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Two-Dimensional Surface Lattice Solitons

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Electromagnetic waves may propagate as stationary states at the interface between two materials. Since surface waves were introduced in 1932, they have been of interest in various areas. In optics, nonlinear stationary surface states were under active consideration since 1980. However, experimental observation was severely limited due to their high power threshold.

Recently, it was shown that, at the interface between one-dimensional continuous media and periodic arrays of evanescently coupled waveguides, the threshold for surface wave excitation is significantly lower.[1,2] In addition to surface waves in materials with a focusing nonlinearity, surface gap solitons were suggested in defocusing media[1,3] and observed experimentally in saturable and quadratic nonlinear materials.[4]

In 2006, it was suggested that two-dimensional lattice interfaces also support surface solitons.[5] Recently, the experimental demonstration of 2D surface lattice solitons was presented in two articles describing the observation of these phenomena in optically induced lattices in a photorefractive crystal[6] and in fs-laser-written arrays in bulk fused silica.[7]

Focusing fs laser pulses into bulk fused silica yields a localized permanent increase in the refractive index. This results in a longitudinal extended waveguide when one moves the sample. A microscope image of the facet of such a "written" 5 × 5 waveguide array is shown in (a), where the marked waveguide was excited. While for low input power a clear spreading of the light into the array can be observed (b), for high input power almost all the light is localized in the excited waveguide, indicating surface wave formation (d).

In a photorefractive crystal, the lattice pattern is generated by a periodic spatial modulation of a partially incoherent optical beam, which enables formation of a square lattice featuring sharp edges or corners (e),(i) that remain almost undistorted through the crystal. Nonlinear propagation is controlled by the lattice beam together with an external bias field. With a high bias field, the spreading of a probe beam is suppressed to form a discrete surface in-phase soliton (e)-(h) or a surface gap soliton (i)-(k), while the beam at reduced intensity undergoes linear diffraction under the same lattice conditions (l).

The experimental demonstration of nonlinear discrete surface solitons will pave the way for the study of new optical surface wave phenomena. Moreover, these promising results indicate that fs-laser-written waveguide arrays and lattices induced in photorefractive crystals show high potential for the investigation of discrete surface phenomena that exist in other systems beyond optics.

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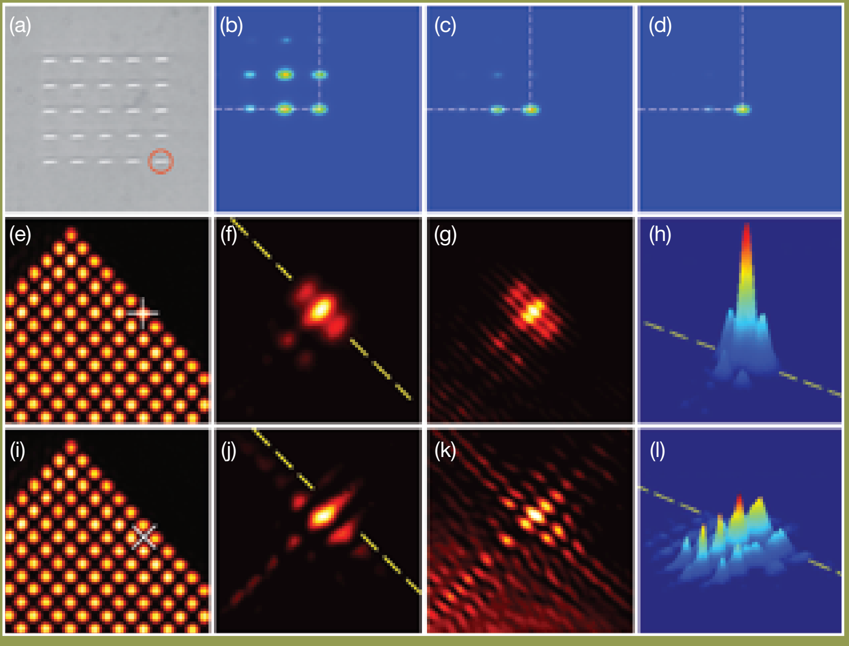

(a) Microscope image of laser-written array with excited waveguide marked by circle. (b-d) Output intensity distributions for progressively increasing input power levels. Observation of surface soliton (middle row) and surface gap soliton (bottom row) in optically induced photorefractive lattice. (e),(i) Lattice patterns with the waveguide excited by the probe beam marked by a cross. (f),(j) Surface soliton intensity patterns. (g),(k) Interference pattern between the soliton beam and a tilted plane wave. (h) 3D intensity plots of an in-phase surface soliton and (l) the corresponding pattern when its intensity is reduced significantly under the same bias condition. In all plots, dashed lines mark the interface.