Photonic quantum simulations of SSH-type topological insulators with perfect state transfer

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Abstract

We show the quantum simulation of a non-crystalline topological insulator using multi-particle photonic interference. The system belongs to the same chiral orthogonal symmetry class as the Su–Schrieffer–Heeger (SSH) model, and is characterised by algebraically decaying edge states. In addition, our simulations reveal that the Hamiltonian describing the system facilitates perfect quantum state transfer of any arbitrary edge state. We provide a proof-of-concept experiment based on a generalised Hong–Ou–Mandel effect, where photon-number states impinge on a variable coupler.

Topological insulators could profoundly impact the fields of spintronics, quantum computing and low-power electronics. To enable investigations of these non-trivial phases of matter beyond the reach of present-day experiments, quantum simulations provide tools to exactly engineer the model system and measure the dynamics with single site resolution. Nonetheless, novel methods for investigating topological materials are needed, as typical approaches that assume translational invariance are irrelevant to quasi-crystals and more general non-crystalline structures.

We simulate a generalised SSH TI which is capable of perfect quantum state transfer by means of multi-particle bosonic quantum interference. The model belongs to the chiral orthogonal class of TIs and reveals weakly localised edge states. This new system features similarities to the SSH TI brought close to its topological phase-transition. The modification w.r.t. the original SSH model lies in fully site-dependent couplings between the chain sites which deprives the system of translational invariance. Our simulation is an analogue of a CTQW that requires only one single step to calculate the outcome of an arbitrarily long QW. It avoids error-accumulation losses which occur during numerous steps in QWs and brings the number of optical components to a minimum at the expense of increasing the number of interfering particles. It is experimentally implemented by interference of photon number states (light pulses with a definite particle number) on a beam splitter (BS) with an adjustable splitting ratio. It relies on a multi-particle Hong–Ou–Mandel (HOM) effect, which we experimentally observed for states with up to five photons. The total number of interfering particles S allows us to simulate a generalised SSH TI with up to $S + 1$ sites.

We have demonstrated that the quantum interference of multi-photon Fock states on a beam splitter is capable of simulating a non-crystalline topological material. The system is characterised by a lack of translational invariance, and also belongs to the same chiral orthogonal symmetry class of 1D systems as the SSH model. Examples of such materials include superconducting nanowires, disordered graphene quasi-1D nanoribbons, disordered cold atoms and quasi-1D organic superconductors. These may find applications in next generation electronics and spintronics operating with almost no energy dissipation and offering speeds exceeding 100 GHz. In addition we revealed that our system is capable of the perfect quantum state transfer of an arbitrary quantum