Observation of Floquet-Bloch states on the surface of a topological insulator

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The unique electronic properties of the surface electrons in a topological insulator [1] **are protected by time-reversal symmetry. Circularly polarized light naturally breaks time-reversal symmetry, which may lead to an exotic surface quantum Hall state** [2]**. Using time- and angle-resolved photoemission spectroscopy** [3] [4]**, we show that an intense ultrashort mid-infrared pulse with energy below the bulk band gap hybridizes with the surface Dirac fermions of a topological insulator to form Floquet-Bloch bands when the pump pulse is present [Fig. 1]** [5]**. These photon dressed surface bands exhibit polarization-dependent band gaps at avoided crossings [Fig. 2A and B]. Circularly polarized photons induce an additional gap at the Dirac point [Fig. 2C], which is a signature of broken time-reversal symmetry on the surface. The size of the gaps are consistent with the calculation based on Floquet-Bloch theory** [6]**. This results in a Chern insulator as originally proposed by Haldane** [7]**. These observations establish the Floquet-Bloch bands in solids and pave the way for optical manipulation of topological quantum states of matter.**

References

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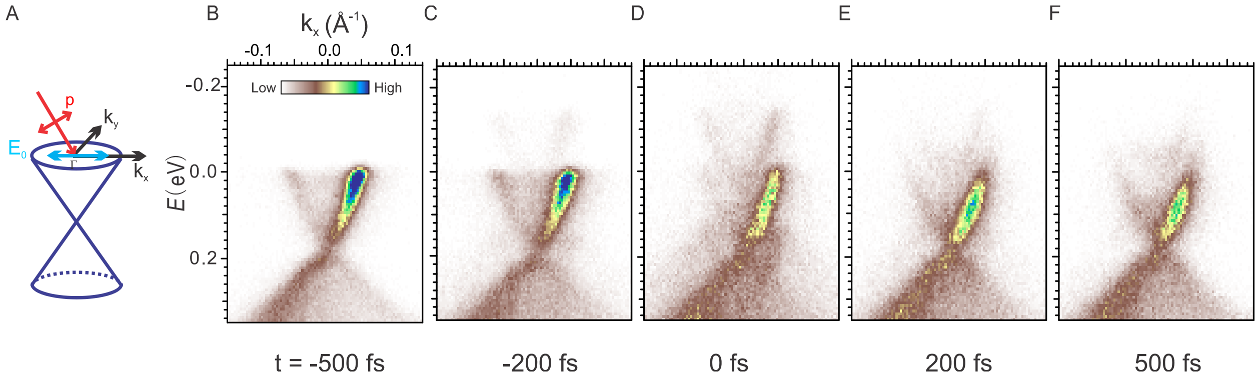

Fig. 1. Angle resolved photoemission spectra (APRES) of Bi_2Se_3. (**A**) A sketch of the experimental geometry for the p-polarized case. k_x is defined to be the in-plane electron momentum parallel to the pump scattering plane**.** (**B-F**) ARPES data for several pump-probe time delays t (values indicated in the figure) under strong linearly polarized mid-infrared (MIR) excitation of wavelength $\lambda = 10$ µm.

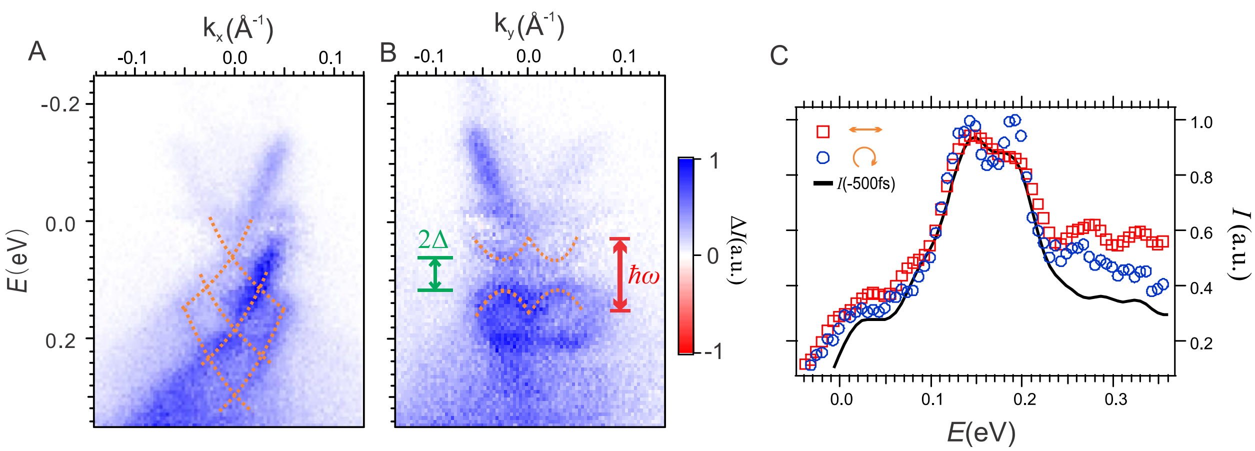

Fig. 2. ARPES spectra at 0 fs time delay under linearly and circularly polarized MIR excitation. (**A**) and (**B**) show the energy-momentum spectra through Γ along $\boldsymbol{k_x}$ and $\boldsymbol{k_y}$ direction respectively with linear pump; (**C**) EDCs through Γ under linearly (red squares) and circularly (blue circles) polarized pump at $t = 0$ fs as well as the EDC through Γ taken at $t = -500$ fs (black)