Dynamic Quantum Spin Hall Effect for Light

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Quantum Hall effects are prominent phenomena in condensed matter physics that consist in a precisely quantized electrical transport along sample edges [1]. Optical analogs of these effects have been proposed and realized experimentally [2]. We demonstrate that electromagnetic waves not only allow for mimicing these condensed-matter physics phenomena but also add a new dimension to their study. In particular, dynamical aspects of transport phenomena in quantum Hall effects can be studied in optical and microwave experiments whereas these aspects are hardly accessible for electrical transport experiments in solid-state setups. Our experiments use microwaves propagating in carefully designed two-dimensional photonic crystals to demonstrate topologically protected transport of the optical orbital momentum along an interface between two topologically distinct crystals (see Fig. 1) or along crystal edges [3]. This is analogous to the quantum spin Hall effects (QSHE) with the optical orbital momentum playing the role of electron spin (intrinsic angular momentum). Signals carrying orbital angular momenta of opposite signs propagate in opposite directions. Together with the sensitivity of the band structure to the properties of the photonic crystal boundary (an interface with another photonic crystal or with the free space), this allows for controlling the direction of signal propagation by choosing the position of the source and tuning its frequency. The emitted pulse propagates at a speed that is two orders of magnitude slower than the speed of light in the free space and goes around obstacles without backscattering. The last property is due to the topological protection resulting from the topologically nontrivial band structure of our photonic crystals. Although our experiments are performed in the microwave frequency range, they can be readily scaled to optical wavelengths. This opens new opportunities for studying questions of fundamental importance as well as for routing optical signals in photonic applications.

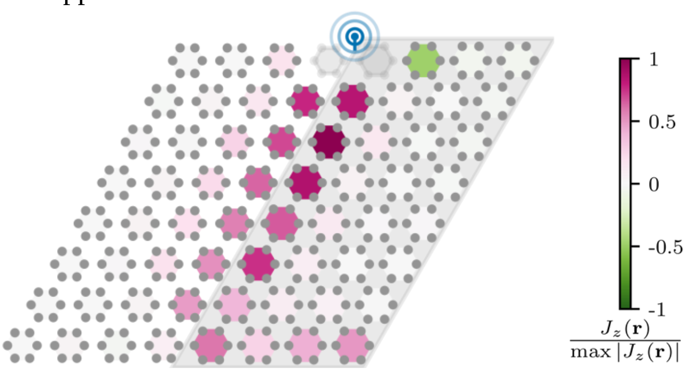

Fig. 1: Signal emitted by a microwave antenna located at the top of the sample (blue concentric circles) propagates along the interface between two topologically distinct halves of the sample and carries an orbital angular momentum J_z shown by the color code.

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