Project title: High-harmonic spectroscopy of topological condensed matter

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Current state of the art

The emission of high-harmonic radiation from laser-illuminated solids opens up new perspectives regarding novel and compact radiation sources and the all-optical probing of ultrafast charge carrier dynamics in condensed matter [1]. After several precedent theoretical studies [2, 3], only recently high-harmonic generation (HHG) in topological insulators is also studied experimentally [4, 5]. The bulk properties change during a topological phase transition, which leads to strong qualitative differences in the laser-driven motion of the electrons and holes between the trivial and the topological phase. This strong change in the charge carrier dynamics affects HHG, e.g., the ellipticity of the emitted, short-wavelength radiation (see Fig. 1).

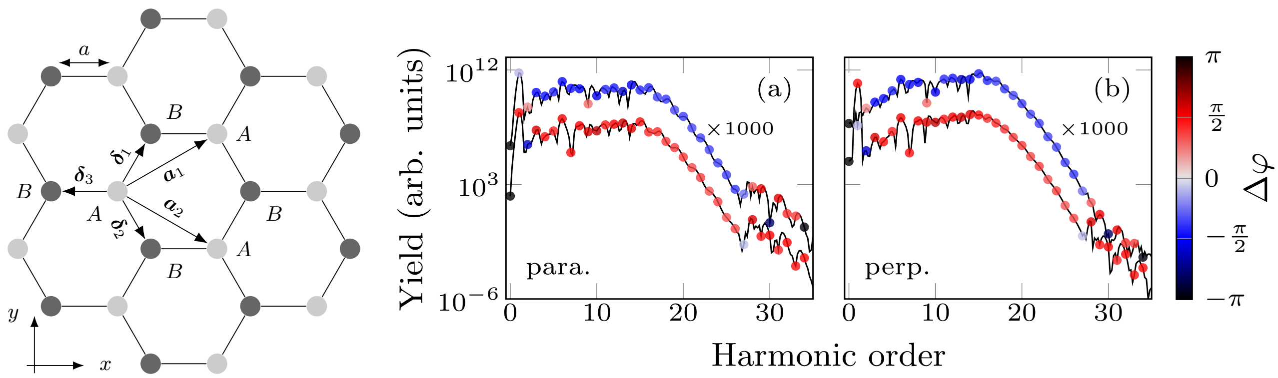

Figure 1: Left: Geometry of the hexagonal lattice used in the Haldane model. The unit cell consists of two sites (A, B). The lattice vectors connecting next-nearest and nearest neighbors are indicated. The incoming laser pulse is linearly polarized in x direection. Right: HHG from the bulk of "Haldanite" [6] (a) calculated in the direction parallel to the polarization of the incoming laser field for the trivial phase (upper curve, multiplied by 1000) and the non-trivial topological phase (lower curve). (b) The same for the perpendicular direction. The phase difference (i.e., helicity) of integer harmonics is color coded in each panel. From [7].

However, the key feature of topological insulators is the presence of ballistic edge currents that are immune to perturbations. Since the interaction between laser and target occurs at the vacuum-solid interface, these egde currents are unavoidable in experiments and expected to play a major role in HHG [4, 5]. In [8], we have compared HHG in finite flakes and bulk of a Haldane-model system (so-called "Haldanite"). Strong features due to size-dependent ring currents around the flakes where observed (see Fig. 2).

Research goals and working program

This project is aiming at (i) a detailed understanding of the laser-driven charge carrier dynamics in finite model systems with topologically protected edge states and (ii) the emitted radiation caused by it. We will start with two-dimensional systems, i.e., effectively one-dimensional edge-currents. We will simulate our laser-driven, finite model systems using the tight-binding approximation in position space (as in [8]) so that edge states are explicitly and self-consistently taken into account (unlike in optical Bloch-equation treatments where they are added by hand). We will investigate whether the edge-state population can be controlled by a second laser or whether the Hilbert space is strictly separated into bulk and edge, as one could think because of topological

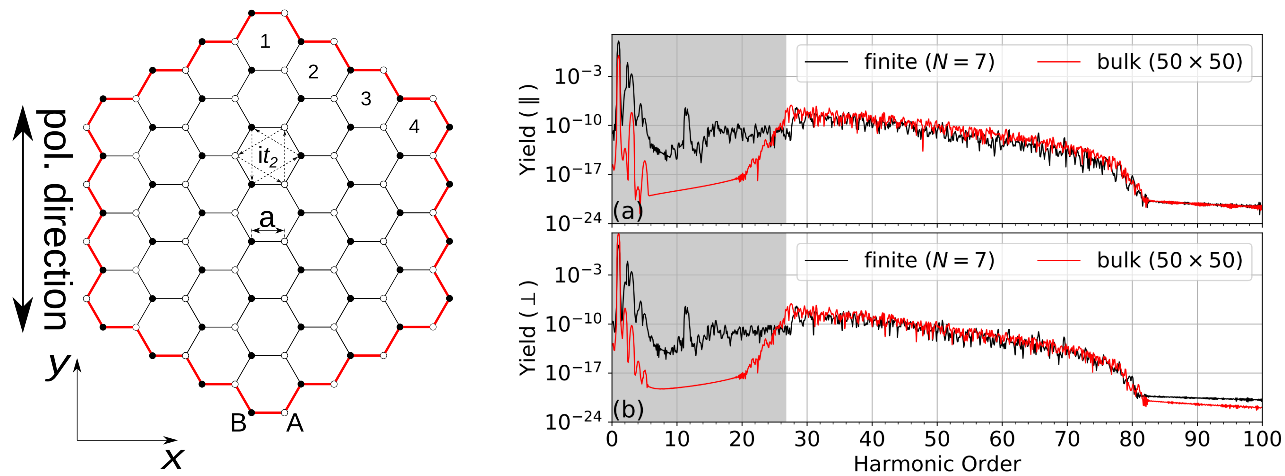

Figure 2: Left: A "Haldanite" flake of size $N = 4$. Right: Comparison between the spectra for the finite ($N = 7$) and the bulk (50×50 points in k-space) system in (a) parallel and (b) perpendicular polarization direction to the external laser field. The shaded areas indicate energies below the band gap of the bulk system. The spectrum of the bulk is shifted in yield such that the fundamental harmonic in parallel direction to the external field has a yield equal to 1. The spectrum of the finite flake is shifted in yield such that the plateaus (non-shaded area) from both systems have a comparable yield in parallel polarization direction. A strong peak around harmonic order 11 is observed for the finite flake but not for the bulk. A topologically protected ring current around the flake were found to cause this peak. From [8].

protection. We will try to separate the various contributions to HHG due to (a) changing populations and injection currents, (b) non-parabolic dispersion relations, and (c) accelerated charges around corners. In the longer term, we may expand our studies towards spin-degrees of freedom and three spatial dimensions.

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