Propagation of Airy beams through unbiased photorefractive media

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Overview

Airy beams are a type of non-diffractive waveforms, which means that they do not spread or change shape as they propagate. Like Bessel beams, Airy functions are exact solutions to the paraxial wave equation and are infinitely wide in the transverse direction. However, Airy beams are unique in that the local intensity features freely accelerate during propagation[1].

Free space

$$i\frac{\partial \phi}{\partial \xi} + \frac{1}{2}\frac{\partial^2 \phi}{\partial s^2} = 0 \qquad \phi(\xi, s) = \mathrm{Ai}(s - (\xi/2)^2)\exp(i(s\xi/2) - i(\xi^3/12))$$

Paraxial Equation — Airy Function

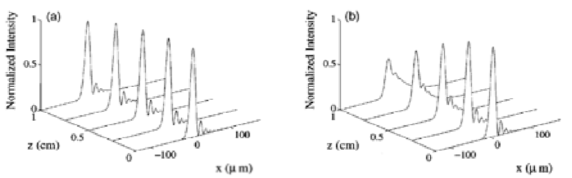
Christodoulides and Coskun[2] have predicted theoretically that *truncated Airy beams* propagate without diffraction through unbiased photorefractive (PR) media, due to charge diffusion in the photorefractive nonlinearity. In this project, we experimentally created truncated Airy beams and observed their propagation through a photorefractive SBN:60 ($Sr_{0.6}Ba_{0.4}Nb_2O_6$) crystal.

PR media

$$i\phi_\xi + \frac{1}{2}\phi_{ss} + \gamma\frac{(|\phi|^2)_s}{|\phi|^2}\phi = 0 \qquad \phi = \phi_0 Ai(\epsilon\eta + 4\gamma^2)\exp(-2\gamma\eta) \times \exp\{i[(\epsilon\eta\xi/2) + (\xi^3/24)]\}$$

Nonlinear Paraxial Equation — Truncated Airy Function

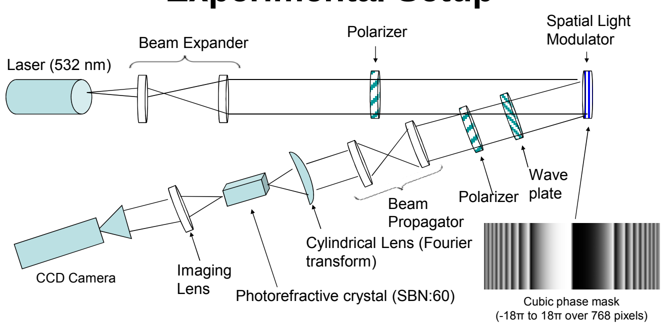
Predictions



Predicted propagation of truncated Airy beam through photorefractive media (SBN:60) when the beam polarization is a) parallel to the x axis and b) parallel to the y axis[2]

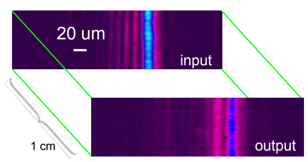
Christodoulides and Coskun[2] have predicted that a truncated Airy beam with wavelength of 500 nm, input intensity FWHM of 19 μm and a nonlinear γ value of 0.142 would propagate without diffraction if polarized parallel to the crystalline axis of SBN:60, but would undergo diffraction if polarized perpendicular to the c-axis. The phenomenon arises from the anisotropic property of SBN:60 crystal (electro-optic coefficients r_{33} = 237pm/V, r_{13} = 1/6 to 1/7 of r_{33}).

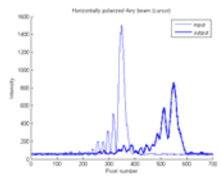
Experimental Setup



A Gaussian beam from a 532 nm He-Ne laser is collimated, then polarized vertically and imprinted with a cubic phase by the spatial light modulator (SLM). This creates the Fourier transform of a truncated Airy beam. The subsequent wave plate and polarizer are used to switch the polarization of the beam. The pattern on the SLM is imaged onto the front focal plane of a cylindrical lens (1D) and undergoes an optical Fourier transform by placing the photorefractive crystal at the back focal plane of the lens. The Airy beam's propagation through the photorefractive media is observed by imaging the front and back faces of the crystal on a CCD camera through a 5x microscope objective.

Generation of Airy beam



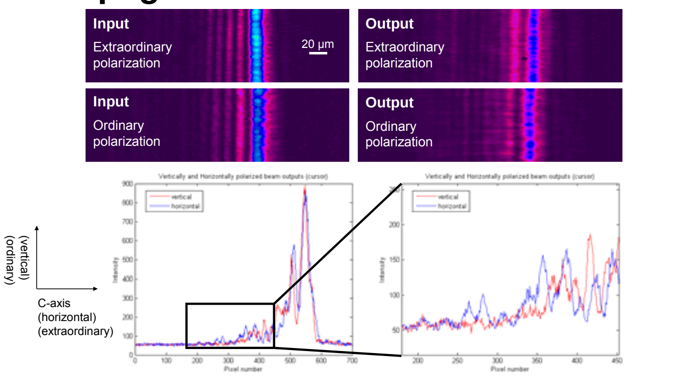


$$V = \nabla S$$

$$\theta_d = \frac{\Delta s}{r} = \frac{30\mu m}{10000\mu m} = 3mrad$$

Due to the cubic phase on its transversal profile, the Airy beam accelerates during propagation. We compared images of the beam at the front and back faces of the crystal to calculate the deflection angle of the beam after it had propagated 1cm, the length of the crystal. We found that the beam had deflected 30 microns, which meant θ_d = 3.0 mrad.

Propagation of Different Polarizations



Since the photorefractive nonlinearity of SBN:60 is much stronger parallel to the c-axis than perpendicular to it, we expect the crystal to provide a competitive, self-focusing effect against diffraction for the extraordinarily-polarized (horizontal) beam but comparatively negligible effect for the ordinarily-polarized (vertical) beam. The images and graphs above show that the extraordinarily-polarized beam does retain the integrity of the local features of the input beam to a greater degree than the ordinarily-polarized beam. The ordinary beam loses the smaller oscillations to diffraction, whereas the extraordinary beam preserves more of the smaller oscillations.

Conclusions & Future Work

Preliminary results indicate that an extraordinarily-polarized Airy beam propagating through an unbiased SBN:60 is more resistant to diffraction than an ordinarily-polarized Airy beam. However, under the current parameters, both beams still experience considerable diffraction.

For future work:

- Adjust parameters, particularly width of beam and chirp of phase mask
- Use rectangular crystal to observe beam after 0.5cm and 1cm of propagation
- Create and observe propagation of 2D Airy beams through unbiased PR media

References

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[2] D.N. Christodoulides and T.H. Coskun. "Diffraction-free planar beams in unbiased photorefractive media", *Optics Lett.* **21.18**, 1460-1462 (1996).

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