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Theory of photo-induced Floquet topological states in graphene and beyond

100-word abstract

Recent experimental and theoretical progress in ultrafast materials science opens up the promising field of photo-induced new states of matter. A tantalizing example is the possibility to realize Haldane's famous model of the Quantum Hall Effect with circularly polarized laser pulses.

Here, I will present numerical results for pump-probe photoemission spectroscopy in graphene [1] and beyond graphene. We predict spectral signatures of topologically nontrivial light-matter coupled Floquet states with energy bands and corresponding Berry curvatures that can be tuned all-optically.

[1] M. A. Sentef et al., "Theory of Floquet band formation and local pseudospin textures in pump-probe photoemission of graphene", Nature Communications 6, 7047 (2015)

250-word abstract (technical review, paper)

Ultrafast materials science holds the promise to revolutionize materials design by including the photon field coupling to a solid beyond linear response. Here we examine in detail theoretical possibilities of nonlinear effects of light-matter coupling. For continuous-wave laser driving with a time-periodic electric field, the concept of Floquet theory can be applied to a many-body Hamiltonian, with intriguing consequences. As an example, the concept of Floquet topological insulators was recently introduced. In essence, it describes a photo-induced electronic

band structure with tunable energy gaps and quantum geometry (Berry curvature) that determines the topology of the band structure.

In our work, we employ Floquet theory and the
the nonequilibrium Keldysh Green function formalism to numerically explore what can be achieved with realistic pump-probe spectroscopy setups. Specifically for graphene, we predict sizeable energy gaps at the Dirac points and nontrivial local Berry curvatures at realistic pump photon frequencies [1]. Importantly, the specifics of the pump laser pulse (polarization, frequency, pulse duration, intensity) play important roles in shaping the achieved state of matter. We make quantitative predictions that can be tested experimentally and used as clear-cut evidence of the Floquet nature of the measured results.

Finally, I will also show new results for topologically interesting materials beyond graphene, with a comparison of model calculations and ab-initio time-dependent density functional theory.

[1] M. A. Sentef et al., "Theory of Floquet band formation and local pseudospin textures in pump-probe photoemission of graphene", Nature Communications 6, 7047 (2015)