Molding Light in Two-Dimensional Photonic Lattices

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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.

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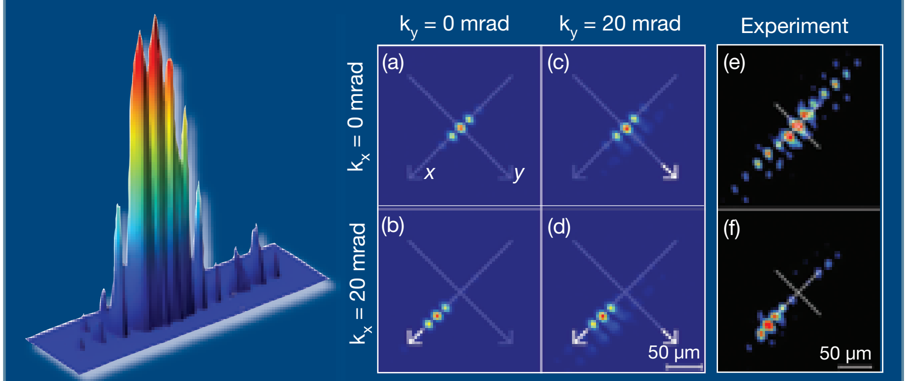

Left: Three-dimensional image of a self-trapped localized mode observed experimentally. *Right*: Numerically calculated output beam profiles for different initial tilts of (a) no tilt of the beam, (b) 20 mrad tilt along *x*, (c) 20 mrad tilt along *y*, (d) 20 mrad tilt along *x* and *y*. (e,f) Two experimental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