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Project title: Exploring nonlinear light-matter interactions with swift electrons

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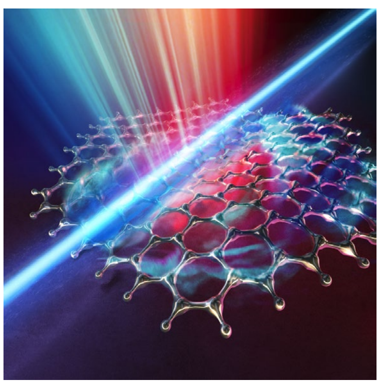
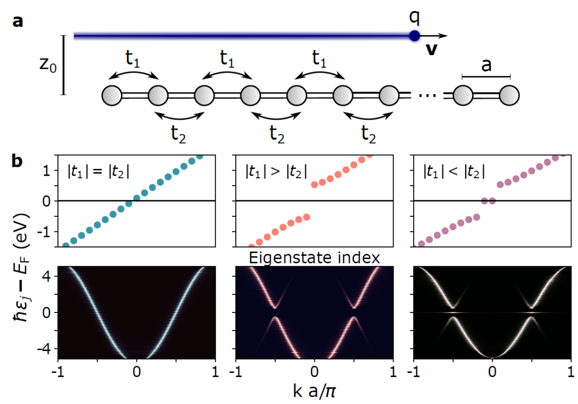
PROJECT DESCRIPTION:

Energetic electrons offer precise spatial and spectral characterization of subwavelength optical excitations supported in a wide range of nanophotonic platforms [1]. Typically, free electrons with relativistic speeds bombard a sample in cathodoluminescence (CL) and electron energy-loss spectroscopy (EELS) measurements to weakly probe the near field, mapping optical resonances on nanometer and millielectronvolt scales [2]. In photon-induced near-field electron microscopy (PINEM), the synchronization of electron beams with impinging light pulses enables exploration of dynamical processes governing nanoscale light-matter interactions [3].





The objective of this project is to theoretically explore nonlinear optical phenomena such as high-harmonic generation and saturable absorption triggered by intense light pulses and swift electrons interacting with optical resonances in low-dimensional condensed matter systems (metals, semiconductors, and topological insulators). In the first step of the project, the student will familiarize themselves with the electronic properties of a simple model in condensed matter physics: the Su-Schrieffer-Heeger (SSH) model for a one-dimensional atomic chain [4,5,6]. The student will then develop his/her own computational code, in the programming language of their preference (e.g., Matlab, C++, or Python), to describe the interaction of light pulses and/or electron beams with the atomic chain, which can describe either a conducting or semiconducting material that supports optical resonances. The simulations can be used to describe experiments where ultrashort light pulses are used to excite a nanostructure and electron beams probe the induced electromagnetic near fields; the reverse process where an energetic electron excites a nanostructure and the optical pulses excites high-energy electromagnetic radiation may also be studied. Depending on time constraints, patterned graphene islands or carbon nanotubes can also be explored [7], in which case the student can adapt their simulations to study hitherto unexplored nonlinear optical phenomena.

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