

Heterostructure based on 2D materials: h-BN/graphene and MoS₂/graphene

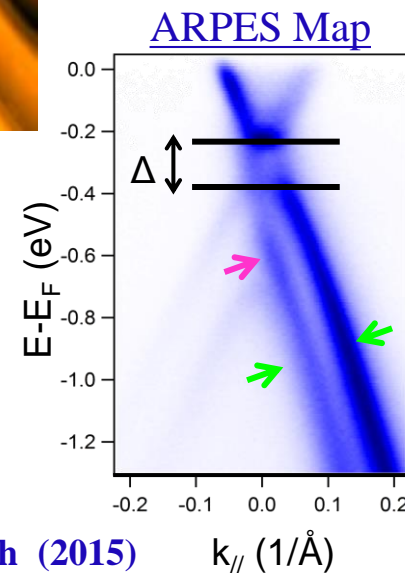
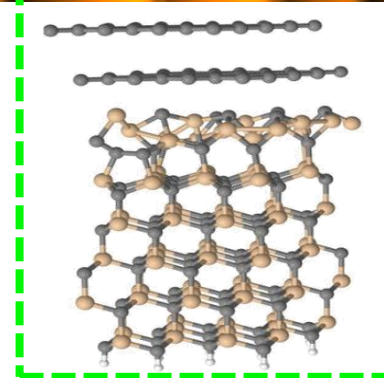
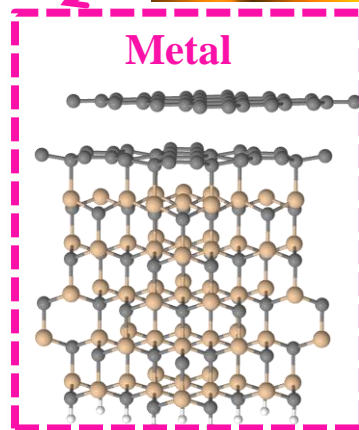
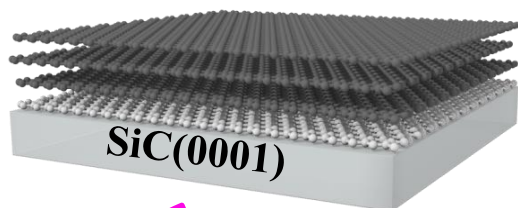
Debora Pierucci

Laboratoire de Photonique et de Nanostructures (LPN/CNRS)



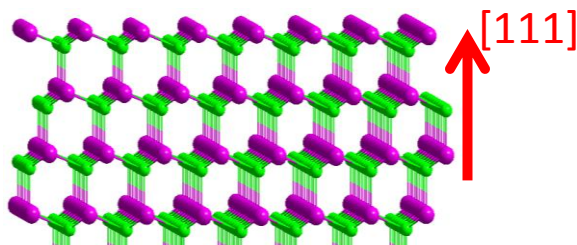
→ Off- axis SiC(0001): Self-organised metal-semiconductor epitaxial graphene layer

Multilayer graphene

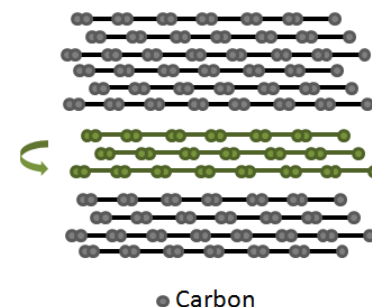
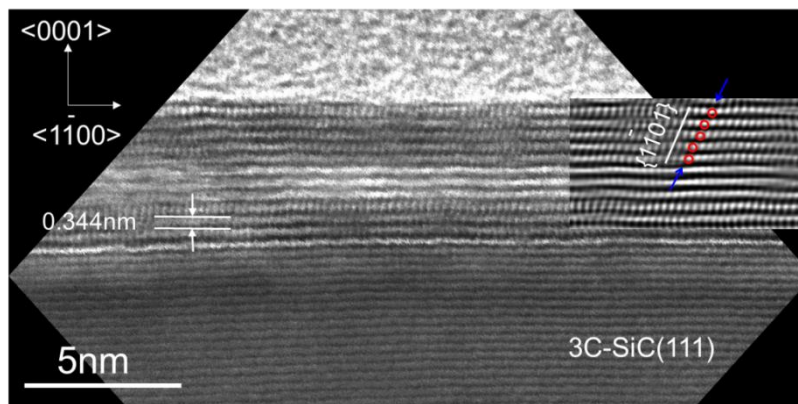


Pierucci, D. *et al.* Nano Research (2015)

→ 3C-SiC(111): Epitaxial Rhombohedral Multilayer Graphene



3C- SiC(111):
ABCABC structure

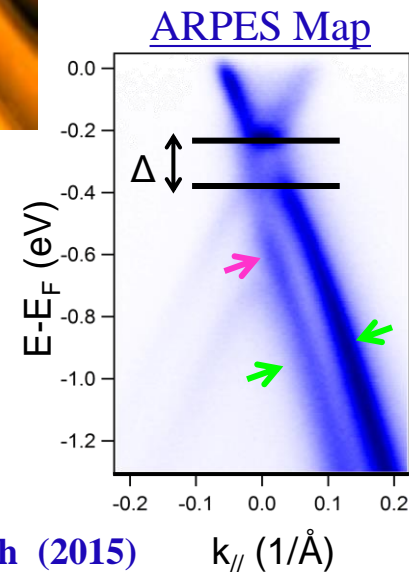
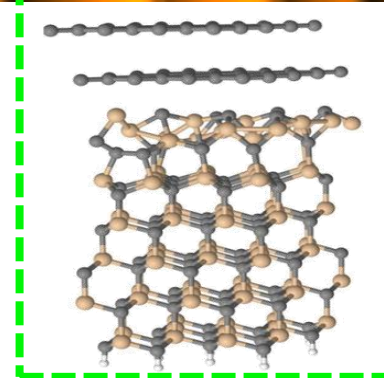
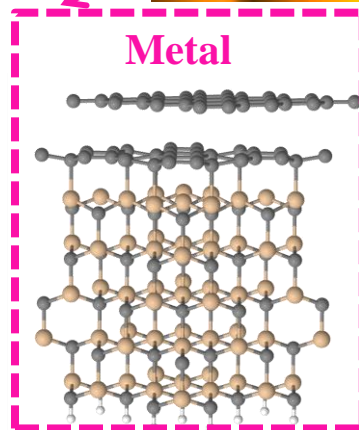
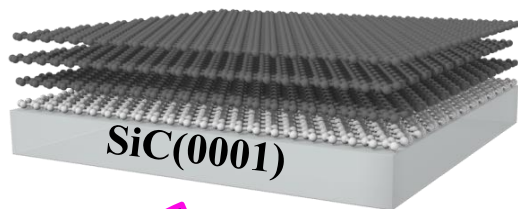


- Stacking fault of ~ three layers
- Coherence length of the rhombohedral domains of ~ 5/6 layers

Pierucci, D. *et al.*
ACS nano (2015)

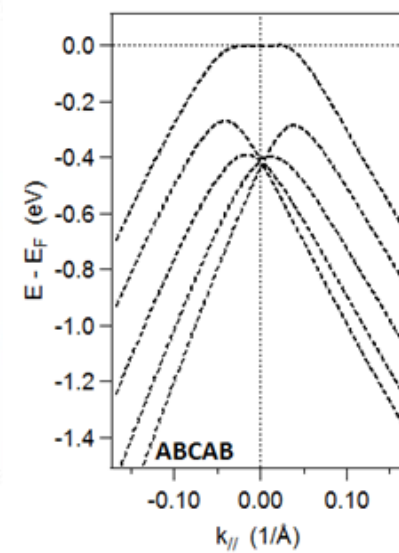
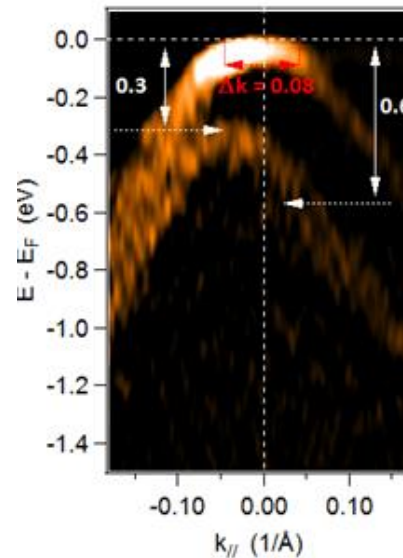
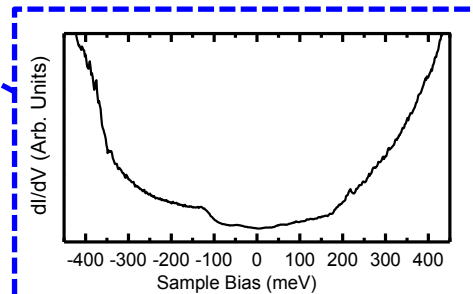
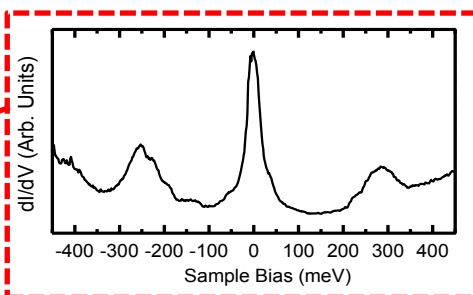
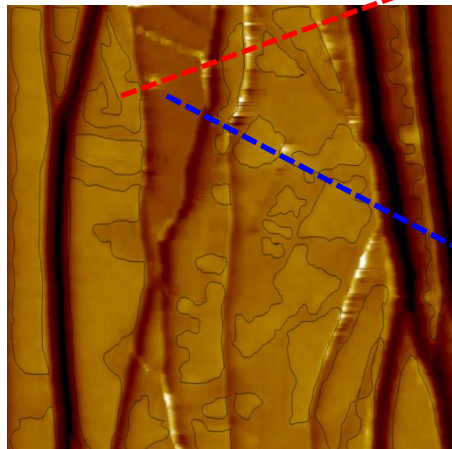
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Multilayer graphene



Pierucci, D. *et al.* Nano Research (2015)

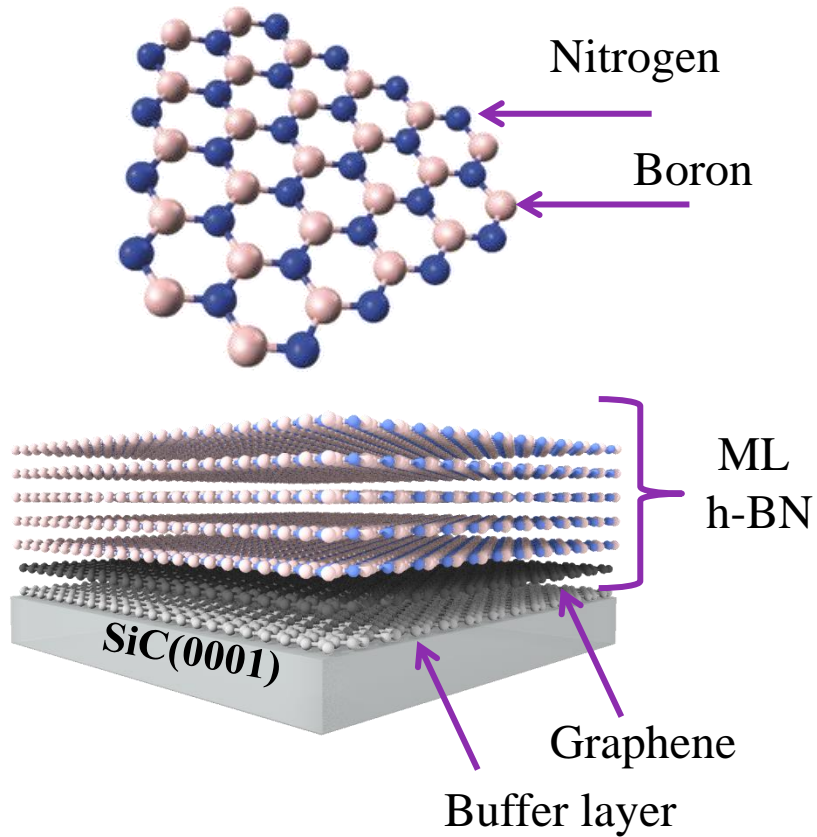
dI/dV Map @ 100 mV



Pierucci, D. *et al.* ACS nano (2015)

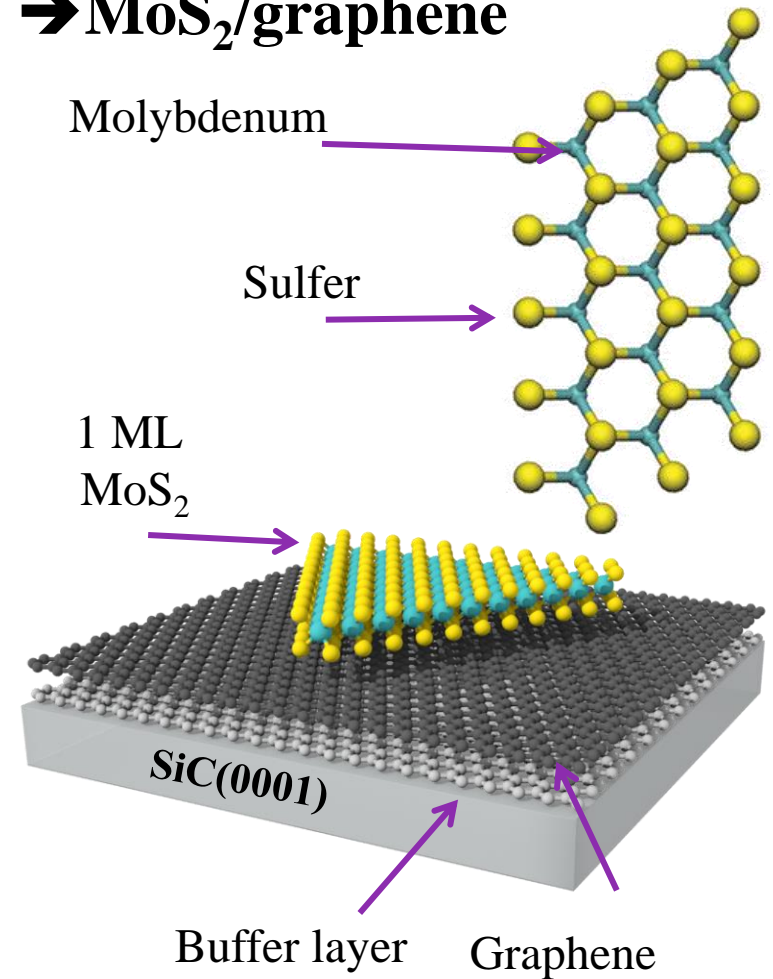
Graphene based heterostructure

→ h-BN/graphene

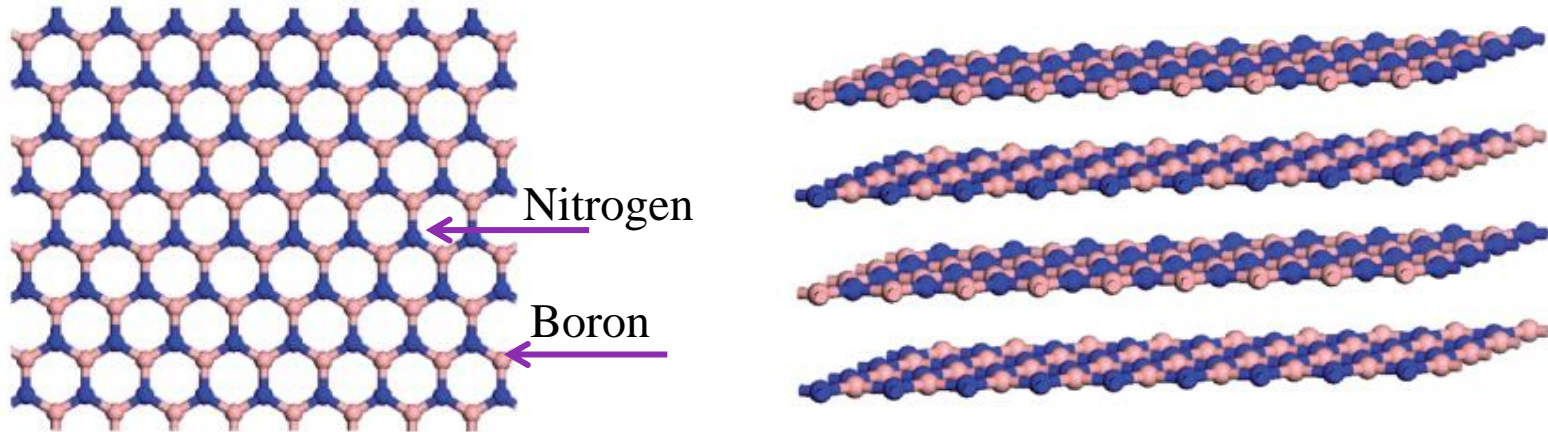


Sediri. H . *et al.* Scientific Report (submitted)

→ MoS₂/graphene



h-BN/Graphene heterostructure



Isostructural to graphite : “ white graphene”

- B and N honeycomb arrangement (sp^2 –bonded)
- Strong covalent bonds in the plane , vdW forces between the planes
- Hexagonal crystal structure $a = b = 2.504 \text{ \AA}$ (only 1.7% lattice mismatch with graphene)
- Good insulator (direct band gap 5.97 eV)

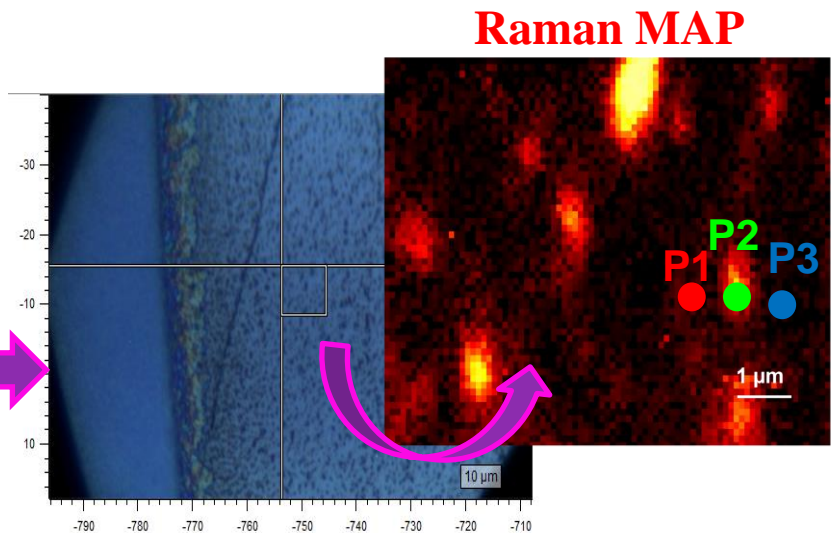
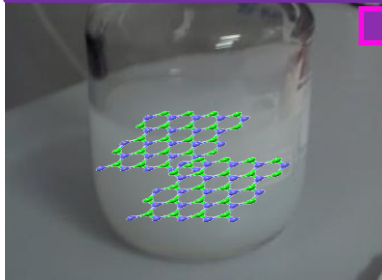
→ New vdW heterostructure h-BN/graphene

- h-BN ideal dielectric interface (chemical inert no DBs)
- Top gate dielectric, cap layer or substrate

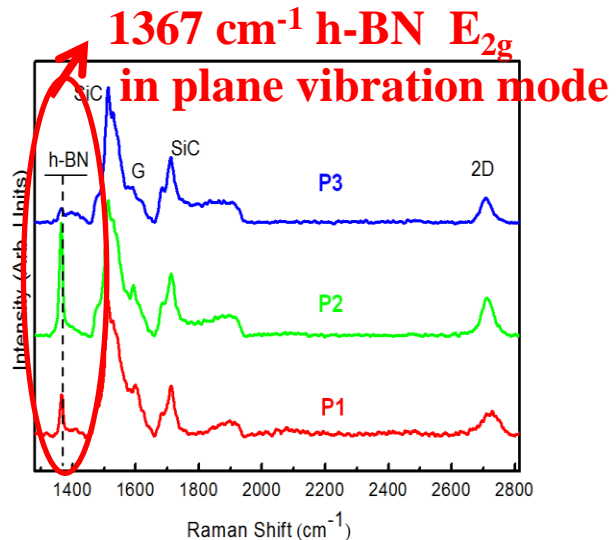
h-BN/Graphene heterostructure

“wet” process

h-BN flakes dispersed in ethanol
B. Toury (LMI- Lyon)



Raman MAP

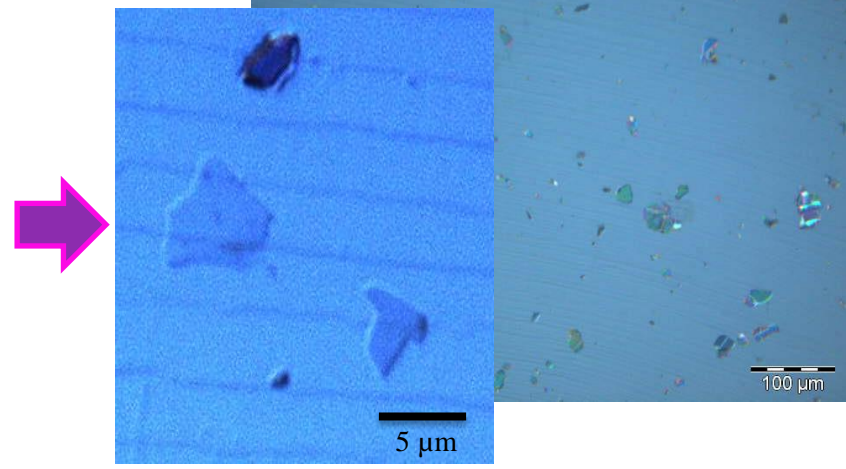


- Multilayer h-BN on Graphene on SiC(001)
- h-BN flakes of few μm

Sediri, H. *et al.* Scientific Report (submitted)

Exfoliation

h-BN powder / crystal

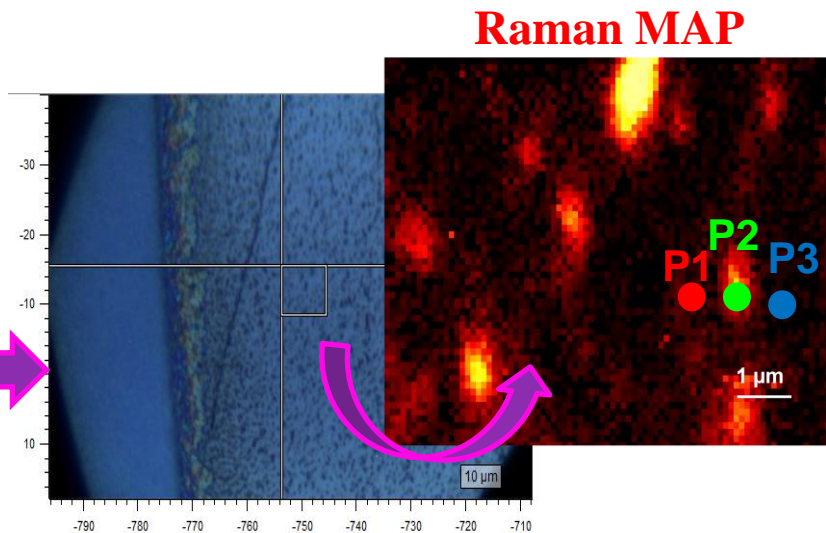
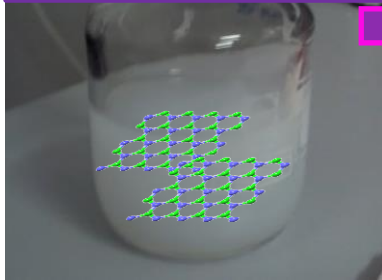


Several flakes width ~ between 5 and 10 μm

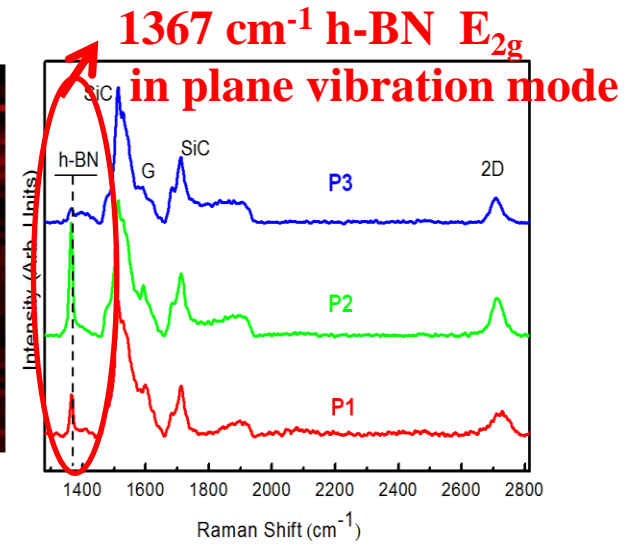
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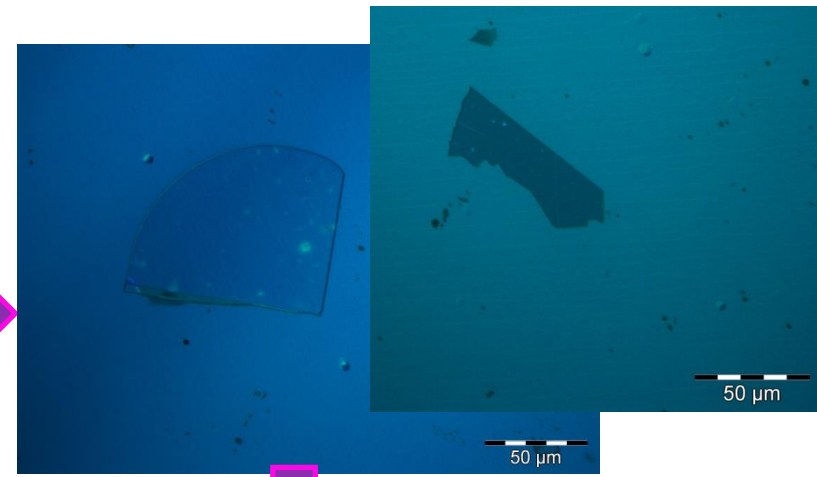


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Sediri, H. *et al.* Scientific Report (submitted)

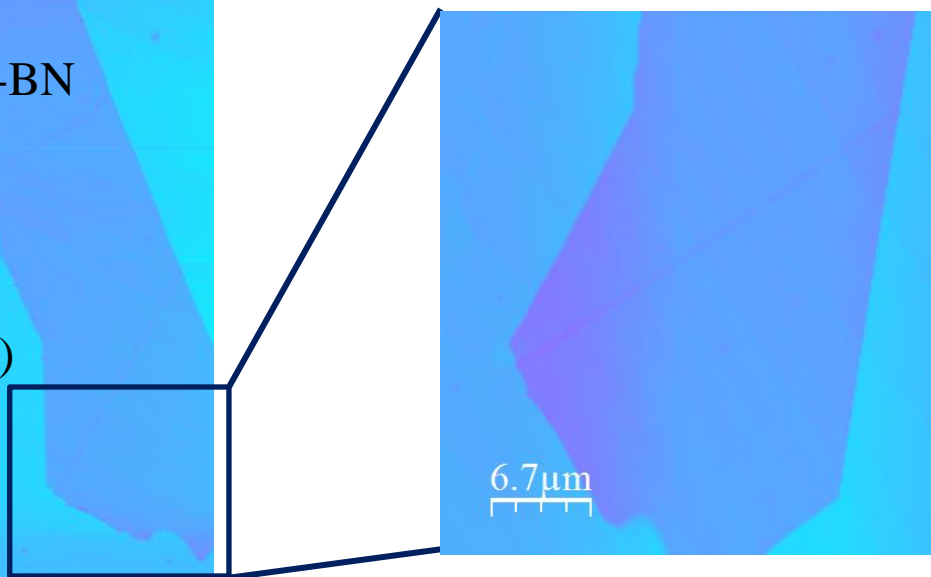
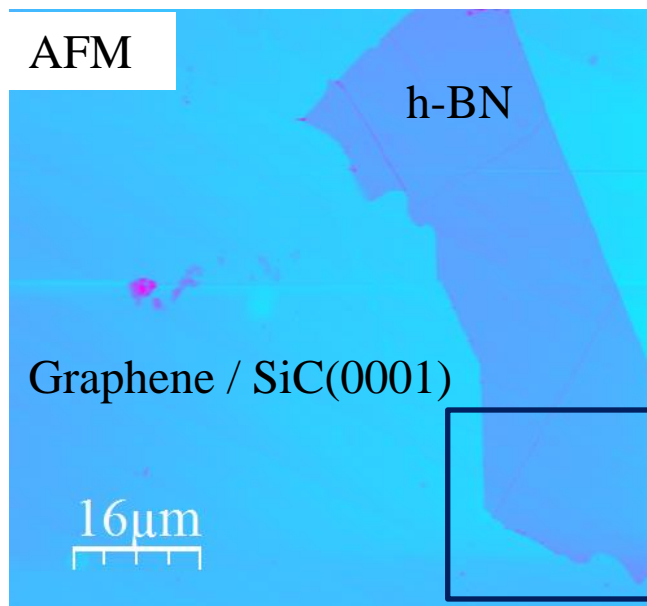
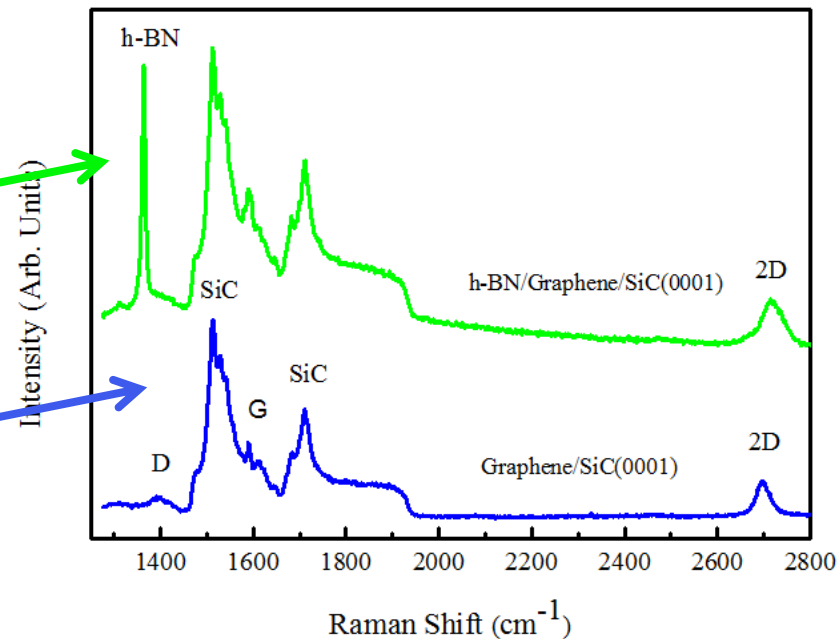
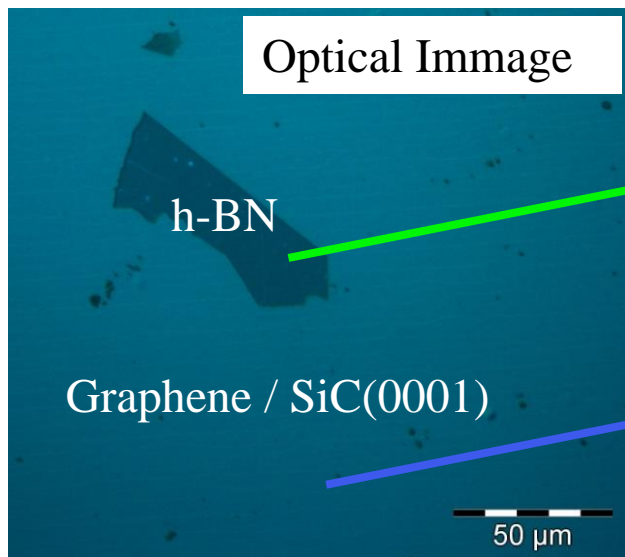
Exfoliation

h-BN powder / crystal

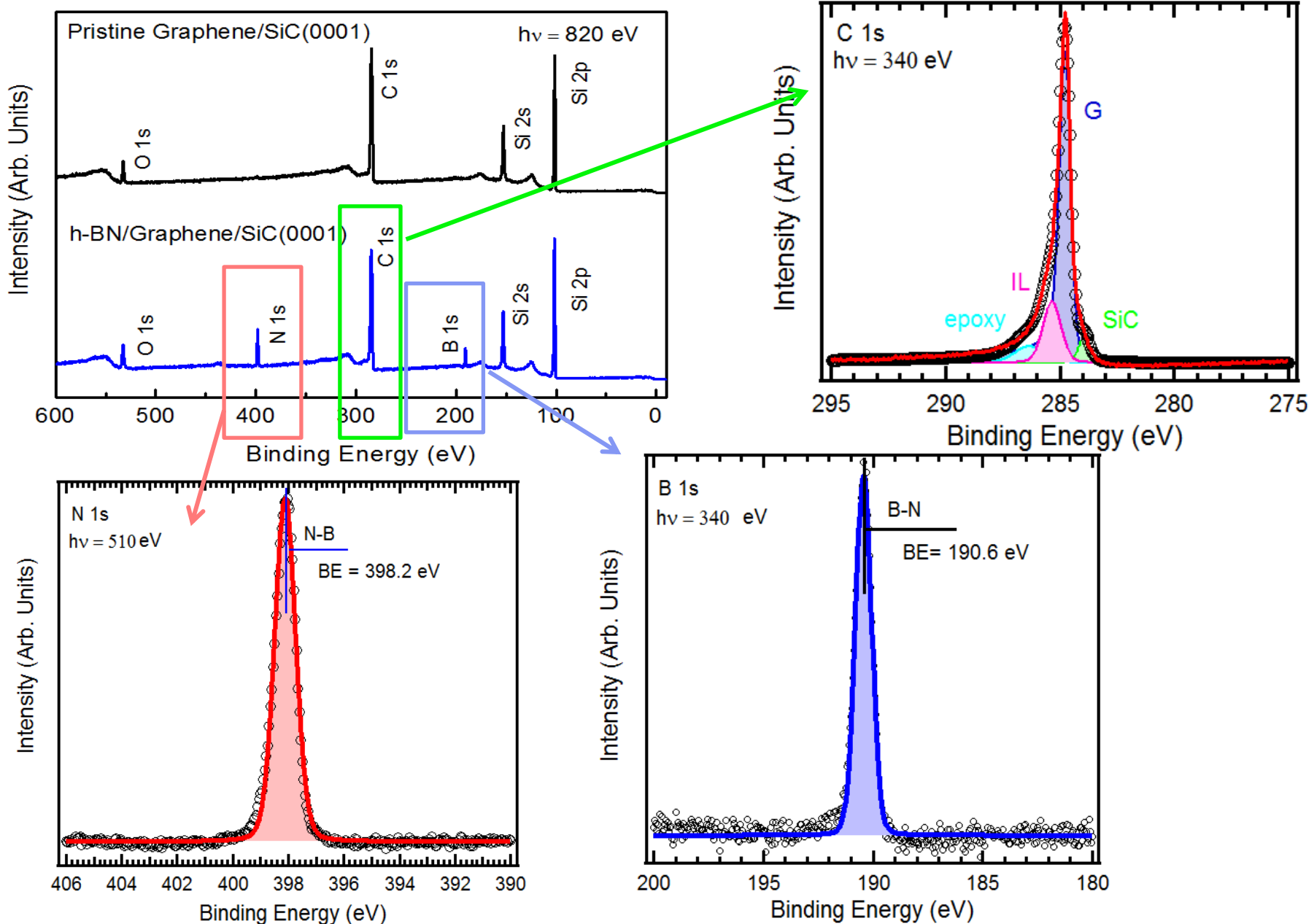


Huge flakes width ~ between 50 and 100 μm

h-BN/Graphene heterostructure: exfoliation

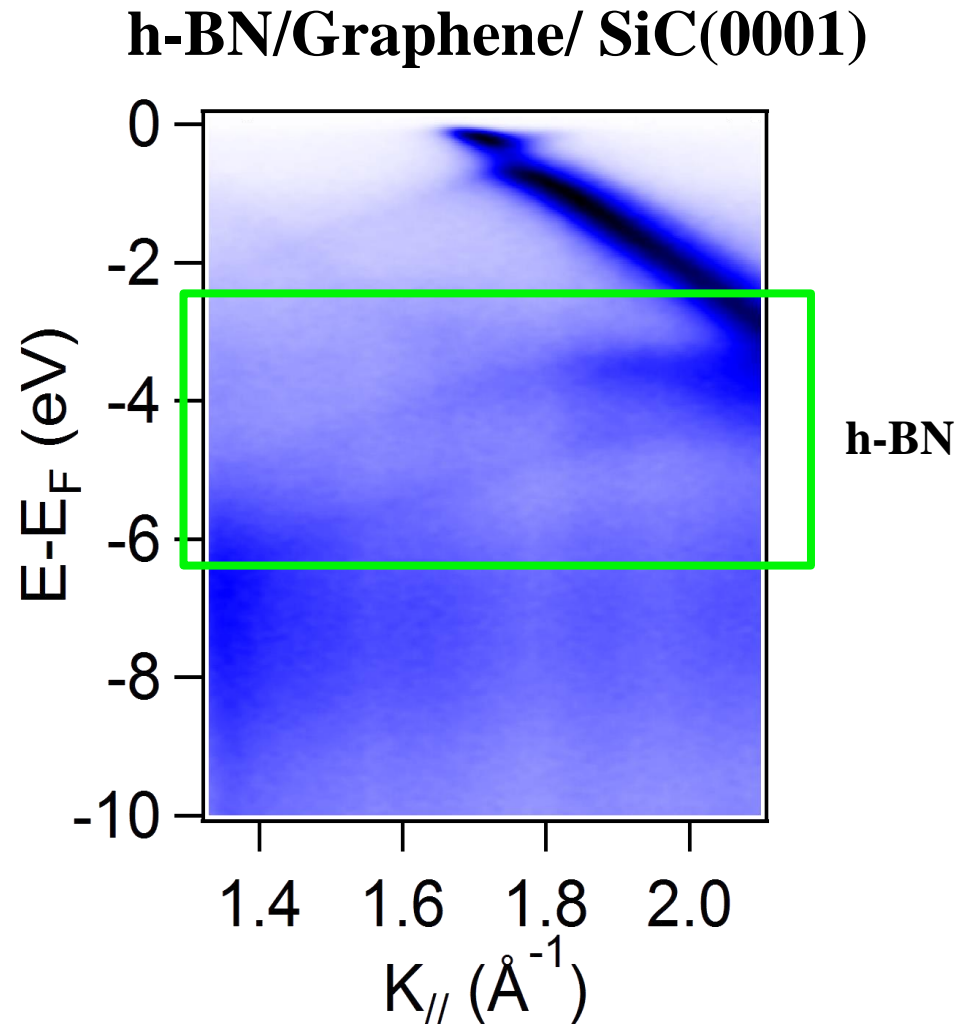
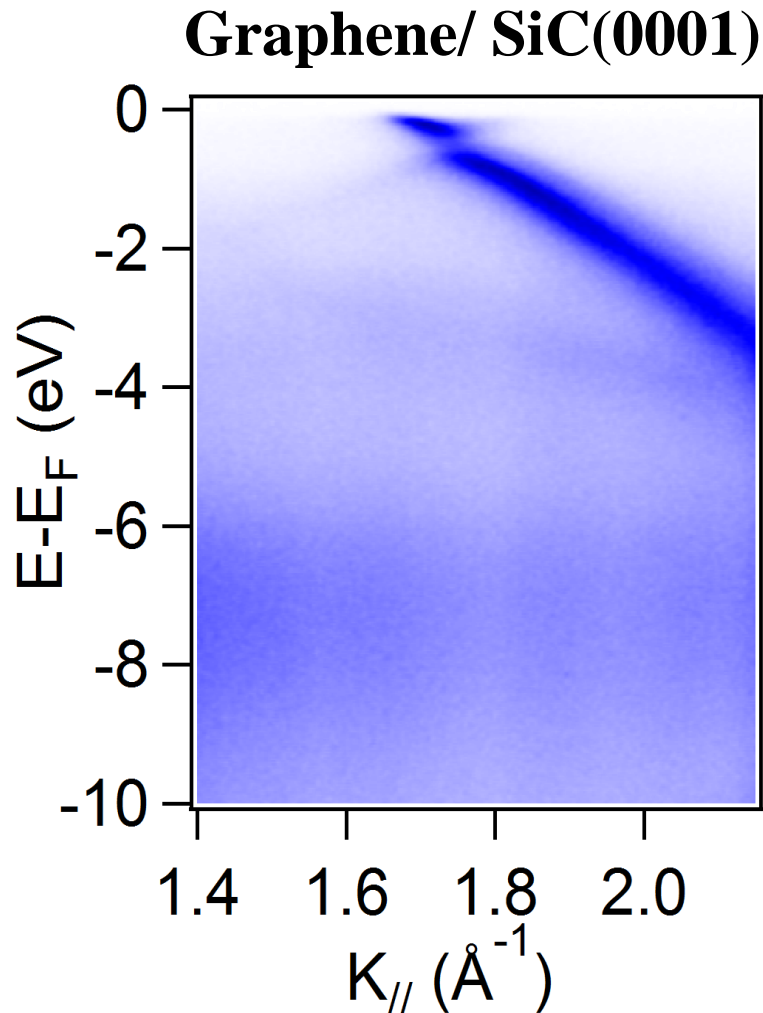


h-BN/Graphene heterostructure: XPS



h-BN/Graphene heterostructure: ARPES

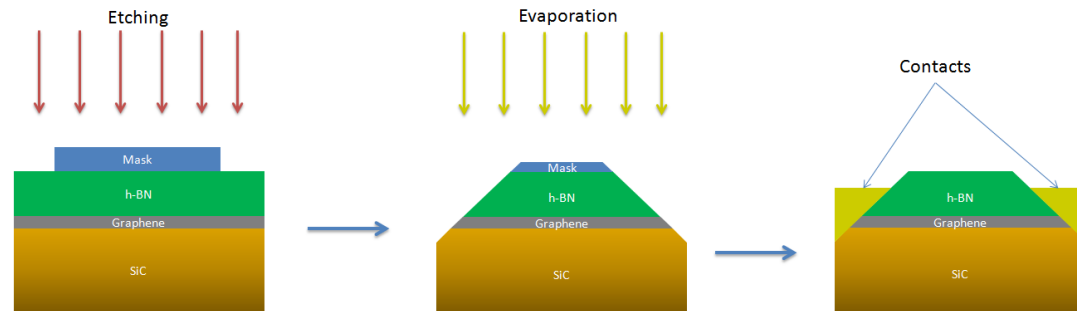
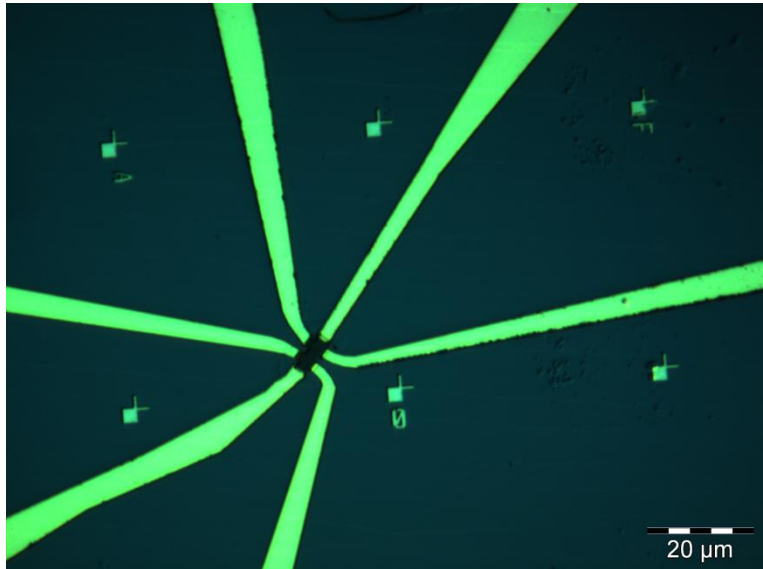
$h\nu = 60 \text{ eV}$



Conclusions et perspectives

→ h-BN/graphene:

- High-quality multilayer h-BN/ graphene heterostructure
- MLs h-BN do not affect graphene properties
- Highly crystalline MLs h-BN without any interdiffusion



h-BN capped layer improve
the graphene mobility

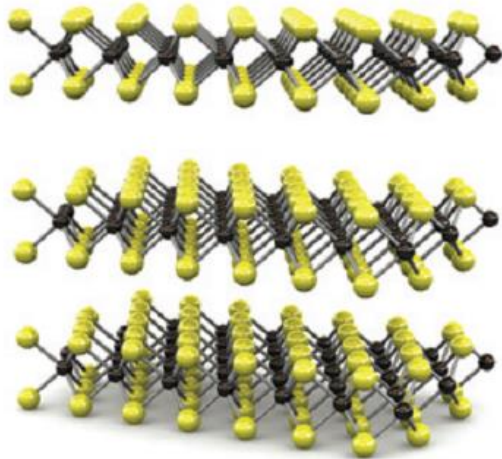


$$\mu (@ RT) \sim 3700 \text{ cm}^2 / \text{Vs for } n \sim 2 \times 10^{13} \text{ cm}^{-2}$$

→ **Perspective:** Gentle hydrogenation to saturate the DBs of graphene /SiC (0001) interface to improve carrier mobility (*Pallecchi et al. Scientific Report (2014)*)

MoS₂/Graphene heterostructure

Transition metal dichalcogenides (TMDCs)

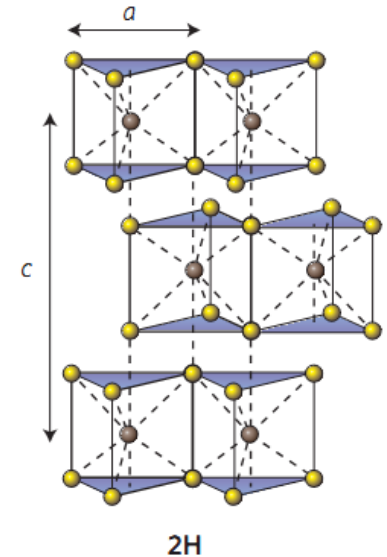


Wang et al. Nature Nanotechnology (2012)

MX_2 : M transition metal element (Mo, W..) and X is a chalcogen (S, Se or Te)



- Layered structure X-M-X
X atom in two hexagonal plane separated by a M atom
- Weakly bounded layer by vdW forces



Layer-dependent properties:

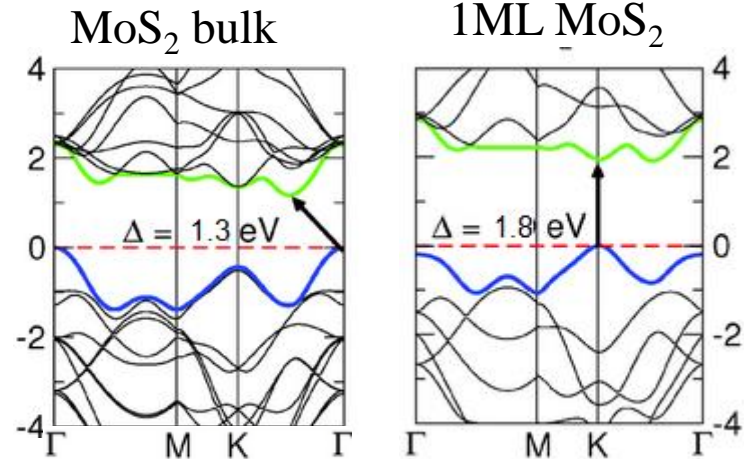
- Transition from an indirect band gap in the bulk to a **direct gap** in the 1 ML

$\Delta = 1.3 \text{ eV}$ in bulk

$\Delta = 1.8 \text{ eV}$ in 1 ML



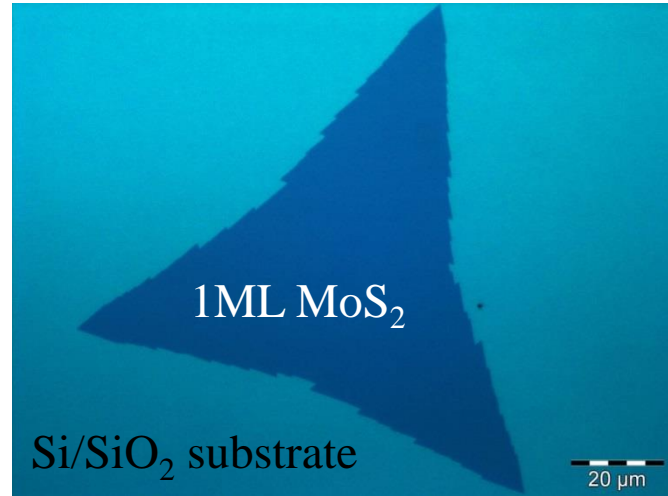
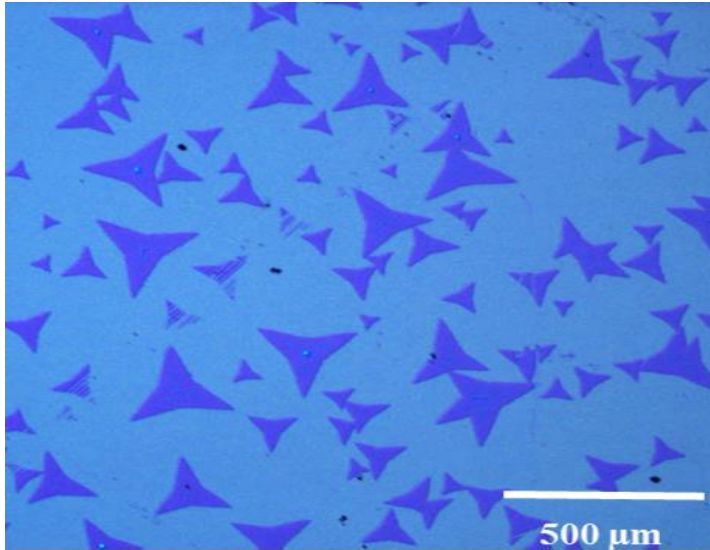
Photoluminescence from ML MoS₂



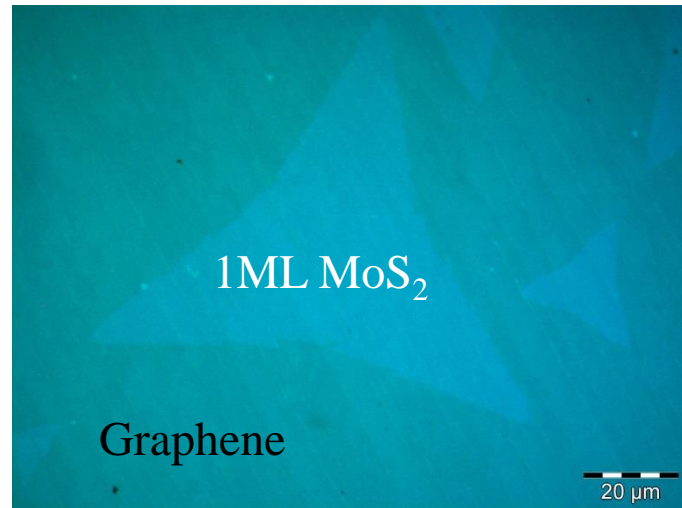
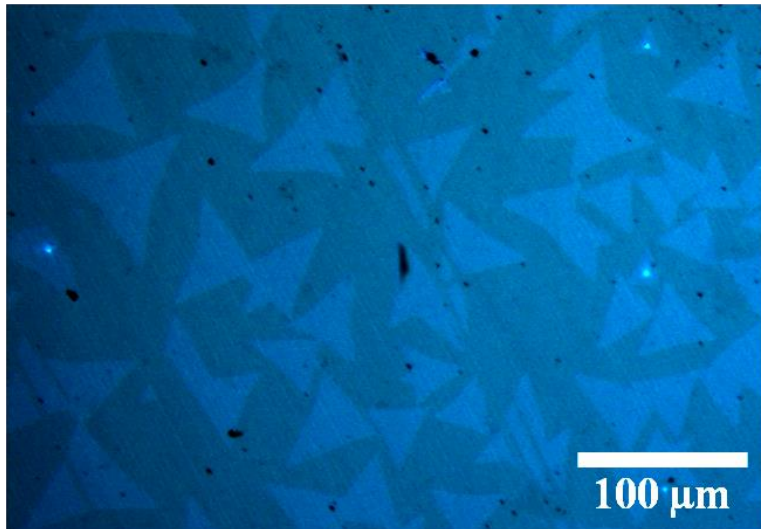
➔ New vdW heterostructure MoS₂/graphene

MoS₂/Graphene heterostructure

MoS₂ grown by CVD on Si/SiO₂ (University of Pennsylvania)



Transfer process on graphene



Acknowledgements

Epitaxial Graphene @ LPN

✓ **A. Ouerghi (Group leader)**

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- ✓ H. Henck (PhD: 2014 – 2017)
- ✓ M. Hajlaoui (Postdoc: 2013 - 2015)

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- ✓ J.C. Girard (LPN)
- ✓ G. Patriarche (LPN)
- ✓ J. Chaste (LPN)
- ✓ A. Balan (CEA)
- ✓ R. Belkhou (HERMES)
- ✓ F. Sirotti & M. Silly (TEMPO)
- ✓ M.C Asensio & J. Avila (ANTARES)
- ✓ Y. Dappe (CEA)
- ✓ F. Mauri & M. Calandra (IMPMP/UPMC)



Thank you for your attention