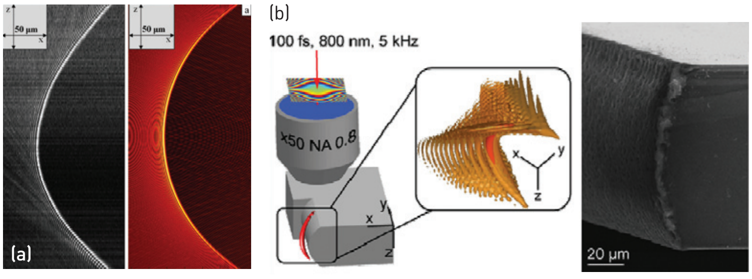
ACCELERATING OPTICAL BEAMS

Accelerating Beyond the Horizon

Research on accelerating beams has developed rapidly since 2007.[1] An ideal paraxial accelerating beam follows a parabolic trajectory while preserving its amplitude structure indefinitely as waves emitted from all points interfere to a propagation-invariant structure shifting laterally on a curved trajectory. This phenomenon has led to many ideas, including particle guidance along curves and nonlinear shape-preserving accelerating beams.

Until this year, however, the only shape-preserving accelerating solutions ever found were derived from the paraxial wave equation, which gave an Airy beam propagating on a parabolic trajectory. This solution is limited to small angles: After some distance, an Airy beam trajectory will inevitably reach a steep angle where the dynamics are no longer shape-preserving. Similarly, the paraxial regime cannot describe accelerating beams with narrow lobes—comparable to the optical wavelength—whose steep bending occurs within tens of wavelengths. Previous attempts to find non-paraxial accelerating beams showed deformation and breakup.

In a recent paper,[1] this apparent limit was tackled through first-principles analysis, starting from Maxwell's equations.[2] This theory found a fundamentally new solution to the Maxwell equations corresponding to nondiffracting spatially accelerating beams along a circular trajectory, exhibiting shape-preserving bending with the Poynting vector of the main lobe displaying a turn of close to 180° (with an initial tilt).[2] Theory was followed by experimental confirmation.[3] The figure depicts experimental and theoretical results. The online video shows formation of a shape-preserving beam propagating at a circular trajectory, bending by almost 90°; the beam results from interference among sequentially added lobes with appropriate amplitude and phase.



(a) Experiments (left) and theory (right) depicting the intensity of a shape-preserving beam bending at more than 90° degrees. (b) The use of accelerating beams also allows novel applications such as femtosecond-pulsed beams propagating on circular trajectories to fabricate micron-scale curved structures in photonic materials such as silicon.

Interestingly, any circular trajectory can support a family of accelerating solutions, whereby their superpositions form periodic accelerating "breathers." In scalar form, these beams are exact solutions for non-dispersive accelerating wavepackets of the common (Helmholtz-type) wave equation describing time-harmonic waves. Hence, this work has implications for many waves in nature, ranging from acoustic and elastic to surface waves in fluids and membranes. It shows that exact non-diffracting beams are no longer necessarily only straight-line Bessel-type beams as believed since Stratton's classic 1941 text on electromagnetism.[4] The family has now been extended to include self-bending beams.[2]

This work generated much follow up, with extensions to nonlinear media, non-paraxial and non-circular trajectories, 3-D accelerating beams with trajectories that do not lie in a single plane, and even technical applications showing material processing with curved features. It also brings the physics of accelerating beams into the regime of super-resolution, through the sub-wavelength features of the solutions. OPN

Visit www.opnmagazine-digital.com to view the video that accompanies this article.

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