Electronic Supplementary Material (ESI) for Nanoscale Horizons.

Supplementary Information

Experimental evidence of a new class of massless fermions

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Materials and Methods

Experiment

The experiments have been performed under ultrahigh vacuum (UHV) conditions with a base pressure of $5 \cdot 10^{-11}$ mbar. Before insertion into UHV chamber Si(110) sample of a size of 18x4x0.4 mm^3 was cleaned in acetone in ultrasound bath. In the next step the substrate was cleaned under UHV by a short direct current flashes until SiC was removed and a clean surface revealing (16x2) reconstruction was obtained. Bi and Pb have been deposited from resistively heated crucibles on the substrate kept at room temperature following by annealing at 250°C for 3 minutes. The amount of the deposited Bi and Pb atoms has been controlled by water-cooled quartz crystal monitor which, prior to the reported experiments, was calibrated either by recording intensity of specularly reflected electron beam (reflection high energy electron diffraction) during monolayer by monolayer growth of Pb on Si(111) or by the appearance of (3x2) and (1x1) Bi reconstructions of Si(110).

The Angle Resolved PhotoElectron Spectroscopy (ARPES) experiments have been performed with helium lamp (unpolarized HeI line, 21.2 eV), hemispherical electron energy analyser (Phoibos 150), multichannel plate detector and 5 axis manipulator. The energy and angle resolutions were set to 40 meV and 0.2°, respectively. The ARPES measurements have been performed at room temperature.

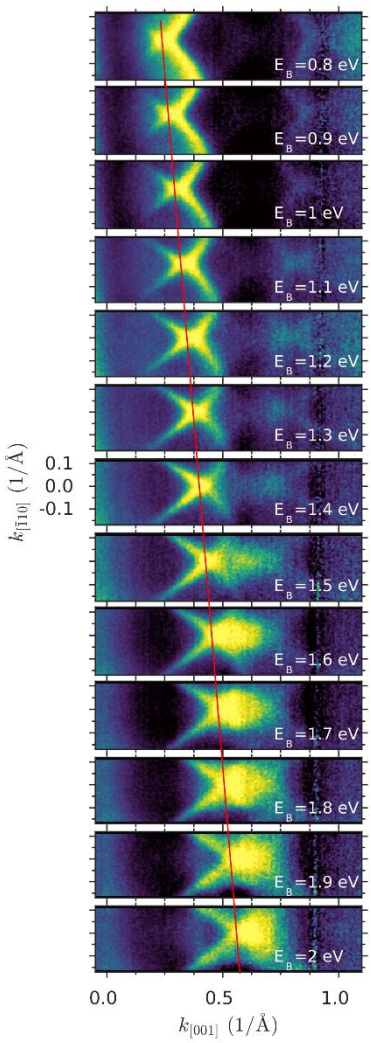
Calculations

First-principles calculations were performed using density functional theory (DFT) with the projector augumented waves (PAW) [15] and Perdew-Burke-Ernzerhof (PBE) [16] generalized gradient approximation (GGA) to the exchange-correlation interaction, available in VASP (Vienna ab-initio simulation package) [17, 18].

The plane wave basis set was restricted by an energy cutoff of 340 eV. The 12x8x1 Monkhors-Pack k-points grid, including the Γ point, was used in the Brillouin zone sampling [19]. The total energy convergence criterion was chosen to be 10^{-6} eV.

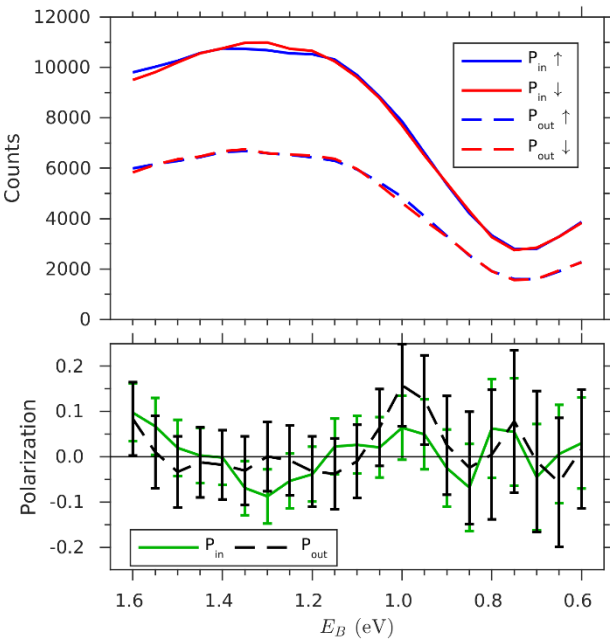
The Si(110) system has been modeled by a symmetric slab of Si layers, featuring two equivalent surfaces. Different number of Si layers have been used in calculations. The Si atoms in the middle layer were fixed at their bulk positions. The positions of the rest of atoms were fully relaxed by a conjugate gradient method until the maximum force in any direction was less than 0.01 eV/Å.

Figures



Supplementary Figure 1

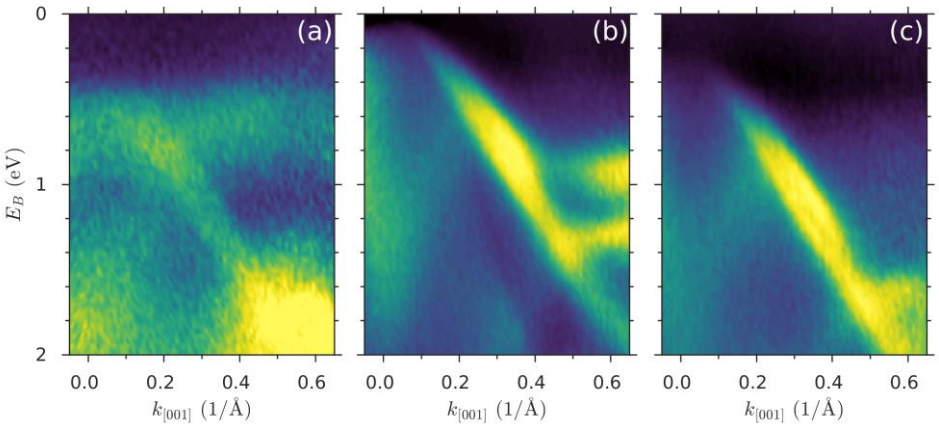
Constant energy photoemission maps of Bi/Si(110) for different electron binding energies. Beside linear character of the four bands presented in each map the red line drawn through the maps indicates linear changes with the electron binding energy position of the entire set of bands.



Supplementary Figure 2

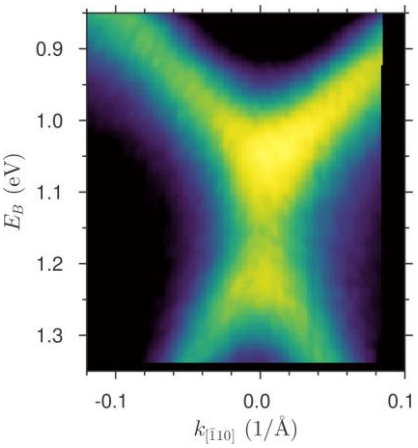
Results of spin-resolved photoemission experiments. The upper plot presents number of electron counts vs electron binding energy for the in plane (solid curves) and out-of-plane (dashed curves) channels of the Mott detector. The resulting in-plane (green solid) and out-of-plane (black dashed) components of the polarization vector of the photoemitted electrons.

Spin-resolved photoemission spectra were collected in the same ARPES system equipped with the Mott spin detector with thorium target and operating at 25 keV. The Sherman function of the spin detector equals S = −0.16.



Supplementary Figure 3

Electronic band structure (photoemission intensity maps) along the [001] direction showing two linear and parallel bands indicative of fortune teller states in the bare Si(110) a), Pb/Si(110) b) and Bi/Si(110) c).



Supplementary Figure 4

Band structure of Bi/Si(110) along the [-110] direction (perpendicular to the [001] shown in Figure 1a) taken at $k_{[001]}$=0.35 1/Å.