High-temperature Majorana corner modes in a d+id′ superconductor heterostructure:

Application to twisted bilayer cuprate superconductors

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Abstract

The realization of Majorana corner modes generally requires unconventional superconducting pairing or s-wave pairing. However, the bulk nodes in unconventional superconductors and the low T_c of s-wave superconductors are not conducive to the experimental observation of Majorana corner modes. Here, we show the emergence of a Majorana corner mode at each corner of a two-dimensional topological insulator in proximity to a d+id′ pairing superconductor, such as heavily doped graphene or especially a twisted bilayer of a cuprate superconductor, e.g., $Bi_2Sr_2CaCu_2O_{8+\delta}$, which has recently been proposed as a fully gapped chiral $d_{x2-y2}+id_{xy}$ superconductor with T_c close to its native 90 K, and an in-plane magnetic field. By numerical calculation and intuitive edge theory, we find that the interplay of the proximity-induced pairing and Zeeman field can introduce opposite Dirac masses on adjacent edges of the topological insulator, which creates one zero-energy Majorana mode at each corner. Our scheme offers a feasible route to achieve and explore Majorana corner modes in a high-temperature platform without bulk superconductor nodes.

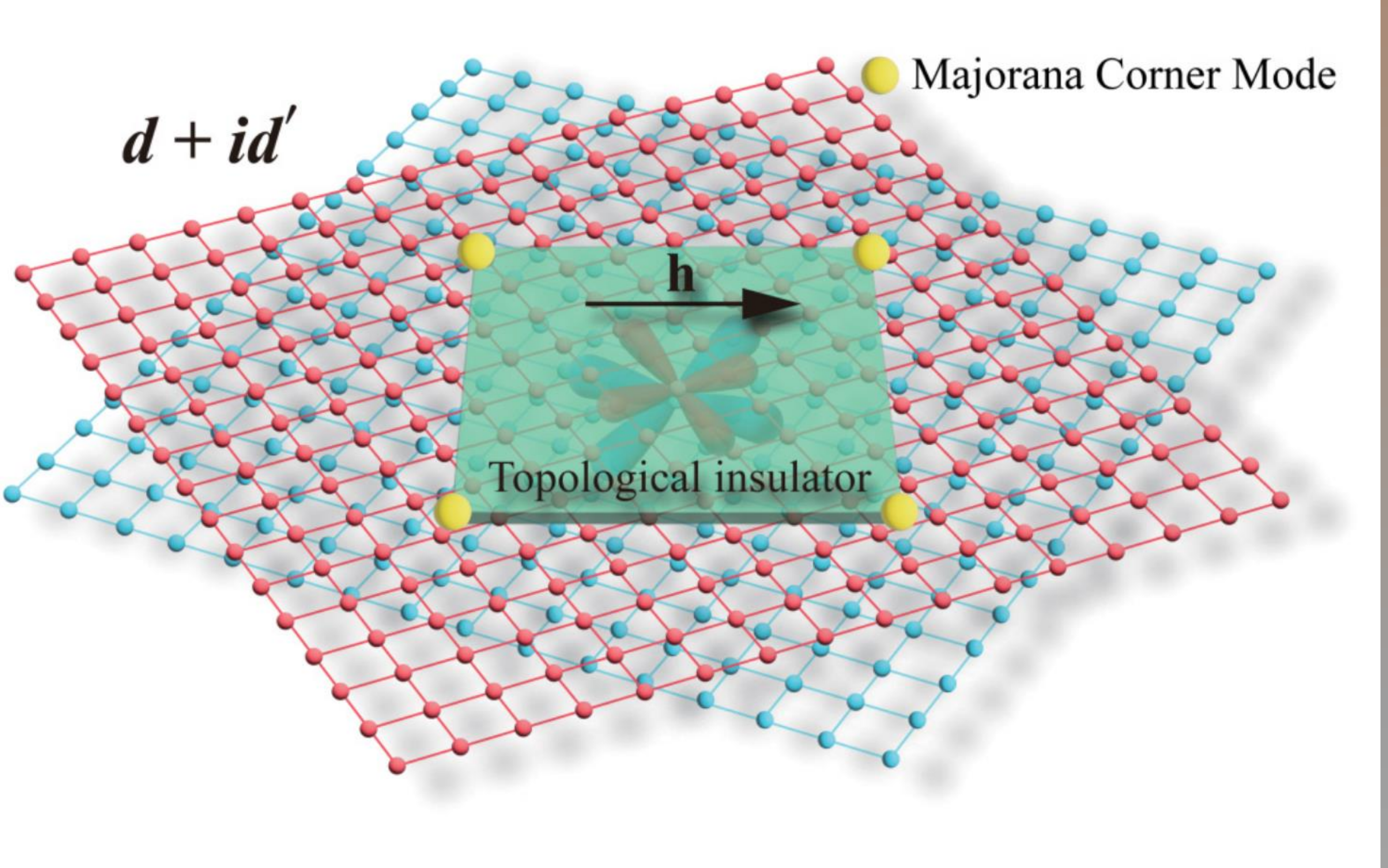

FIG. 1. Schematic diagram of the proposed setup. A heterostructure composed of a 2D topological insulator deposited on a high-T_c fully gapped $d + id'$ pairing superconductor such as a twisted bilayer of cuprate superconductor monolayers and subject to an in-plane Zeeman field. The sphere at each corner represents one zero-energy Majorana corner mode.

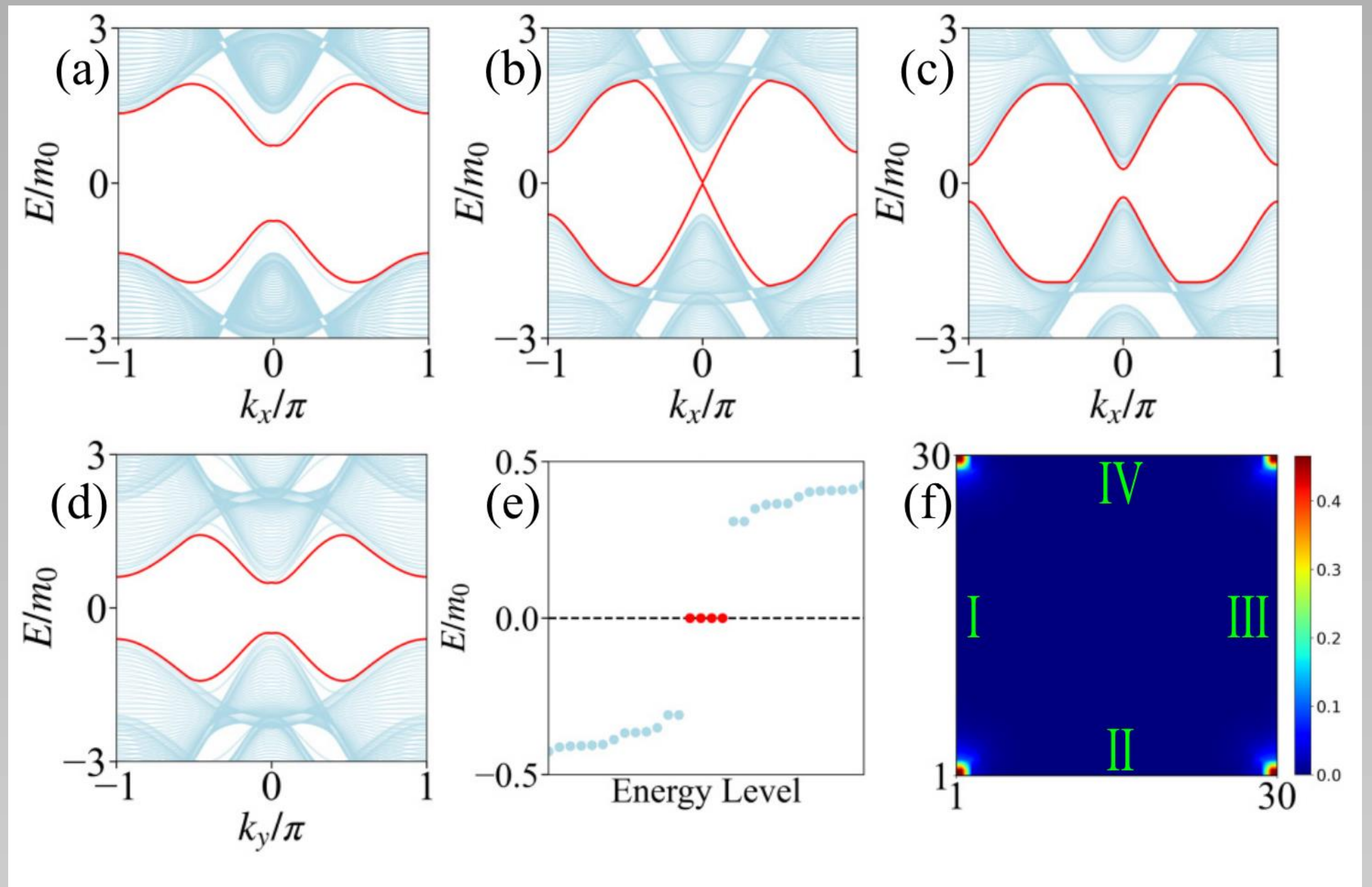

FIG. 2. Quasiparticle bands with edge spectra (red lines) and bulk spectra (light blue lines) for an open boundary condition along the y direction for (a) $h_x = 0$, (b) $h_x = 0.75$, and (c) $h_x = 1$. The gap for the edge spectrum closes at the critical Zeeman field $h_x = 0.75$. (d) Quasiparticle bands with the edge spectrum (red lines) and bulk spectra (light blue lines) for open boundary conditions along the x direction with the critical Zeeman field $h_x = 0.75$. (e) Eigenvalues of the real-space TB Hamiltonian with $h_x = 1$ for a 30×30 square size sample. (f) The density plot displays the corner localized probability distribution of the four zero-energy MCMs in (e). I, II, III, and IV label the four edges. Common parameters are $m_0 = 1$, $t_x = t_y = \lambda_x = \lambda_y = 2$, $\Delta_1 = \Delta_2 = 0.5$, $\mu = 0.1$.

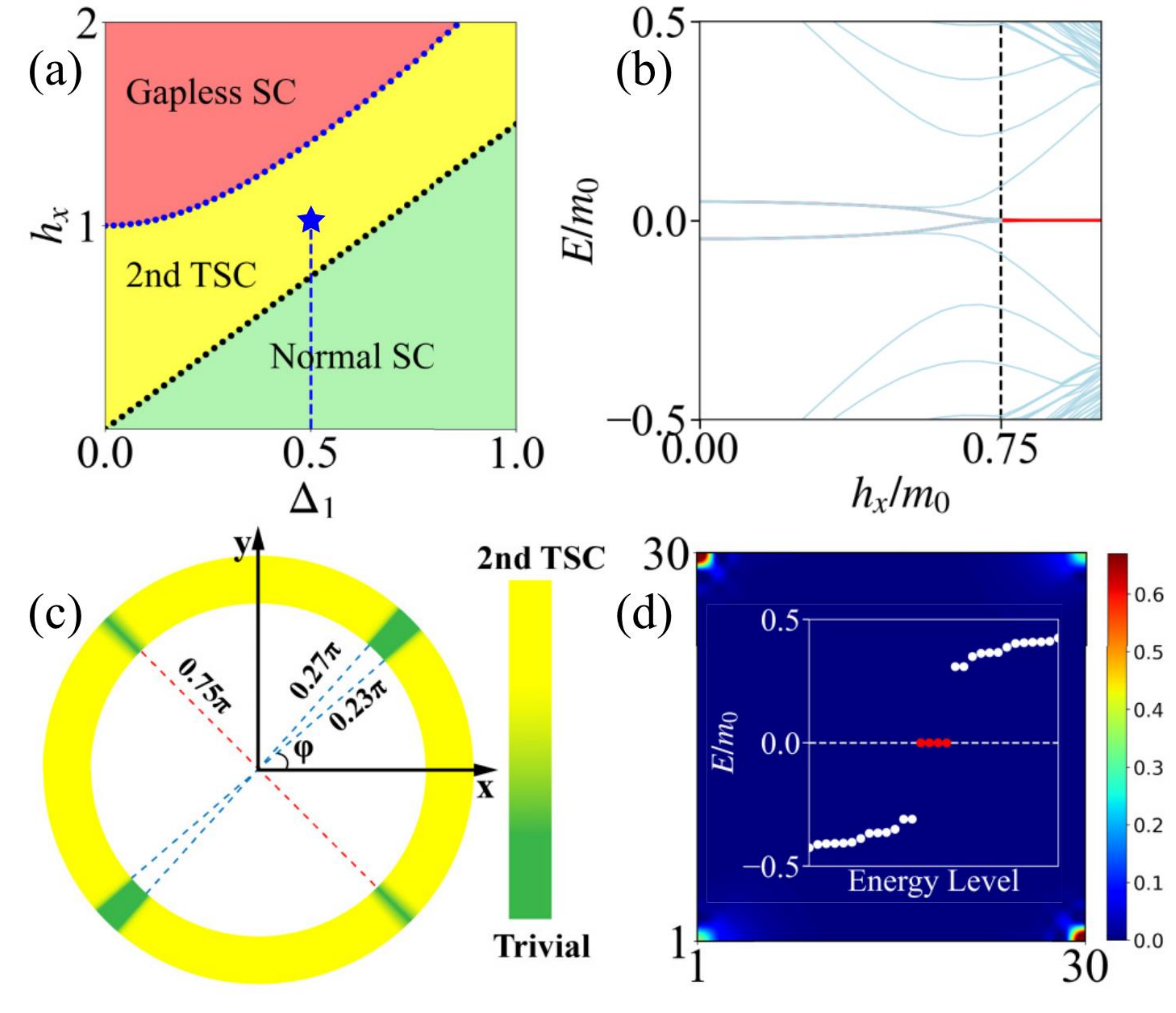

FIG. 3. (a) Phase diagram vs h_x and Δ_1. (b) Line-scan real-space spectra along the blue dashed line in (a). $\mu = 0.1$. (c) Phase diagram as a function of the azimuth of the in-plane Zeeman field. Parameters are $h_\parallel = m_0$, $h_x = h_\parallel \cos\varphi$, $h_y = h_\parallel \sin\varphi$, $\mu = 0$. (d) Energy spectrum of the real-space TB Hamiltonian at $\varphi = 0.4\pi$, $\mu = 0.1$ for a 30×30 square size sample. The density plot exhibits the corner localized probability distribution of the four zero-energy MCMs.

In conclusion, we have demonstrated that a heterostructure composed of topological insulators and twisted bilayer cuprate superconductors can host MCMs when an in-plane Zeeman field is applied. Our proposed setup with fully gap pairing and high transition temperature has great advantages for the experimental observation of the zero-energy MCM signals. Our work may also stimulate further studies of MCMs in twisted systems.

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