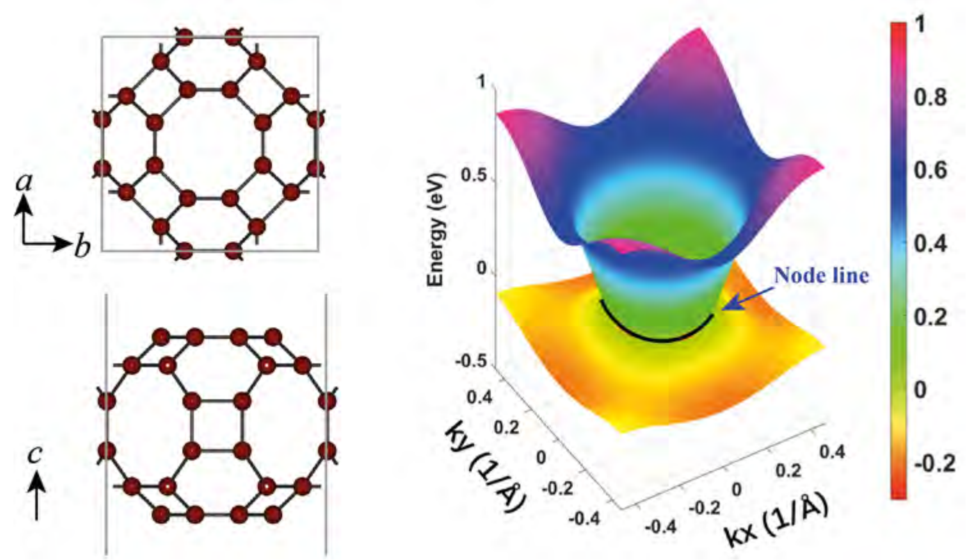
A novel 2D all-carbon Dirac node-line semimetal

– DOI: 10.1051/epn/2024403

Topological semimetals are a class of materials that possess unique electronic properties due to their topological characteristics. Unlike conventional metals, topological semimetals exhibit band structures where conduction and valence bands touch at discrete points or along lines in momentum space.

These features give rise to exotic quasiparticles and robust electronic states that are protected by the material's topology. There are several types of topological semimetals, including Dirac semimetals, Weyl semimetals, and Dirac node-line semimetals.[1]

Among them, Dirac node-line semimetals are a class of materials characterized by their unique electronic properties, where the energy bands form closed loops or lines in momentum space, rather than discrete points. These materials are of significant interest in condensed matter physics due to their potential applications in fractional topology, high transition temperature superconductivity, and other advanced technologies. Theoretical calculations have predicted that a new all-carbon allotrope, the three-dimensional (3D) Mackay-Terrones crystal, can realize a node-line topological semimetal state.[2] So far, only a very few of these novel node-line semimetals have been experimentally observed, and the theoretical prediction of the materials is also lacking.



▲ Top and side view of TCH-SSH-2D, and the band structure with Dirac node-line.

Through theoretical calculation, it is predicted that a new two-dimensional (2D) all-carbon single substance (named TCH-SSH-2D) can realize the node-line semimetal state.[3] This 2D structure is constructed based on the Su-Schrieffer-Heeger (SSH) lattice model, utilizing Truncated Cubotahedron (TCH) polyhedra as building units (Figure 1). In this Dirac node-line material, the conduction and valence bands touch along a loop at the Fermi surface, rather than a single point as in Dirac or Weyl semimetals. This results in a linear dispersion relation near the node-line, and the Fermi velocities of TCH-SSH-2D exhibit isotropy and share the same order of magnitude with that of graphene.[4] The symmetrical constraint imposed by the crystal structure of TCH-SSH-2D prevents the node-lines from being disrupted or damaged by small disturbances, ensuring the robust existence and protection of the node-line feature. This work further extends the concept of Dirac node-line from 3D to 2D systems, introducing a novel 2D Dirac node-line carbon allotrope, and provides a new potential candidate for carbon-based high-speed electronic devices.

Overall, Dirac node-line materials represent a fascinating frontier in condensed matter physics, with the potential to unlock new technologies and deepen our understanding of topological phases of matter. Of course, there are still many challenges in the research of node-line semimetals. Creating high-quality single crystals of node-line materials can be challenging, which is necessary for detailed experimental investigations; understanding how to manipulate the node-line through external fields, doping, or strain is crucial for practical applications; investigating how node-line materials interact with other electronic phases, such as superconductivity or magnetism, remains an active area of research. ■

References

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