RECENT PROGRESS IN GRAPHENE & 2D MATERIALS RESEARCH

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Hetero-integration of Graphene and hBN towards Nano-electronics

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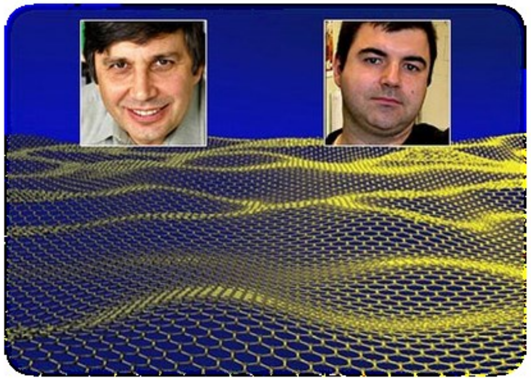
2017/9/19

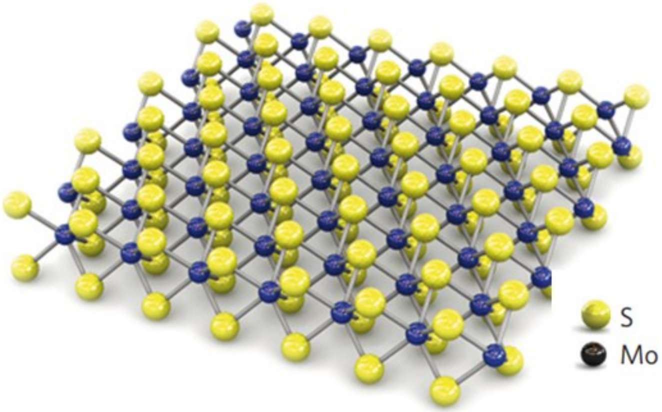
Outline

- **Background**
- **Our Approach**
- **Growth Mechanism**
- **GNRs Preparation**
- **Summary**

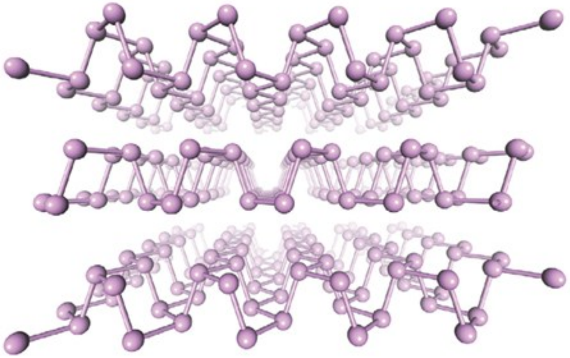
Family of 2D Materials



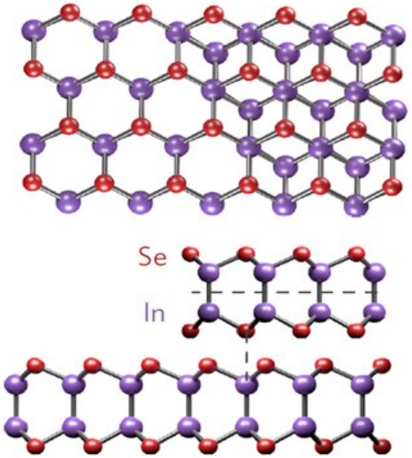
2004 Graphene
2010 Nobel Prize



2010 MoS_2



2014 black Phosphene

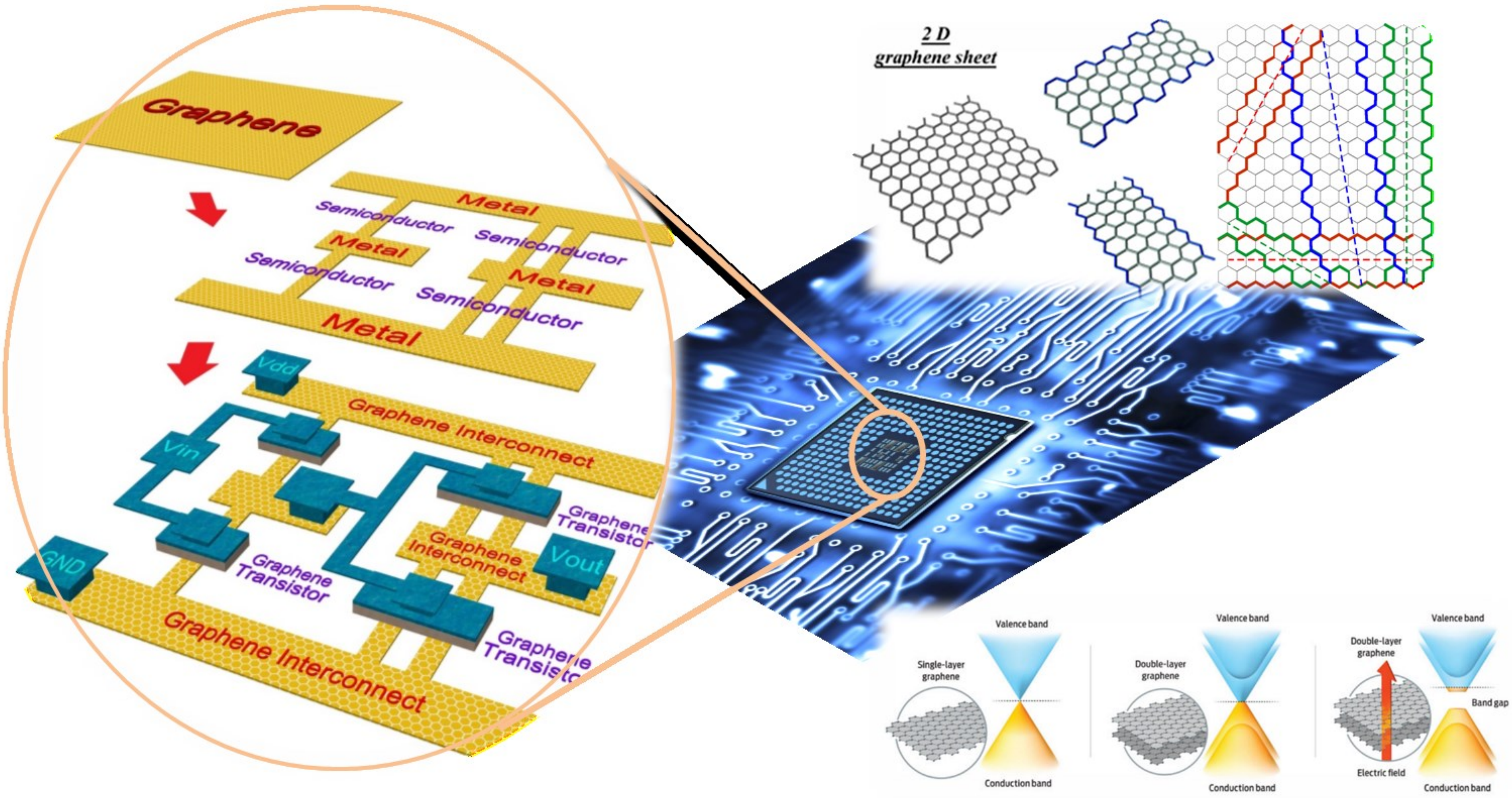


2016 InSe

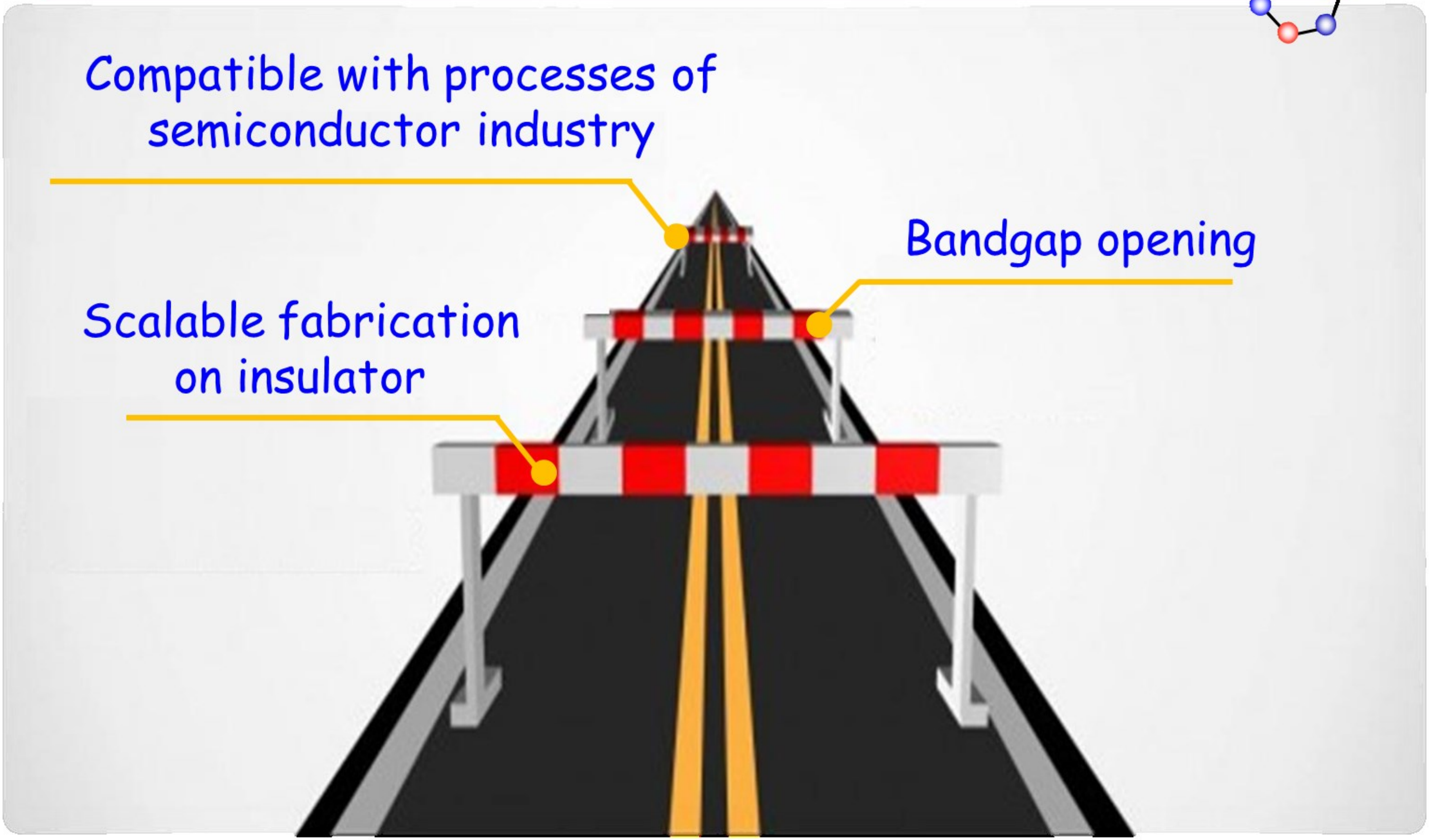
Why still graphene?

Research Focus

Development of graphene materials for micro/nanoelectronics



Challenges in Materials Preparation



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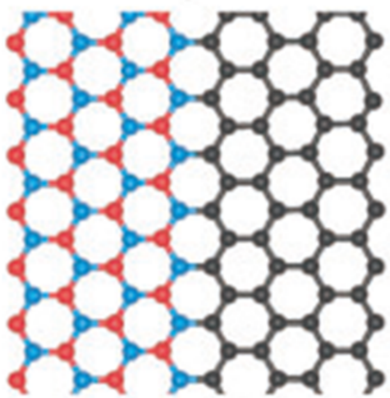
Hetero-integration of graphene and *h*-BN

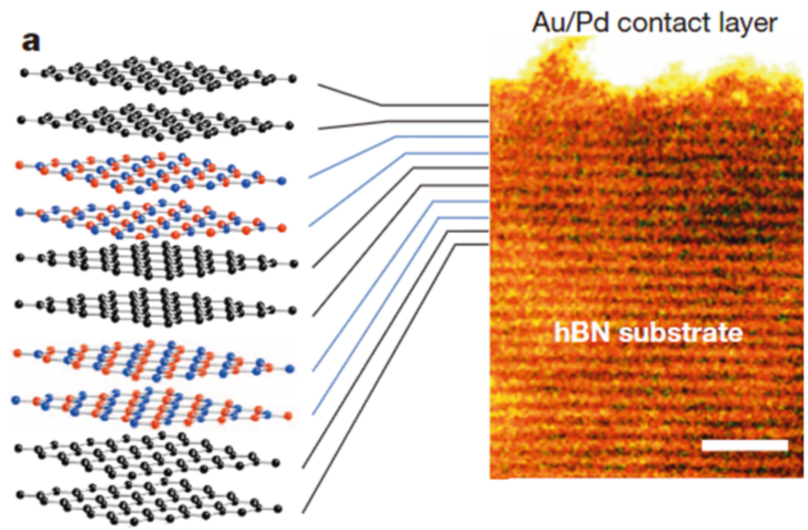
In-plane



h-BN Graphene

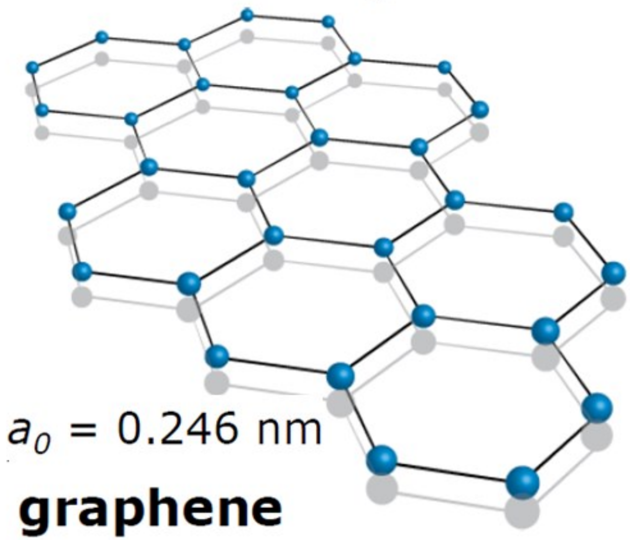
+

van der Waals

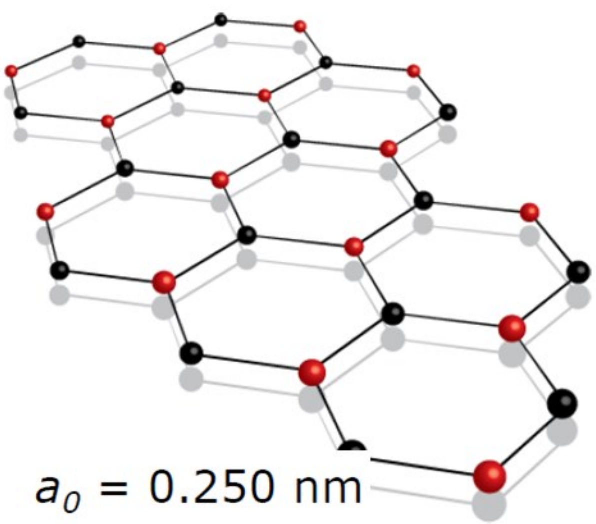


Adapted from Geim *et al.* Nature (2013),
Ajayan, *et al.* Nature Materials (2014)

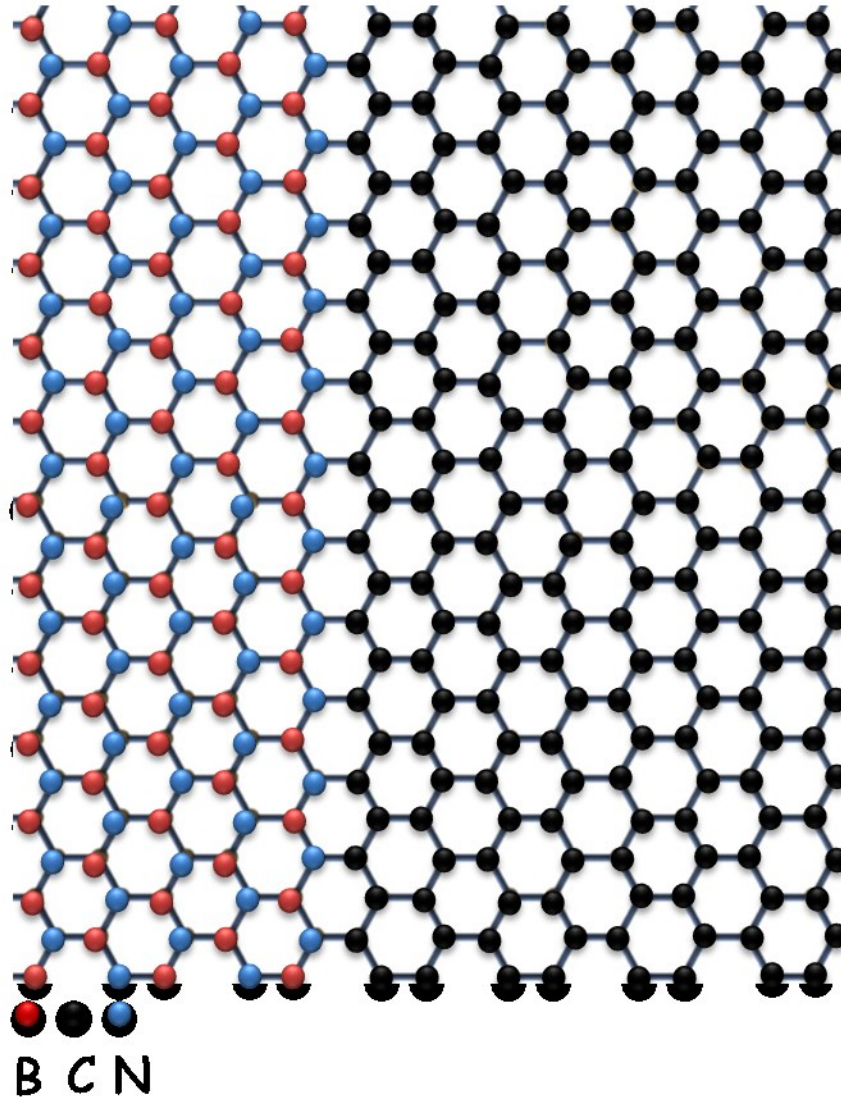
In-plane Heterostructure



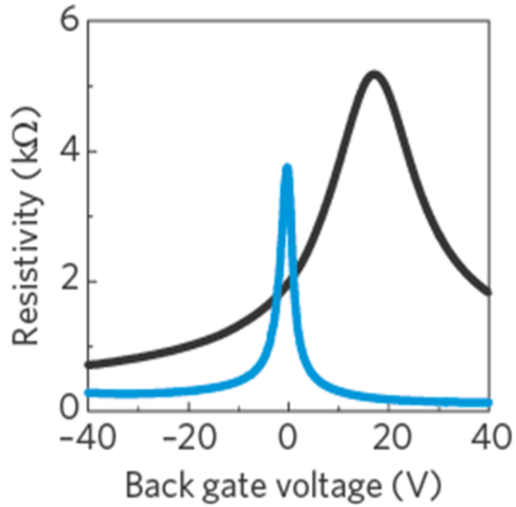
graphene

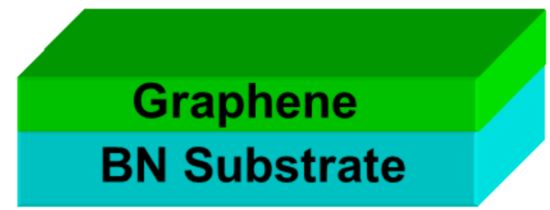


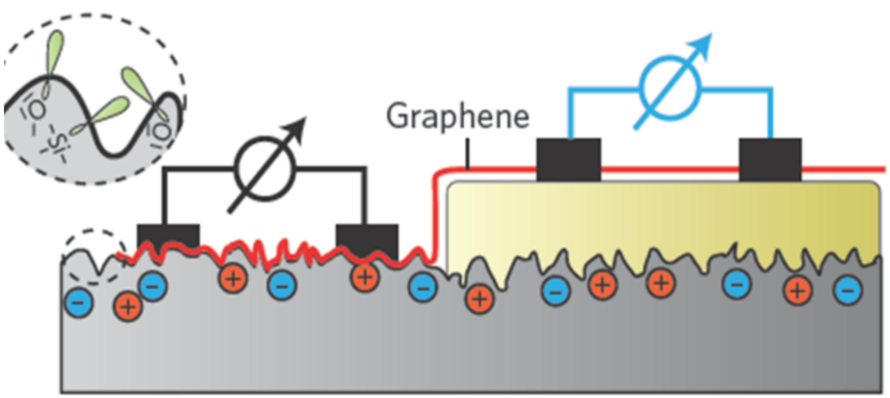
Boron Nitride

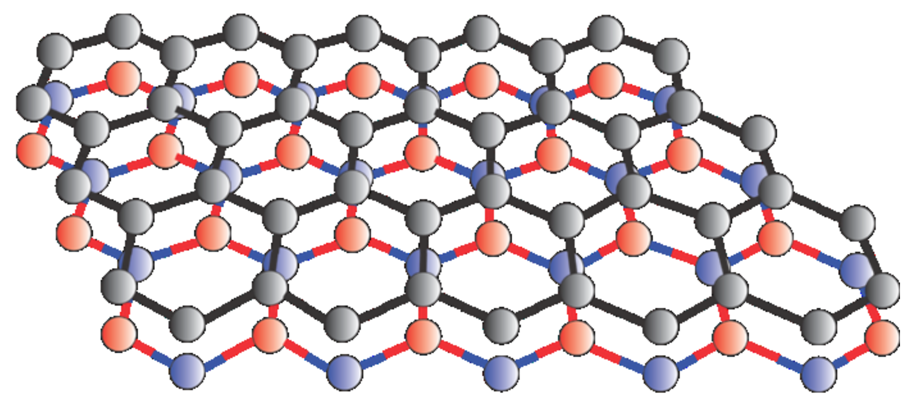


van der Waals Heterostructure









Credit :R. Thomas Weitz and Amir Yacoby
Dean, C. R. *et al.* Nature Nanotech. 5, 722–726 (2010).

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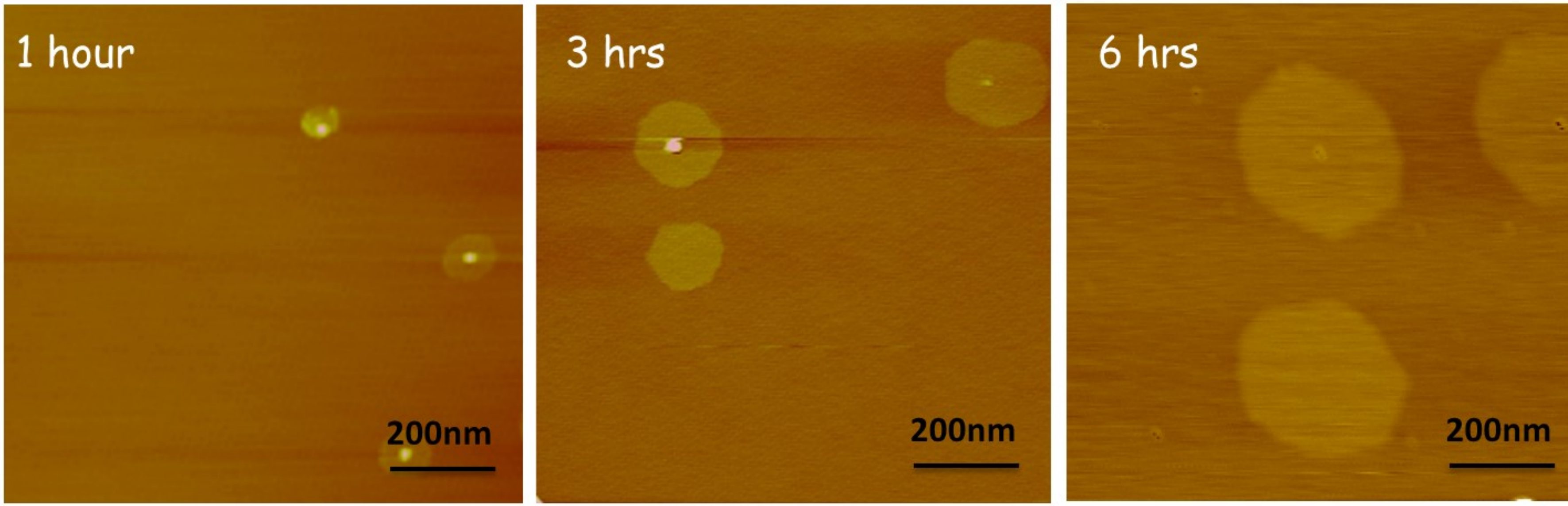
Nucleation at Imperfections

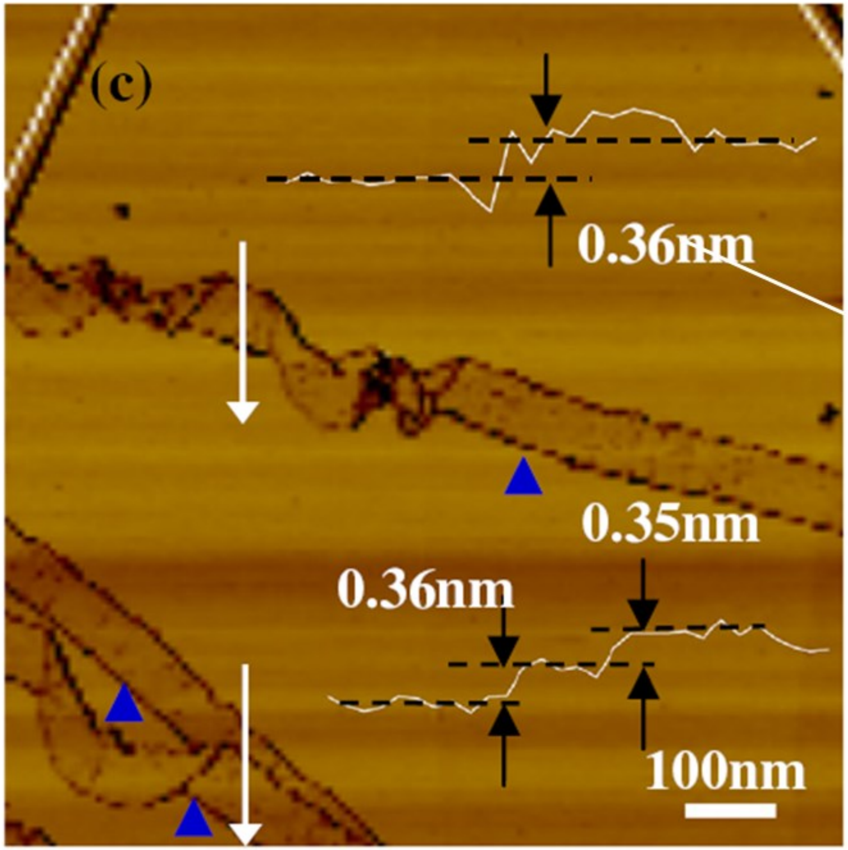


1200° C; CH_4/H_2 = 5 : 5sccm; Growth rate = 1~2nm/mins

- Domains nucleate at defective sites
- Domain size grow with increasing of deposition time

Tang S., et al. Carbon, 50, 329-331 (2012)

Nucleation at Imperfections

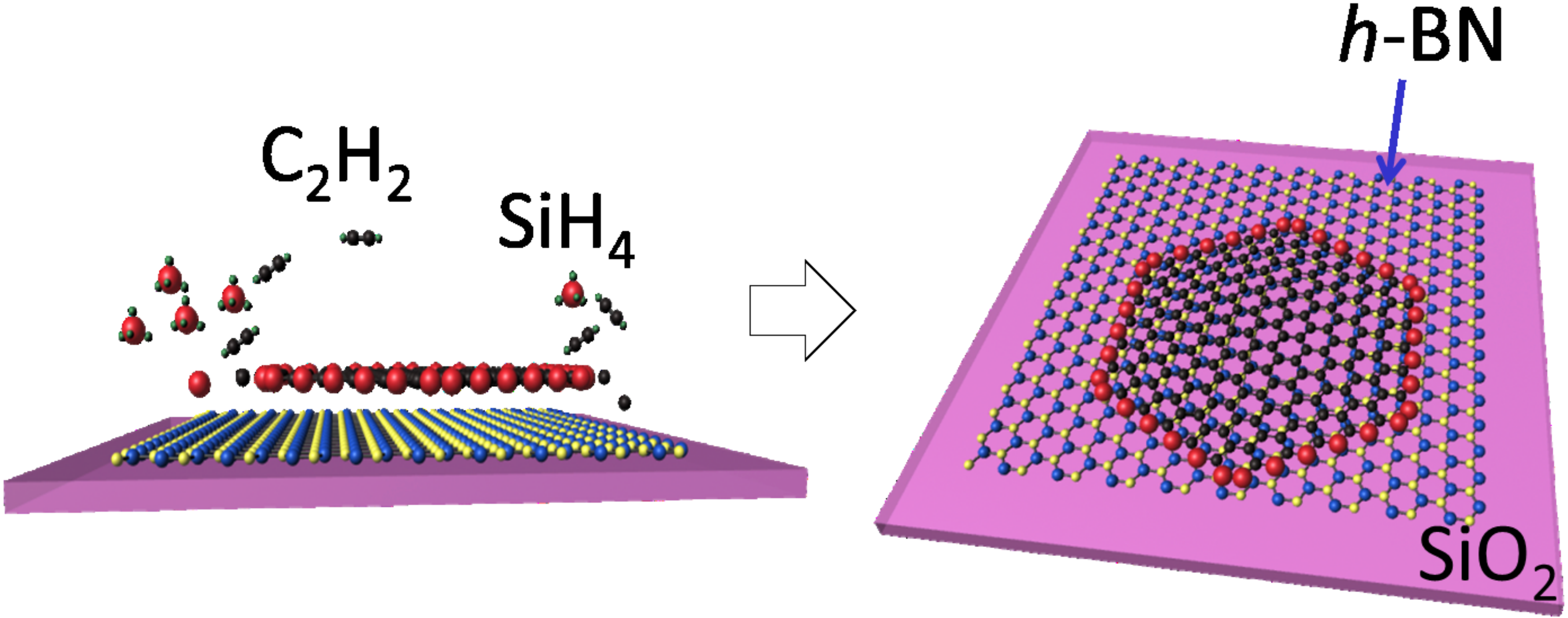


Most likely by step-flow mechanism

Tang S. *et al.* Carbon, 50, 329-331 (2012)

Strategy for Graphene Growth on *h*-BN

- **Gaseous catalyst assisted growth**



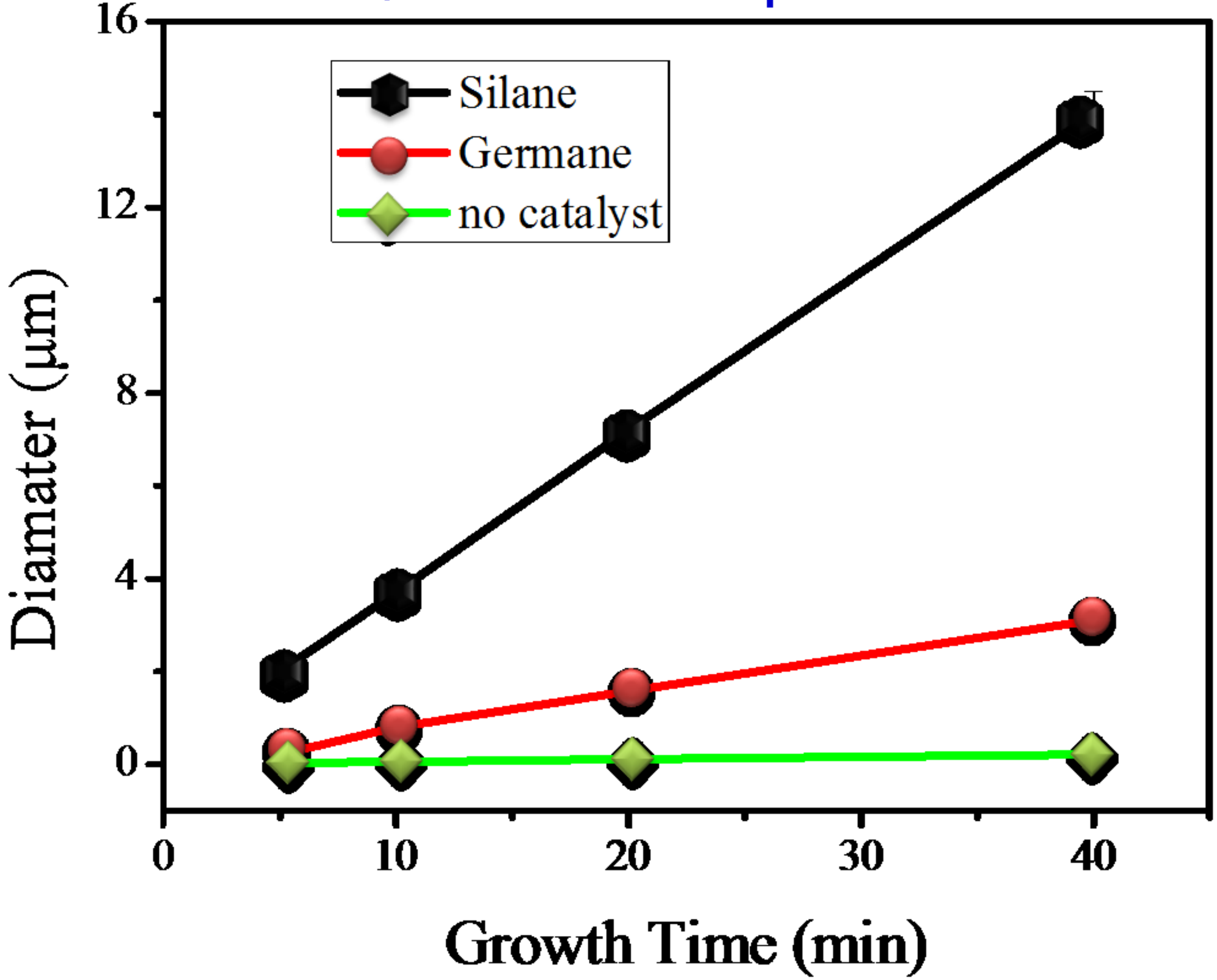
Growth rate increases from 1~2nm/min to 1 μm/min

Diameter of crystal grain from 300nm to 20μm

Tang S. Wang H. *et al.* Nature Commun., 6, 6160 (2015)

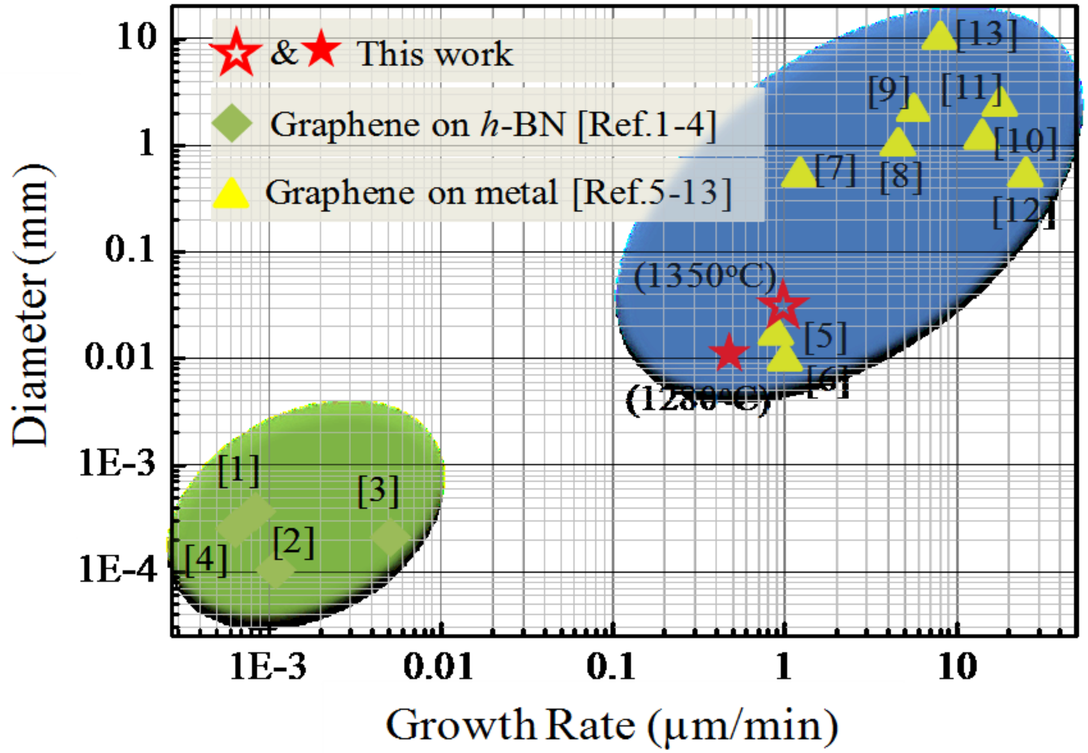
To Increase Growth Rate

Metal, Si and Ge vapors work well.



Tang S. Wang H. *et al.* Nature Commun., 6, 6160 (2015)

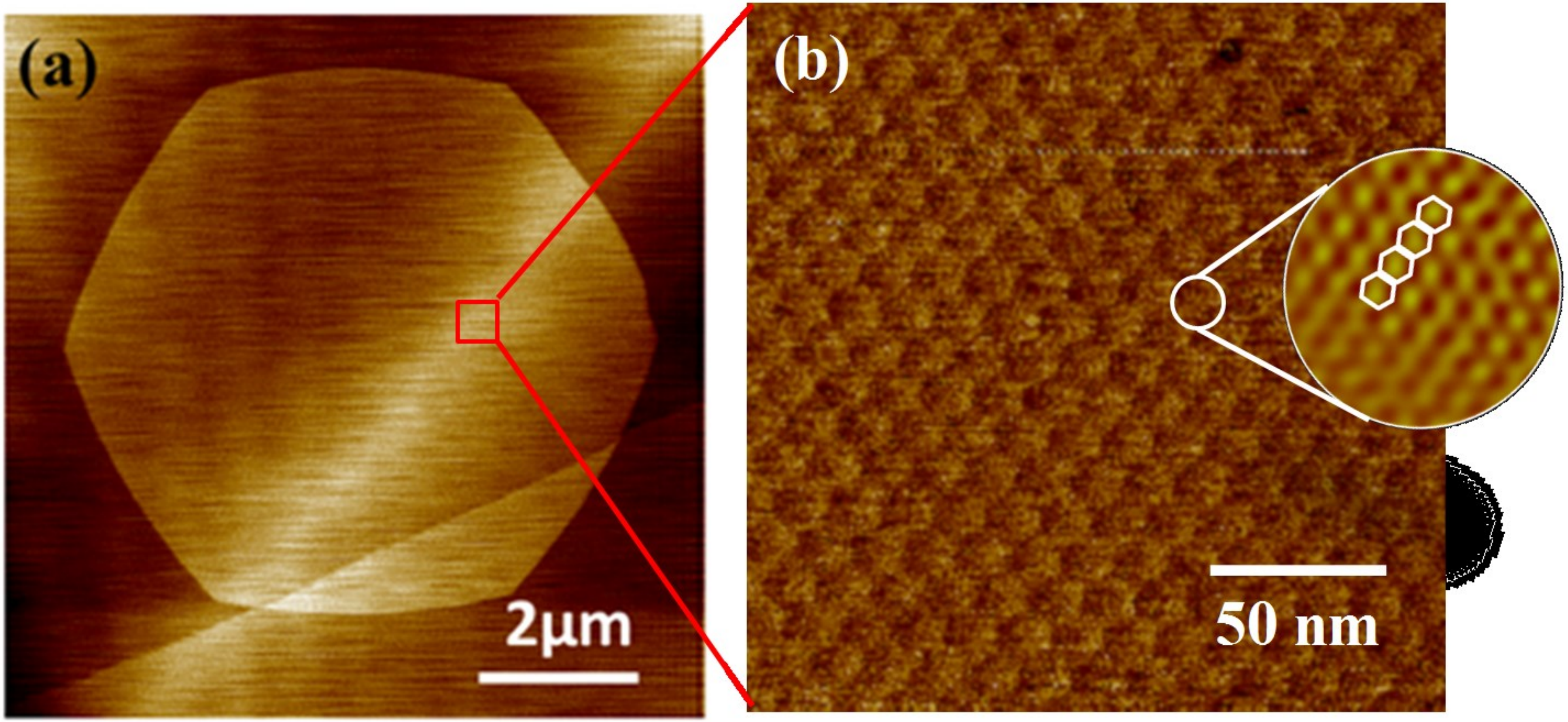
Growth Rate and the Domain Size



- ✓ Growth rate up to 1 μm/min
- ✓ single crystal up to 20μm
- ✓ Comparable with CVD graphene on Cu in the early days

Tang S. Wang H. *et al.* Nature Comm., 6, 6160 (2015)

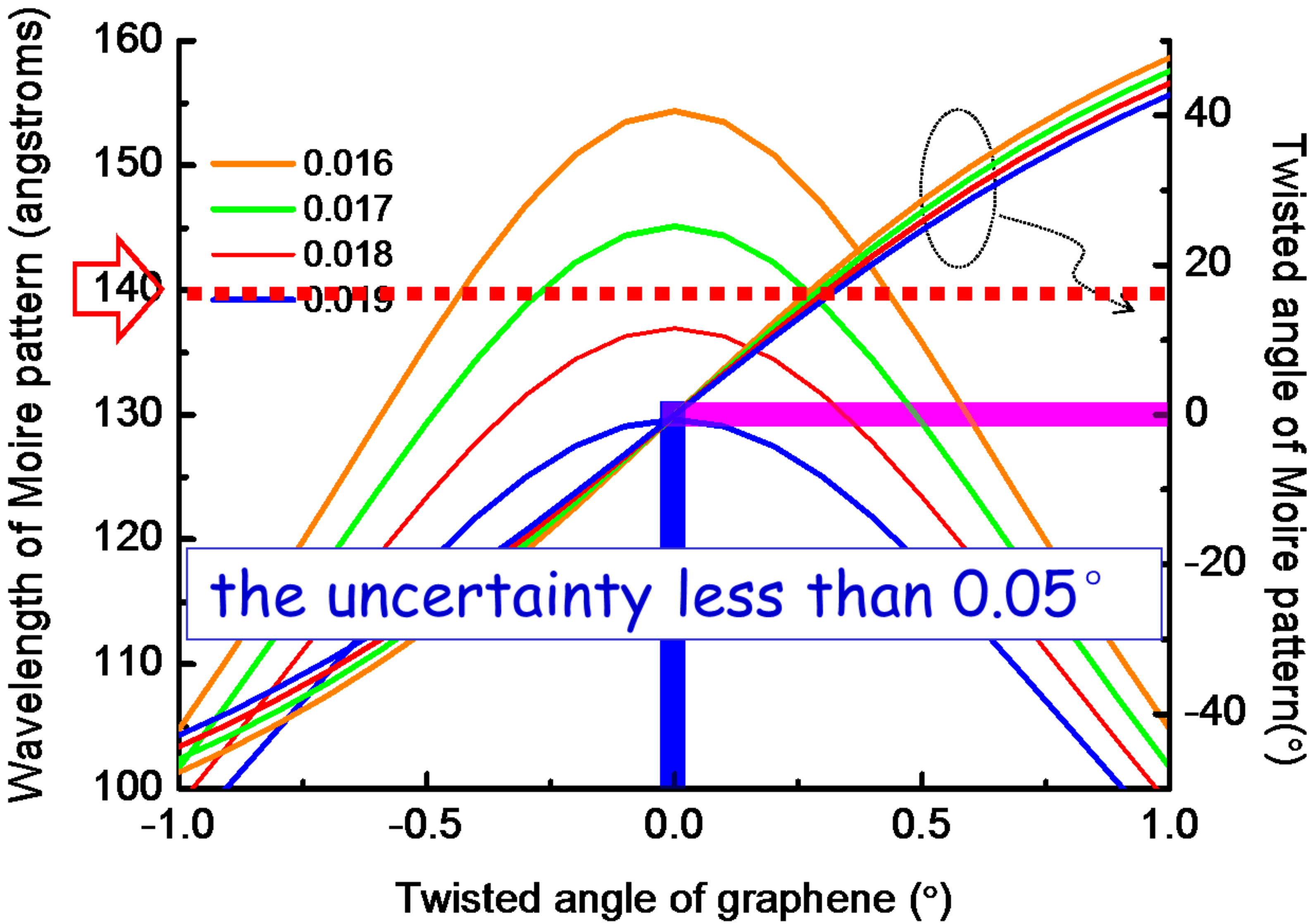
Precisely Aligned Graphene Domains



Moire pattern gives the information of graphene alignment on *h*-BN

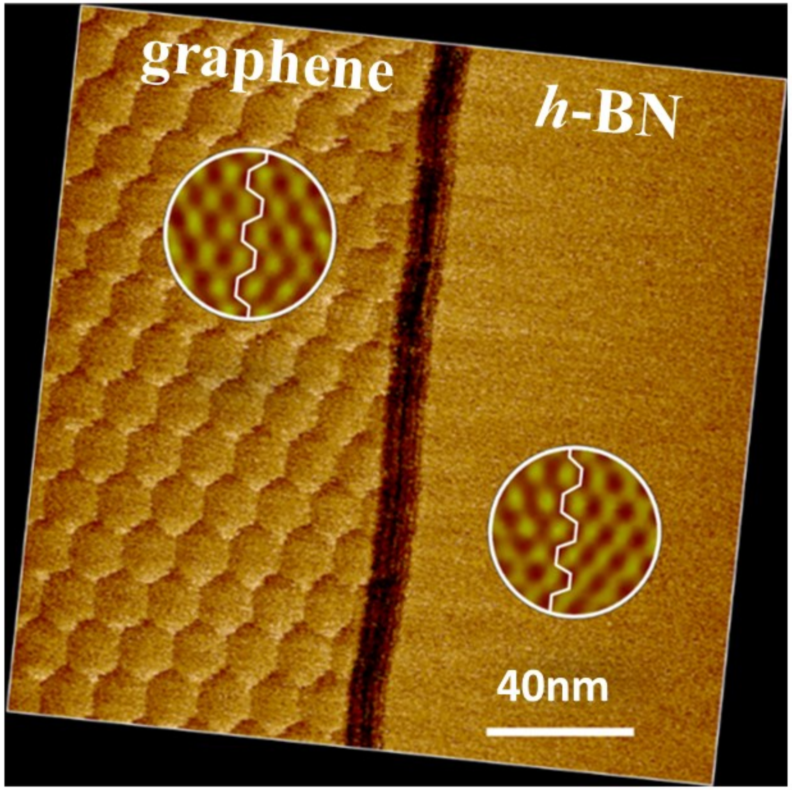
Tang S., Scientific Reports 3:2666 (2013)

High Sensitivity of Moiré Patterns

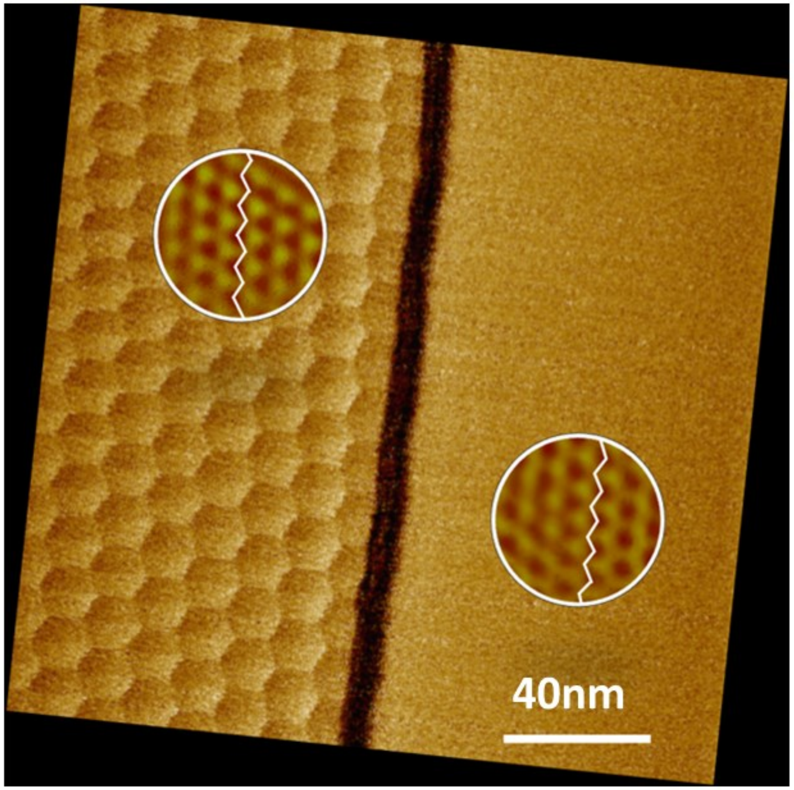


Tang S., Scientific Reports 3:2666 (2013)

Edge Control of Graphene Domains



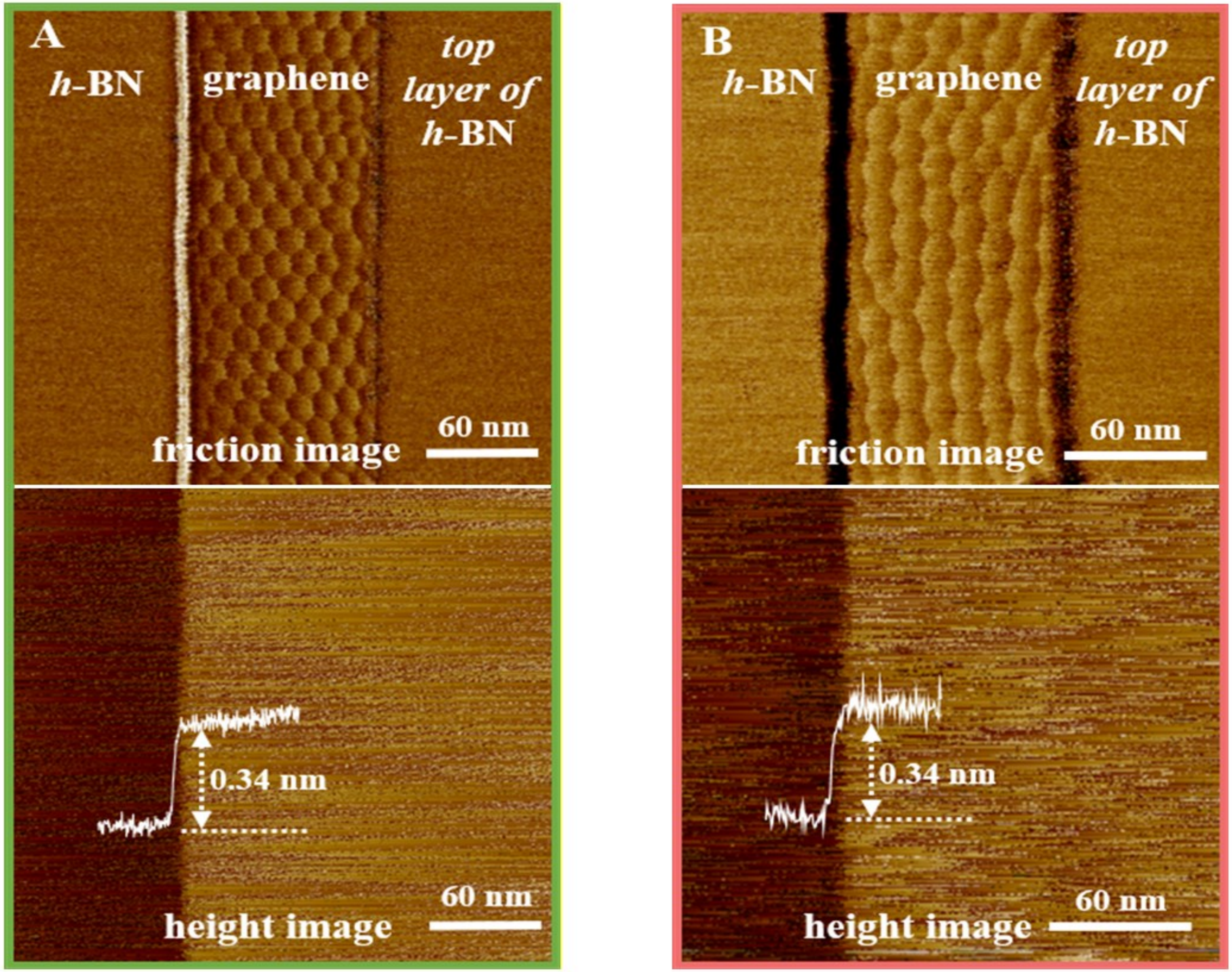
Edge along Armchair(AC)



Edge along Zigzag (ZZ)

Chen L. *et al.* Nanoscale, doi:10.1039/C7NR02578E (2017)

Epitaxial Graphene Ribbons Grown from hBN Step-edges



Chen L. *et al.* Nanoscale, doi:10.1039/C7NR02578E (2017)

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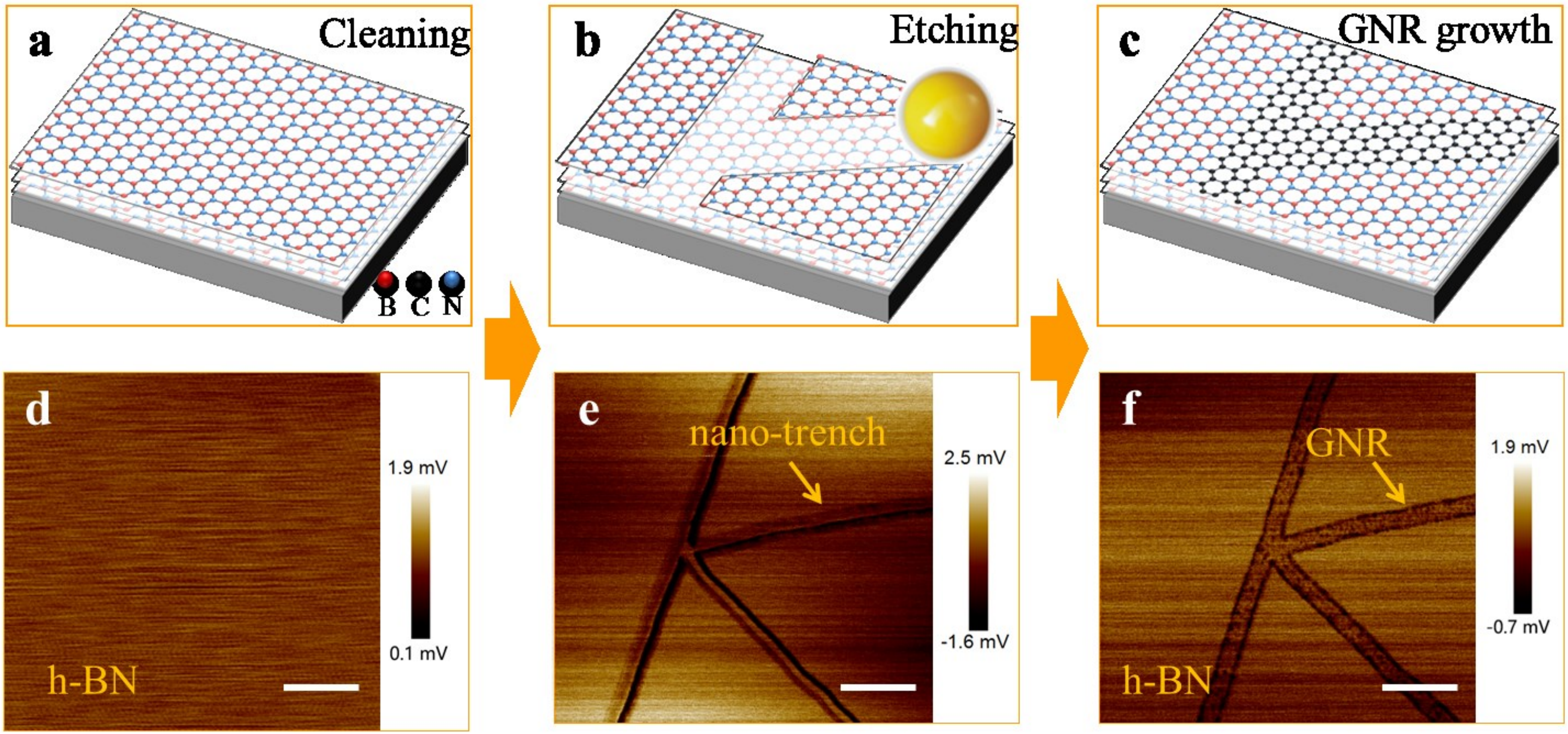
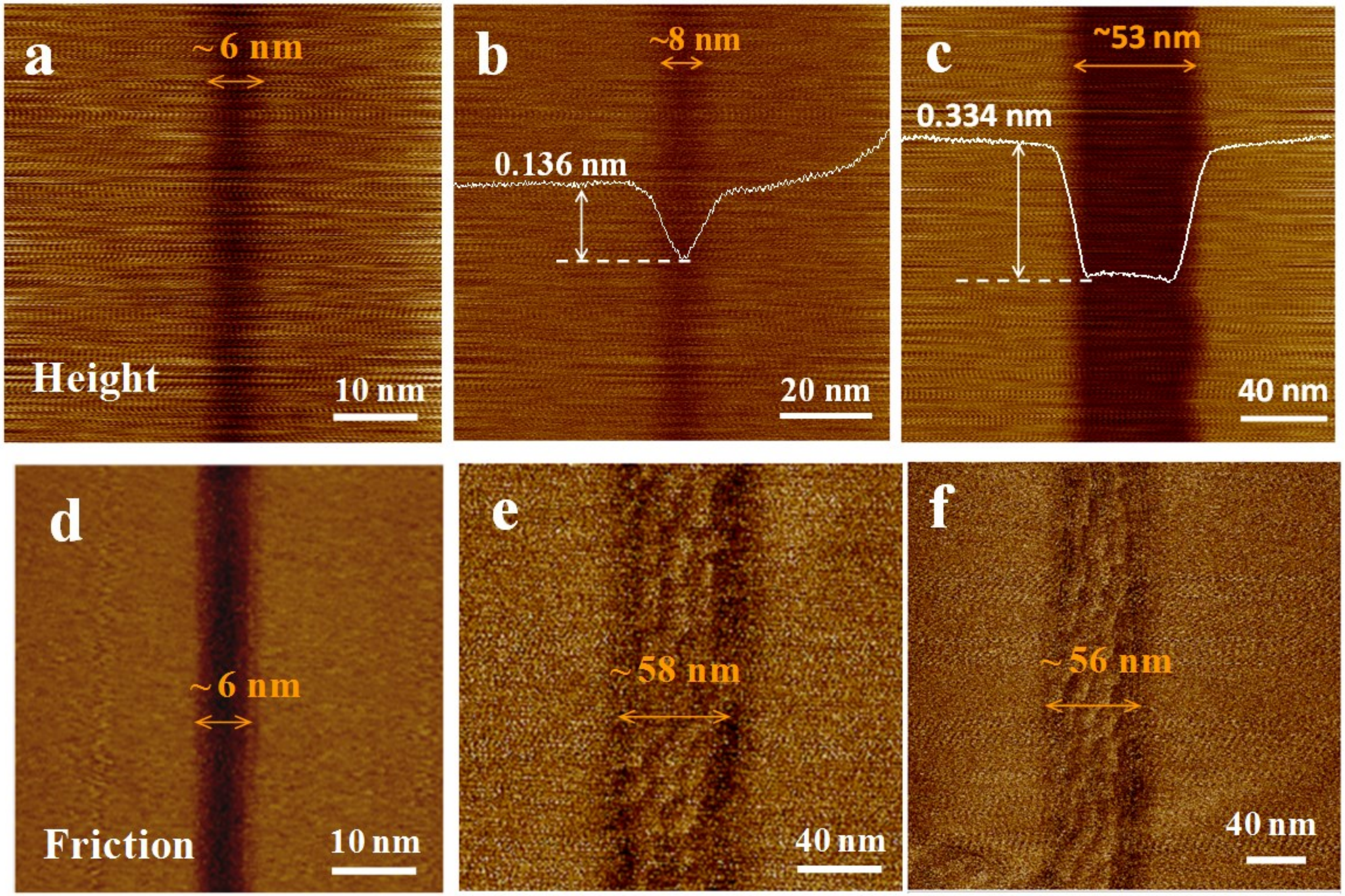
Synthesis concept for GNRs on hBN



Chen L. Wang H. *et al* Nature Commums.8,14703 (2017)

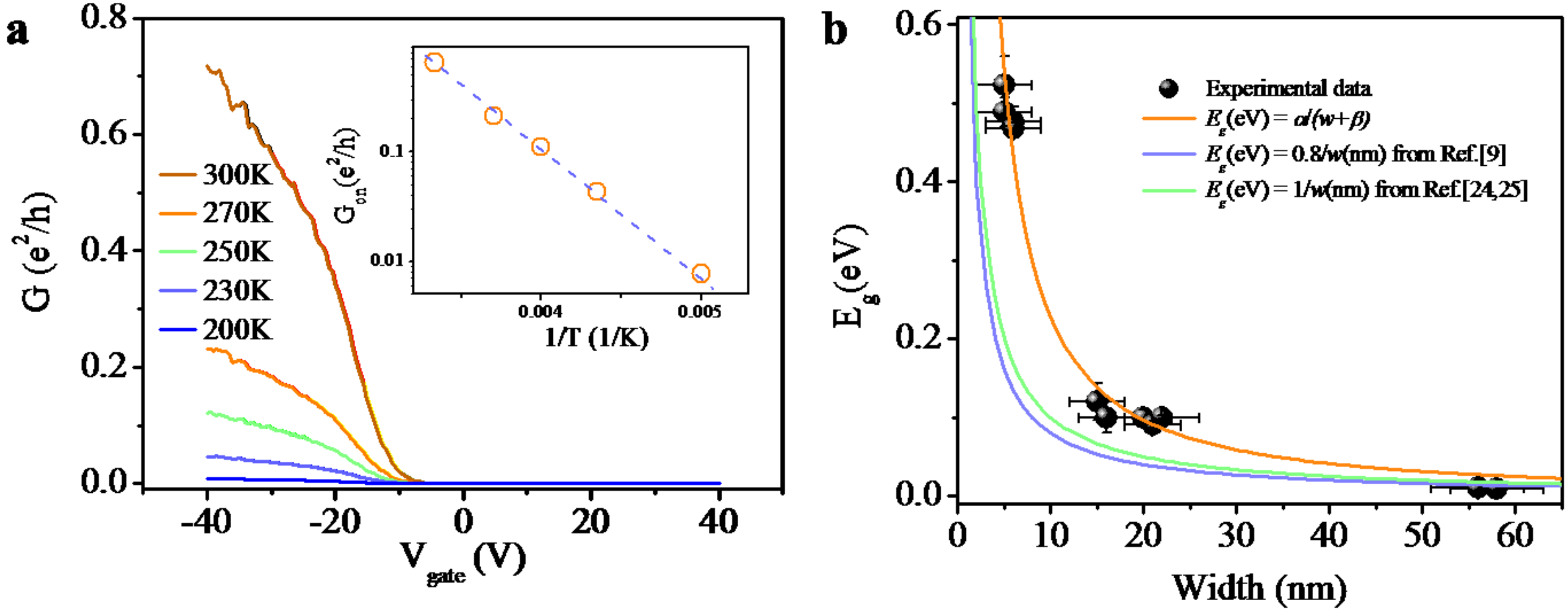
Characterization of Trenches and GNRs



Chen L. Wang H. *et al* Nature Communs.8,14703 (2017)

PCT/CN2011/078070；特願2015-206777；P2015-206777，US 13/580,240

Band Gap Engineering of GNRs



- Sub-5nmGNR-FET On/Off ratio beyond 10^4;
- Mobility is more than 700 cm^2/Vs;
- Transport gap more than 0.4eV

Chen L. Wang H. *et al* Nature Communs.8,14703 (2017)

Summary

- **Nucleation at imperfections**
- **Gaseous catalyst assistance**
- **Alignment determination**
- **Nano-trench templates**
- **GNRs from spatial confinement**

Acknowledgements

Experiments @ SIMIT: *Lingxiu Chen, Li He, Huishan Wang, Shujie Tang, Hong Xie, Tianru Wu, Xiaoming Xie and Mianheng Jiang*

Modeling @ IBS: *Feng Ding, Qinghong Yuan*

Raman @ NTU& Fudan: *Ting Yu , CX Cong*

hBN Crystals @ NIMS & KSU: *T. Taniguchi, K. Watanabe & J. H. Edgar*

Nature Comm. 8:14703 (2017);
Nanoscale, 10.1039/C7NR02578E(2017);
Nature Comm.6:6499 (2015);
Scientific Reports 3:2666 (2013);
Carbon 50, 329-331 (2012).
Carbon 49, 2522-2525 (2011).

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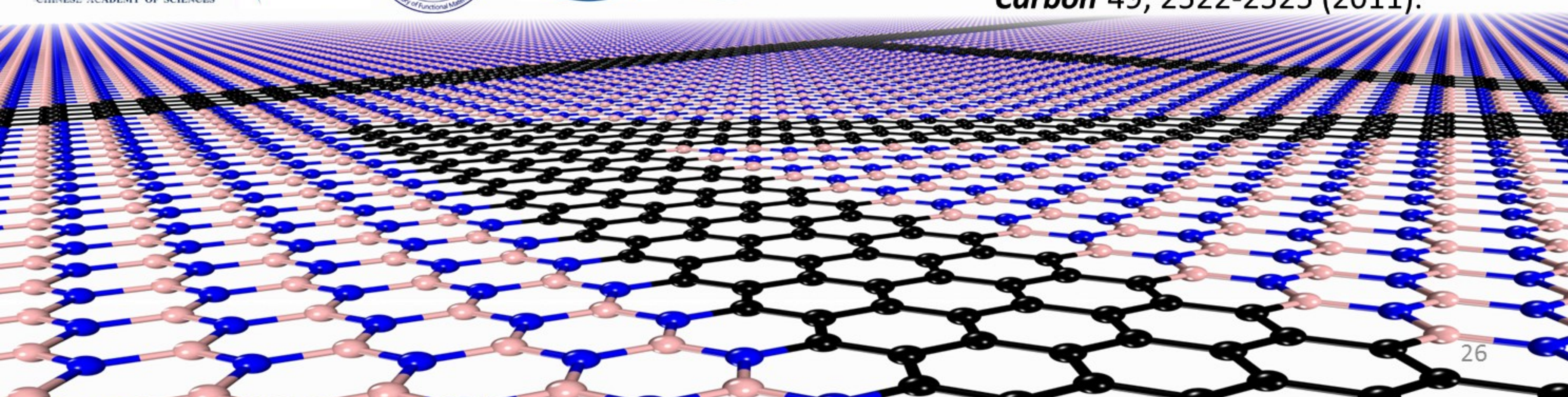

Thank you for your attention!