Self-guiding of matter waves in optical lattices

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Optical lattices have proven to be a powerful tool for the manipulation of BECs, and for uncovering new effects in the coherent matter wave due to the interplay of periodicity and nonlinearity. This work demonstrates three new results on the nature of BECs in the lattice: (1) that self-induced waveguide structures are possible in the lattice; (2) that these waveguides may support continuous or pulsed atom flow; (3) that waveguide localisation may be achieved, and spontaneous flow may emerge, as an initially deep lattice is reduced in depth [1].

Earlier work carried out within ACQAO demonstrated that the ground state nonlinear Bloch wave may be truncated and localised by Bragg reflection within the linear band gaps of an optical lattice [2] (see Fig. 1(a,b)). Extending this work to lay the foundation for possible applications of matter wave control in two-dimensional lattices, it is found that states with complex geometries, and even high aspect ratios like waveguides with flow (see Fig. 1(c)) may be truncated and are stable, provided the lattice is sufficiently deep (here found to be six recoil energies and deeper). States with flow are found to be stable provided the phase change between neighbouring sites does not exceed $\pi/2$. Single site waveguides are found to support the propagation of solitonic density pulses (see Fig. 1(d)), which propagate without change of shape (even around sharp corners), and pass through each other without dependence on phase.

A possible scheme for generation of waveguides with and without flow is to begin with a deep lattice and use single-site addressability techniques [3] to obtain the geometry of interest. Initially the phase will be random between sites (see Fig. 1(e), left panels), but gradually reducing the depth of the lattice will lead to the development of phase coherence and the possibility of spontaneous flow through the Kibble-Zurek mechanism (see Fig. 1(e), right panels).

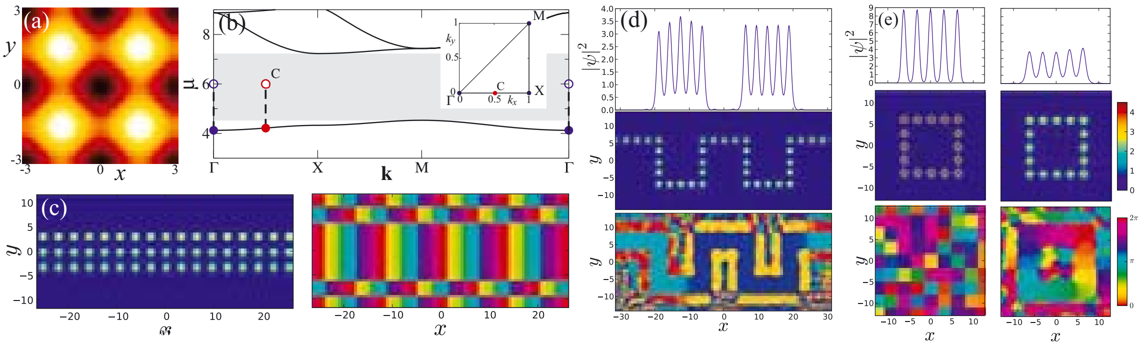

Fig. 1: (a) Intensity plot of optical lattice. (b) Band diagram including position of linear (solid circles) and nonlinear (open circles) Bloch waves showing shift of chemical potential into linear gap where truncation can occur. Inset: the associated Brillouin zone, with high symmetry points Γ, X and M. (c) State with nonzero $\mathbf{k}$ marked as C in (b) (left: density, right:phase). (d) Single site waveguide with bends supporting solitonic pulse propagation and (e) generation of a toroidal flow (right panels) from an initially random phase state (left panels) through the Kibble-Zurek mechanism. Color bars on the right show density (top) and phase (bottom) values for associated panels in (d,e). Top panels: cut through density profile. In all cases the lattice depth is $V_0 = 6$ in units of lattice recoil energy.

References

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[3] P. Würtz *et al.*, Phys. Rev. Lett. **103**, 080404 (2009); S. Whitlock *et al.*, New. J. Phys. **11**, 023021 (2009).