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Interfaces between graphene and MoS_2 probed STM and ARPES

Matthias Batzill
University of South Florida, Tampa

<u>At USF:</u>

Horacio Coy-Diaz
Dr. Rafik Addou

<u>Antares beamline at SOLEIL:</u>

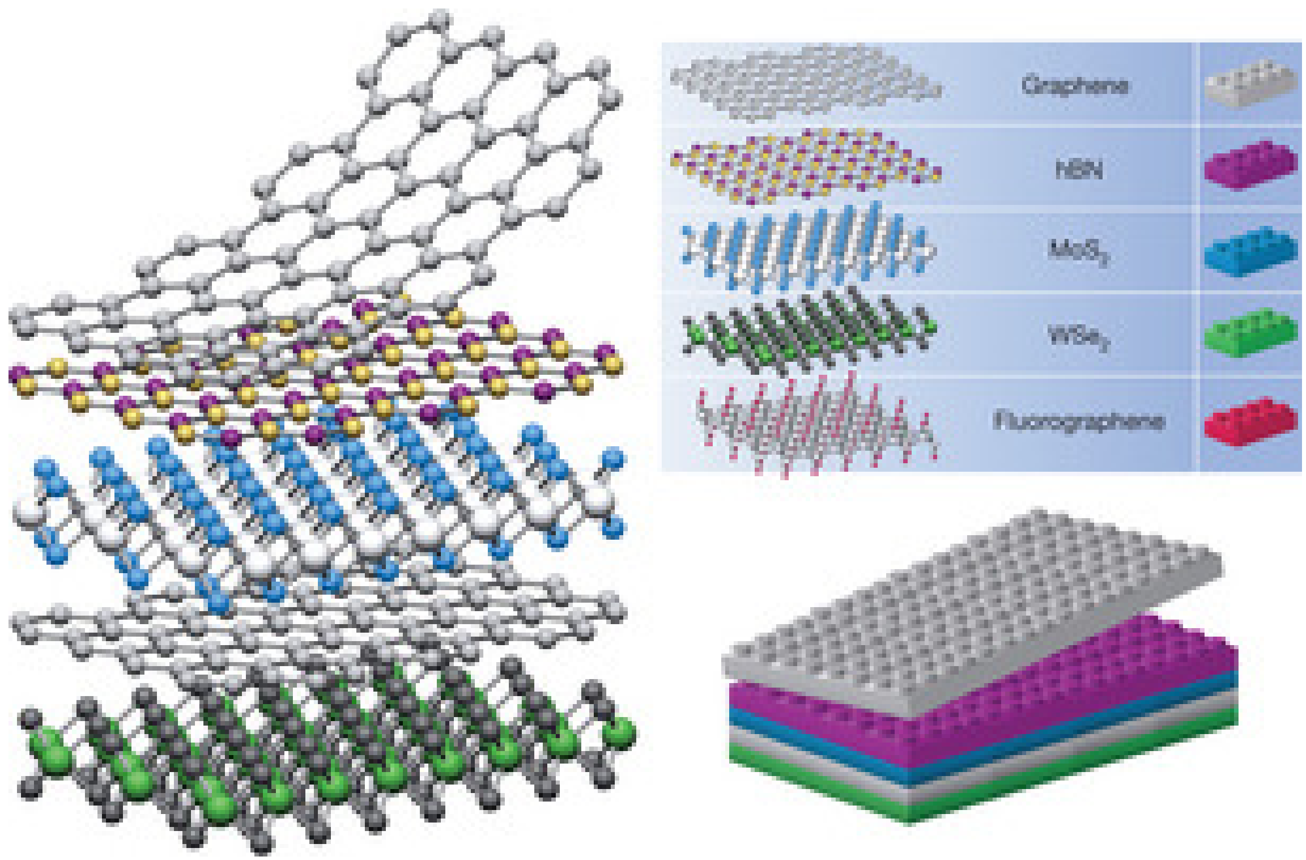
Dr. José Avila
Dr. Chaoyu Chen
Prof. Maria C. Asensio

rtificial crystals or device-structures made of 2D-materials

Van der Waals heterostructures

K. Geim[1,2] & I. V. Grigorieva[1]

25 JULY 2013 | VOL 499 | NATURE | 419



How do interactions between layers modify properties?

305 (2010) PHYSICAL REVIEW LETTERS week ending 24 SEPTEMBER 2010

Atomically Thin MoS_2: A New Direct-Gap Semiconductor

Kin Fai Mak,[1] Changgu Lee,[2] James Hone,[3] Jie Shan,[4] and Tony F. Heinz[1,*]

[1]*Departments of Physics and Electrical Engineering, Columbia University, 538 West 120th Street, New York, New York 10027, USA*

[2]*SKKU Advanced Institute of Nanotechnology (SAINT) and Department of Mechanical Engineering, Sungkyunkwan University, Suwon 440-746, Korea*

[3]*Department of Mechanical Engineering, Columbia University, New York, New York 10027, USA*

artment of Physics, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, Ohio 44106, USA

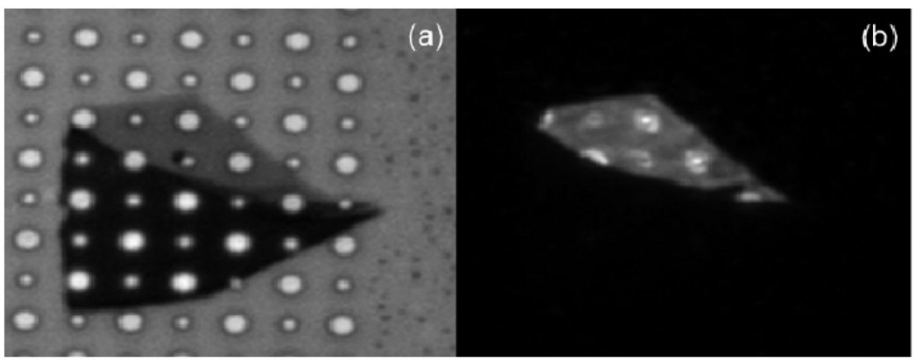
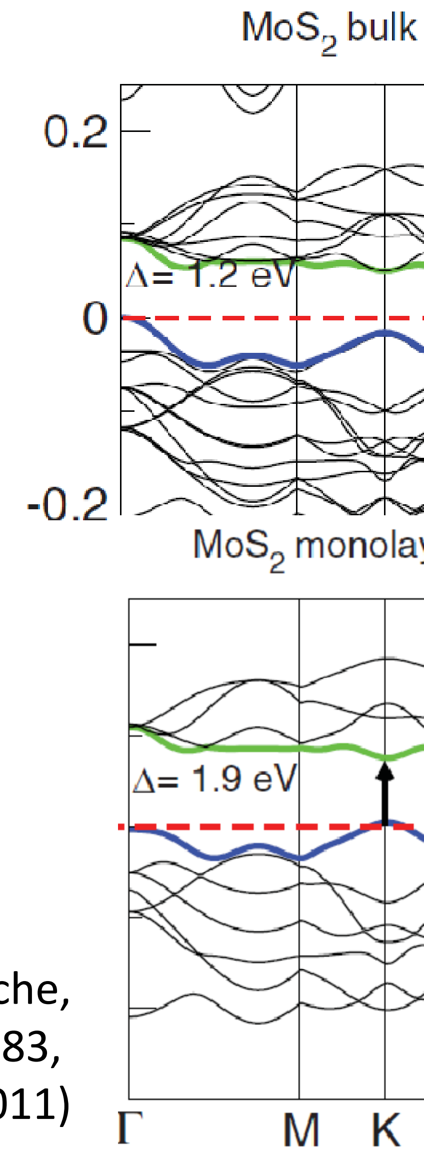


FIG. 2. (a) Representative optical image of mono- and few-layer MoS_2 crystals on a silicon substrate with etched holes of 1.0 and 1.5 μm in diameter. (b) PL image of the same samples. The PL QY is much enhanced for suspended regions of the monolayer samples, and the emission from the few-layer sample is too weak to be seen in this image.

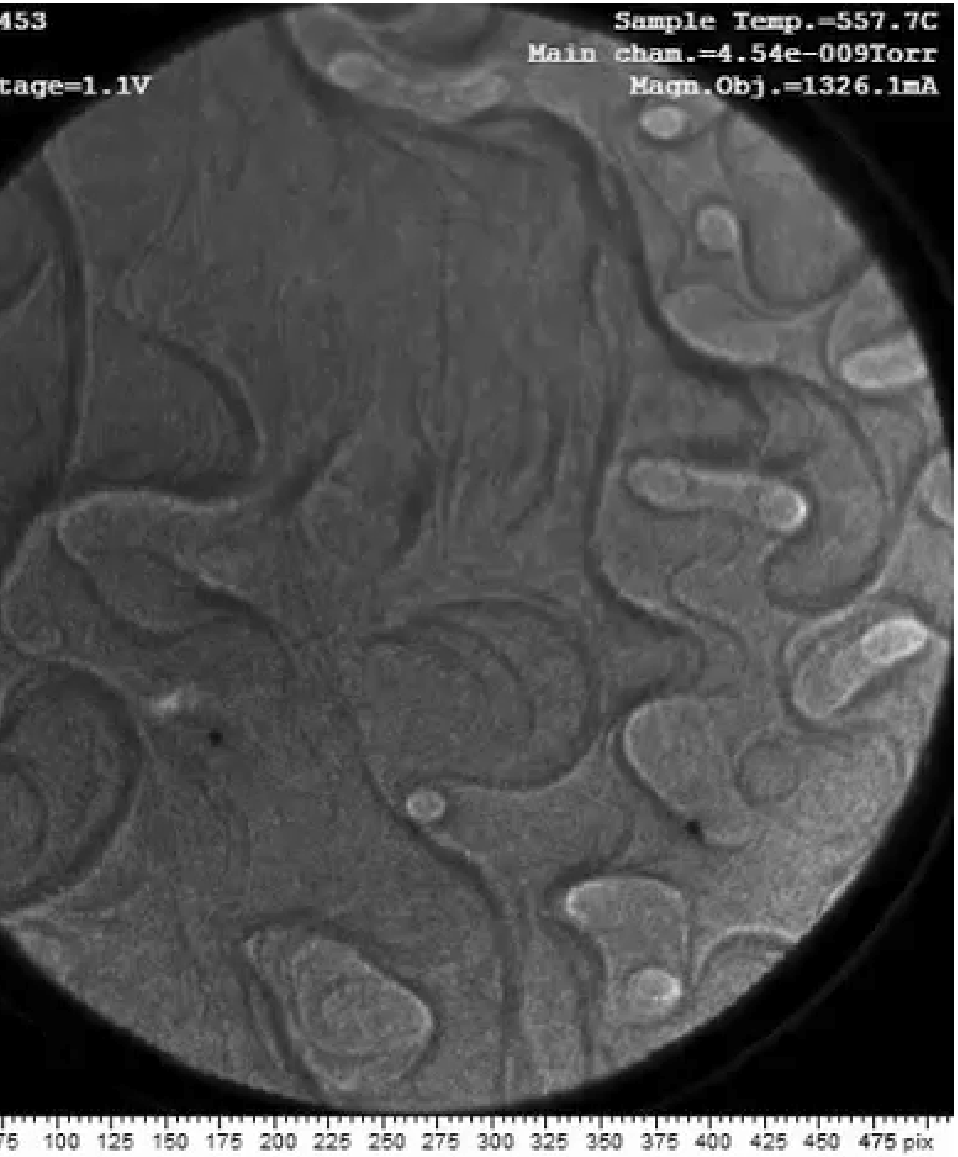


Kuc, Zibouche, Heine PRB 83, 245213 (2011)

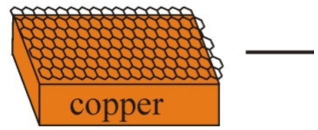
If interlayer interactions are important for the electronic structure of van der Waals materials, how do interlayer interactions affect heterostructures of van der Waals materials?

Here we study graphene/MoS_2 interfaces.

Preparation of graphene/MoS_2 samples

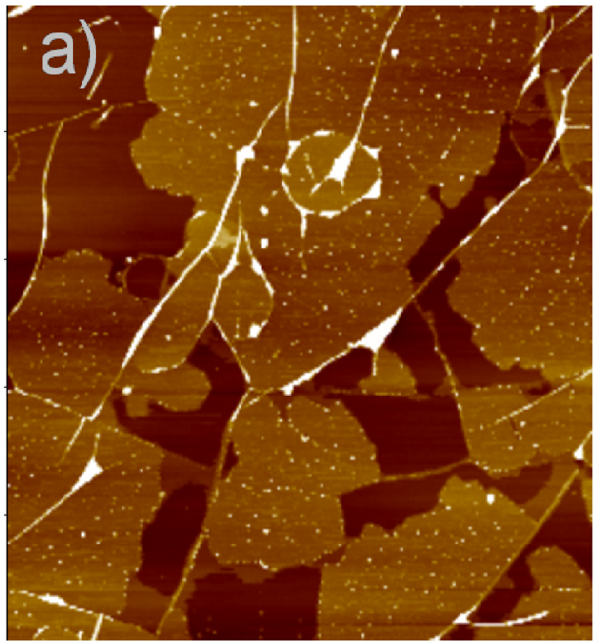


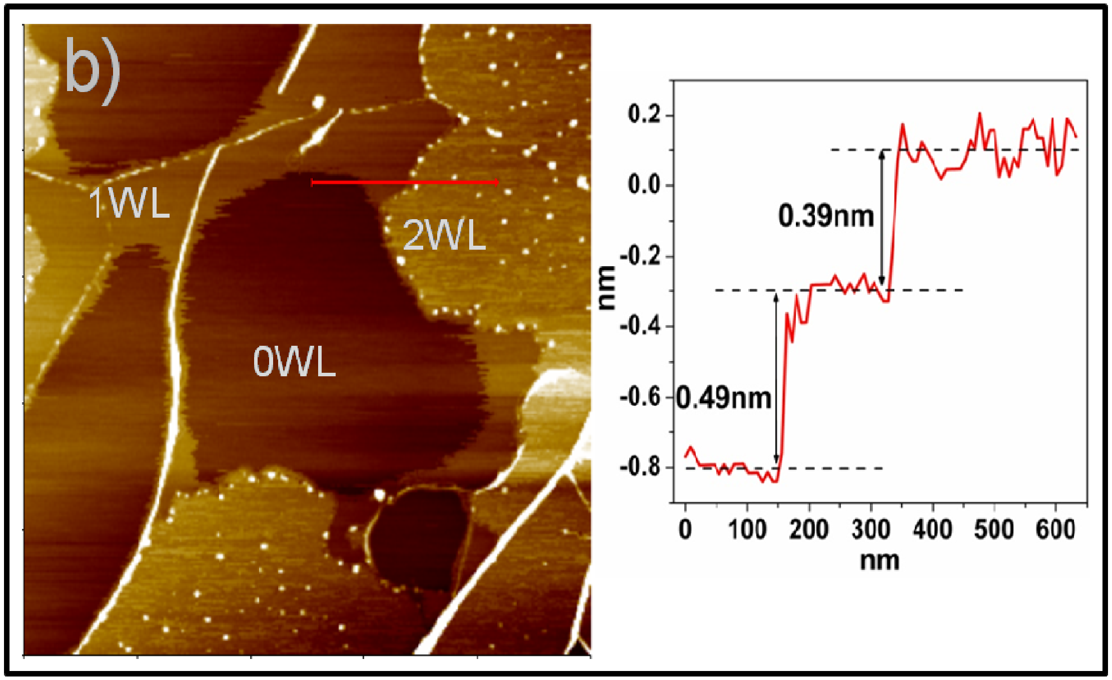
1. chemical vapor deposition (CVD) synthesis of graphene on metal



Characterization of transferred graphene on MoS_2

water-layer after transfer (ambient AFM)





Characterization of transferred graphene on MoS_2

nnealing in UHV at 300 C:

ally sharp interface => moire
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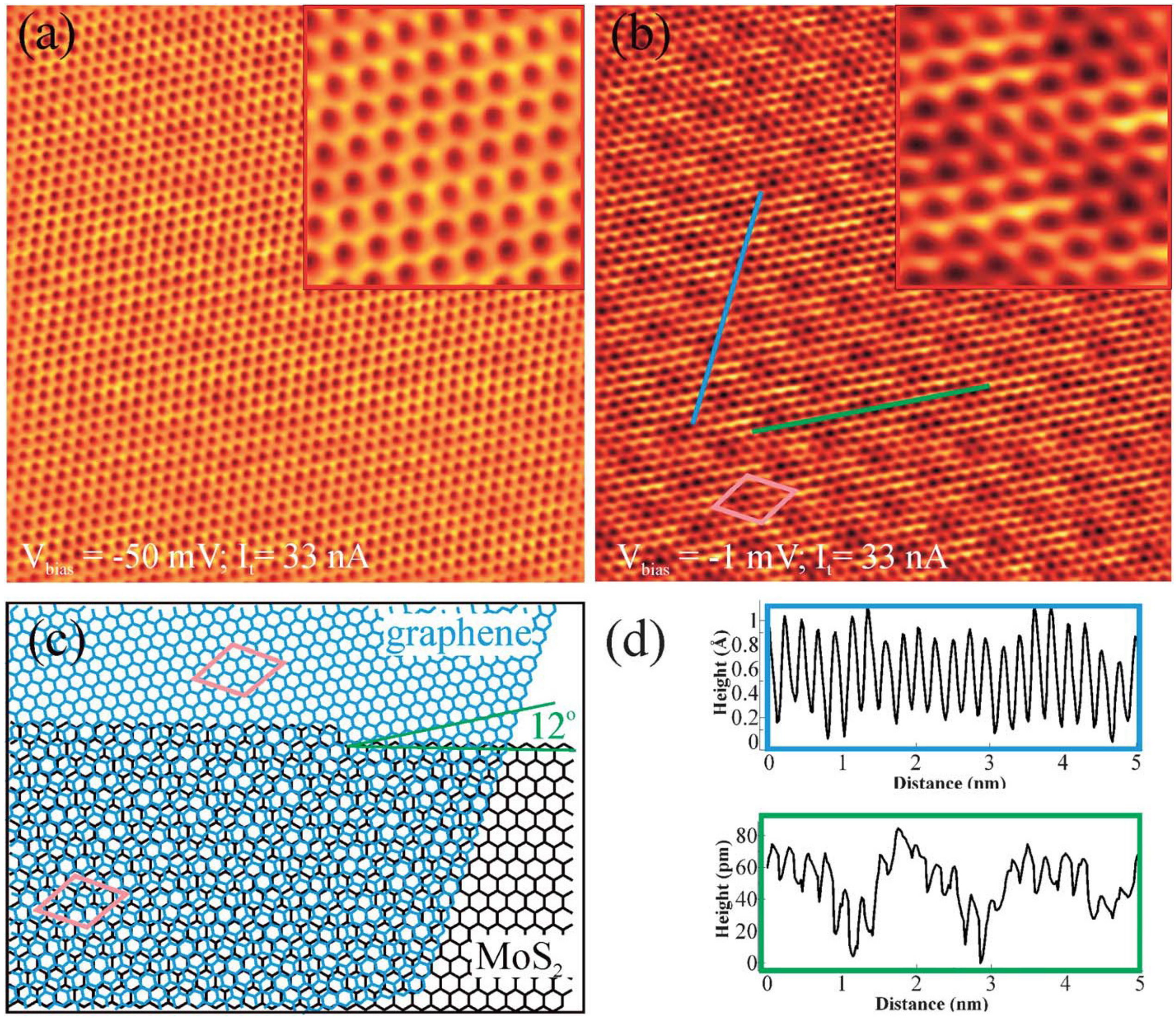
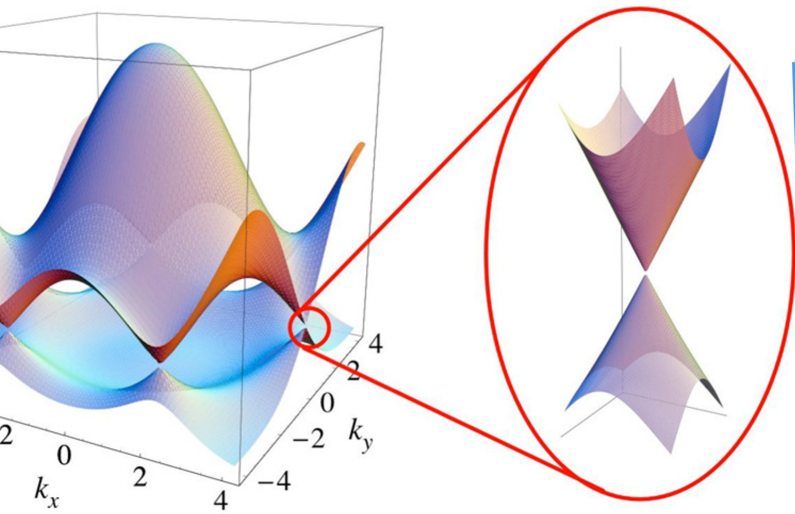
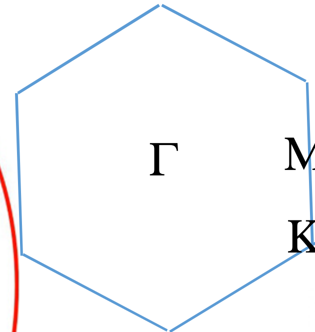
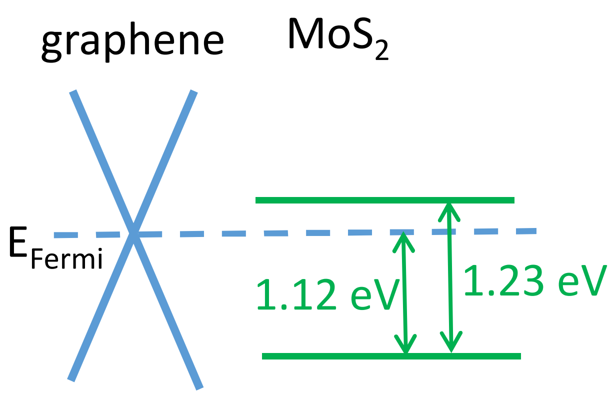
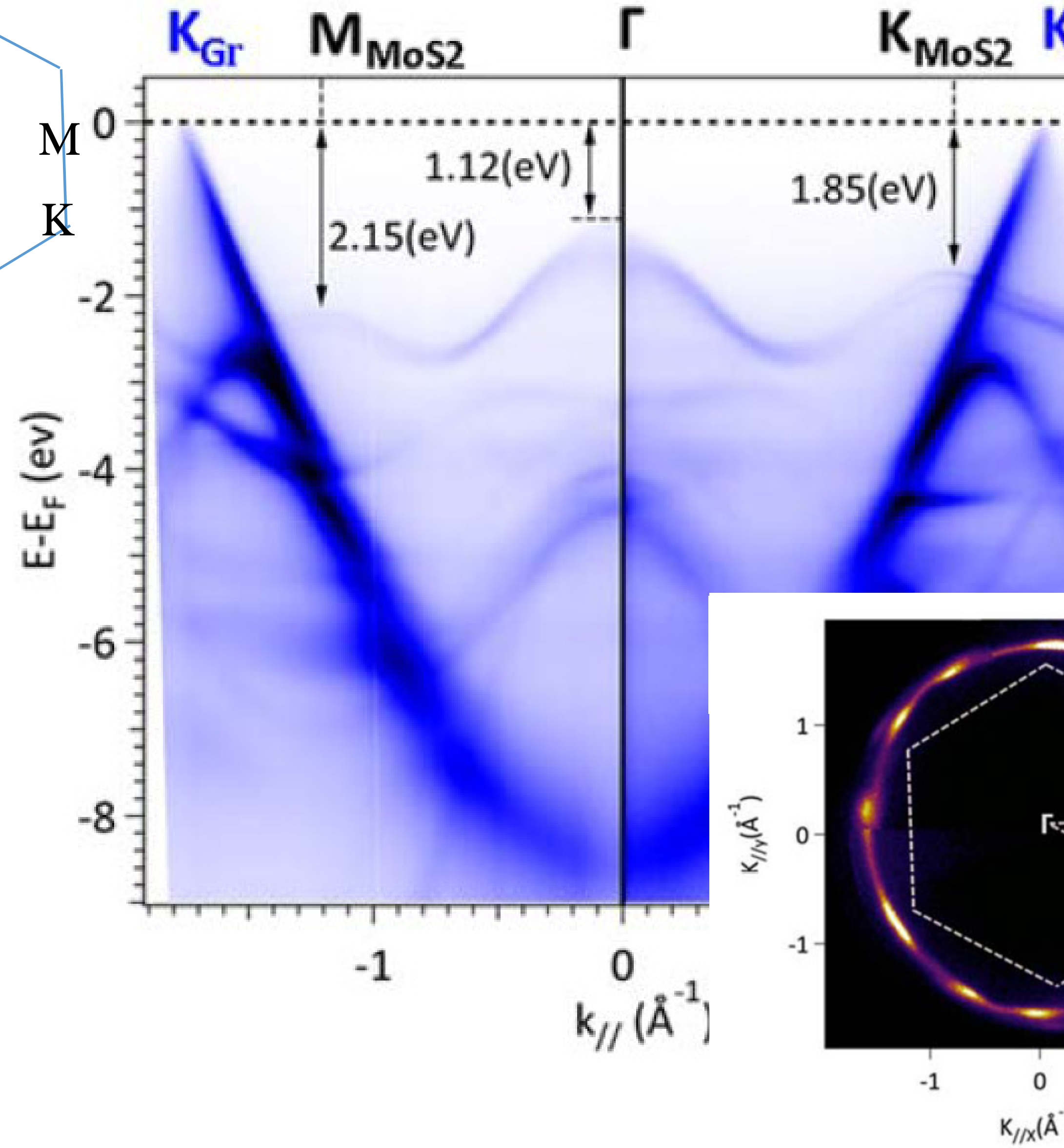


Electronic structure of transferred graphene on MoS_2









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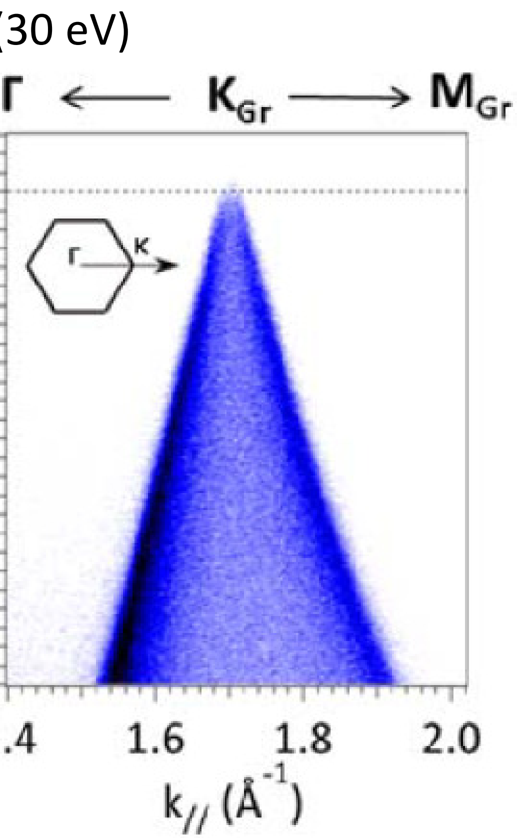
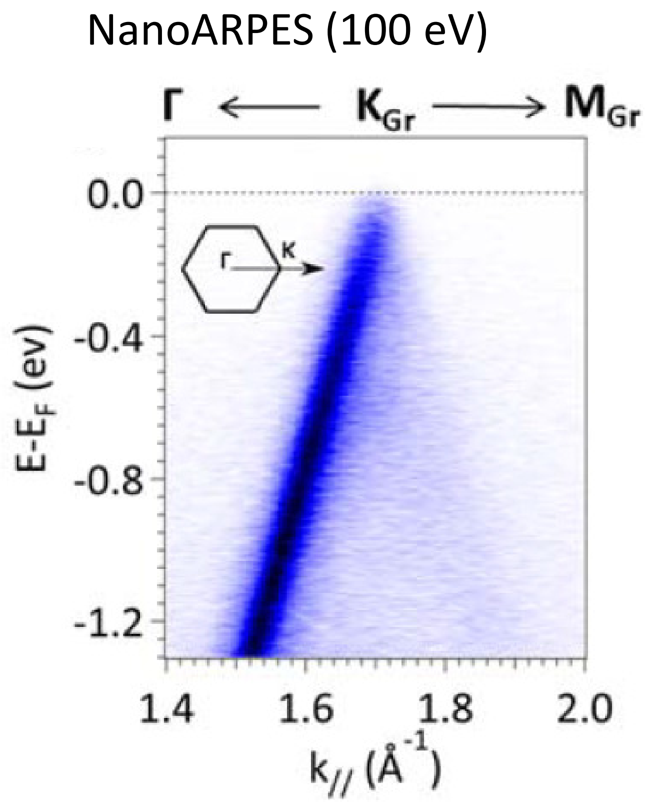
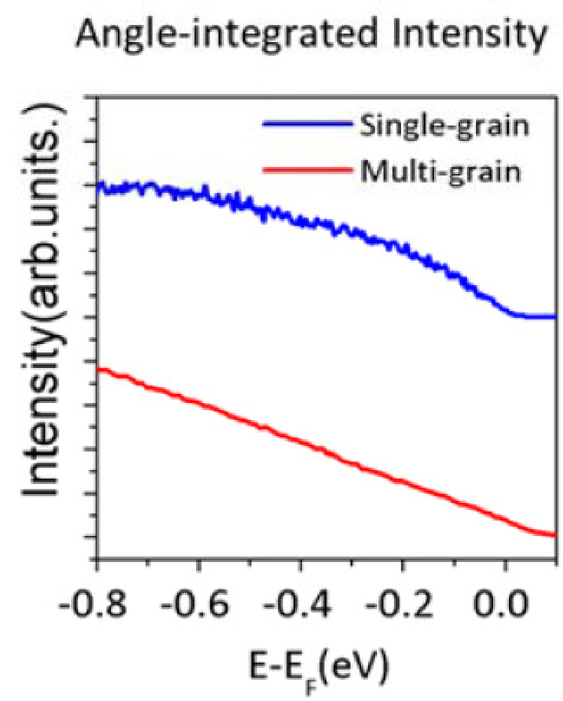
Intact Dirac-cone with no charge transfer doping



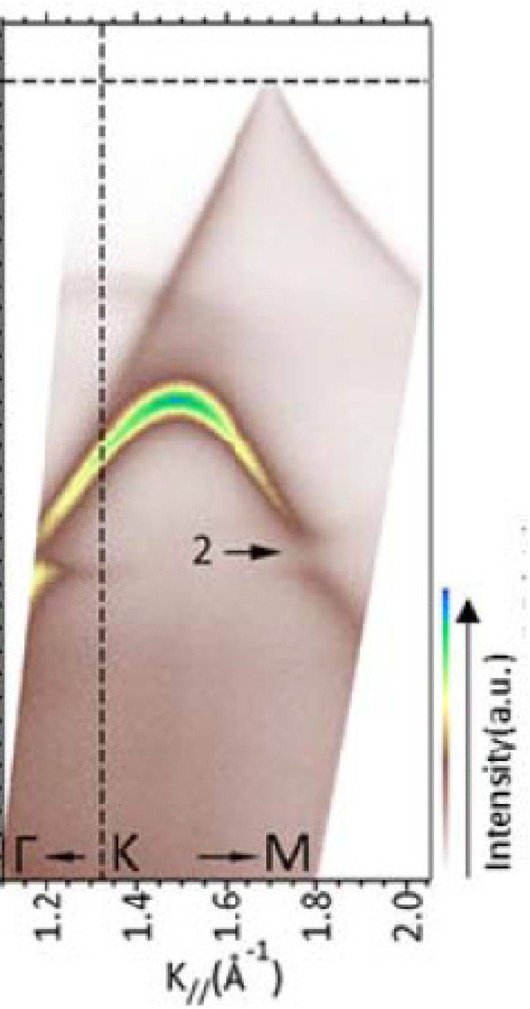




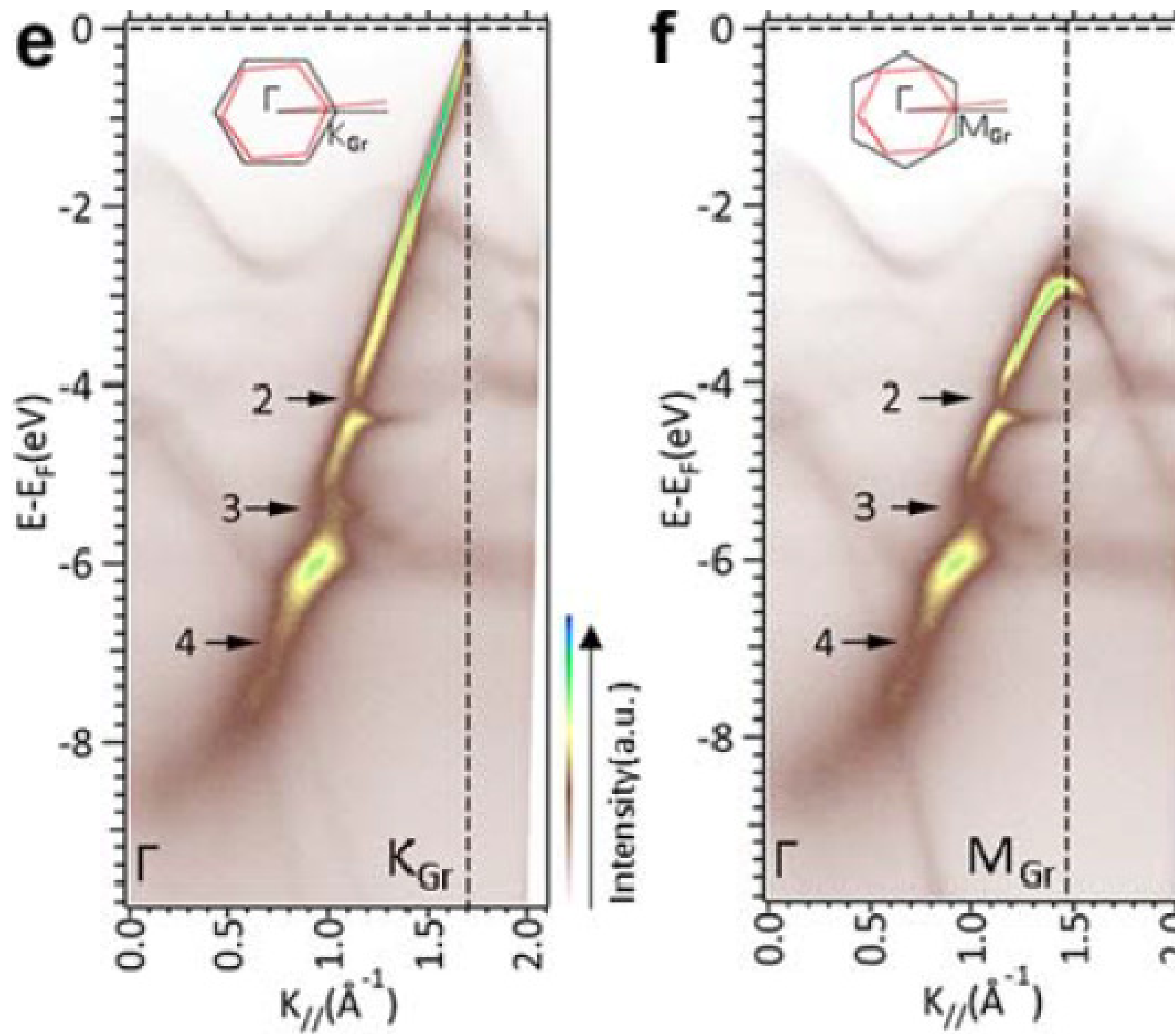
=> The Dirac cone of graphene is very close to that expected for free-standing graphene, i.e. linear dispersion and no doping (Fermi-level at the Dirac point).

Band-gaps in graphene π-band

RPES

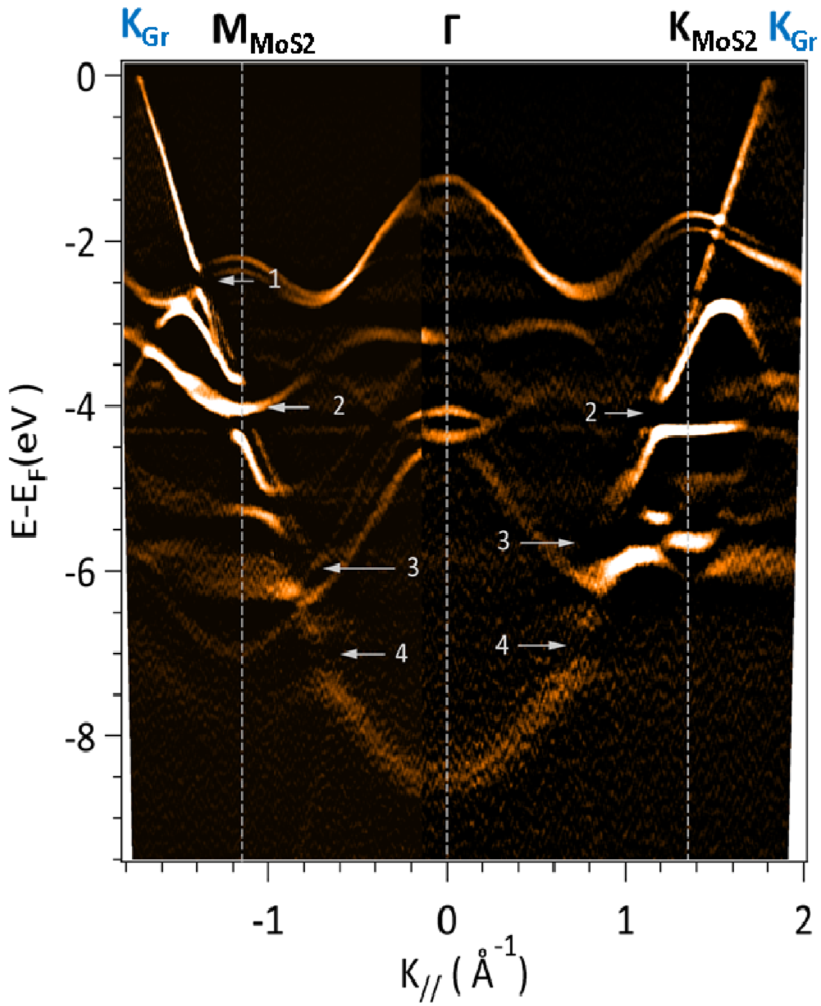


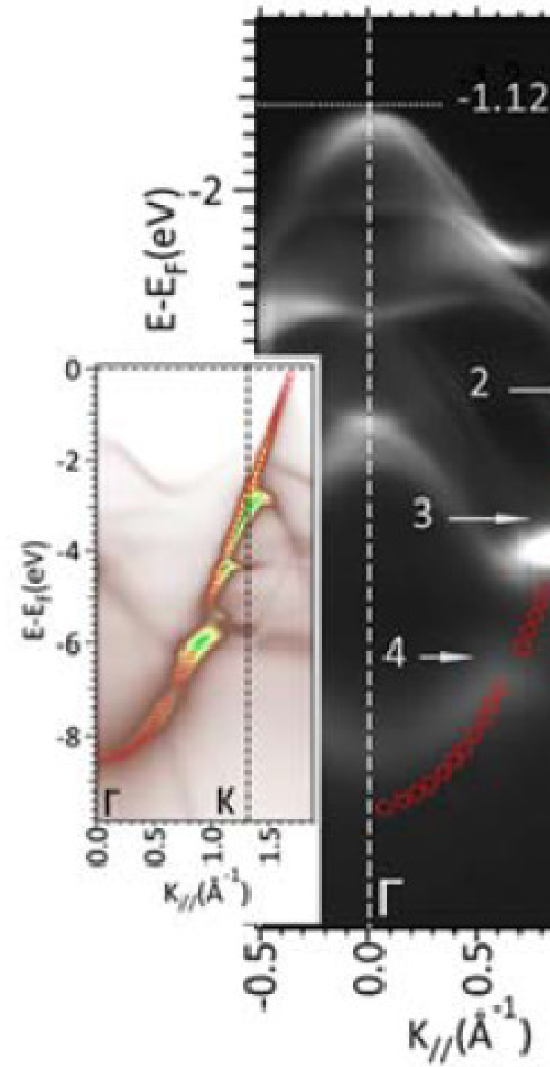
NanoARPES 100 eV



Same gaps in graphene for same substrate-direction=> substrate induce

elation of band-gaps in graphene with MoS_2 'out-of-plane' orb



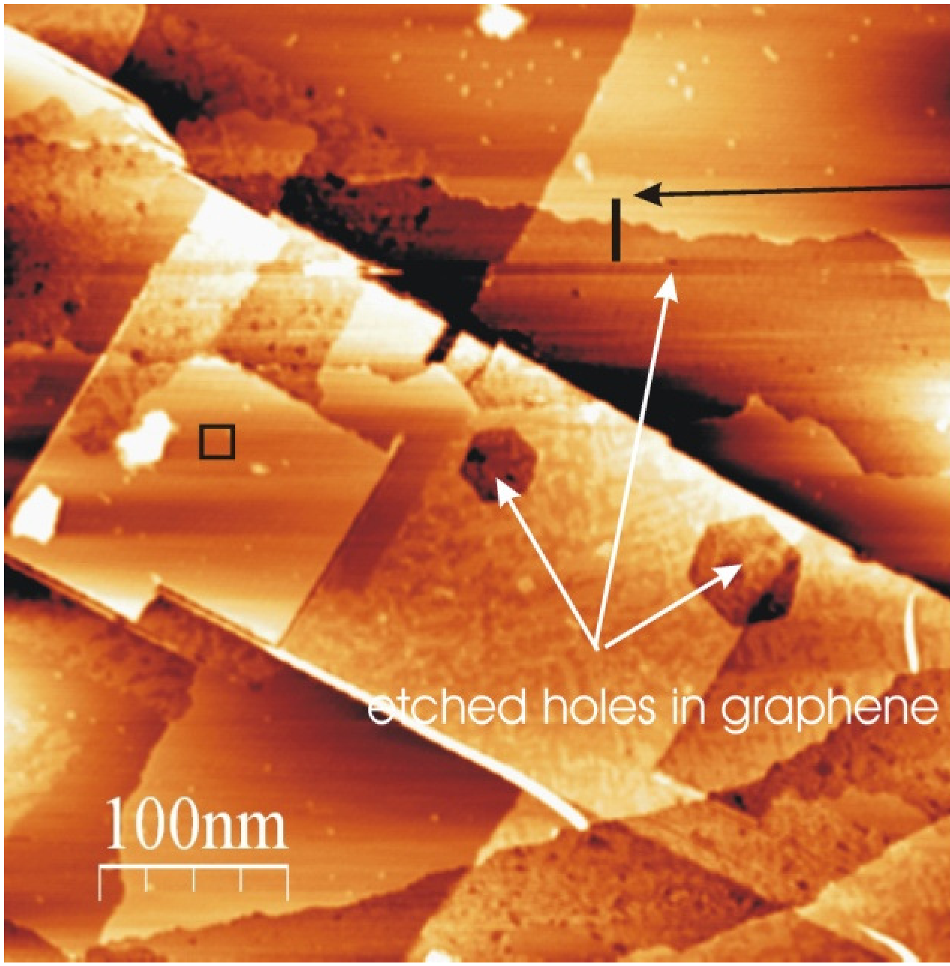


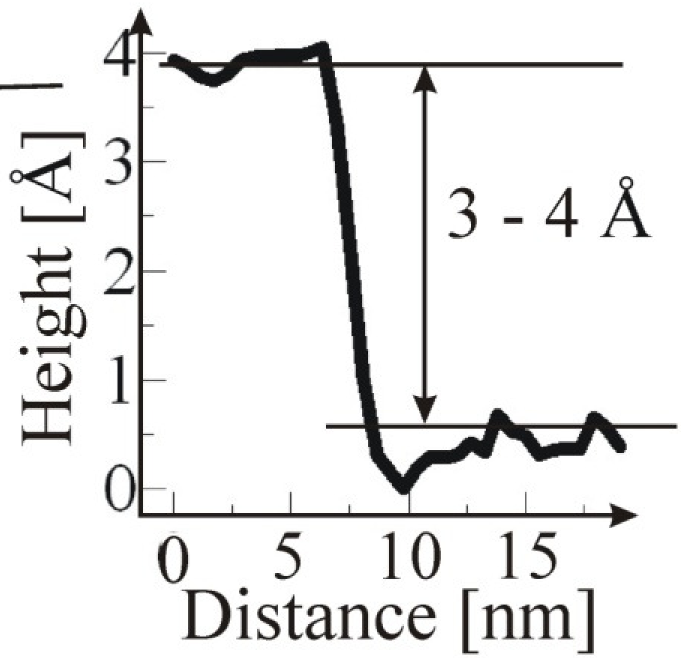
=> Band gaps open in graphene due to hybridization of π-states with 'out-of plane' MoS_2 molecular orbit

Conclusions: graphene/MoS2 'van der Waals' interfaces

- Macroscopic (tens of mm-sized) CVD-grown graphene can be transferred with excellent quality to MoS_2 with atomically sharp and clean interfaces.
- The interface band alignment between graphene and MoS_2 suggests a close to barrier-less electron injection from graphene into MoS_2.
- A close to ideal Dirac-cone of graphene is observed.
- Overlap of out-of-plane molecular orbitals of MoS_2 with graphene π-band causes hybridization and opening of band-gaps in graphene.

Graphene transfer to other materials: e.g. $SrTiO_3(001)$



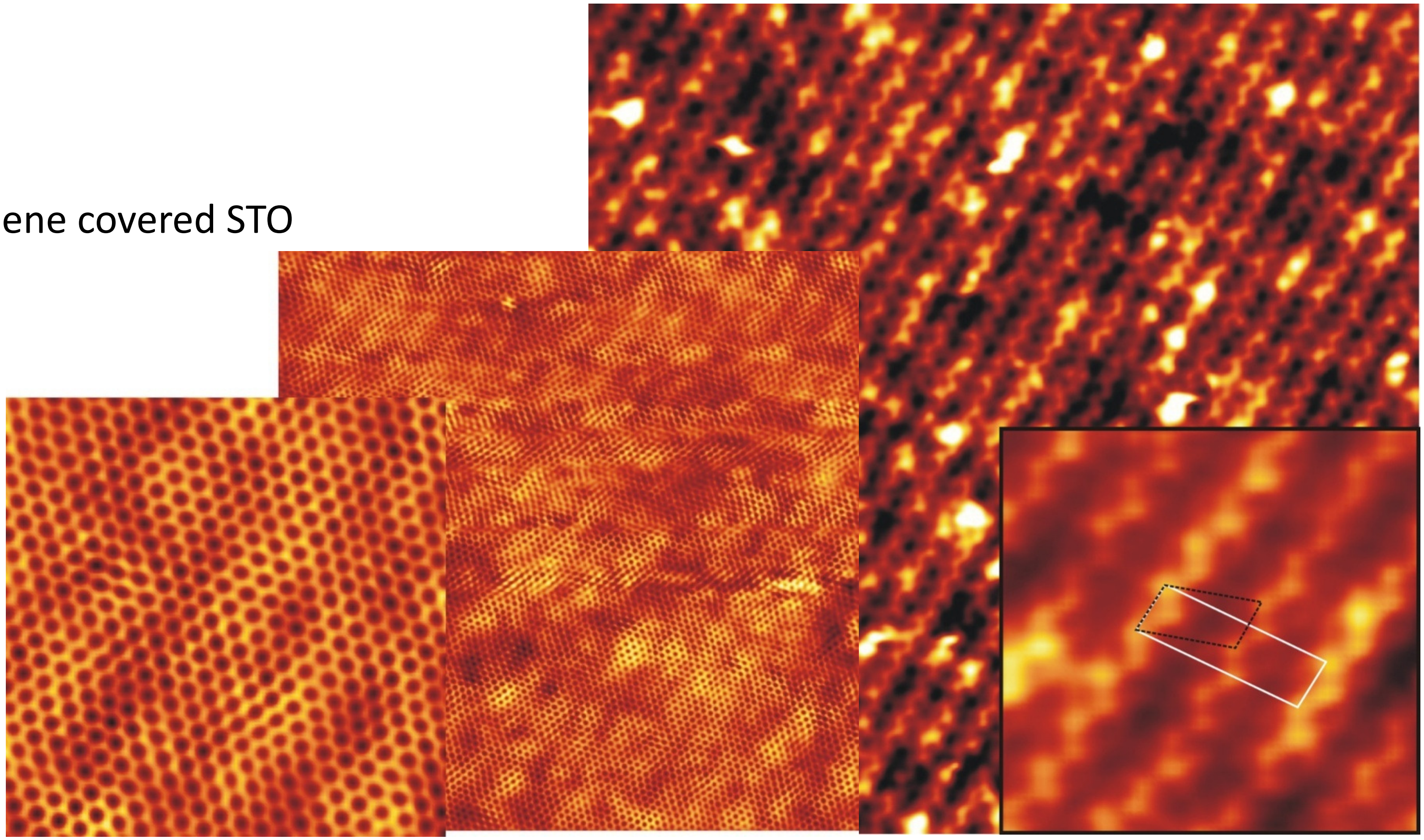


Graphene transfer to other materials: e.g. $SrTiO_3(001)$

Interface structure of graphene/$SrTiO_3(001)$

Reconstructed **bare** $SrTiO_3$ surface.

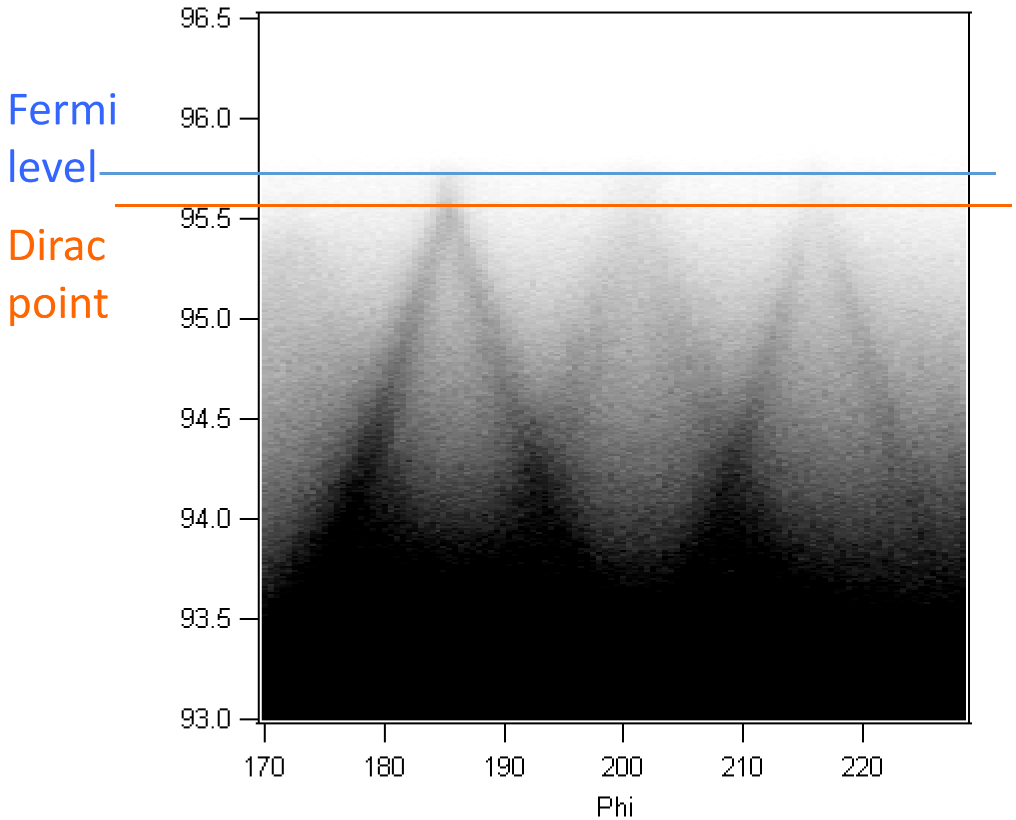
Graphene covered STO

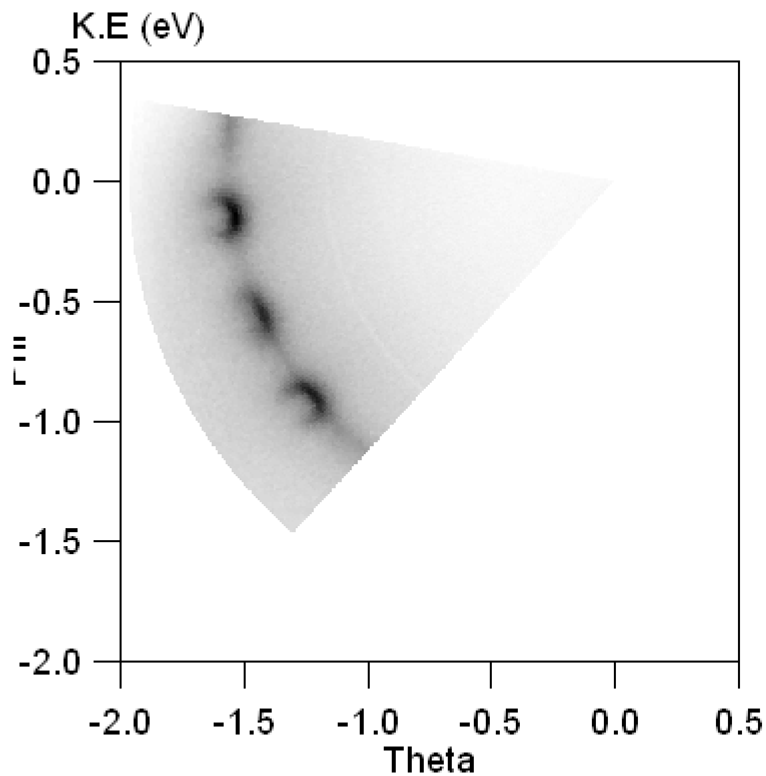


=>This suggest an atomically sharp interface between graphene and the oxide substrate!

H. Coy-Diaz, R. Addou, M.B J. Phys. Chem. C 117, 21006 (2013)

Graphene transfer to other materials: e.g. $SrTiO_3(001)$





=>Dirac cone of graphene is maintained: Interface charge transfer results in n-type doping

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