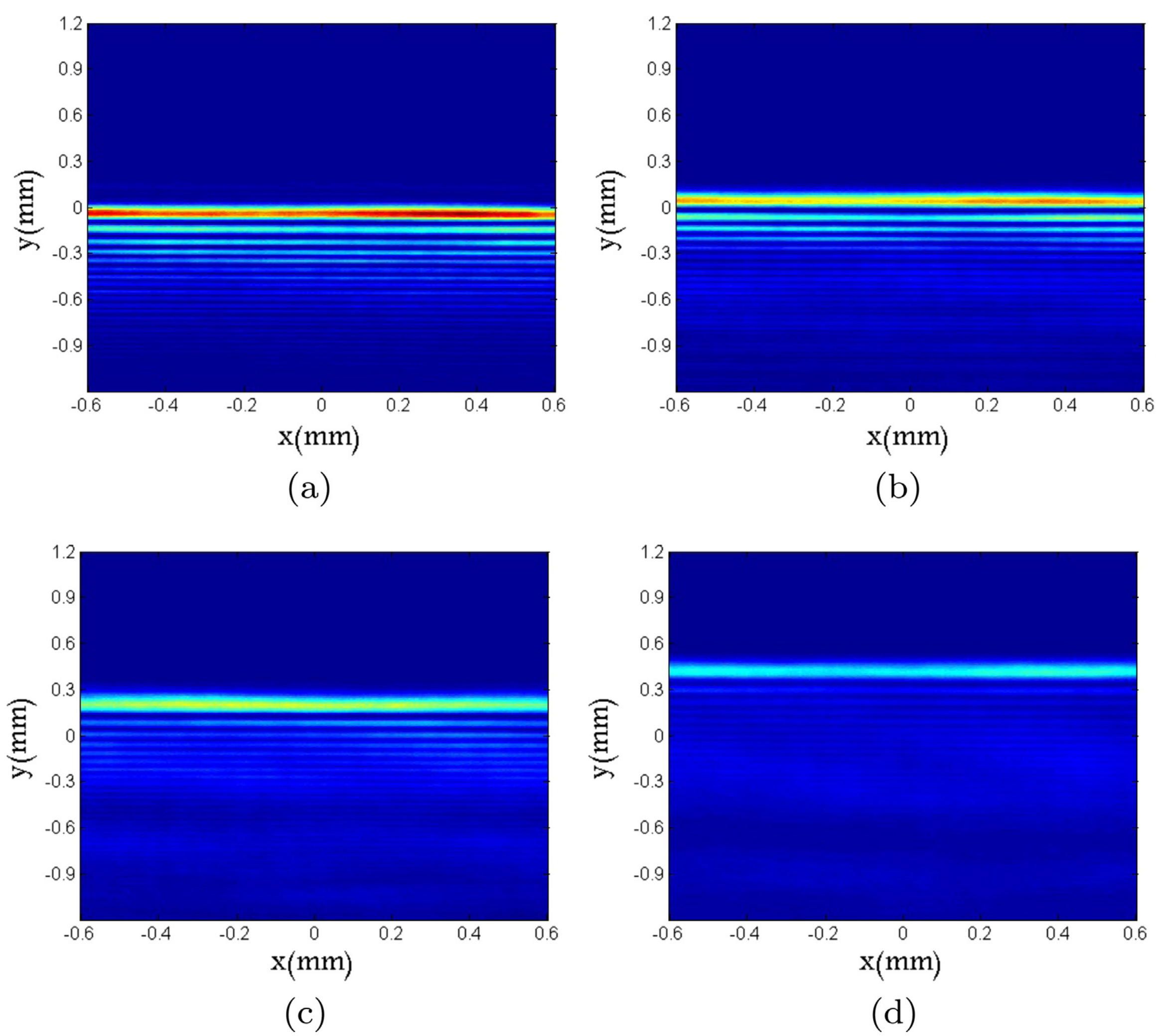

Fig. 2. Transversal intensity pattern for an Airy beam in (1+1)D via computational holography when $x_0=50\ \mu m$ and a=0.07 in (a) z=3 cm, (b) z=7 cm, (c) z=11 cm, (d) z=15 cm.