OPTICAL BEAMS

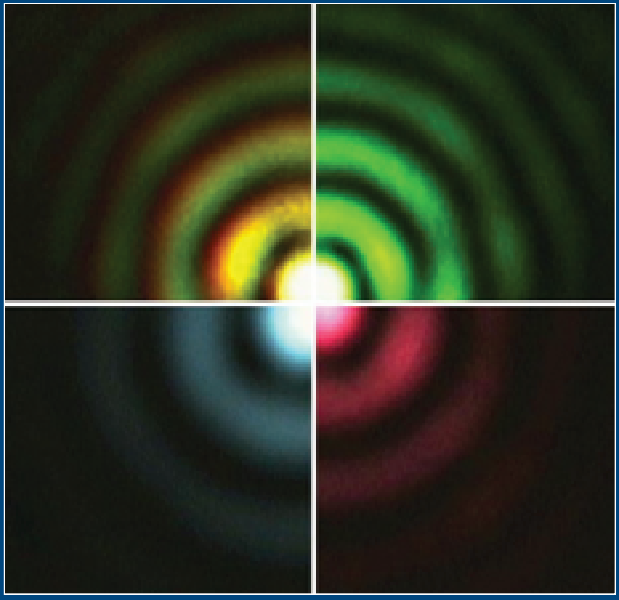
White Light Takes Shape

Pascal Fischer, Ewan M. Wright, Tom Brown, Wilson Sibbett, Jill E. Morris, Carlos López-Mariscal, Antonia E. Carruthers and Kishan Dholakia

Coherence in both the temporal and spatial domains is central to understanding the rich and diverse range of phenomena involving light and matter interactions. Indeed, the ability to predict the relative phases between light beams, for instance, may lead to well-defined interference. With broadband light that has relatively poor phase coherence, interference is observed in the temporal domain only when the optical path lengths are matched, as exploited for optical sectioning using coherence tomography.

By contrast, lasers more typically exhibit outstanding spatial and temporal coherence properties. These sources normally operate with a Gaussian output beam profile but recently more specialized light patterns have enabled dramatic impacts to be made in many areas of physics. The Bessel beam is a primary example in this respect and represents an intriguing propagation invariant or pseudo "non-diffracting" light source. Durnin elucidated the zeroth-order Bessel beam solutions for the free-space scalar wave equation: The beam comprises a narrow central region surrounded by a series of concentric rings.[1]

So how may we interpret this Bessel beam? Any light beam can be thought of as a superposition of plane waves. As the waves propagate, they experience relative phase shifts. In most cases, each plane wave component suffers a distinctive phase shift such that the resultant beam—the interference pattern of the plane waves changes shape. There exist, however, particular light beams where the phase shift is the same for each plane wave component. These beams are invariant on propagation and therefore may be considered "diffraction-free."



The white light Bessel beam and its spectral composition. The top left shows a quadrant of the white light Bessel beam. We observe the Bessel beam through various interference filters at 500 nm (top right), 700 nm (bottom right) and 850 nm (bottom left).

An approximation to such a beam may be realized with a conical lens known as an axicon. This also leads one to ask the following question: If all of the component waves for such a beam traverse the same distance (and equivalent phase shift), could such a non-diffracting beam be made without having a temporally coherent source? In other words, would it be possible to sculpt or shape white light to form such a beam?

In recent work, we have explored the generation of such "non-diffracting" light fields using broadband and incoherent light sources.[2] We have made "white" Bessel light modes from laser diodes operating below threshold, supercontinuum light sources and even halogen bulbs. The main criterion we found was the need to ensure good spatial coherence in the light field. Remarkably, the superposition of the conical wave-vectors arising from passage through the axicon and the inherent absence of chromatic aberration results in a pure focal line of white light.

White light sources such as these are coming to prominence for a wide variety of applications, including imaging using optical coherence tomography[3] as well as fundamental studies of light propagation, angular momentum, depth penetration,[4] micro-manipulation[5] and quantum information. We anticipate that exploiting the coherence properties of light in combination with sculpting the wavefronts should lead to new and unexpected innovations in these fields in the future. ◭

[P. Fischer, C.T.A. Brown, A. Carruthers, J.E. Morris, W. Sibbett and K. Dholakia are with the School of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews, Scotland. C. López-Mariscal is with the Photonics and Mathematical Optics Group, Tecnologico de Monterrey, Monterrey, Mexico. E.M. Wright is with the College of Optical Sciences and Department of Physics, University of Arizona, Tucson, Ariz.]

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Molding Light in Two-Dimensional Photonic Lattices

Robert Fischer, Denis Träger, Dragomir N. Neshev, Andrey A. Sukhorukov, Wieslaw Krolikowski, Cornelia Denz and Yuri S. Kivshar

Fabricated dielectric periodic structures such as photonic crystals are attracting increasing attention, opening new possibilities for engineering transmission and reflection of light and developing novel applications of photonic-crystal devices for all-optical signal processing and switching.[1] Conventional approaches to guiding light in such periodic structures are based on wave transport through permanent waveguides, combined with resonant Bragg reflection and total internal reflection. However, these approaches may only allow limited flexibility in the light molding and routing that is inherently restricted by the fabricated geometry.

Recently, we demonstrated, both theoretically and experimentally, that increased flexibility can be achieved when the light itself induces its own waveguide through the nonlinear response of the material.[2] The internal structure and symmetry of the generated nonlinear self-trapped state selects itself the propagation direction in defect-free periodic structures. The symmetry of such localized optical waves is intrinsically defined by the physical mechanisms responsible for light localization—i.e., by total internal reflection and Bragg scattering.

In particular, we demonstrated that, in two-dimensional periodic optically induced photonic lattices created in biased photorefractive crystals, it is possible to use both localization mechanisms to obtain self-trapped states with different mobility properties along the two principal directions in a square lattice. We described theoretically the families of such highly anisotropic gap solitons and studied them experimentally.

An example of such a localized mode generated experimentally is shown in the figure (left). It originates from the *x*-symmetry point of the lattice bandgap spectrum, and possesses a reduced symmetry with highly anisotropic diffraction properties. Because of this anisotropy, such modes exhibit high mobility along the direction of their spatial modulation, and they are trapped by the lattice in the other transverse direction, enabling directional wave transport with possible applications for optical routing and switching in nonlinear periodic photonic structures.

We predicted and verified experimentally the unique mobility of these nonlinear modes and a novel mechanism for directional nonlinear wave transport in symmetric lattices. The figure summarizes our results. We imposed an initial tilt of the input beam along the different directions and studied the beam displacement at the output. In simulations, an initial tilt of 20 mrad (15 percent of the Bragg angle) along *x* moves the output by two lattice sites (b), whereas the same tilt in *y* leads to no motion of the output state (c).

Even with both tilts superimposed, the soliton moves the same two lattice sites along the *x*-axis only (d). Two examples of the corresponding experimental results presented in (e,f) demonstrate the high mobility of the localized states along *x* direction. We underline that the lattice itself is uniform in *x* and y, and the direction of mobility is only determined by the symmetry of the localized state itself. This unique property offers greater flexibility than earlier proposed techniques for soliton-based optical signal routing and switching.[3] The mode ability to move robustly along one particular direction of the lattice makes it a good candidate for two dimensional flexible soliton network applications. ◭

[R. Fischer, D.N. Neshev, A.A. Sukhorukov, and Y.S. Kivshar are with the Nonlinear Physics Center, Australian National University, Canberra, Australia. D. Träger and C. Denz are with the Institut für Angewandte Physik and Center for Nonlinear Science, Westfälische Wilhelms-Universität, Münster, Germany. W. Krolikowski is with the Laser Physics Center, Australian National University, Canberra, Australia.]

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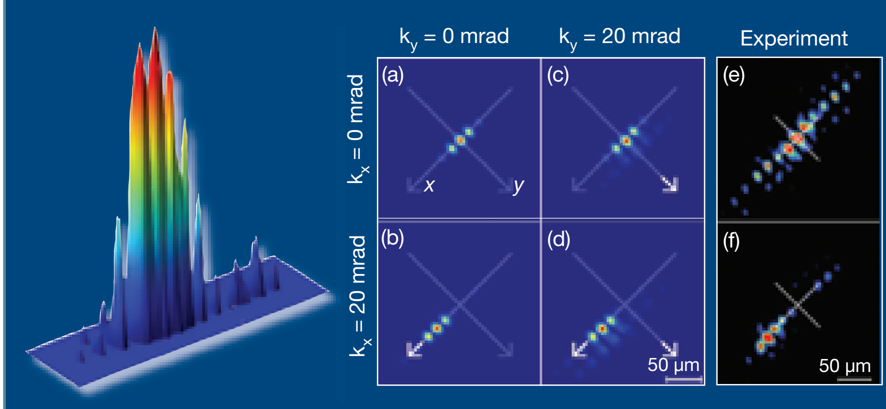

Left: Three-dimensional image of a self-trapped localized mode observed experimentally. *Right*: Numerically calculated output beam profiles for different initial tilts of (a) no tilt of the beam, (b) 20 mrad tilt along *x*, (c) 20 mrad tilt along *y*, (d) 20 mrad tilt along *x* and *y*. (e,f) Two experimental examples for the mode-enhanced mobility along *x*, the cross marking the beam center at the crystal front face.