Mažesnio už bangos ilgį periodo optinė gardelė šaltiesiems atomams

Subwavelength optical lattice for ultra-cold atoms

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Ultra-cold atoms in optical lattices represent a unique tool for simulating various condensed matter systems due to their wide tunability. This allows the realization of many paradigmatic Hamiltonians. One seeming limitation of optical lattices is that the spatial lattice period has an apparent lower limit of half the laser beam wavelength [1]. However, there are many methods of adding a subwavelength structure to the lattice, one of which shall be discussed here.

In this work, we consider the center of mass dynamics of atoms characterized by three internal states which are cyclically coupled by the laser beams accompanied by a recoil. It is shown that for zero detuning, the atom-light Raman coupling provides three independent sinusoidal lattices with a periodicity determined by the recoil wave-vector. The individual lattices are shifted by a third of the lattice constant. The atoms in each of these lattices are in different dressed states representing different superpositions of the atomic bare states.

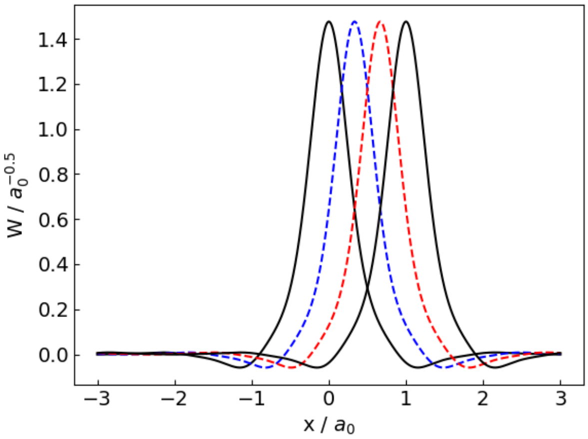

Fig. 1. Wannier functions of the lowest band for Raman coupling $\Omega = 1.00E_R$ and zero detuning ($\Delta_j = 0$).

Inclusion of the detuning induces transitions between atoms in different internal dressed states and thus enables transitions between atoms in different potential wells of the lattice. Depending on the type of the detuning, the transitions between the atomic Wannier functions of individual lattices corresponding to different internal dressed states can be described by both real and complex tunneling matrix elements. It is shown that detuning a single internal state yields real tunneling matrix elements, while antisymmetrically detuning two internal states leads to purely imaginary matrix elements. Thus, one can fully control the phases of the matrix elements. The direct and nearest neighbor tunneling may be calibrated by changing the Raman coupling and detuning in a certain way. For complex matrix elements, a non-zero magnetic flux is formed in the triangular plaquettes of a semi-synthetic lattice.

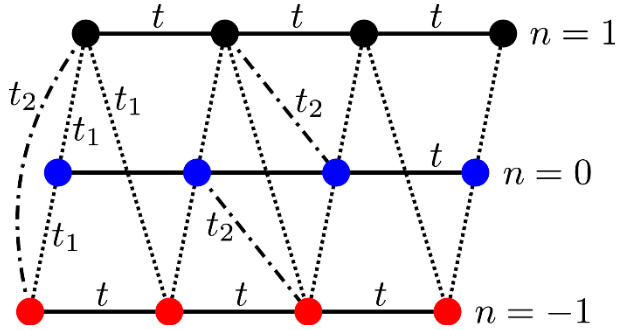

Fig. 2. Representation of the lattice involving direct tunneling t between neighboring sites corresponding to the same dressed states, as well as the nearest neighbor (NN) tunneling t_1 and next nearest neighbor (NNN) tunneling t_2. Only some of the NNN couplings t_2 are shown to maintain clarity.

The state-dependent Raman lattice considered here resembles a semi-synthetic zigzag ladder [2]. However, that system had a pre-existing state-dependent optical lattice and the tunneling in the synthetic dimension was induced by the Raman coupling, while our system's lattice potential comes from the cyclic Raman coupling and the synthetic tunneling is controlled by the atom-light detuning. Thus, one can engineer the necessary complex matrix elements by adjusting properly the detuning.

Keywords: optical lattice, ultra-cold atoms, cyclic coupling, atom-light detuning, dressed states, synthetic dimension, Wannier functions.

Literature

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