


2D Topological Semimetals grown by Molecular Beam Epitaxy

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Topological Dirac and Weyl semimetals, often called the « new 3D graphene», are a new state of matter that shows linear dispersions (Dirac cones) in all three dimensions in the reciprocal space. Weyl fermions predicted by quantum field theory have never been observed in free space, so their low energy « incarnations » in semimetals offers a unique opportunity to merge high energy elementary particle physics with condensed matter. Discovering and engineering topological semimetals from the family of 2D Transition Metal Dichalcogenide materials could open the way to the exploitation of their unique topological properties by fabricating thin epitaxial films and devices on suitable crystalline substrates.

At the Epitaxy and Surface Science Laboraotory (ESSL) of INN / NCSR DEMOKRITOS in Greece, we grow 2D $HfTe_2$, $ZrTe_2$, $TiTe_2$ and $MoTe_2$ thin films by MBE on technologically important AlN/Si and InAs/Si substrates. ESRF synchrotron GIXD and STEM at INAC show that the materials are rotationally aligned with the InAs substrates having low in-plane mosaicity (lowest observed so far) and a clear quasi van der Waals (vdW) gap with the substrate indicating high quality vdW epitaxy (Fig. 1). Imaging of electronic band structure by in-situ ARPES at NCSRD provides for the first time compelling evidence that 1T-$HfTe_2$ and 1T-$ZrTe_2$ are Dirac semimetals (Fig. 2). The 2D Dirac cones persist down to the ultimate 2D limit of a single layer indicating that $ZrTe_2$ could be regarded as an electronic analogue to graphene.

Moreover, using STEM, we made the first direct observation at room temperature of the orthorhombic (Td), type-II Weyl semimetal phase in epitaxial $MoTe_2$ (Fig. 2). Its stability at room temperature is a result of tensile strain from the substrate which stabilizes an elongated interlayer antibonding state characteristic of Td-$MoTe_2$.

In a single monolayer 1T-$TiTe_2$, using in-situ STM we obtained evidence for a charge density wave instability at room temperature which is not expected on the basis of electronic band structure imaged by in-situ ARPES.

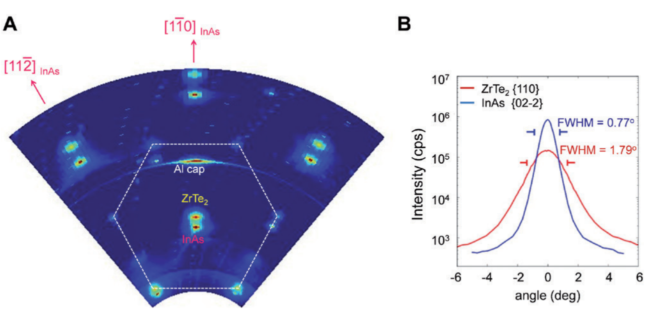

Fig. 1: XRD reciprocal space map (A) and rocking curves (B) showing excellent epitaxial alignment of $ZrTe_2$ epilayer substrate

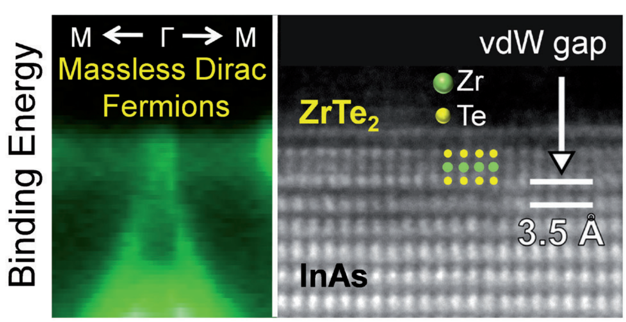

Fig. 2: ARPES imaging (left) showing Dirac cone of 1 ML $ZrTe_2$. STEM (right) showing quasi vdW gap at the interface.

OUTCOMES

[1] Massless Dirac Fermions in $ZrTe_2$ semimetal grown on InAs (111) by vdW epitaxy, ACS Nano 12, 1696 (2018)

[2] MBE of thin $HfTe_2$ semimetal films, 2D Mater. 4, 015001 (2017)

[3] Direct observation at room temperature of the orthorhombic Weyl semimetal phase in thin epitaxial $MoTe_2$, Adv. Funct. Mat. (2018) doi.org/10.1002/adfm.201802084

Invited presentations (A. Dimoulas)

-EUROMBE19, St. Petersbourg, Russia, 2017

-EW-MOVPE17, Grenoble, 2017

-EUROMAT 2017, Thessaloniki, Greece, 2017

-FLATLANDS beyond Graphene, Lausanne, Switzerland (2017)

-NANO-KISS Summer School, Seoul, Korea 2017

-ECS 223rd meeting, Seattle, 2018

Leverage:

-ERC-AdG-SMARTGATE-291260

-Equipex ANR-11-EQPX-010