SUNG KYUN KWAN UNIVERSITY

SAINT SKKU Advanced Institute of Nano technology

ARON Lab Atomic Research of Nano-materials Lab

Synthesis and Characterization of Atomic and Electronic Properties of Graphene Directly Grown on Dielectric Substrates

Young Jae Song

송영재

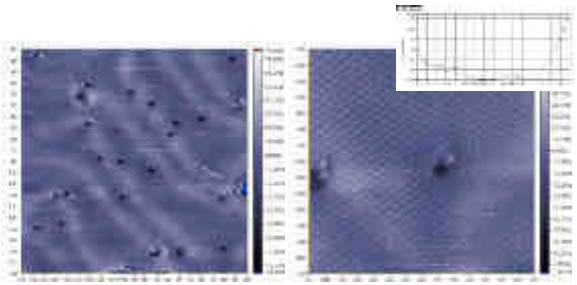
SAINT & Depart. of Physics

Sungkyunkwan University (SKKU), Suwon, Korea

Colloquium @Korea Univ., Oct. 18, 2017

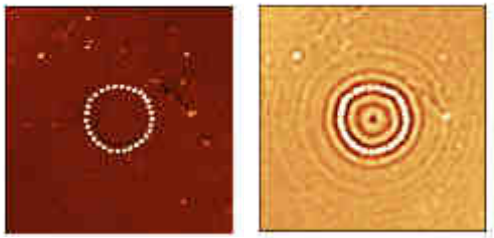
Research Issues in ARON Lab

Nano Electronics



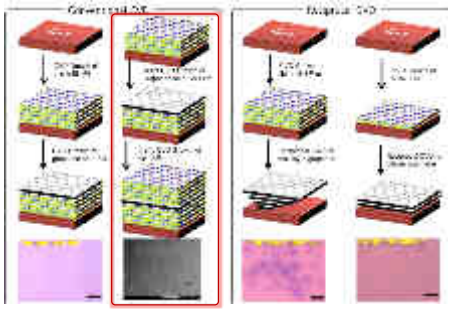
- CVD Graphene/H-Ge(110) & Graphitic Carbon Nitride
- TMD (WSe2 & ReS2) & TMC
- *In-house* DFT Calculations

Nano Optics



- Photofluidics of AuNP Corral
- Graphene Plasmonics w/ AuNP
- EL Study of QD for Display
- Perovskite for Solar Cell
- *In-house* Simulations

Graphene-based Heterostructures



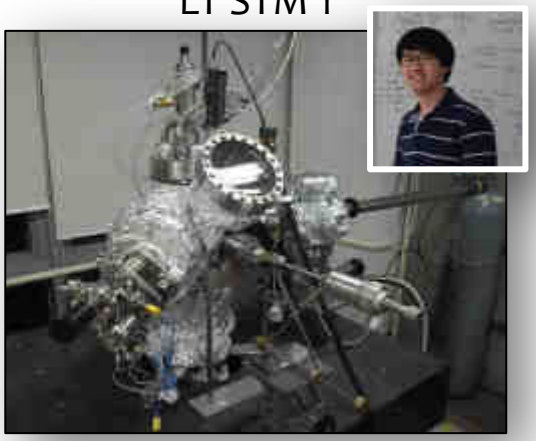
- Direct CVD Growth of Graphene/h-BN and BGB
- Direct CVD Growth of Graphene on Dielectric Substrates
- Reciprocal CVD Growth of Polycrystalline Bilayer Graphene

Qingshan YANG

Facilities in ARON Lab

Low Temperature STM

LT STM 1



LT STM 2

Ambient STM

Air STM

SPM

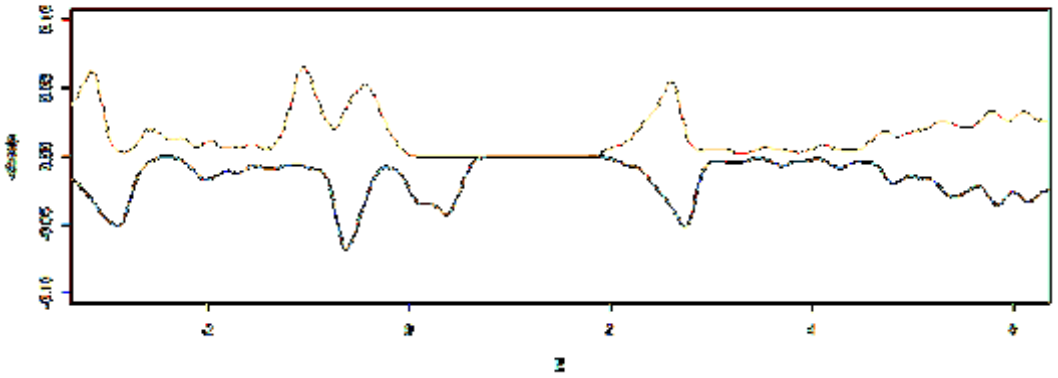
apertureless NSOM
(under upgrade w/ Park Systems)

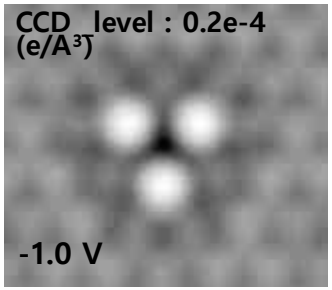
AFM/KPFM/EFM
(to be upgraded for SGM)

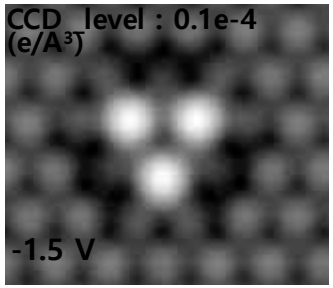
Micro Raman

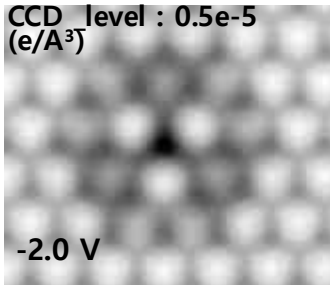
Commercial Raman

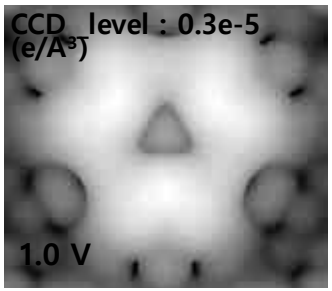
In house DFT Calculations

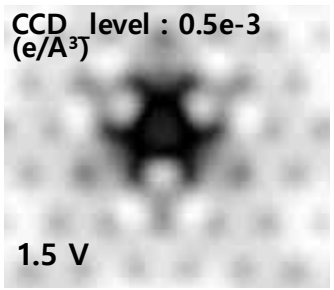


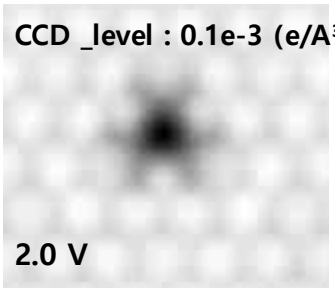








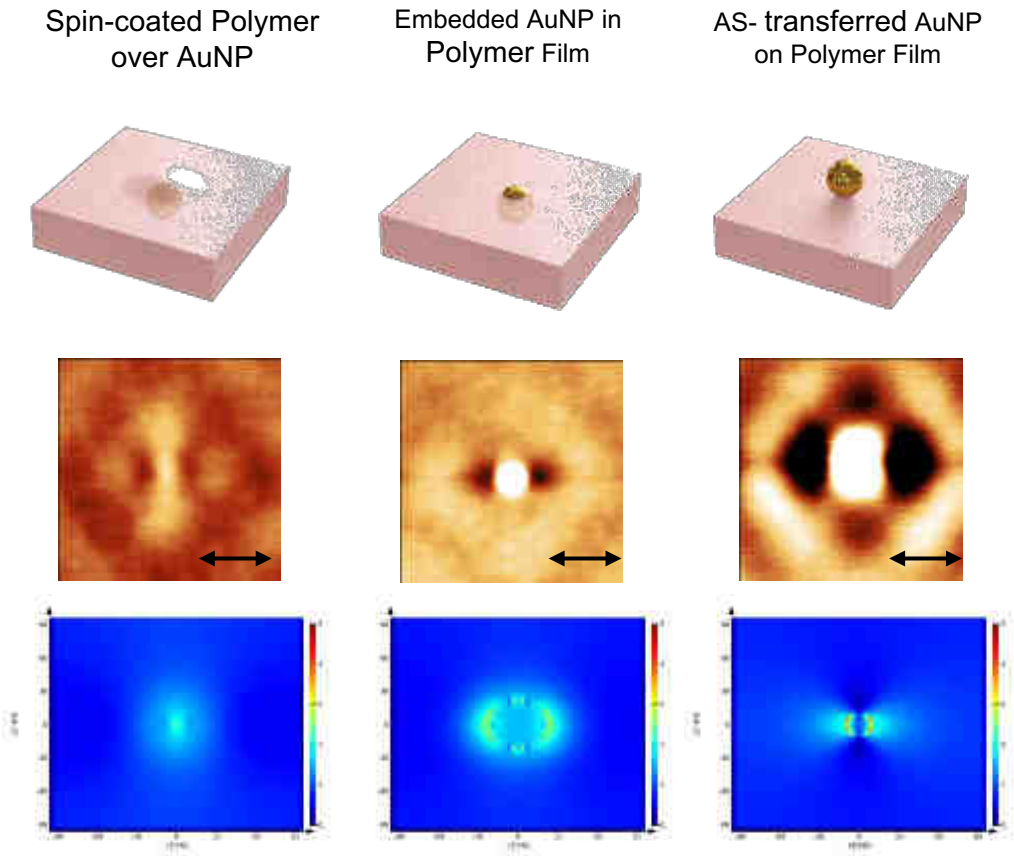




- Tools: VASP or Quantum Espresso
- GGA within PBE formalism was employed for the exchange–correlation potential.
- PAW method and a plane-wave basis set with an energy cutoff of 500 eV
- Van der Waals Correction
- Spin-polarized DOS
- Band Calculation by HSE Exchange Correction
- STM Image Simulation

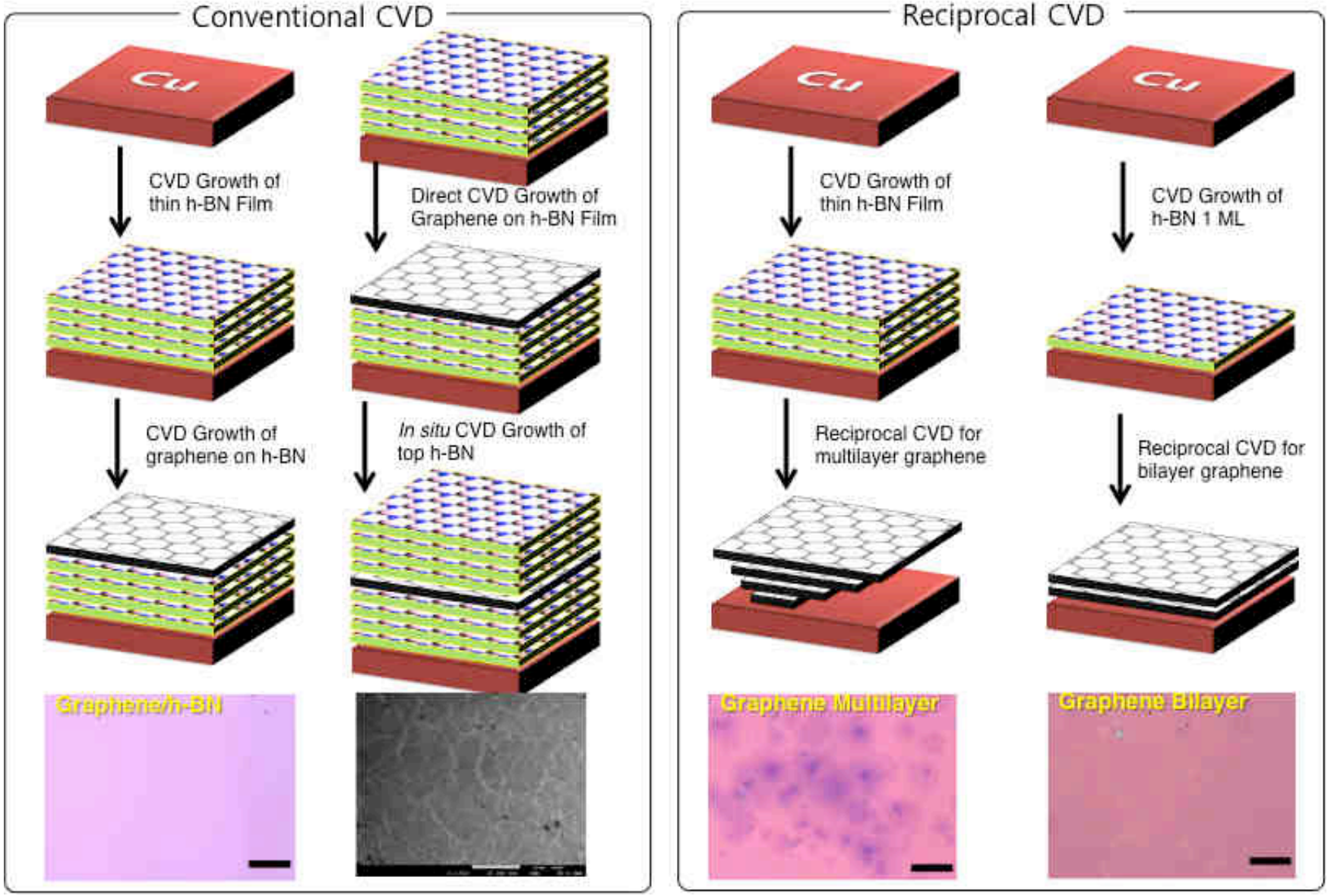
- 1 node of 20 cpu's in CINAP(IBS)@SKKU
- Tachyon 2 @KISTI

In house FDTD Simulation

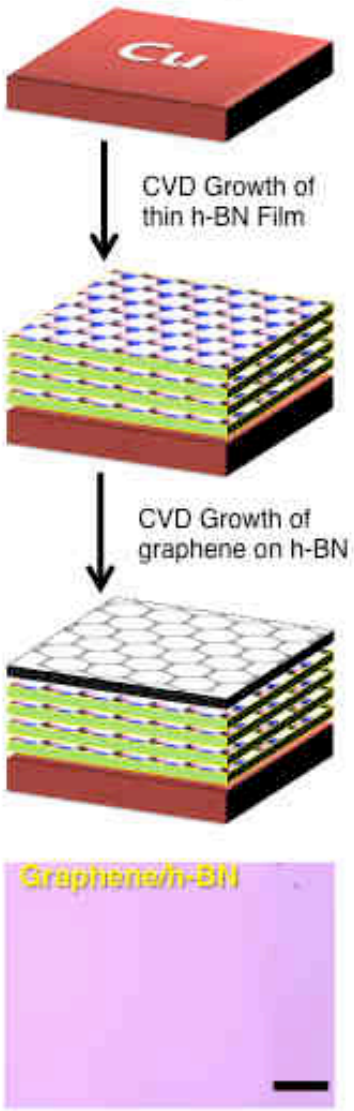


- Tools: Lumerical FDTD Solution –Maxwell equation solver by FDTD (Finite-Difference Time-Domain) method in 3 dimension
- Simulation for azo-benzene polymer (pDR1) with superspherical gold nano particle
- pDR1 index = 1.5
  Background index = 1.0
  AuNP's diameter = 60nm

Graphene Grown on/with *h*-BN



Issue 1 : Graphene/h-BN Heterostructure



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COMMUNICATION

A Platform for Large-Scale Graphene Electronics – CVD Growth of Single-Layer Graphene on CVD-Grown Hexagonal Boron Nitride

Min Wang, Sung Kyu Jang, Won-Jun Jang, Minwoo Kim, Seong-Yong Park, Sang-Woo Kim, Se-Jong Kahng, Jae-Young Choi, Rodney S. Ruoff, Young Jae Song, and Sungjoo Lee**

ARTICLE

Catalytic Transparency of Hexagonal Boron Nitride on Copper for Chemical Vapor Deposition Growth of Large-Area and High-Quality Graphene

Min Wang,[†,‡] Minwoo Kim,[†,‡] Dorj Odkhuu,[§] Noejung Park,[§] Joohyun Lee,[†,‡] Won-Jun Jang,[∥] Se-Jong Kahng,[∥] Rodney S. Ruoff,[⊥,*] Young Jae Song,[†,‡,#,*] and Sungjoo Lee[†,‡,⊗,*]

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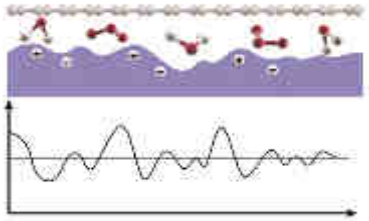
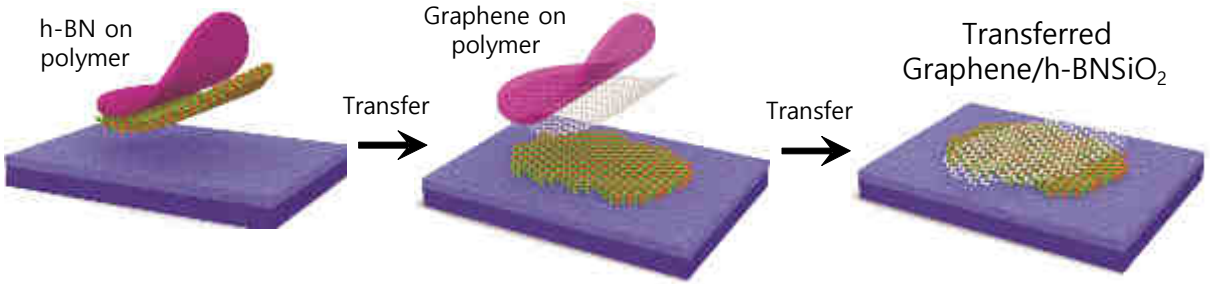
Motivation

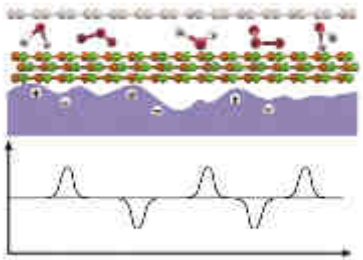
Transferring Graphene on SiO_2



- Most of graphene measurements were done on this way.
- Roughness (1) and charge impurities (2) of SiO_2 with chemical impurities (3) underneath of graphene disturbs the graphene properties.

Transferring h-BN and Graphene sequentially on SiO_2

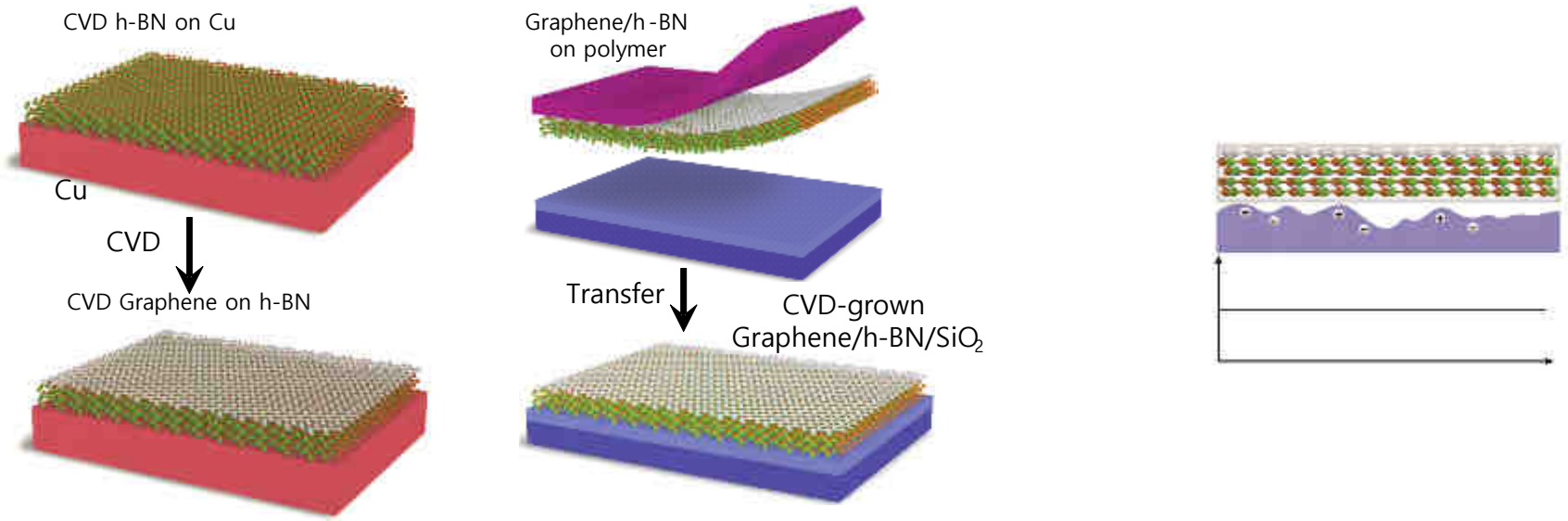




- h-BN layers are used as a flat surface without charge impurities.
- Chemical impurities by transferring graphene or h-BN with wet chemistry still remains as scatter.

Motivation

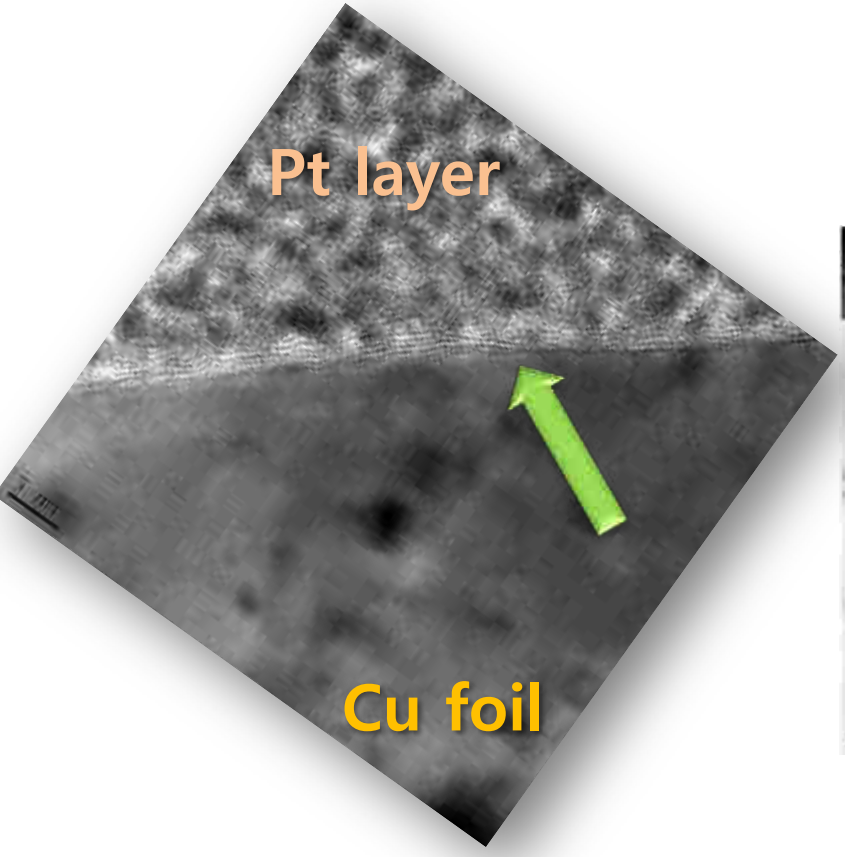
Transferring Graphene/h-BN on SiO_2

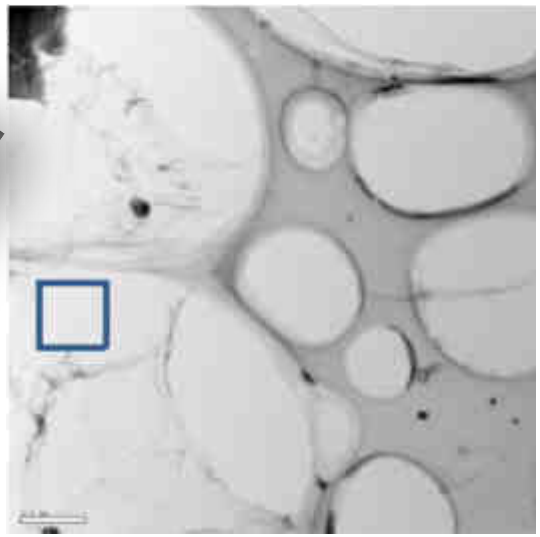


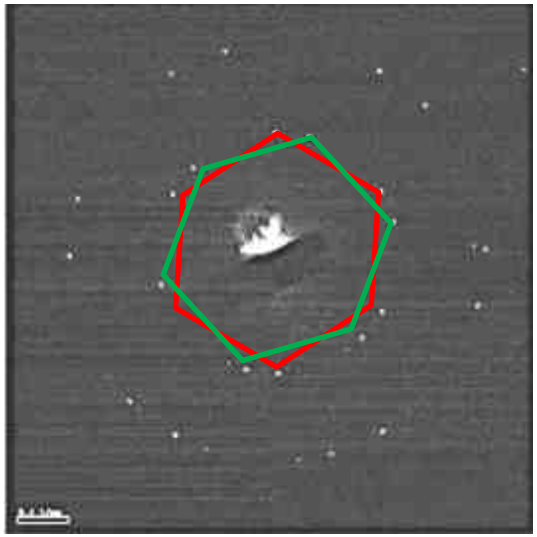
- Approach: Transfer the clean interface by using a hybrid structure.

  I. Large Area CVD Growth of h-BN on Cu foil
  II. Sequential CVD Growth of Graphene on h-BN/Cu
  III. Etching Cu foil
  IV. Transfer this Graphene/h-BN structure with keeping the clean interface.

Crystallinity (TEM & SAED)



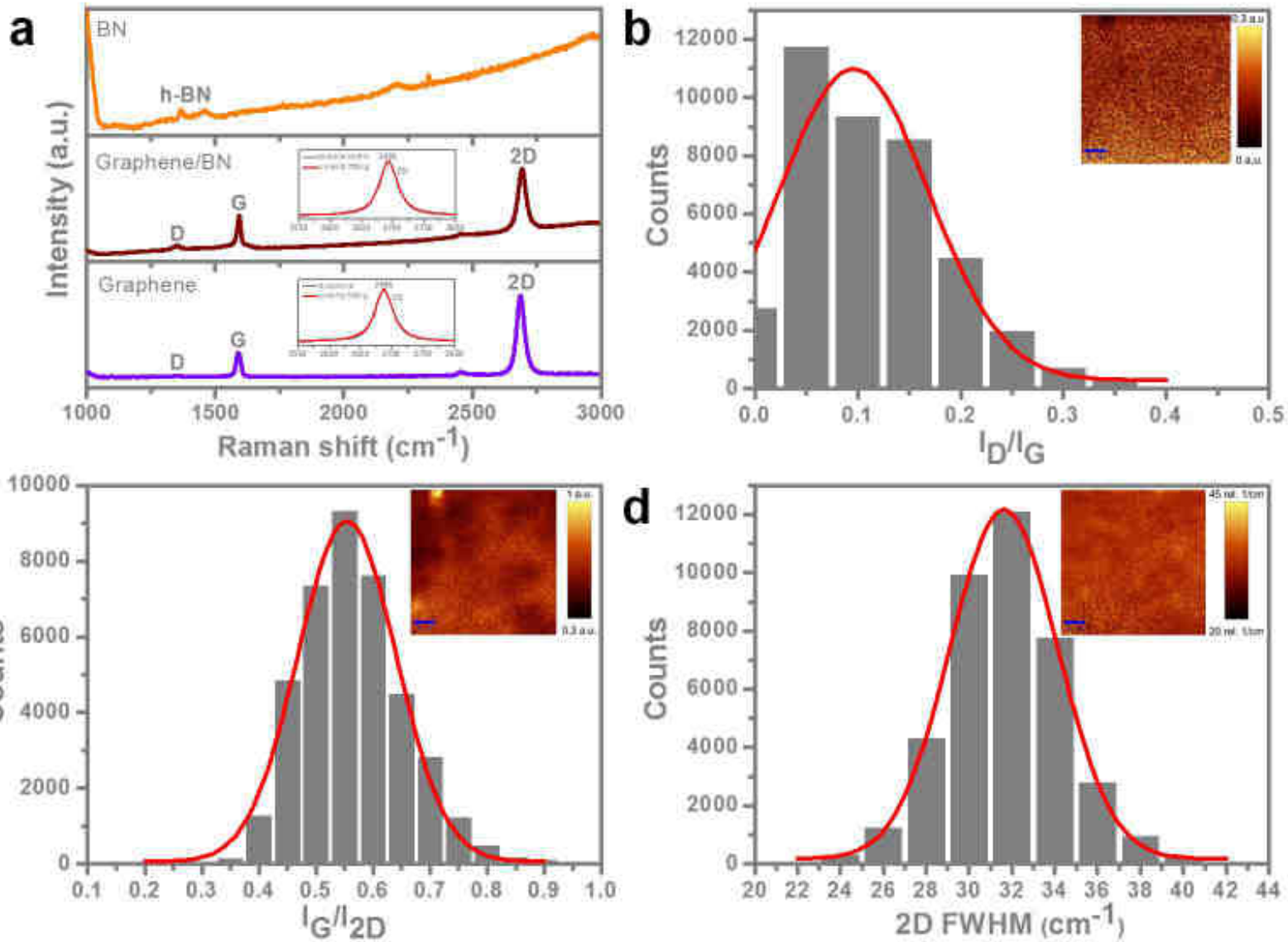




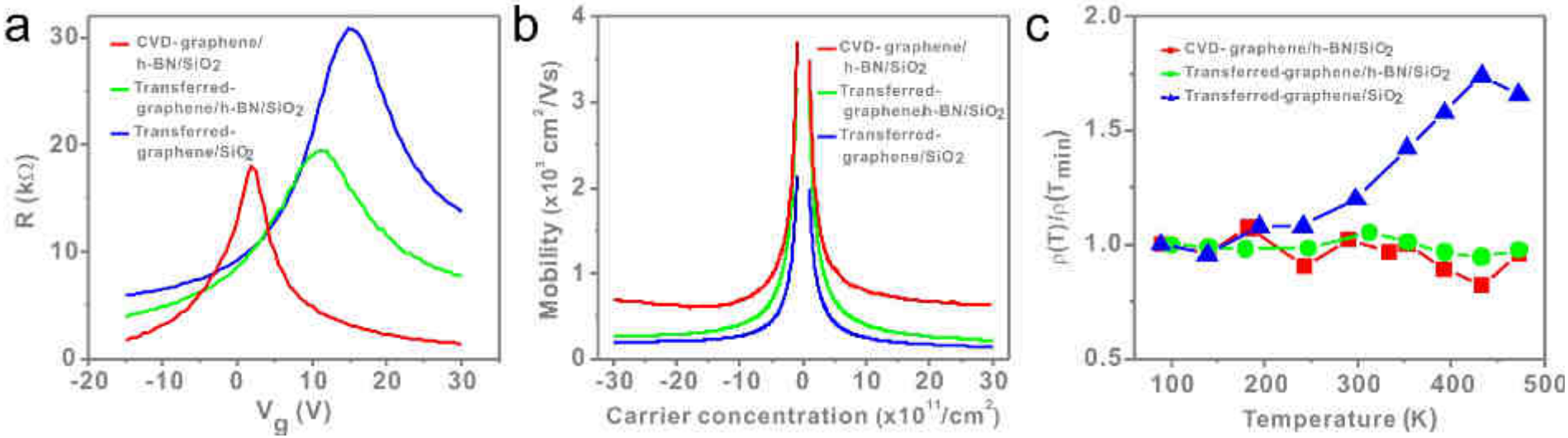
Robust enough to keep the layered structure

Two distinct Single crystal phases from both of graphene and h-BN at least 200 nm x 200 nm

Graphene Quality (Raman Spectroscopy)



Electrical Properties

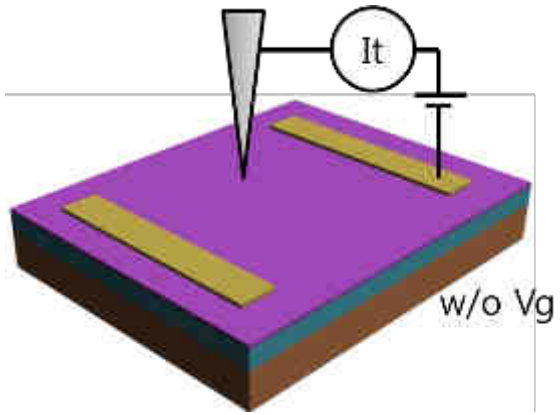


a) Resistance versus applied gate voltage for CVD-grown graphene/h-BN, mechanically transferred graphene/h-BN, and graphene on SiO_2.

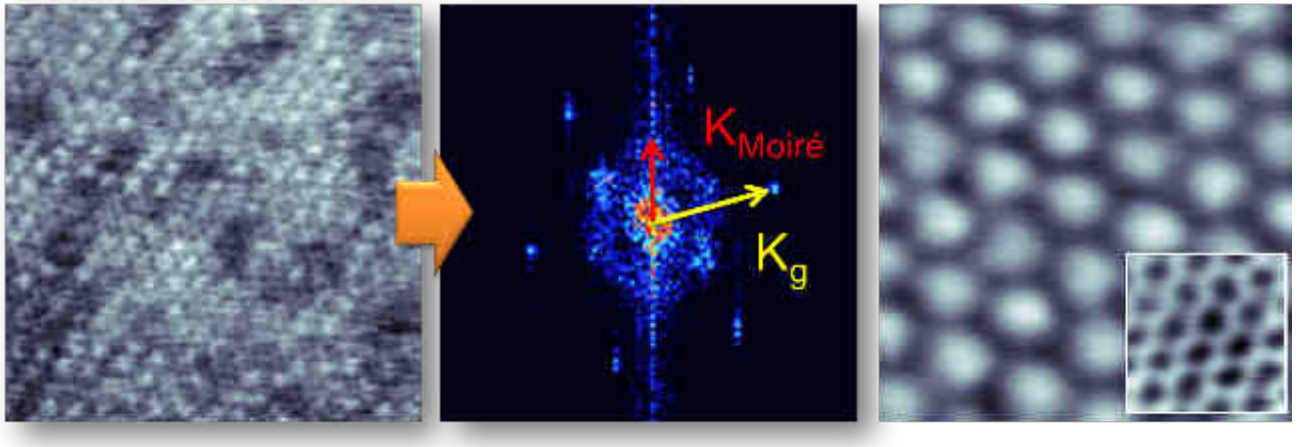
b) Carrier mobility as a function of charge carrier density for the three devices.

c) Temperature dependences of the resistivity at $V_g - V_{Dirac} = 10$ V for the three devices.

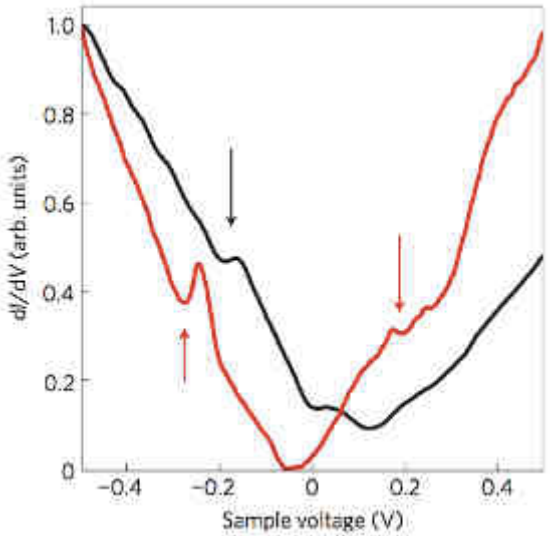
Atomic and Electronic Structures (STM/STS)

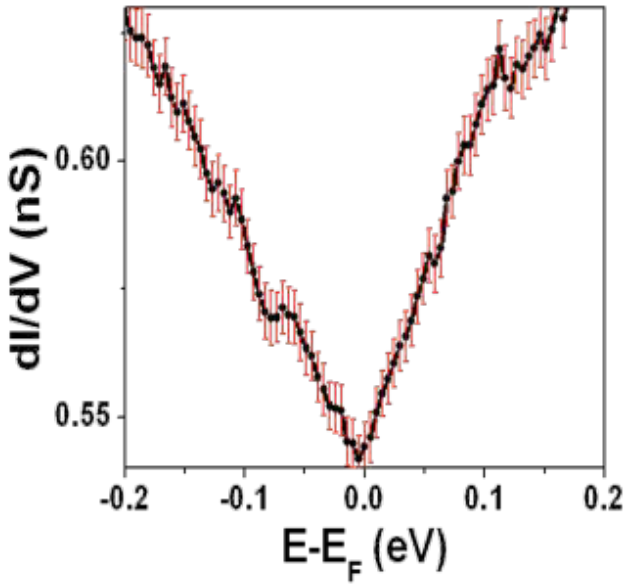


STM and FFT



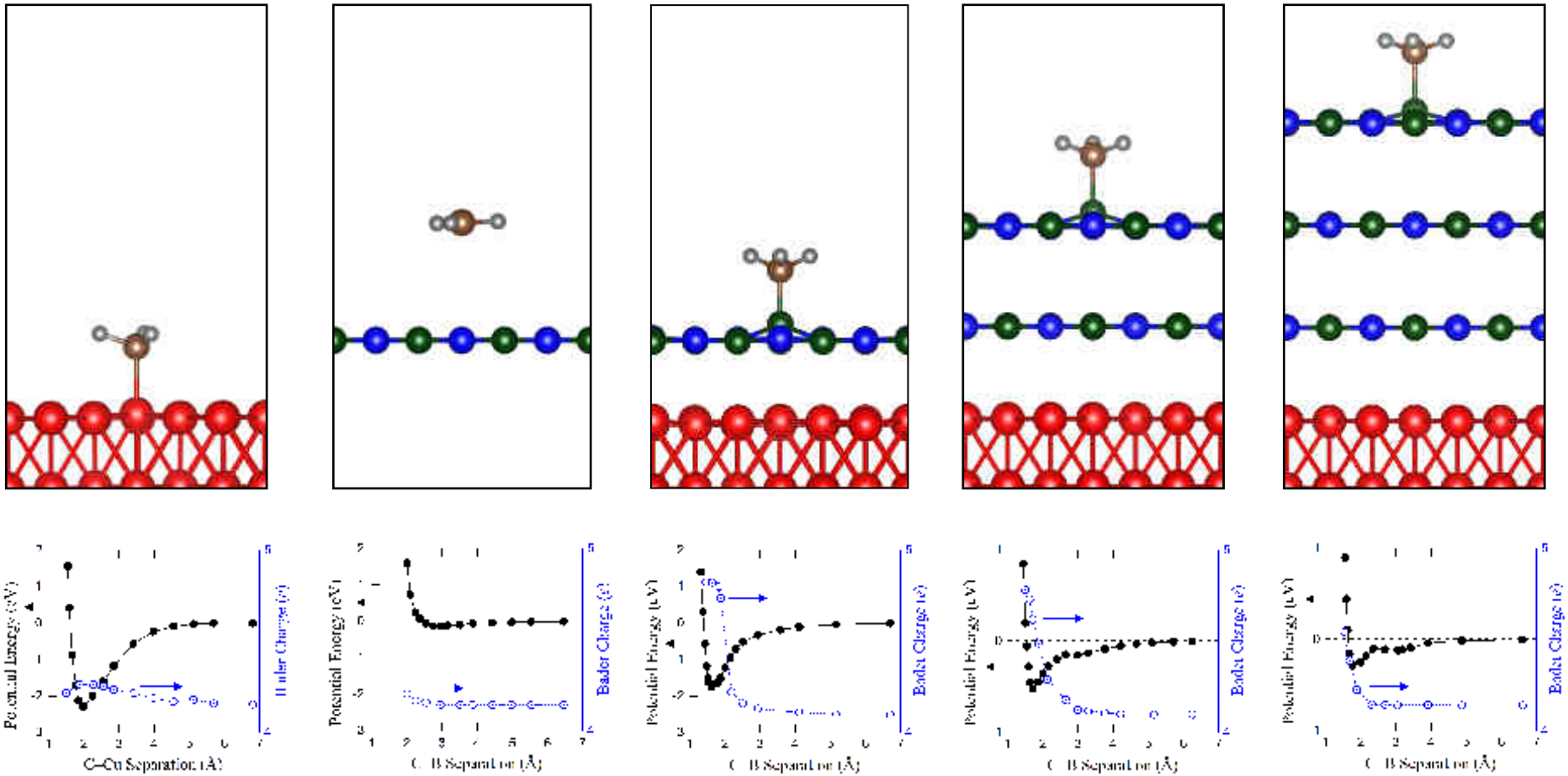
STS





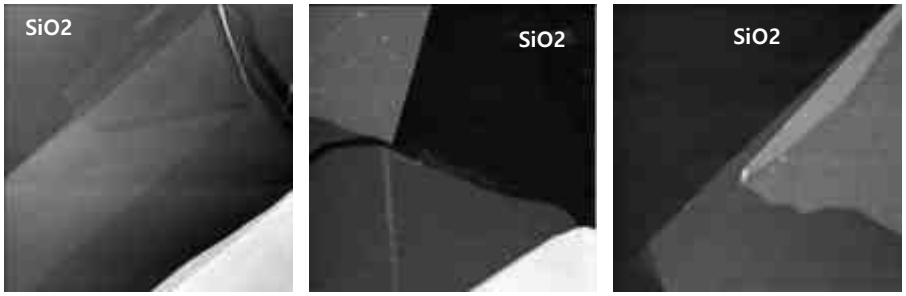
Nat. Mat. v10, 282 (2011)

Growth Mechanism (DFT Calculations)



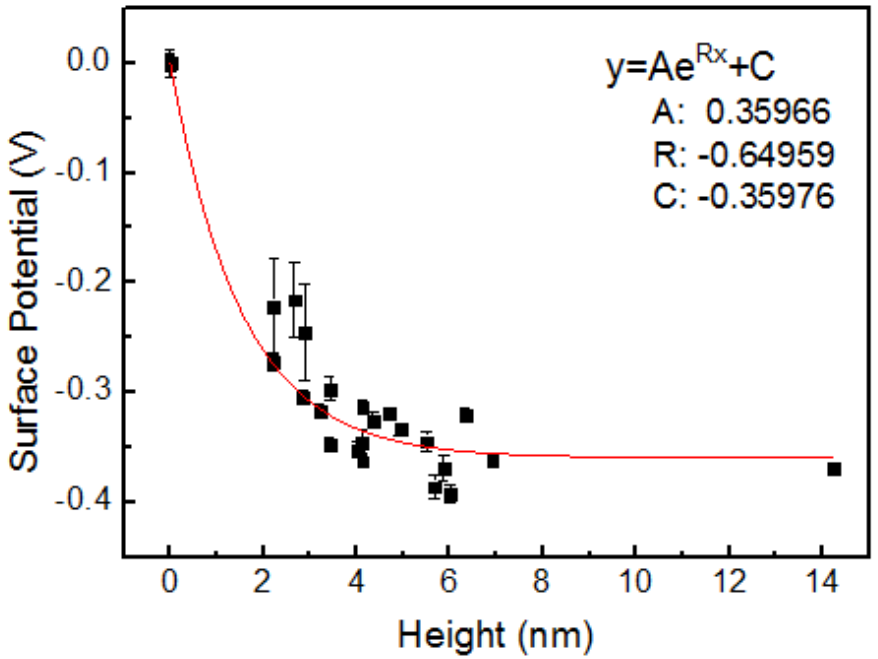
Growth Mechanism (Surface Potential)

AFM Topography

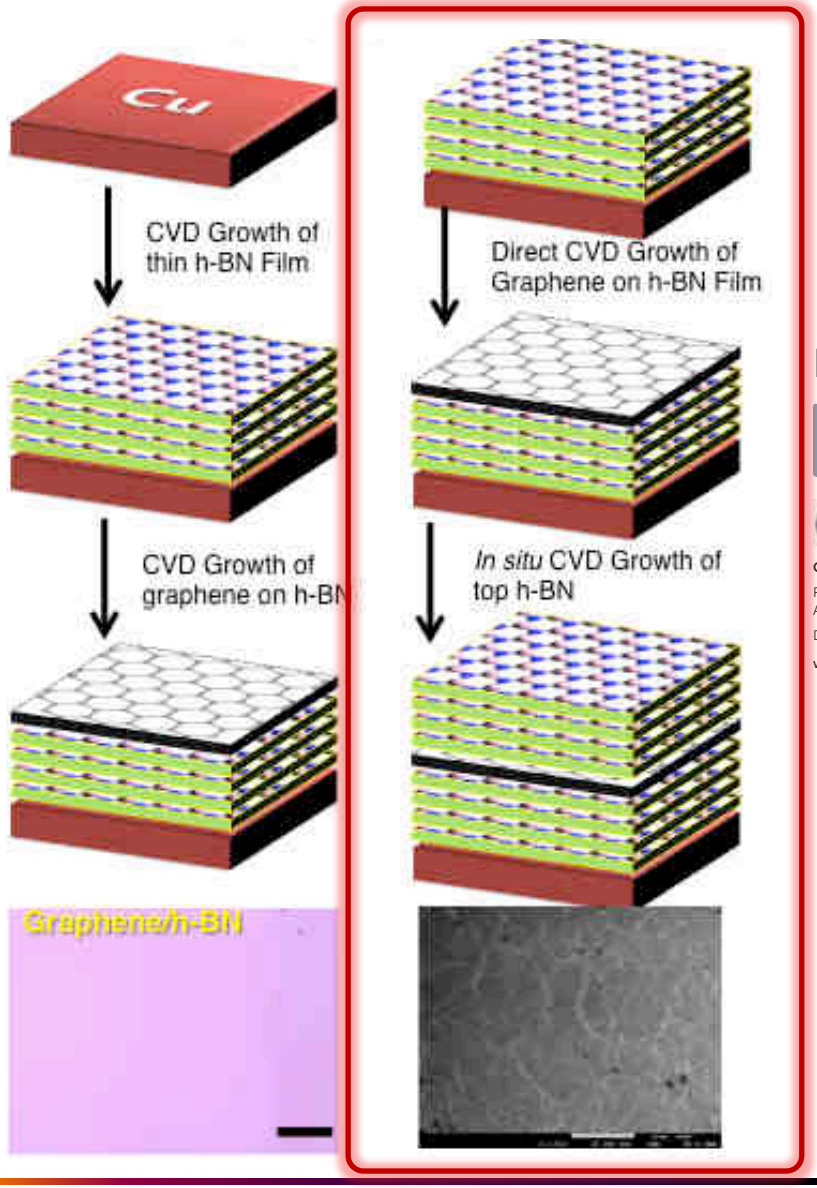


Raman Peak (h-BN) Mapping

KPFM Mapping



Issue 2: BN/Graphene/BN Heterostructure (BGB)



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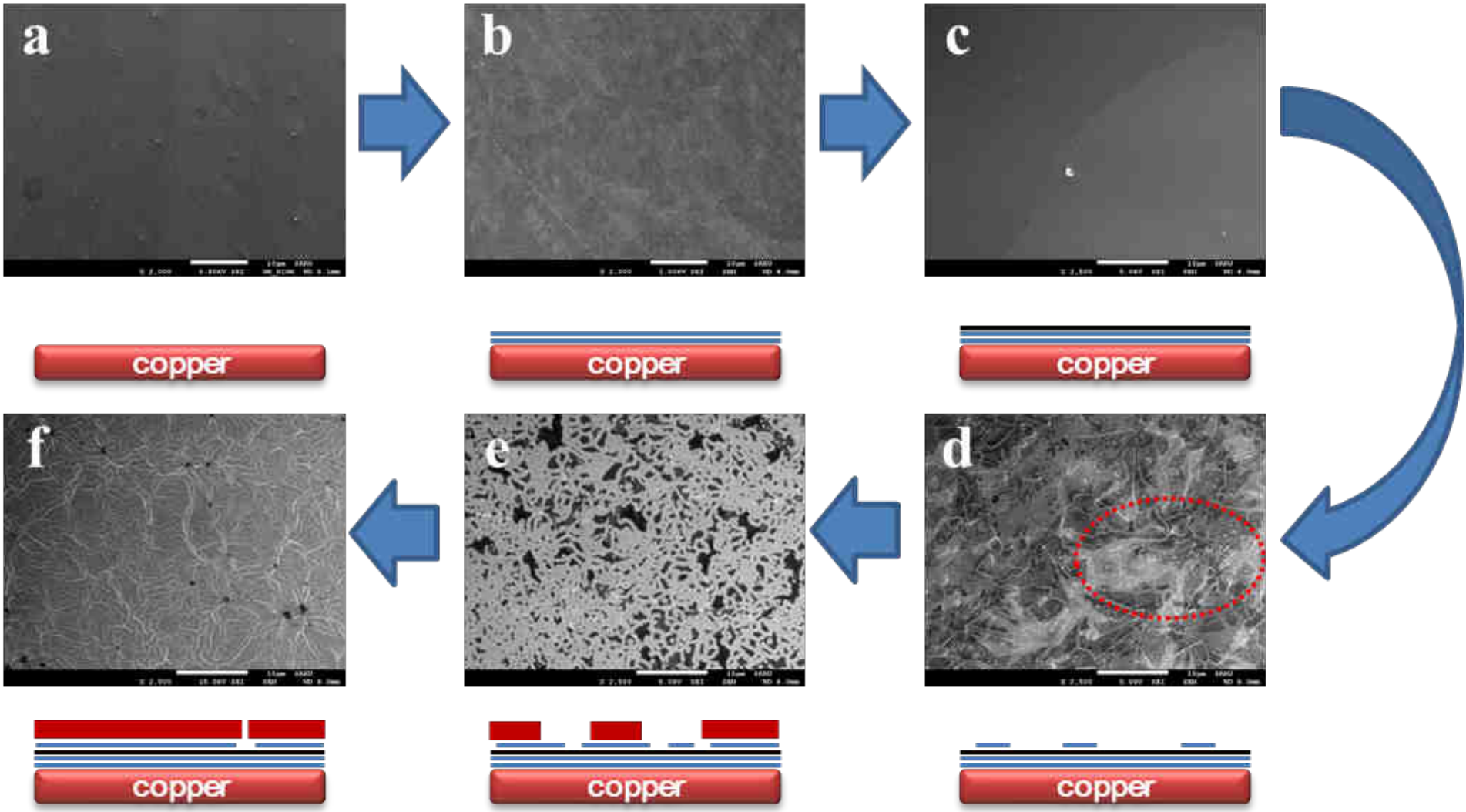
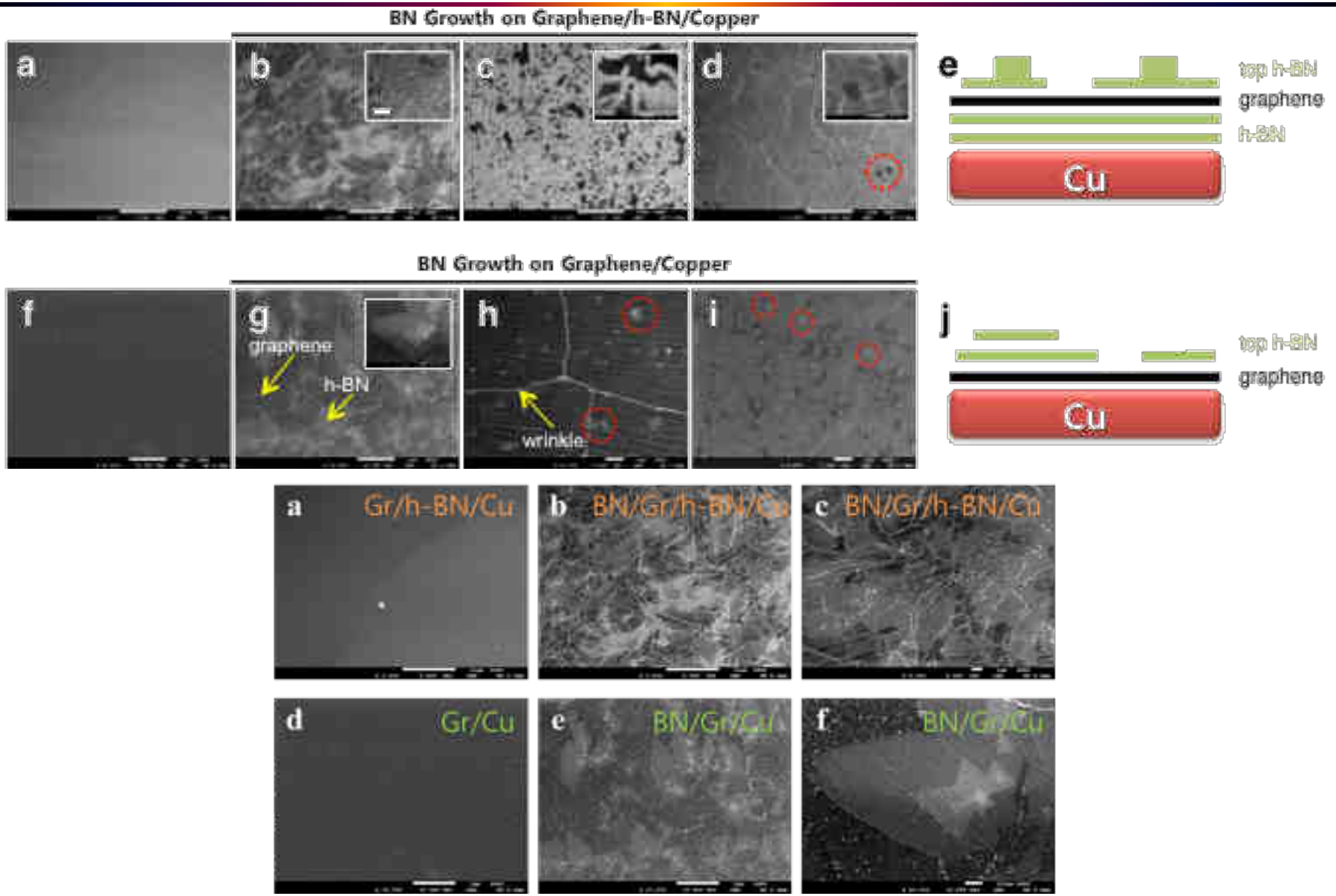
In situ synthesis of a large area boron nitride/graphene monolayer/boron nitride film by chemical vapor deposition†

Qinke Wu,[a] Sung Kyu Jang,[a] Sangwoo Park,[a] Seong Jun Jung,[a] Hwansoo Suh,[b] Young Hee Lee,*[c] Sungjoo Lee*[a,d,e] and Young Jae Song*[a,c,f]

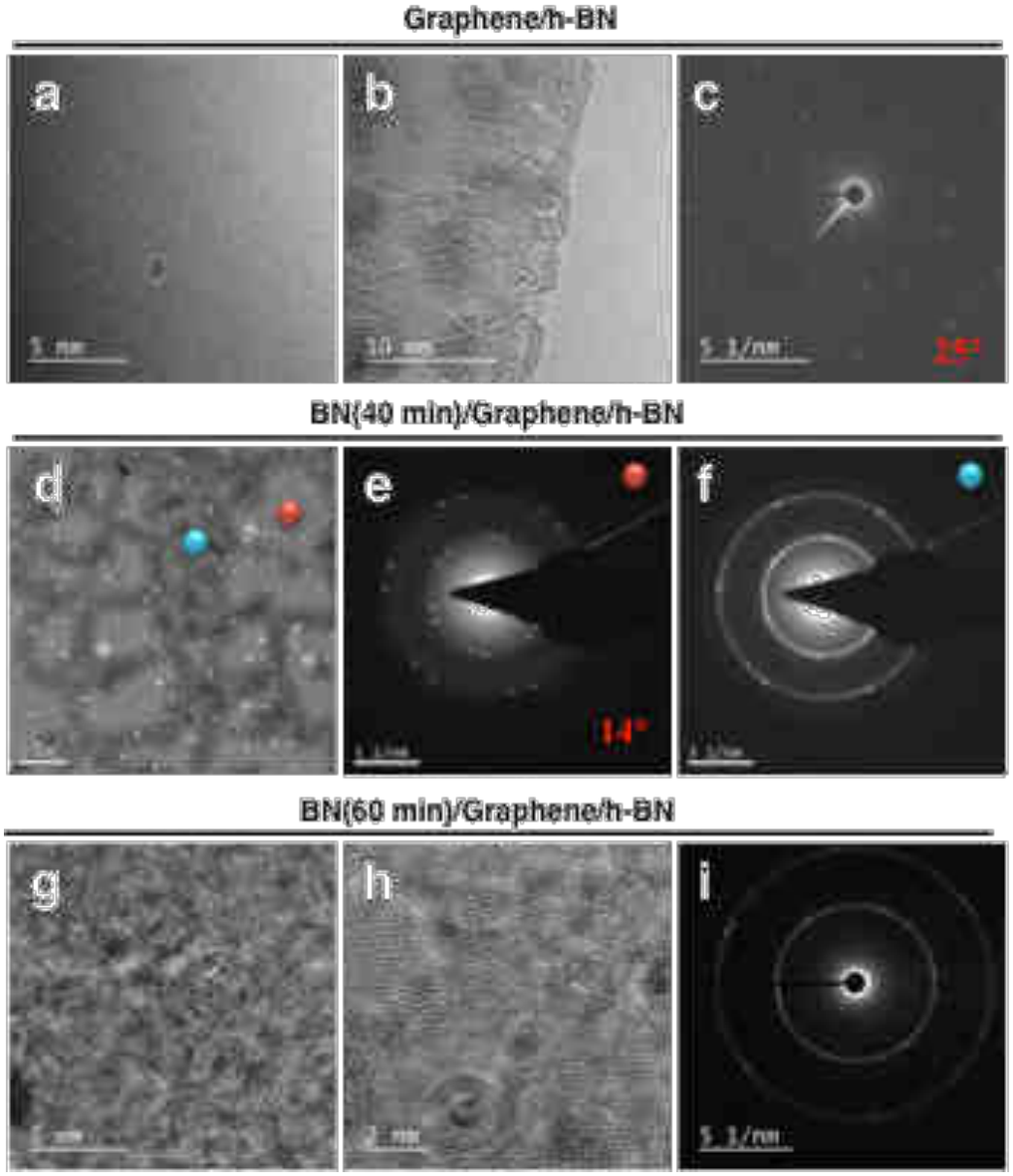
Growth Dynamics



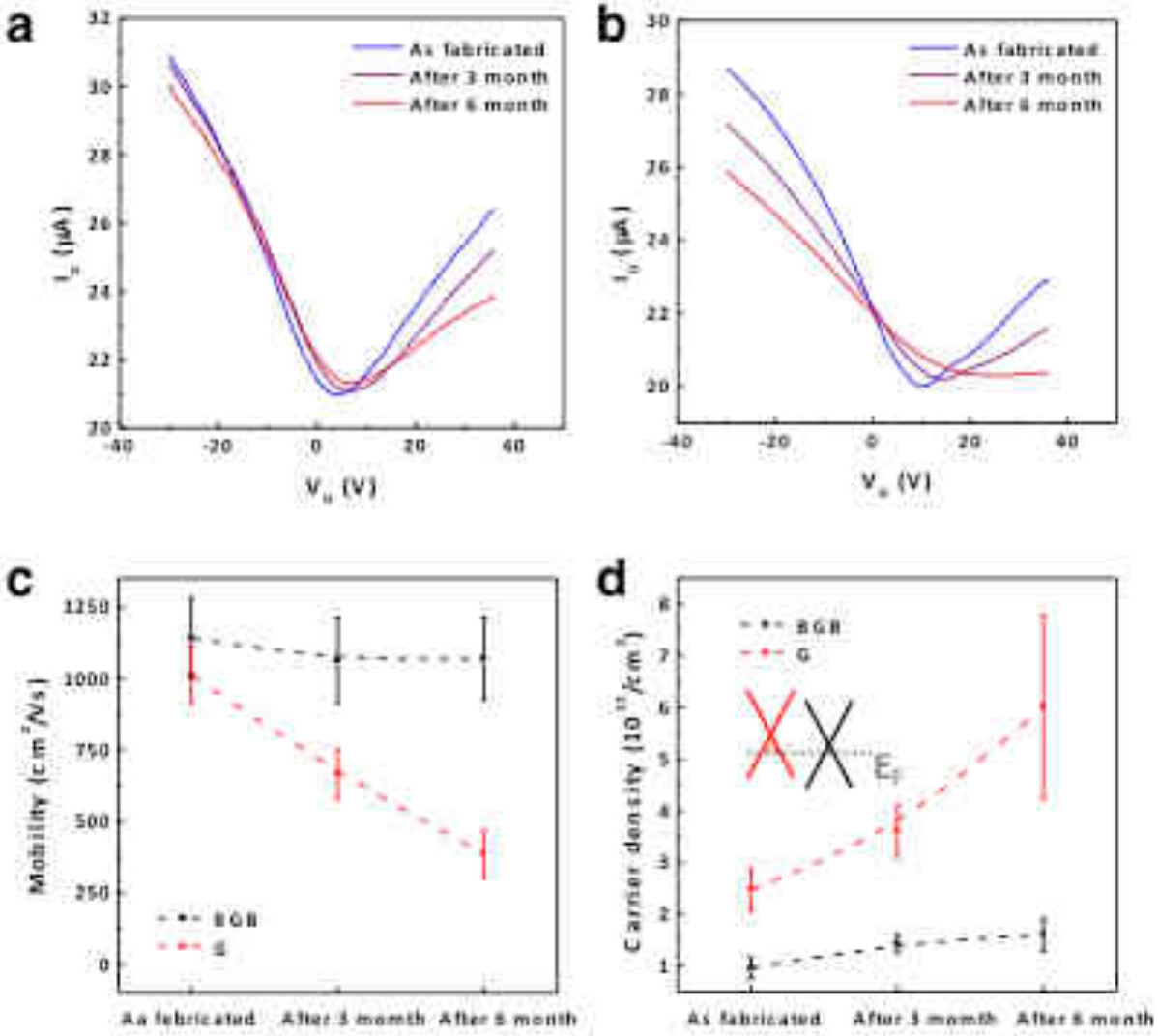
Growth Dynamics



Crystal Structure (TEM/SAED)



Device Performance



Issue 2 : Double Layer Graphene Film

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Controllable poly-crystalline bilayered and multilayered graphene film growth by reciprocal chemical vapor deposition†

Qinke Wu,[a] Seong Jun Jung,[a] Sung Kyu Jang,[a] Joohyun Lee,[a] Insu Jeon,[b] Hwansoo Suh,[b] Yong Ho Kim,[a,c] Young Hee Lee,*[d] Sungjoo Lee*[a,e,f] and Young Jae Song*[a,d,g]

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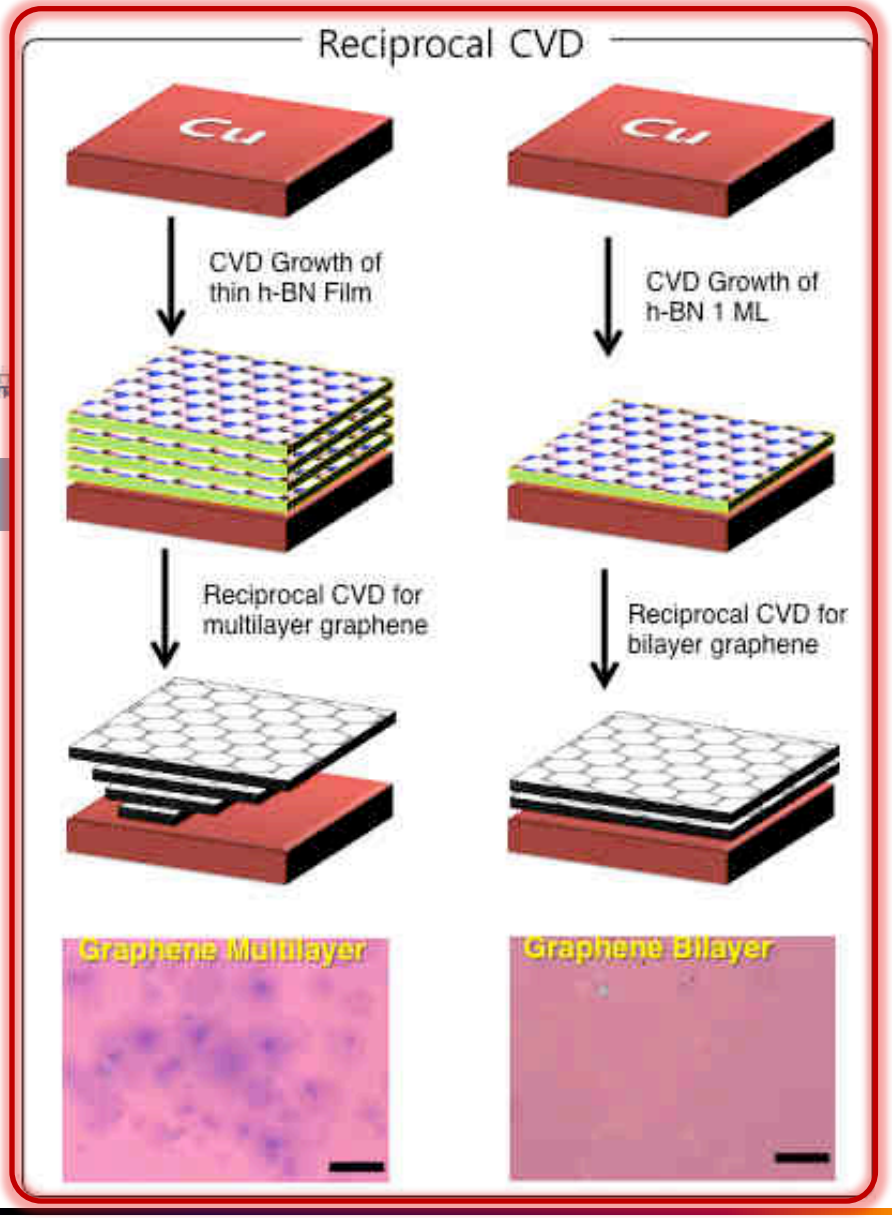
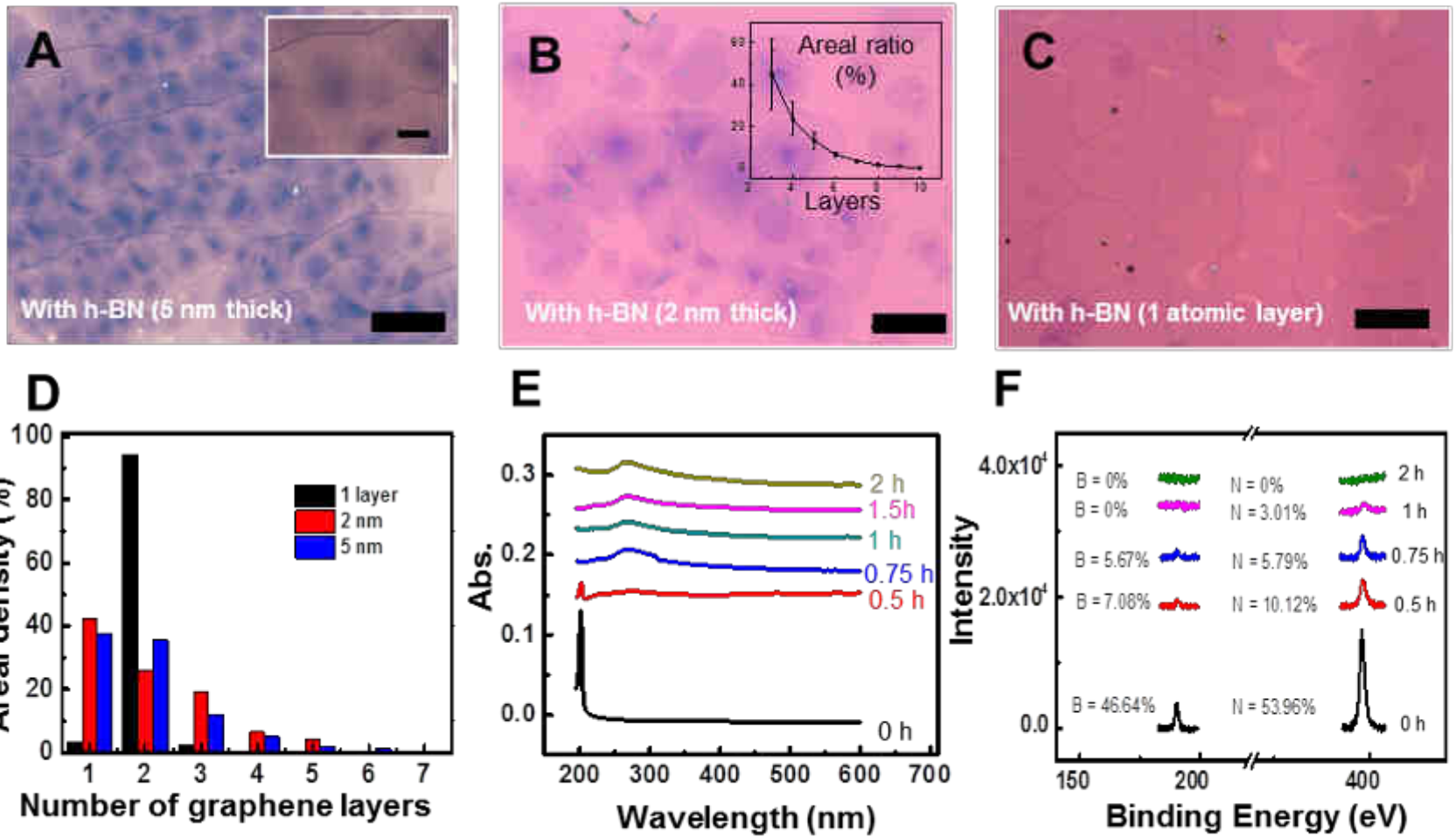
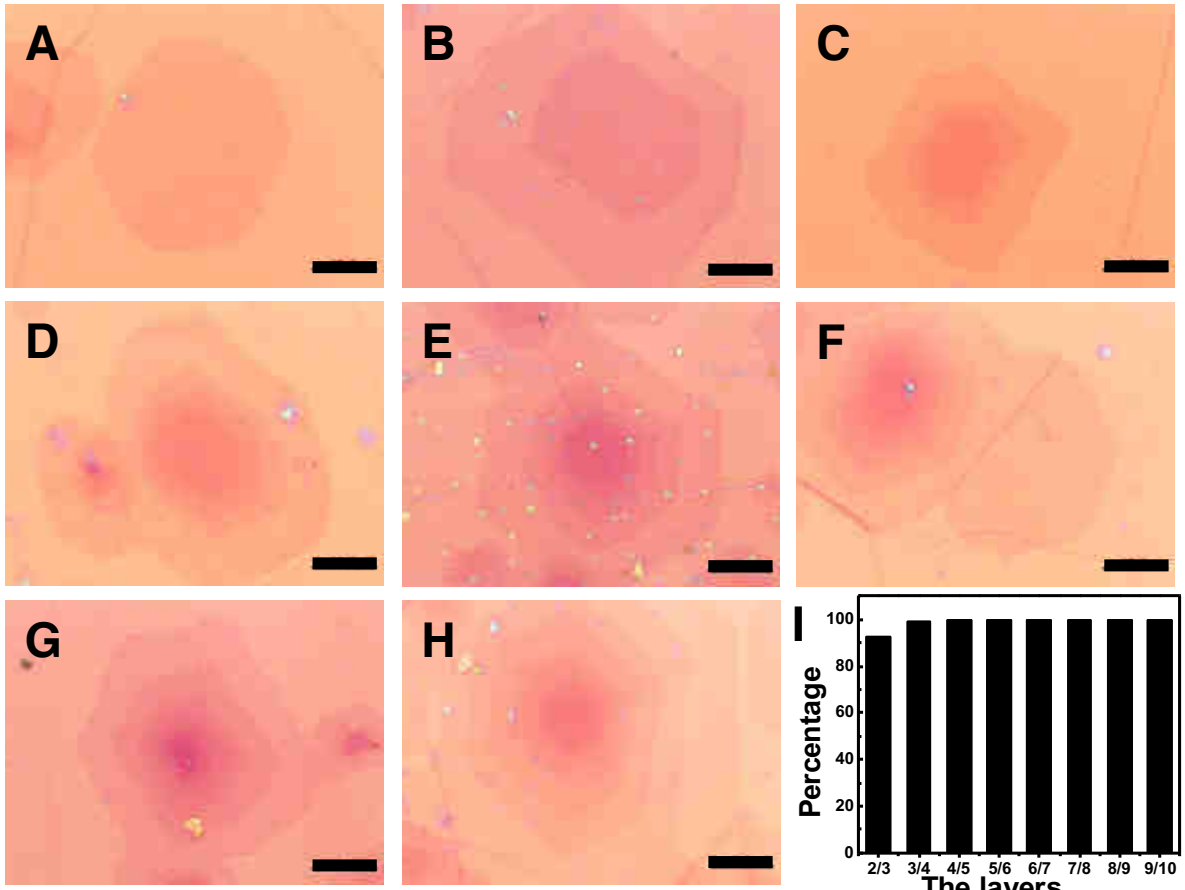


Growth Dynamics : A Role of h-BN

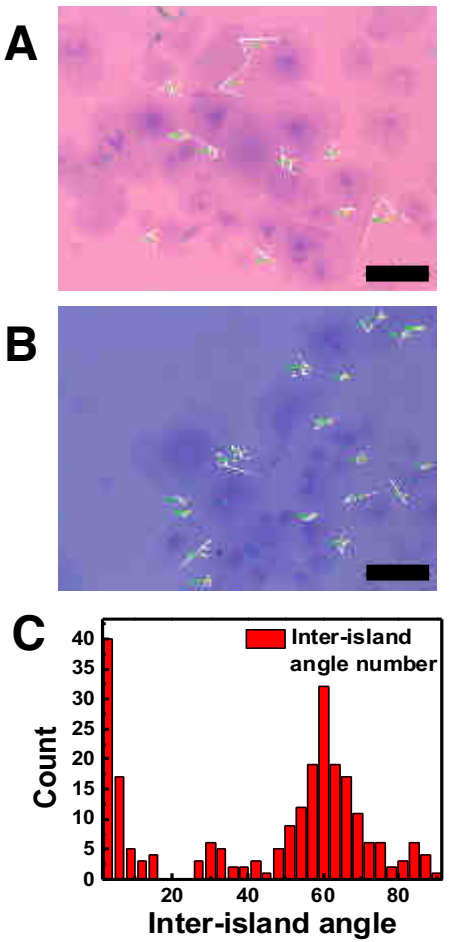


Statistical Study (Optical Microscopy)

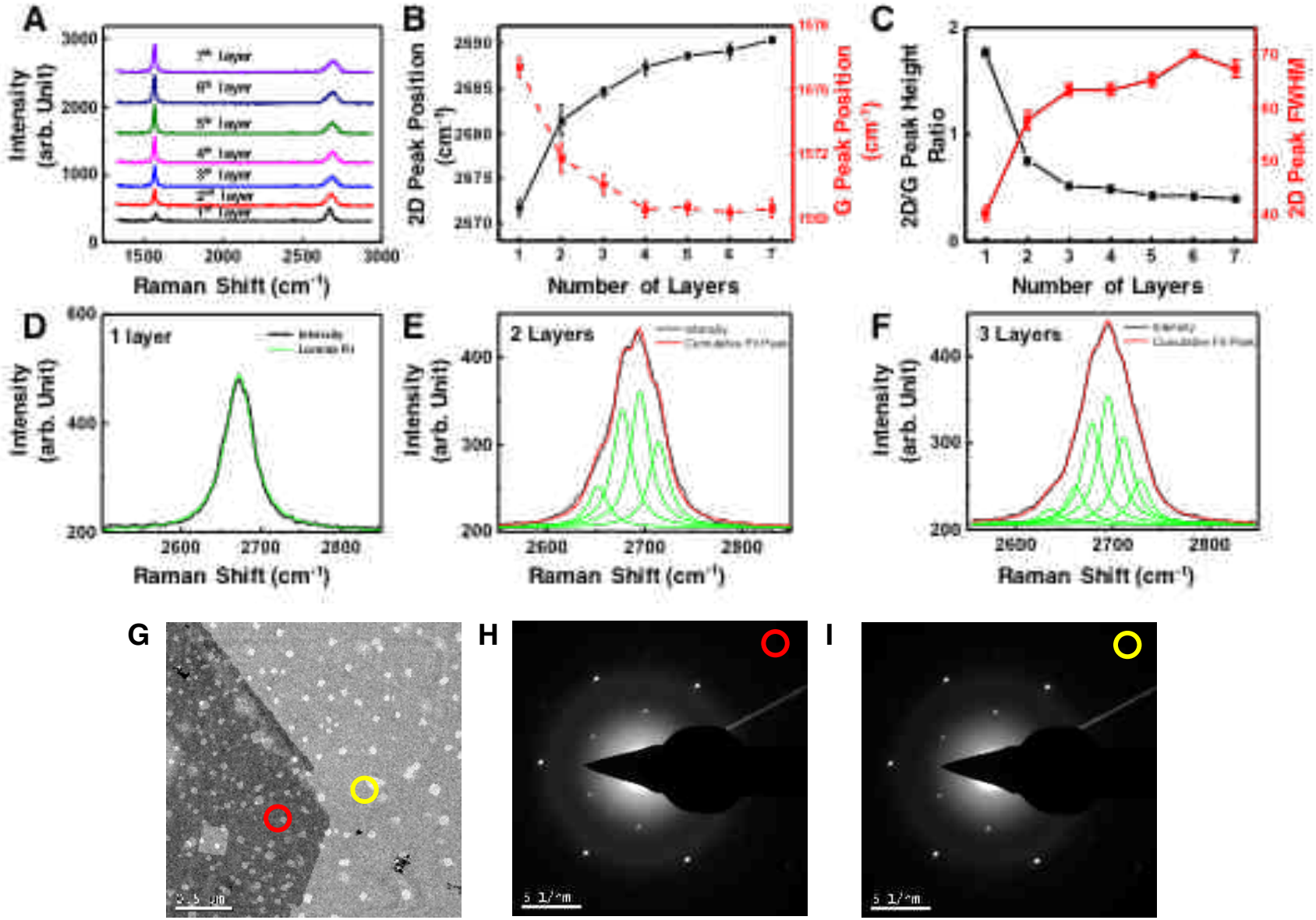
Intra-Island Angles



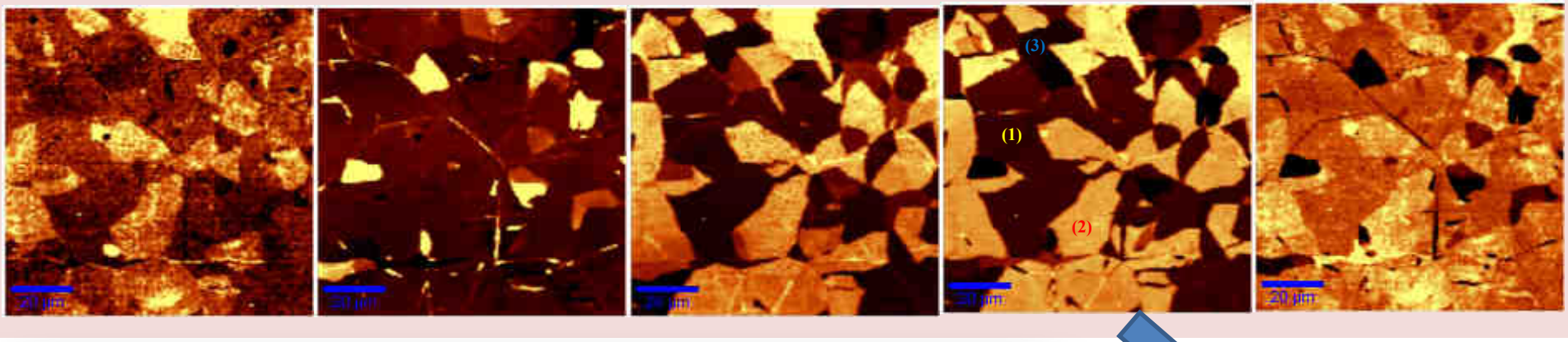
Inter-Island Angles



Quality and Epitaxy of Multilayer Graphene



Quality and Epitaxy of Bilayer Graphene



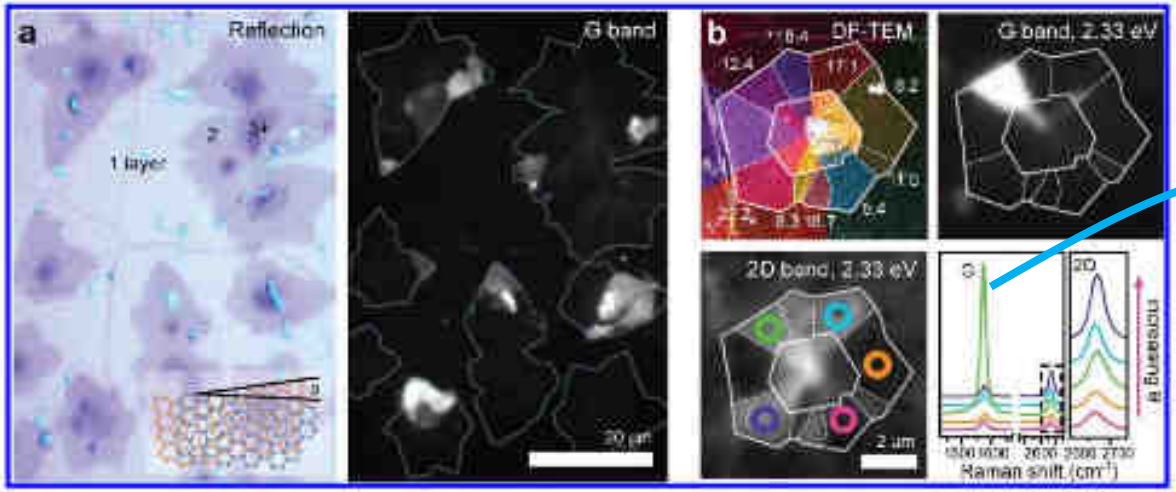
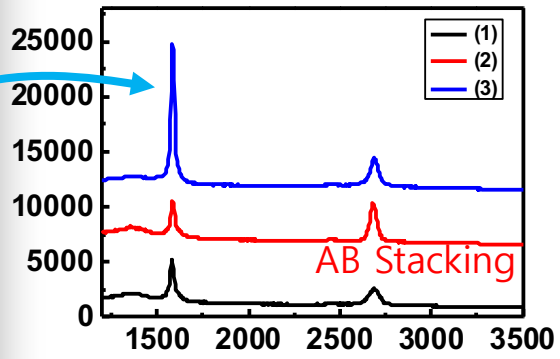
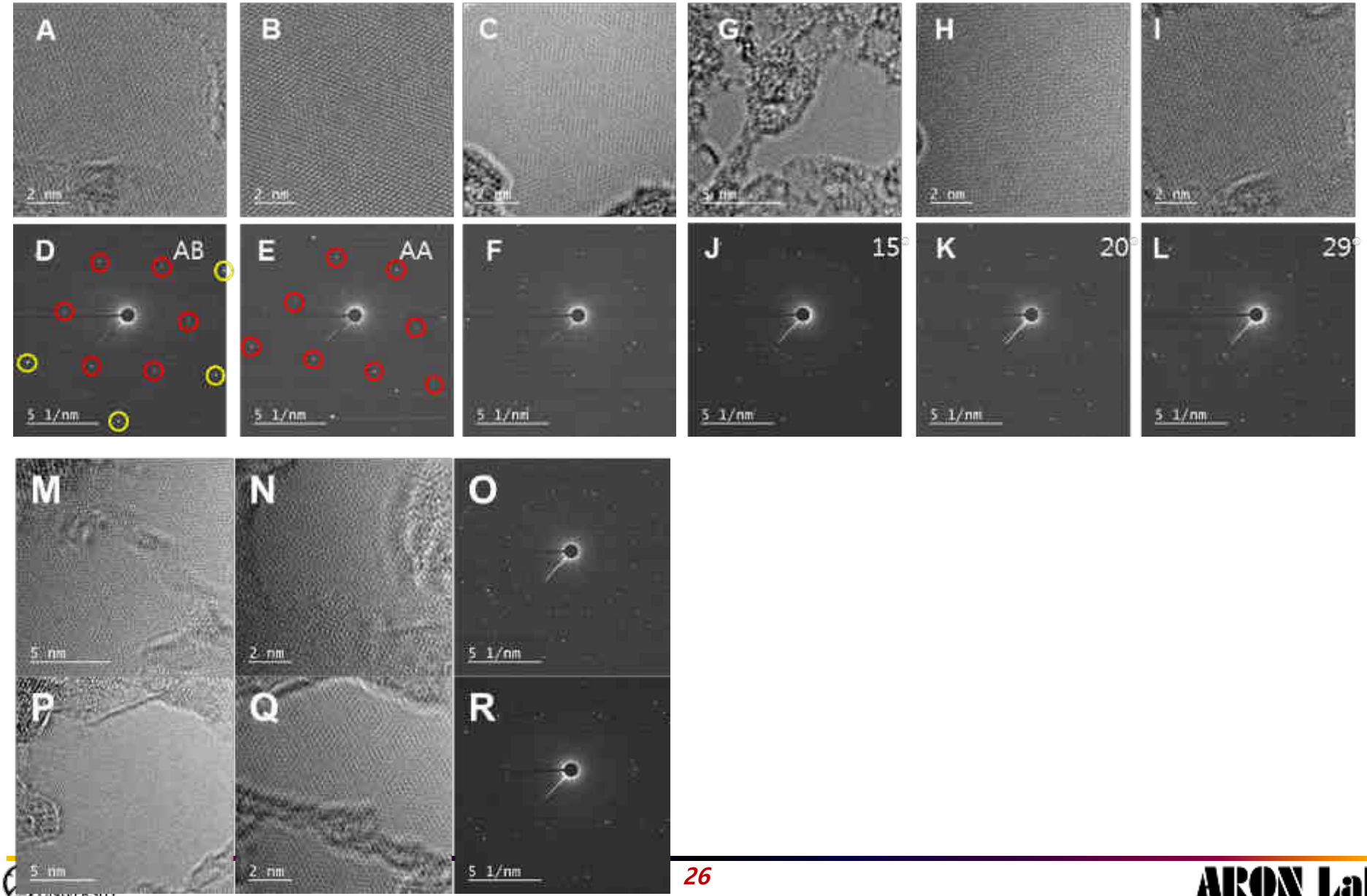


Figure 1. (a) An optical reflection image of CVD graphene transferred to Si/285 nm SiO_2 and a large area widefield G band Raman image of the same region. The G band image contains striking features in the multilayer regions, which are not seen in the reflection image. (inset) Structure of tBLG with a twist angle θ. (b) Dark-field TEM, G band, and 2D band Raman images of the same multilayer tBLG sample. The features in the Raman image correspond well with twisted bilayer domains identified with DF-TEM (θ is labeled for each domain in the TEM image). Raman spectra for several domains are also shown.



Quality and Epitaxy of Bilayer Graphene



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- ***Samsung Advanced Institute of Technology (SAIT)***
  - Dr. S. J. Park, Dr. H. S. Suh
- ***UNIST***
  - Prof. Rodney S. Ruoff, Prof. Noejung Park
- ***Postech***
  - Dr. U. D. Ham

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Nano Electronics (STM Team)

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