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Crossover from 2-D metal to 3-D Dirac semimetal in metallic PtTe2 films with local Rashba effect

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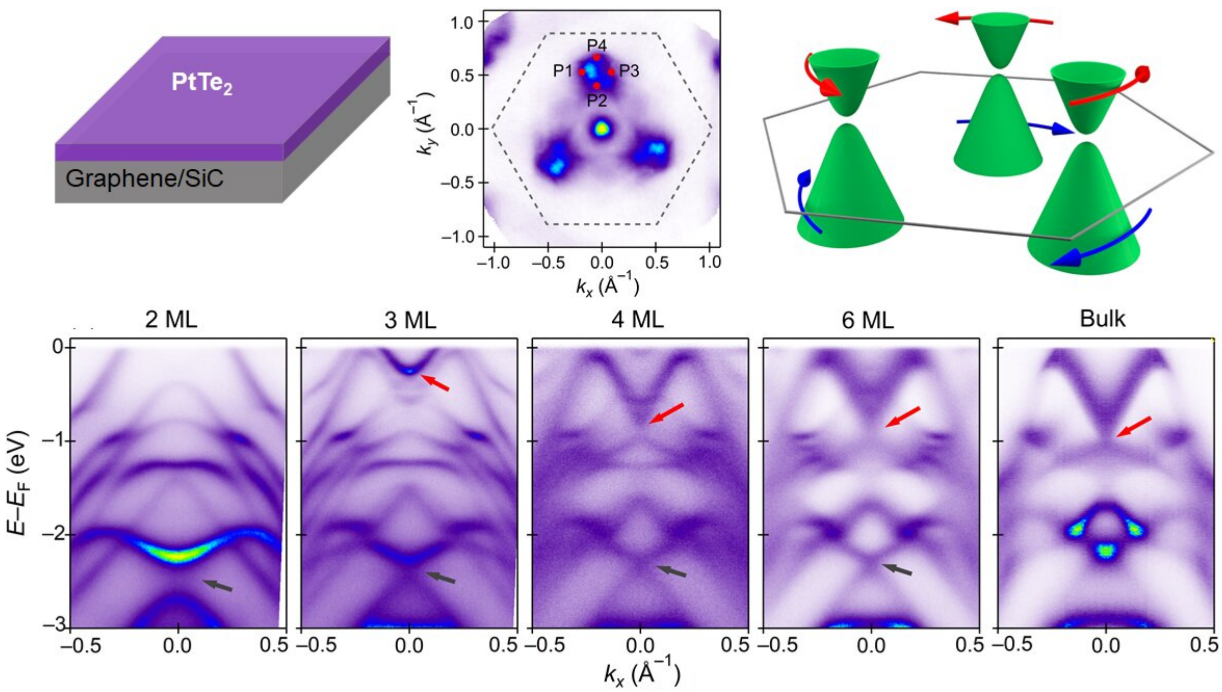

Thickness dependent band structure of PtTe2 thin films and helical spin texture of bulk PtTe2 crystal Credit: ©Science China Press

Transition metal dichalcogenides (TMDCs) formed by group 10 metals (e.g. $PtSe_2$, $PtTe_2$) have emerged as important materials with intriguing properties discovered both in bulk single crystals and atomically thin films. While bulk $PtSe_2$ and $PtTe_2$ are type-II Dirac semimetals, monolayer (ML) $PtSe_2$ film is a semiconductor with helical spin texture induced by local Rashba effect. However, the properties of atomically thin $PtTe_2$ films and the evolution with film thickness remain unexplored. Recently, Shuyun Zhou's group from Tsinghua University reported a systematic study on the electronic structure of high quality $PtTe_2$ thin films with thickness from 2 ML to 6 ML grown by molecular beam epitaxy (MBE). This work provides direct experimental evidence for a crossover from 2-D metal (2ML film, distinguished from the semiconducting $PtSe_2$ film) to 3-D Dirac semimetal in $PtTe_2$ films with spin texture induced by local Rashba effect.

In bulk $PtTe_2$ crystal, massless Dirac fermions are found to emerge at the topologically protected touching points of electron and hole pockets. The strongly tilted Dirac cone along the out-of-plane momentum direction breaks the Lorentz invariance and therefore the low energy excitations are Dirac fermions that do not have counterpart in high-energy physics. Their previous work shows that the isostructural material $PtSe_2$ is also a type-II Dirac semimetal, and there is a 3-D Dirac semimetal-semiconductor transition with decreasing thickness. In addition, monolayer $PtSe_2$ shows interesting helical spin texture induced by local Rashba effect (R-2) despite the fact that the monolayer film itself is centrosymmetric. Such hidden spin texture induced by local Rashba effect has been expected to provide an important platform for realizing novel topological superconductivity with odd parity if superconductivity with s-wave pairing can be induced. However, considering that monolayer $PtSe_2$ is a semiconductor with a large gap size of 1.2 eV, it is difficult to tune the Fermi energy in such a large range to make it a superconductor. It is therefore critical to find a similar centrosymmetric film with a local Rashba effect yet with a metallic property, which can provide a better opportunity for realizing topological superconductivity.

In this work, by using ARPES, Shuyun Zhou's group directly detects the electronic structure of $PtTe_2$ thin films with different thickness, and observed metallic band dispersion of $PtTe_2$ thin films even down to 2 ML. A crossover from 2-D metal (2ML, distinguished from the 2 ML semiconducting $PtSe_2$ film) to 3-D Dirac semimetal is also revealed. The electronic dispersion exhibits strong thickness dependent: with increasing film thickness, the V-shaped pockets at the Fermi level in 2 ML and 3 ML films move down in energy and eventually touch the hole-like pocket at higher binding energy, leading to the formation of a three-dimensional type-II Dirac fermions in 4-6 ML films, which show similar dispersion to bulk crystal and thus are effectively a topological semimetal. Further spin-ARPES measurements on $PtTe_2$ bulk crystal reveal a helical spin texture induced by local Rashba effect. Since the Rashba effect is determined by the crystal symmetry and bulk and thin film $PtTe_2$ share the same symmetry, similar spin texture by local Rashba effect is also expected in $PtTe_2$ thin films.

This systematic investigation on $PtTe_2$ thin films with controlled thickness offers a unique platform to study the metallic thin films with local Rashba effect, and opens up opportunities for further investigating the intriguing properties, e.g. doping induced superconductivity or topological superconductivity.

More information: Ke Deng et al, Crossover from 2D metal to 3D Dirac semimetal in metallic $PtTe_2$ films with local Rashba effect, *Science Bulletin* (2019). DOI: 10.1016/j.scib.2019.05.023

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