Theoretical Study of Radiation Effects on Electronic Properties in Topological Insulator

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Abstract

We investigate the electronic transport in topological insulators under the influence of circularly polarized radiation. Interestingly, the radiation breaks time reversal symmetry, leading to finite Berry curvature. We evaluate the Hall conductivity in terms of the Berry curvature. We find that when the Fermi energy is in the band gap region, the Hall conductivity reaches its maximum value and exhibits minimum value away from the gap region. Further the effects of temperature is also investigated.

Introduction:

Topological insulators (TIs) are an emerging class of quantum matter that has attracted a considerable attention in condensed matter physics and materials science. They possess gapped states in the bulk and gapless non-trivial boundary conducting states [1,2], including edge states of 2D TIs and surface states of 3D TIs. Such states are originated from intrinsic properties such as spin-orbit coupling, band inversion, bulk bands of opposite parities and are topologically protected by time-reversal symmetry. These conducting states in TIs are robust against disorder/impurities scattering and many-body interactions, leading to their potential applications in spintronics [3]. At low energies, these gapless surface states play very important role in the transport processes which are described by the massless Dirac equation in relativistic quantum mechanics. These materials are characterized by orthogonally locked spin-momentum metallic surface states, where the Dirac cone is centered at the time-reversal invariant momentum point in the Brillouin zone with spin polarized Berry phase [4, 5]

Model Hamiltonian :

$$H = v_F\left[\sigma_x \pi_y(t) - \sigma_y \Pi_x(t)\right]$$

With

$$\boldsymbol{\pi}(t) = \boldsymbol{P} + e\boldsymbol{A}(\boldsymbol{t})$$

Where

$$\boldsymbol{A}(\boldsymbol{t}) = A_0(\sin(\Omega t), \cos(\Omega t))$$

Here **A**(t) is a time dependent vector potential with $\mathbf{E}(t) = -\frac{\partial \boldsymbol{A}(t)}{\partial t}$

Where Ω is the frequency of light

The light intensity is characterized by the dimensionless parameter

$$A = \frac{eAa}{\hbar}$$

In the limit of $A^2 \ll 1$, the effective Hamiltonian of topological insulator is

$$H_{eff} = v_F\left(\sigma_x P_y - \sigma_y P_x\right) + \Delta$$

Where $\Delta = \frac{e^2 A^2 v_F^2}{\hbar\Omega}$

Eigen values :

$$E_\lambda(k) = \sqrt{\varepsilon_k{}^2 + \Delta^2},\ \varepsilon_k = \hbar k v_F$$

Eigen states:

For $\lambda = +$: $|\psi_+ > = \begin{pmatrix} \iota \cos\frac{\theta}{2} e^{-i\phi} \\ \sin\frac{\theta}{2} \end{pmatrix}$

For $\lambda = -$: $|\psi_- > = \begin{pmatrix} -\iota \sin\frac{\theta e^{-i\phi}}{2} \\ \cos\frac{\theta}{2} \end{pmatrix}$

Berry curvature:

For $|\psi_+ >$:

$$F_{k_x,ky} = \frac{-\hbar^2 v_F^2 \Delta}{2(\mathcal{E}_k^2 + \Delta^2)^{3/2}}$$

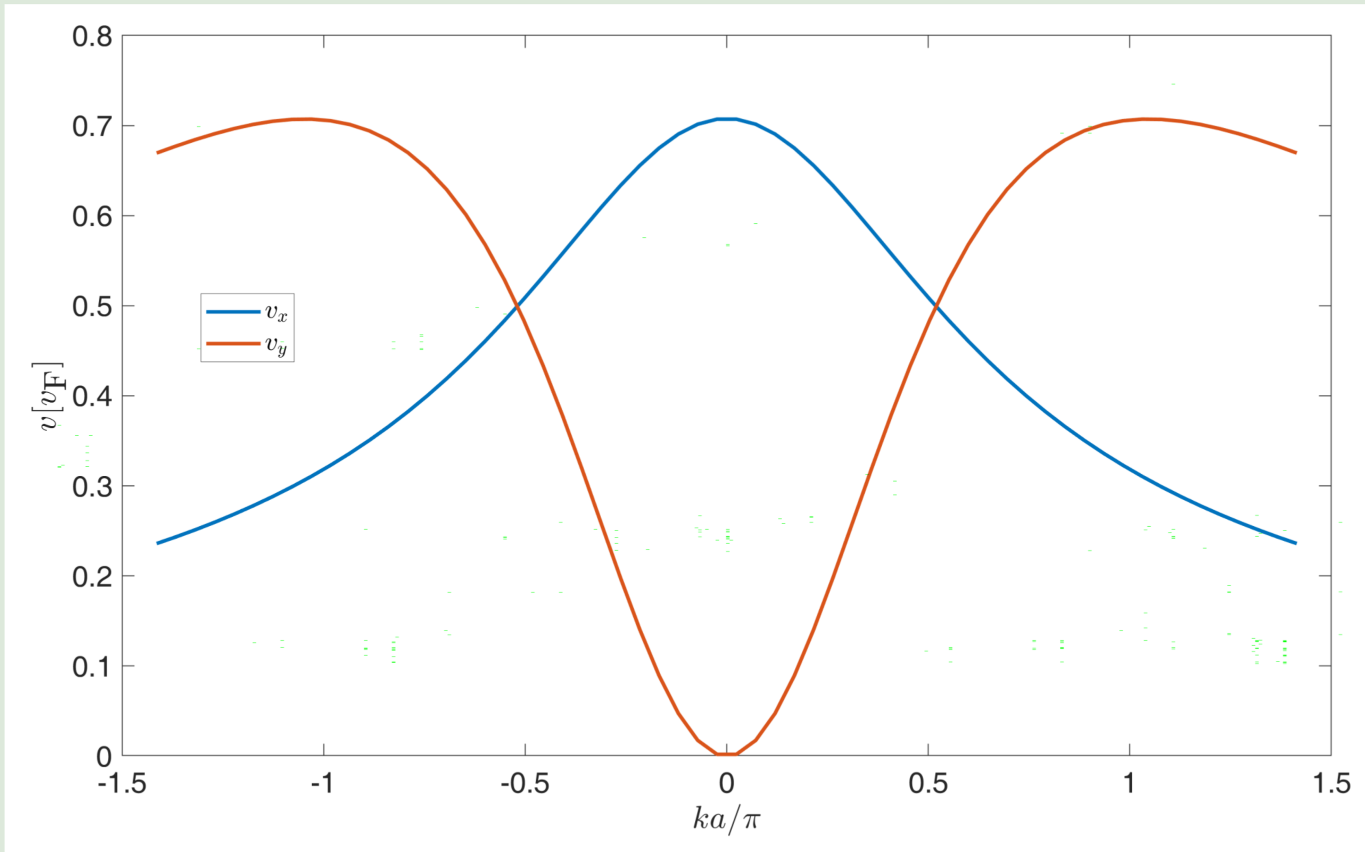
Velocity:

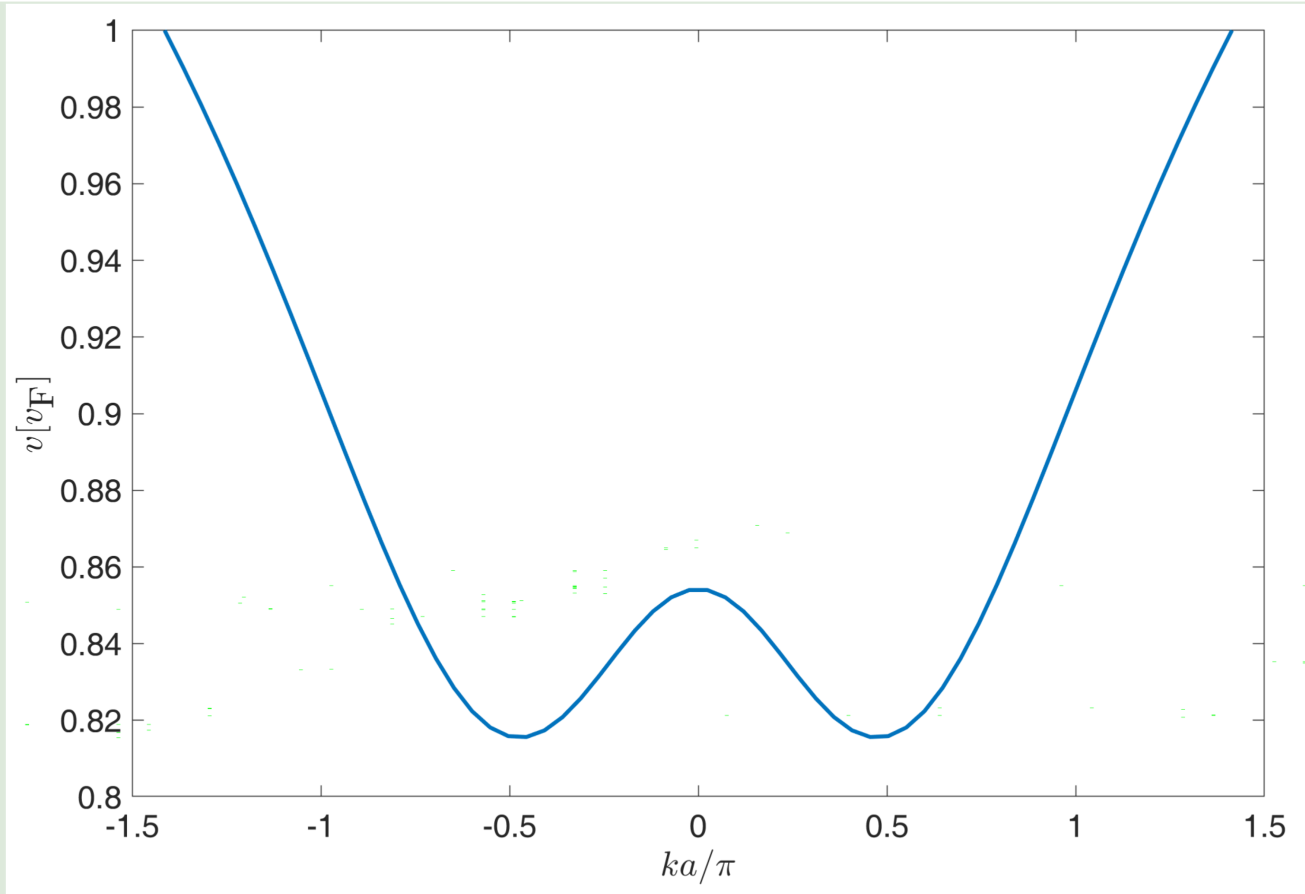
$$v(k) = -v_F\left[\frac{\hbar v_F k_x}{(\mathcal{E}_k^2+\Delta^2)^{1/2}} + \frac{E_g E_{Rad}\Delta}{2(\epsilon_k^2+\Delta^2)^{3/2}}\right]\boldsymbol{e_x} - v_F\left[\frac{\hbar v_F k_y}{(\mathcal{E}_k^2+\Delta^2)^{1/2}} - \frac{E_g E_{Rad}\Delta}{2(\epsilon_k^2+\Delta^2)^{3/2}}\right]\boldsymbol{e_y}$$

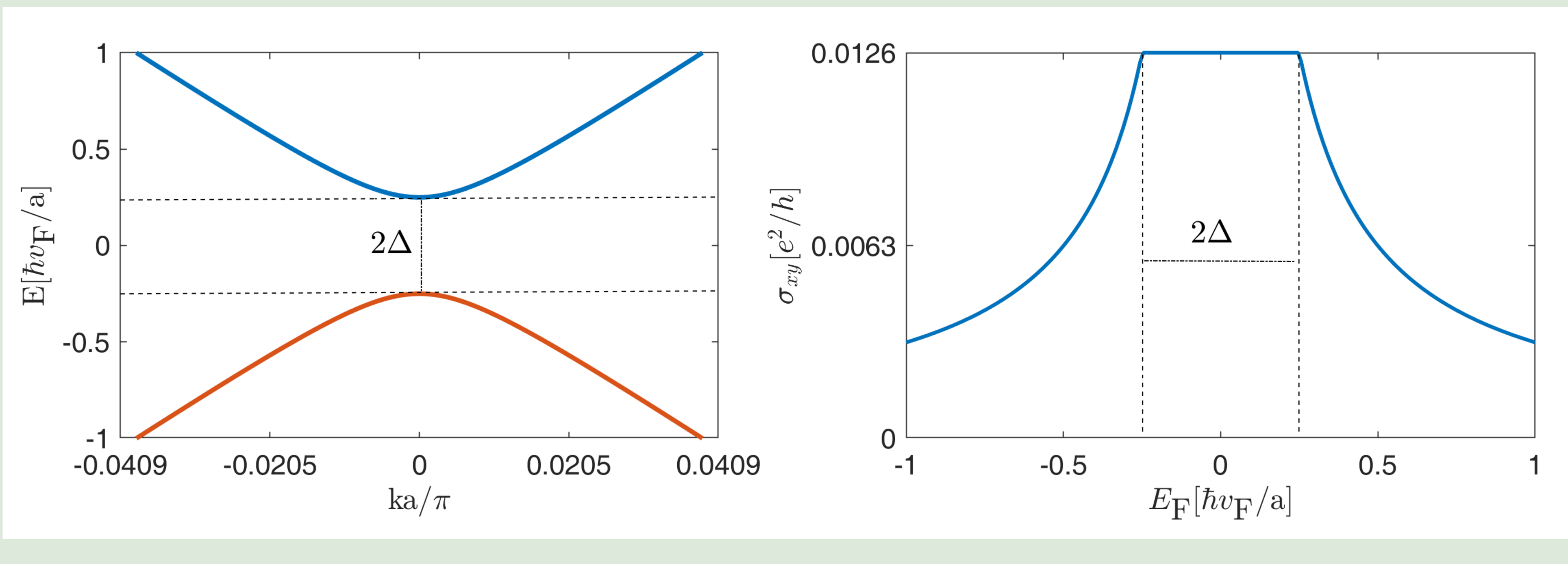
Hall Conductivity:

$$\sigma_{xy} = -\frac{e^2}{\hbar}\frac{\Delta\hbar^2 V_F^2}{2\pi}\int_0^{\frac{2\pi}{a}} dk_x \int_0^{2\pi/a} dk_y \frac{1}{(\mathcal{E}_k^2 + \Delta^2)^{3/2}}\left[f(E_+ - E_F) - f(E_- - E_F)\right]$$

Numerical Simulations and Results:







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