Doping and Characterization of Graphene & GNWs

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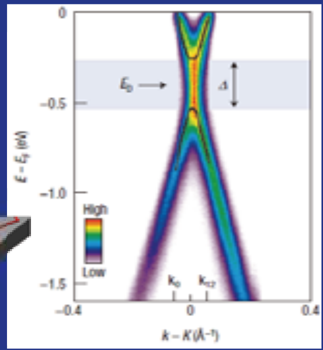
Outline

- Introduction
- N-doping of GNWs
- BN-codoping of graphene
  - In-situ doping
  - XPS, UV-Vis analysis
  - STEM analysis
  - XES & XANES analysis
- Summary

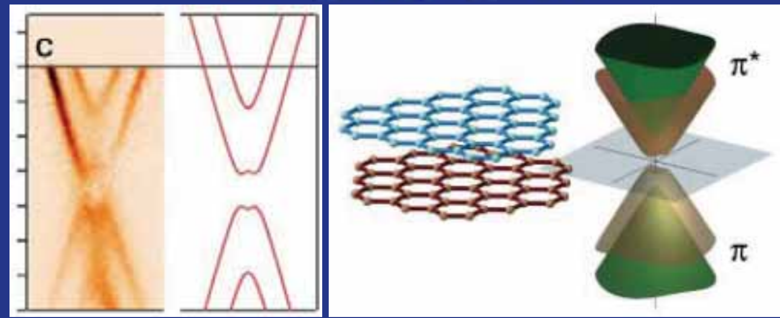
Gap-opening in Graphene

Substrate-induced bandgap opening



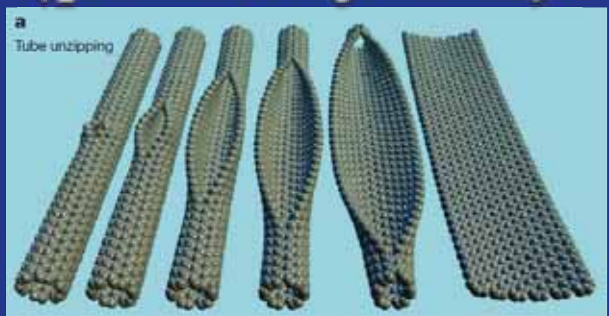
Nature Materials 2007, 6, 770

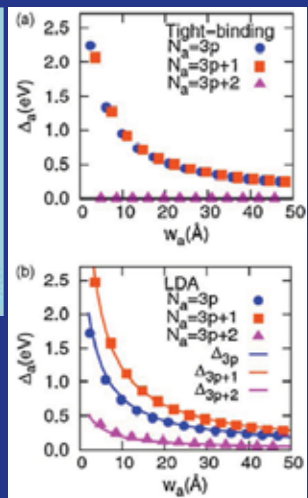
Bilayer graphene



Science 2011, 313, 951

Graphene nanoribbons (quantum confinement)

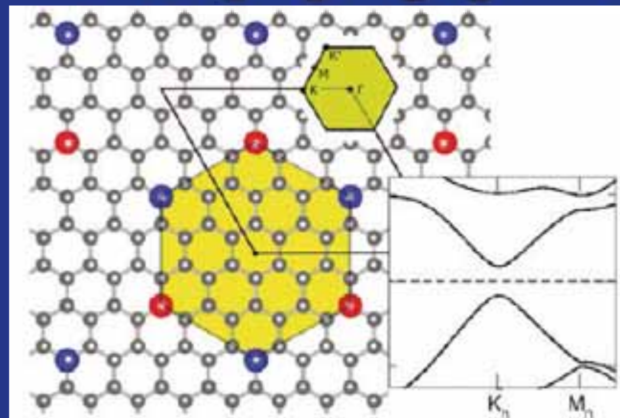




Nature 2009, 458, 872

Phys. Rev. Lett. 2006, 97, 216803

BN doping in graphene



J. Phys. Chem. C 2011, 115, 3250
ACS Nano 2011, 5, 385
ACS Nano 2010, 4, 7619
J. Appl. Phys. 2010, 108, 073711

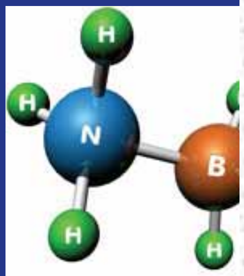
B-N Co-doping

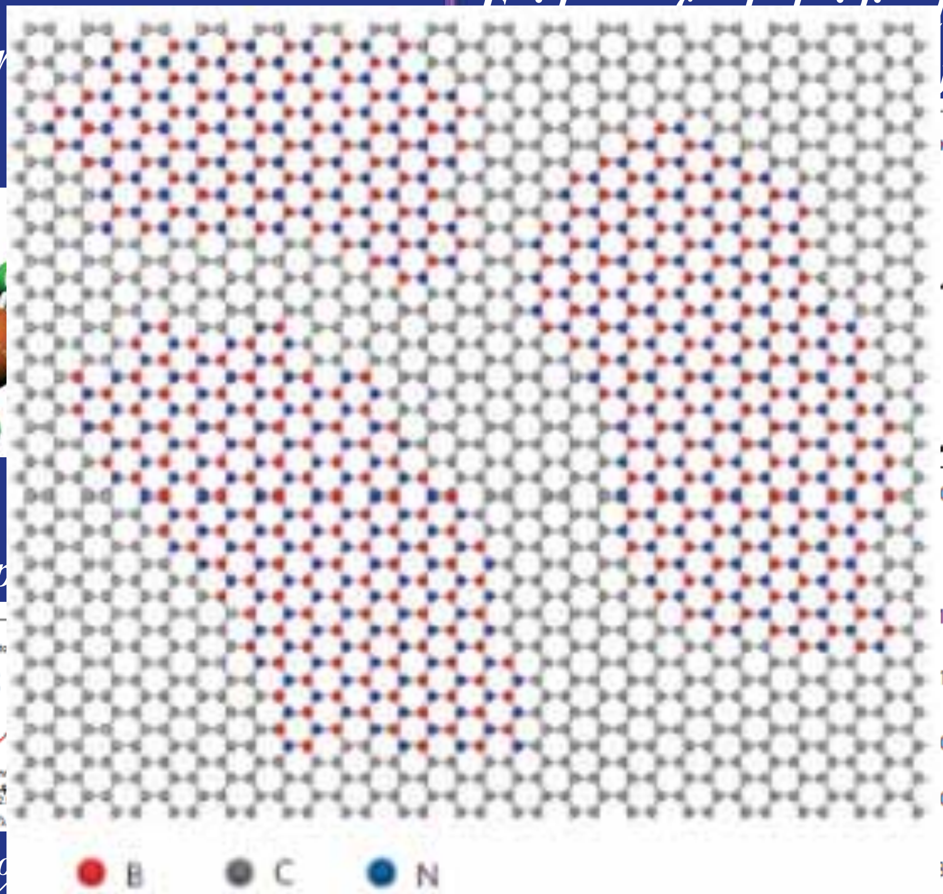
Atomic layers of hybridized boron nitride and graphene domains

nature materials

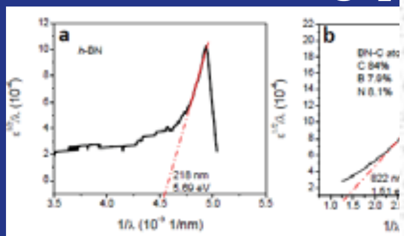
Evidence of hybridized h-BN and graphene ... of h-BCN

Ammonia Bor...

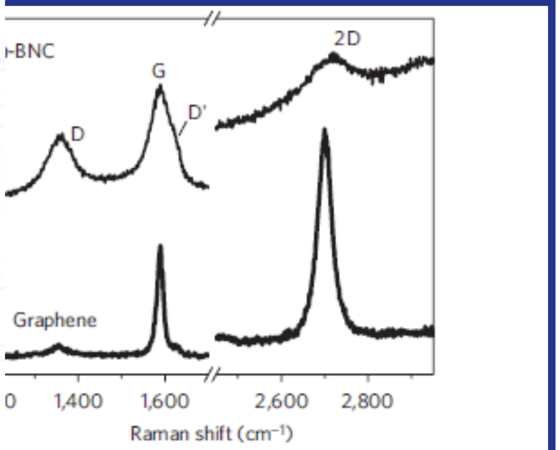


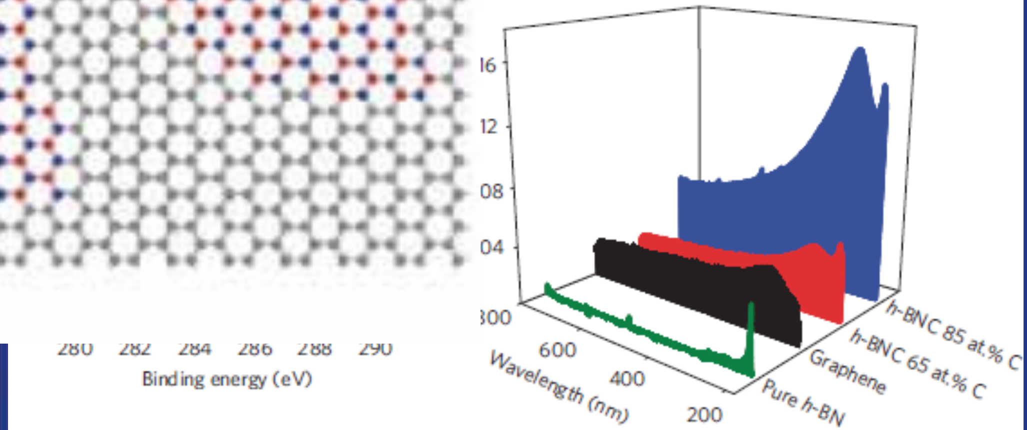


Band gap...



Pure h-BN	16% ...	
5.69eV	1.51eV	1.62eV
	3.85eV	4.48eV





Pulickel M. Ajayan et al. Nature Materials, 9, 430 (2010)

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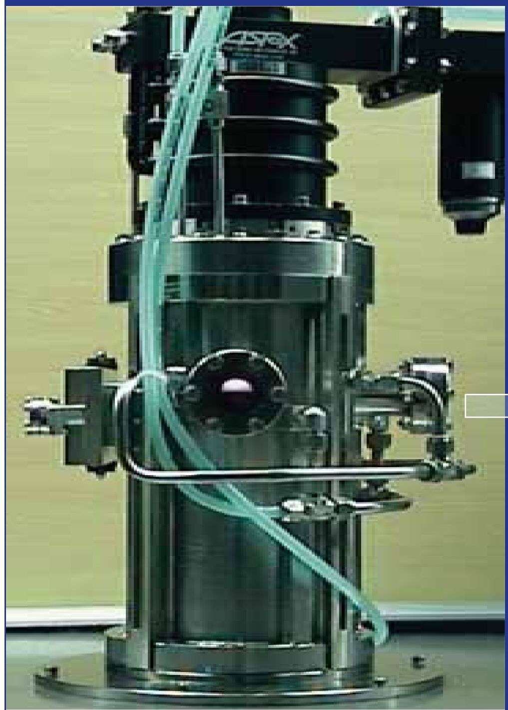
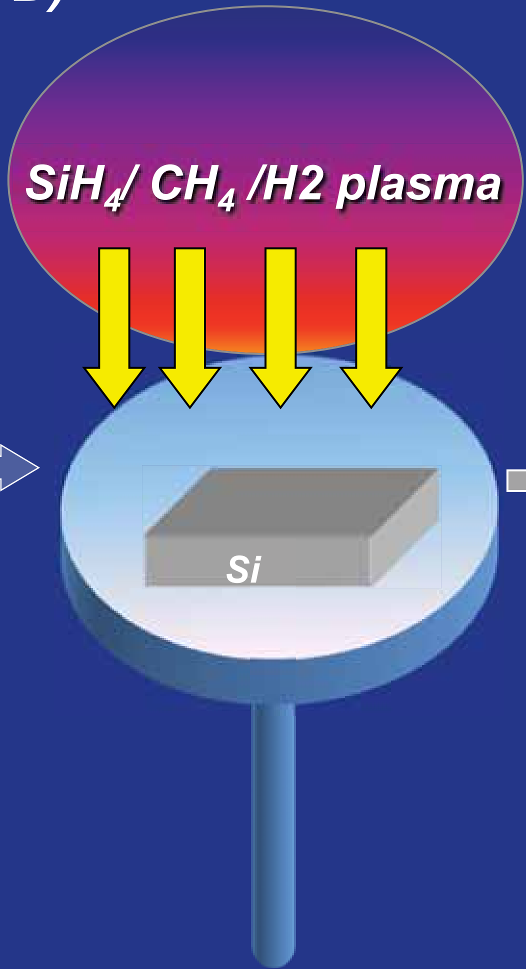
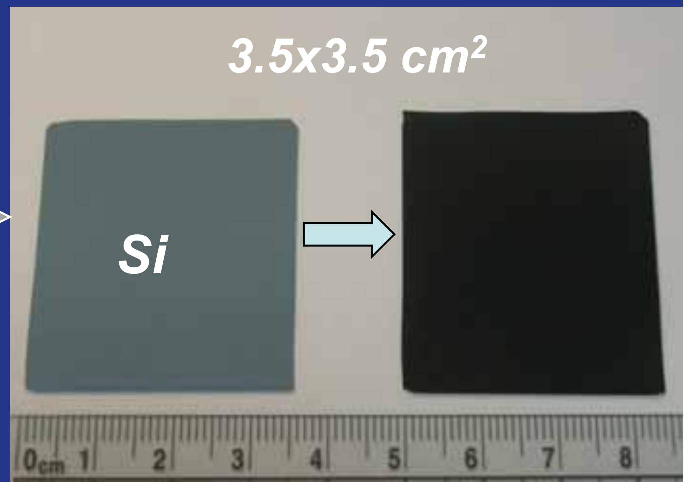
Growth of Graphene Nanowalls

Microwave Plasma CVD reactor (MWCVD)



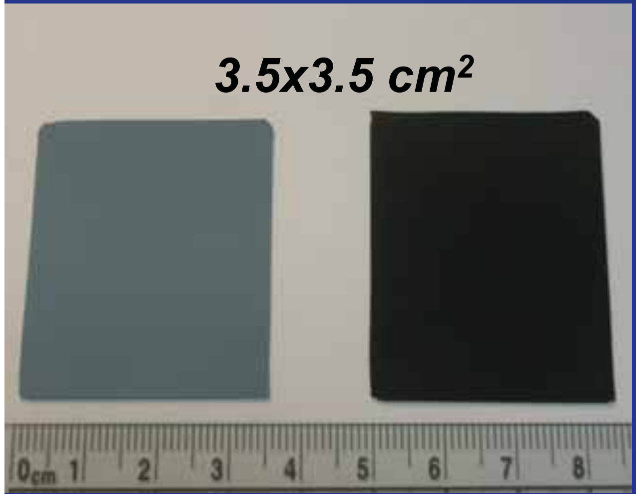


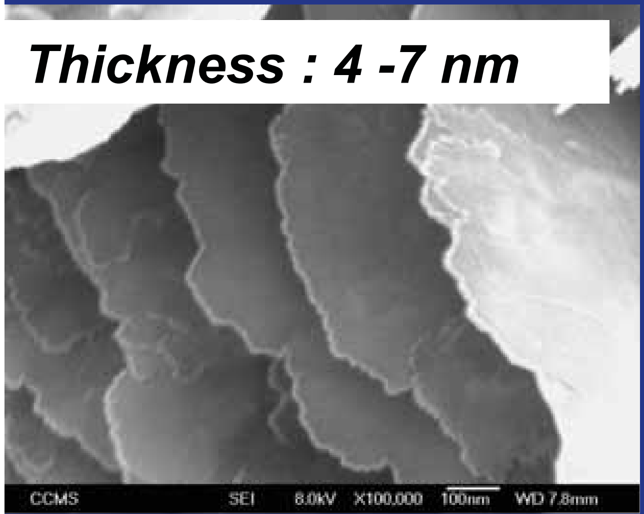
Source reactants: SiH_4 / CH_4 / H_2
Gas ambient : H_2
Microwave power :1000-2000 W
Growth temperature : 900-1100 ^{0}C

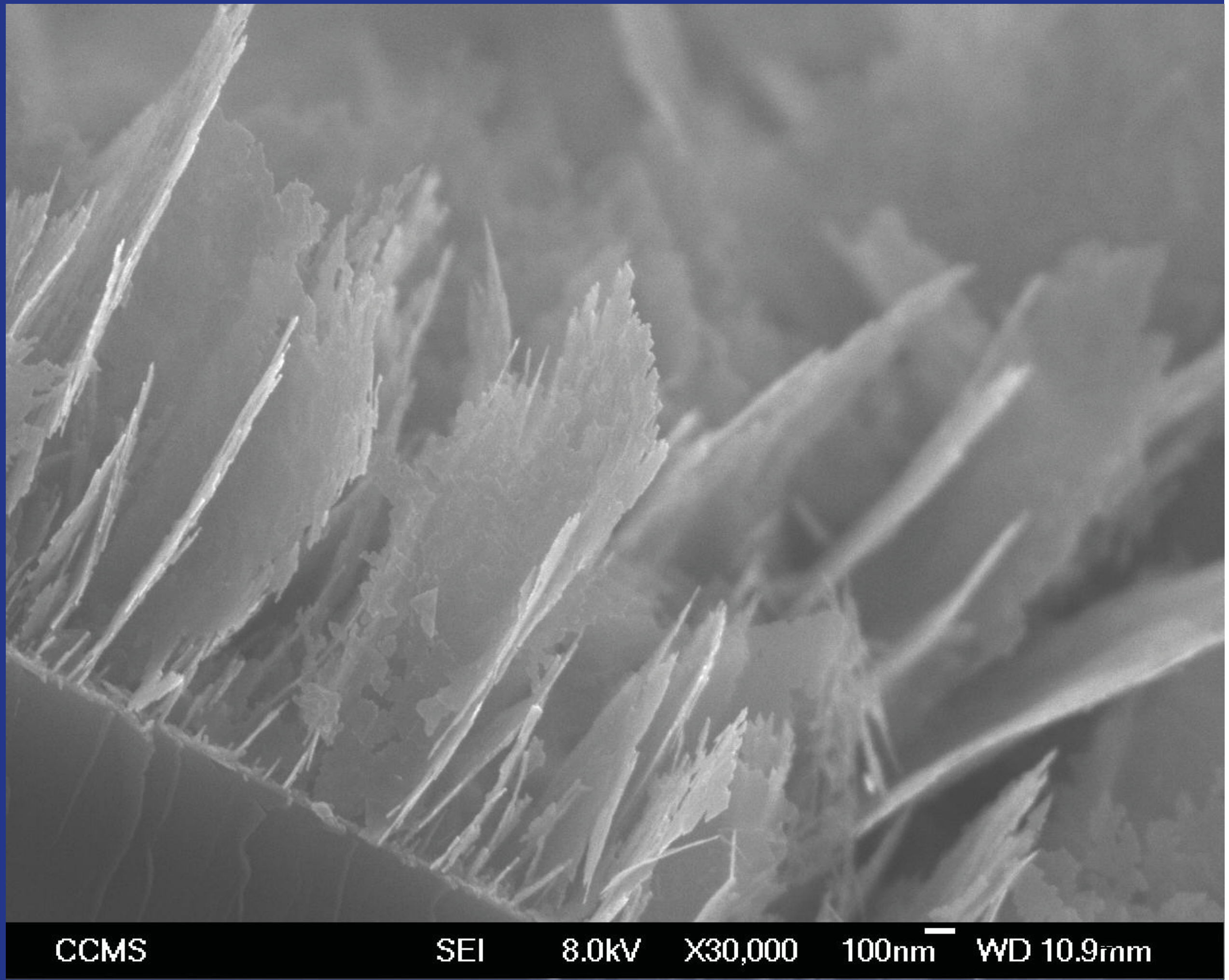


Carbon 49, 4911 (2011)

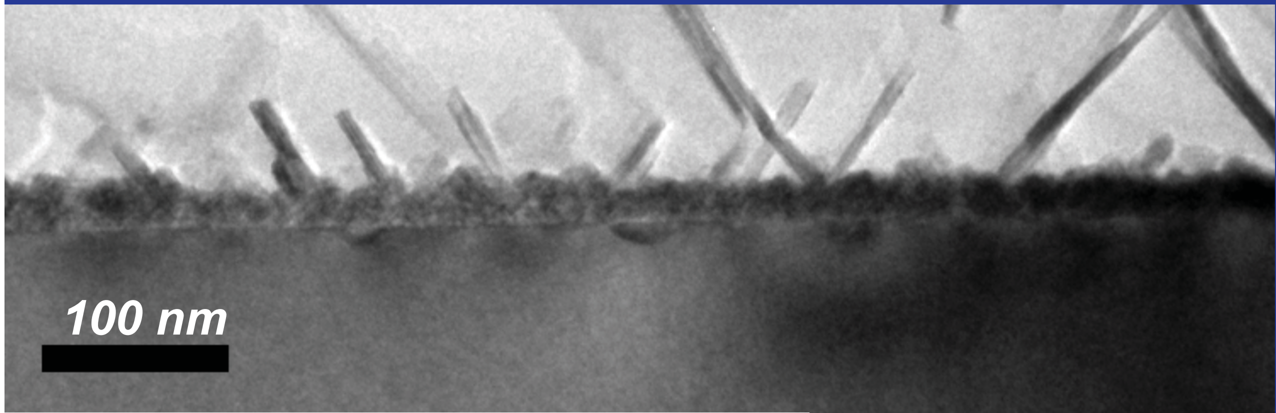
Large-Scale Production
Ultrathin Sheet-like Morphology

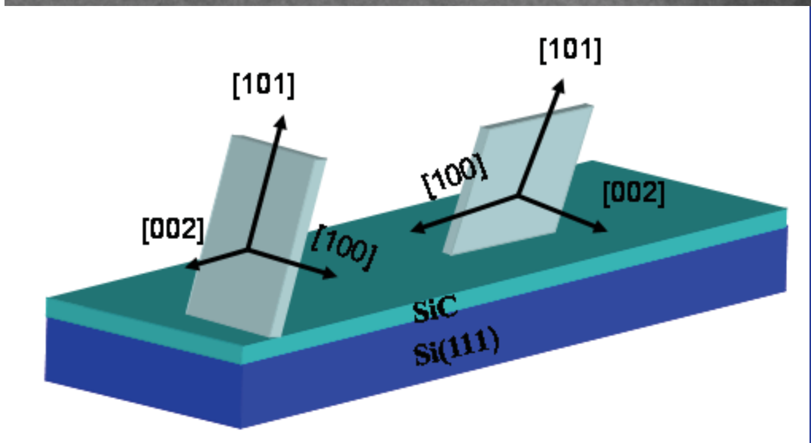


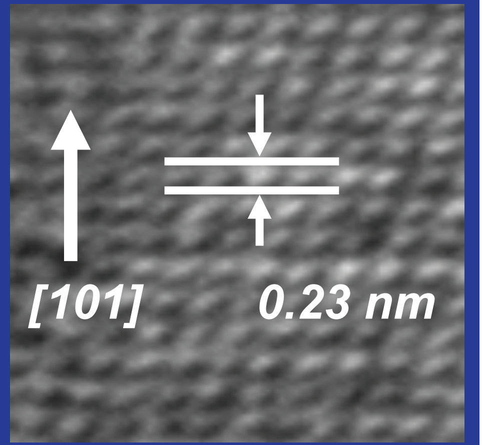


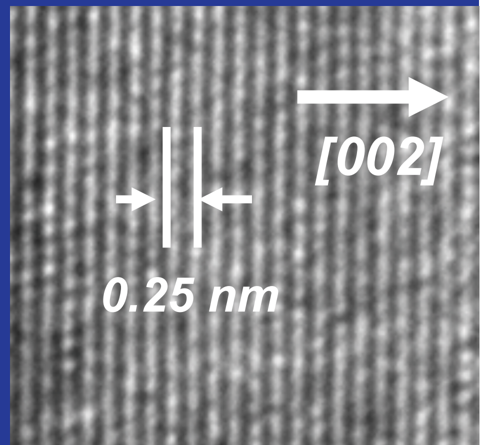


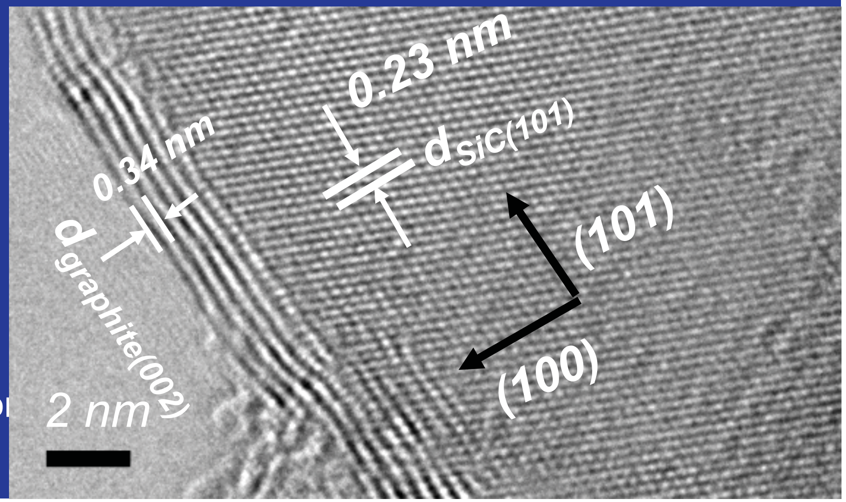
Microstructures



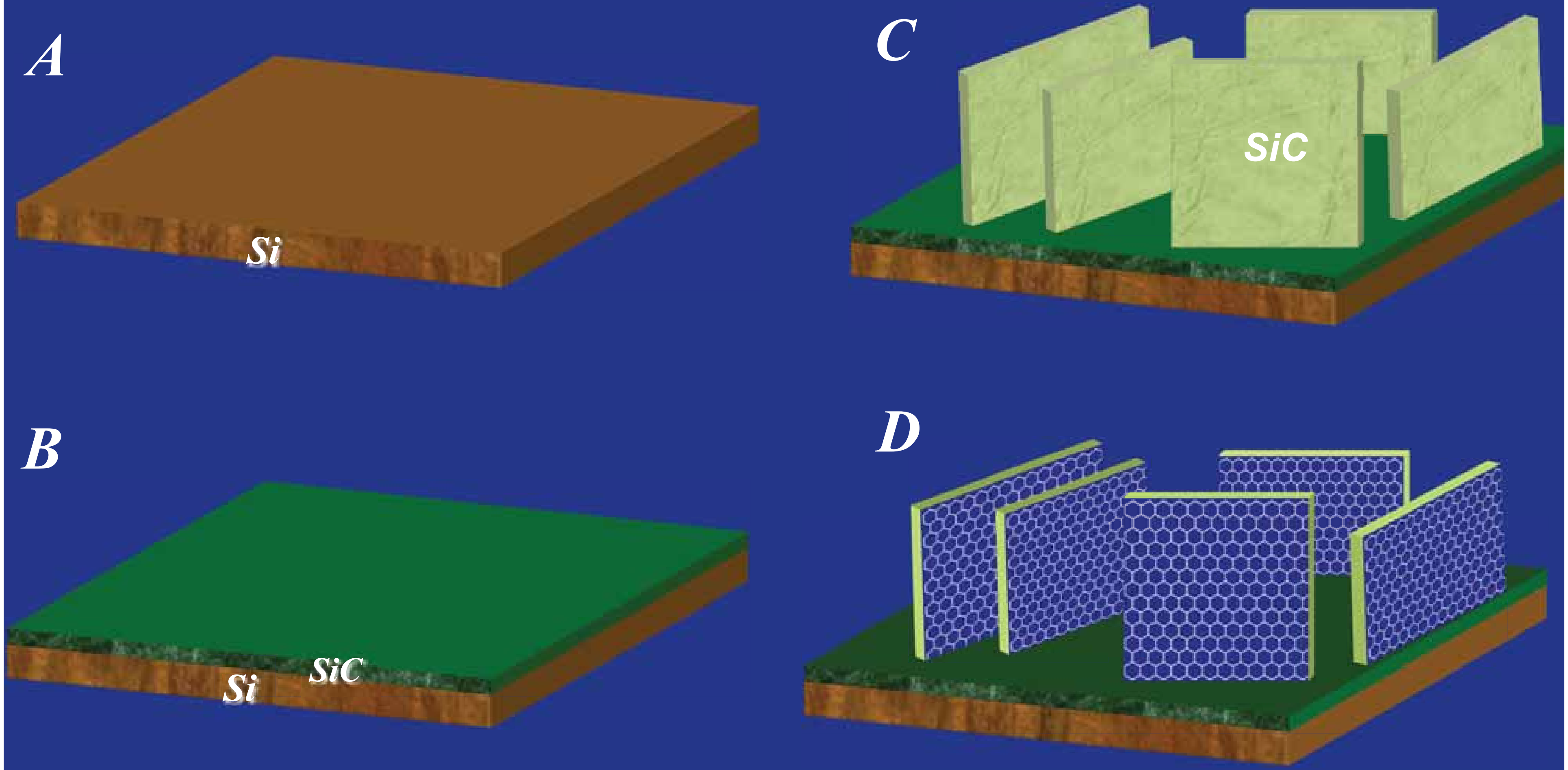




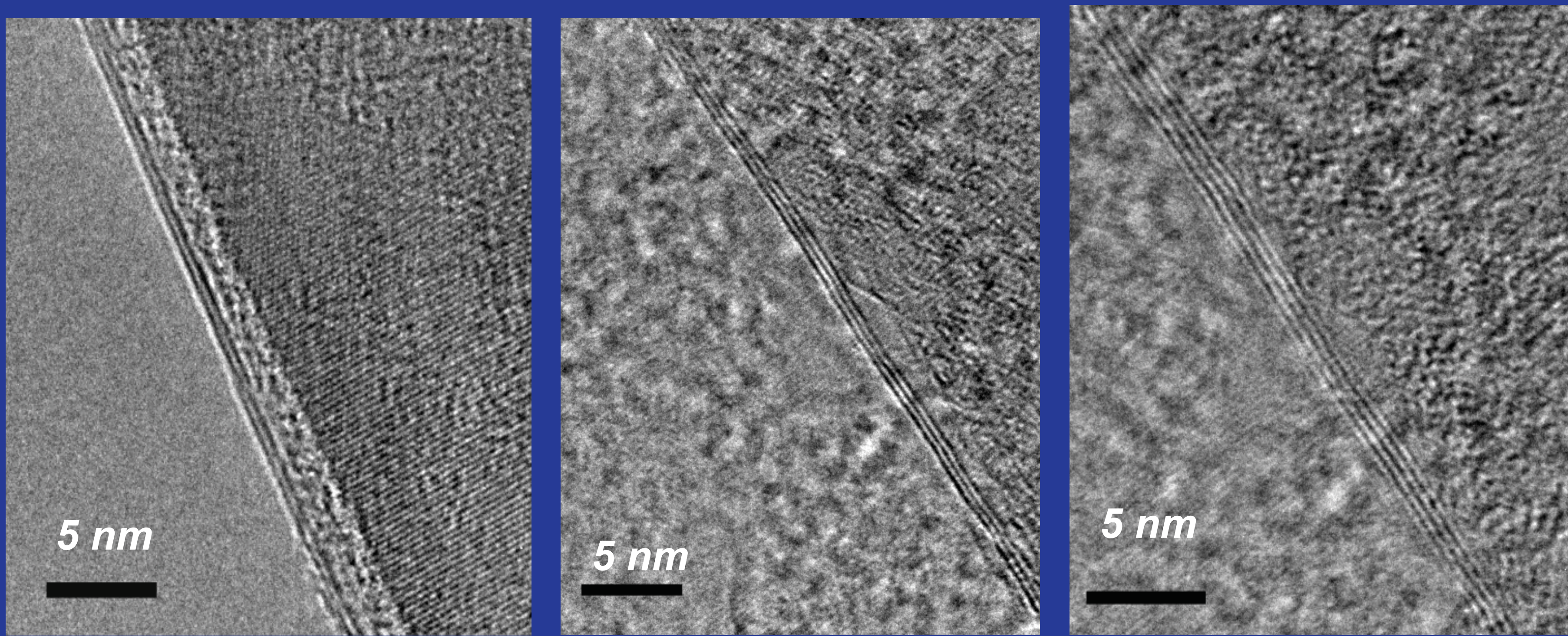




Schematic of Hybrid GNWs Growth

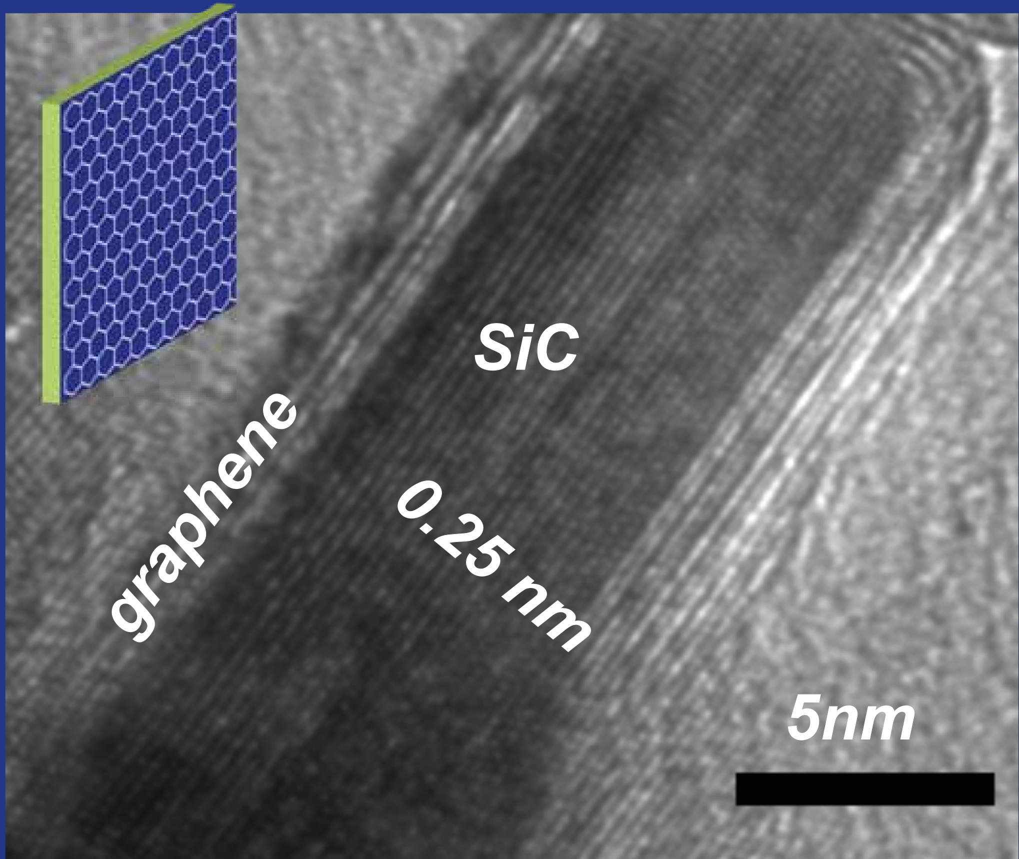


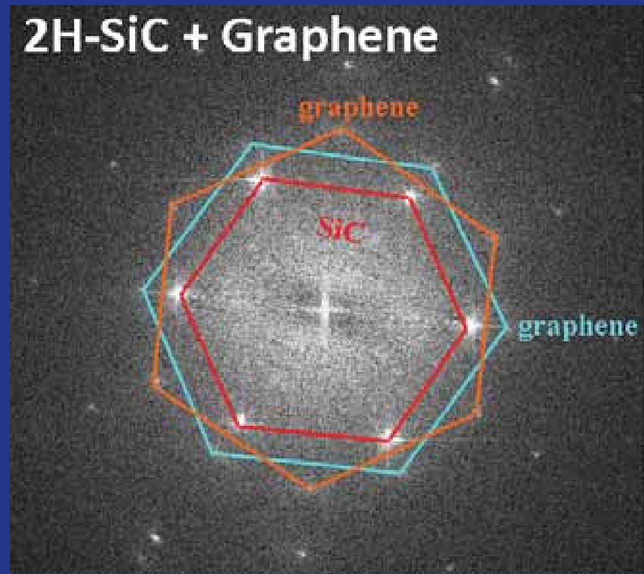
Layer Number Control

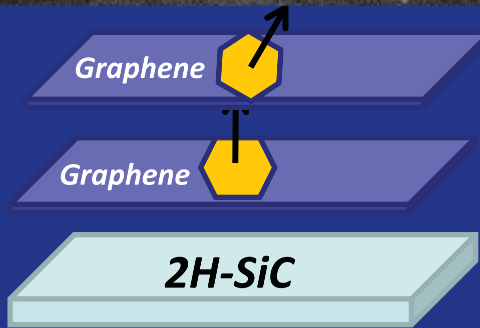


Carbon 49, 4911 (2011)

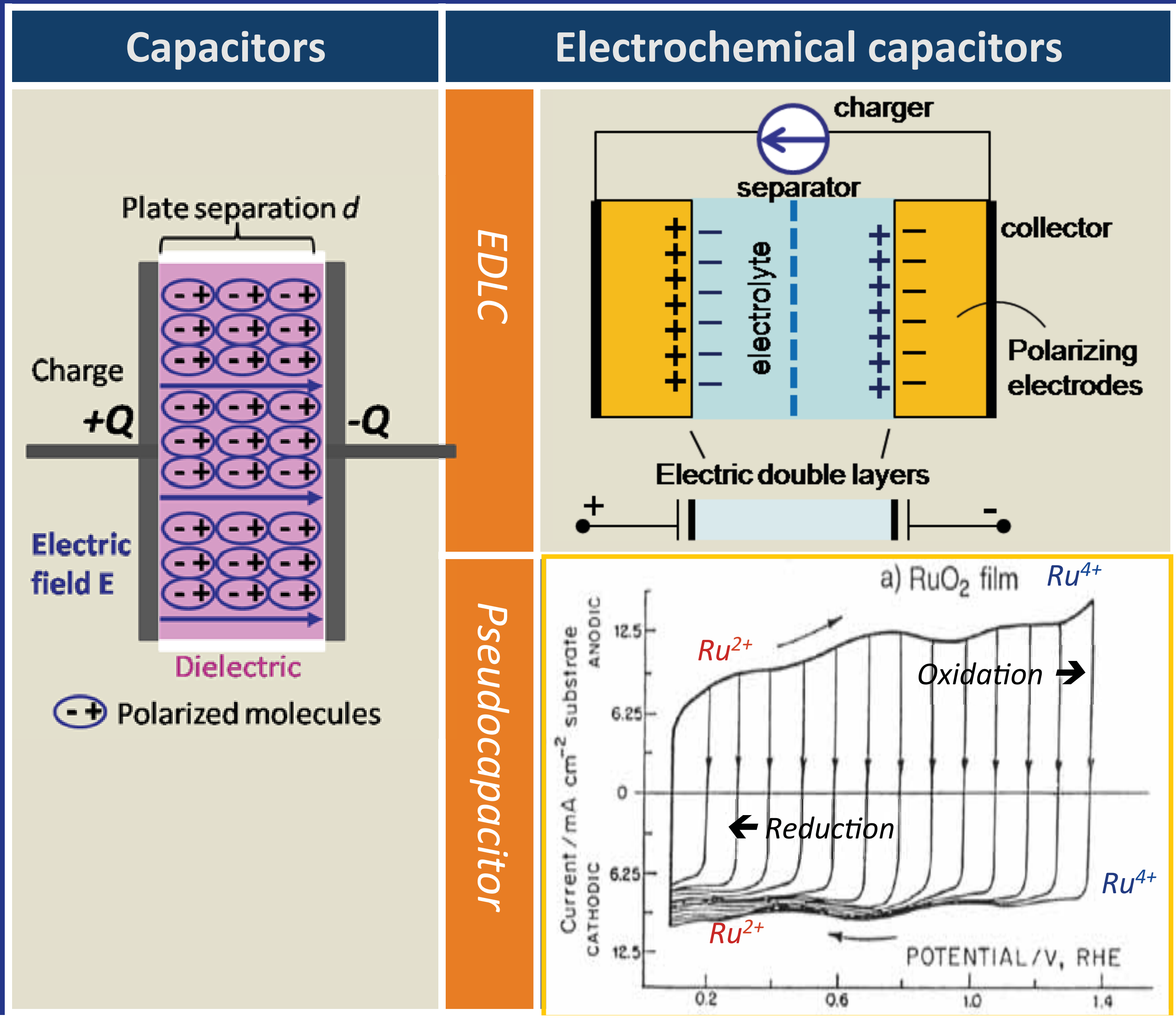
TEM Analysis



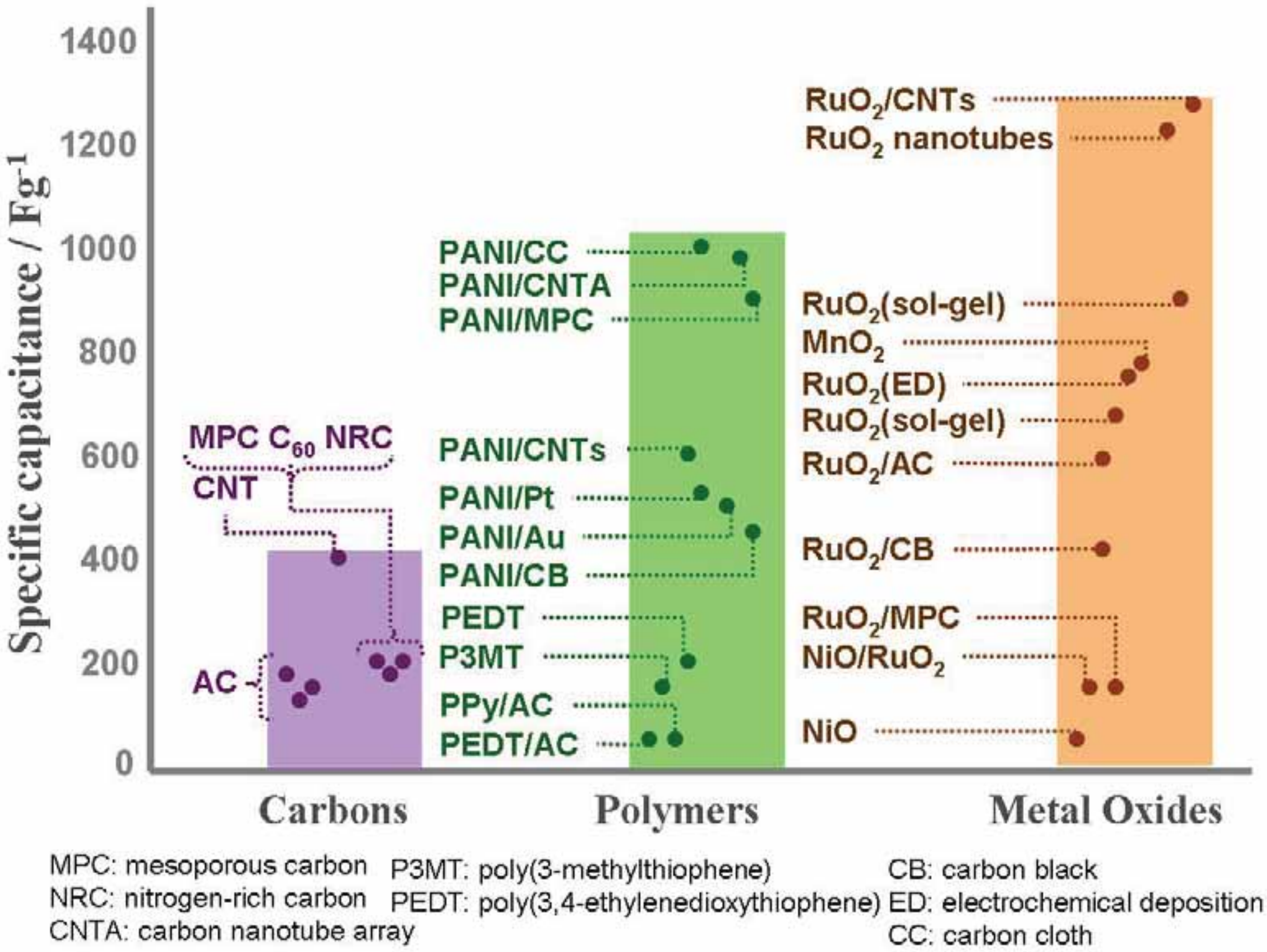




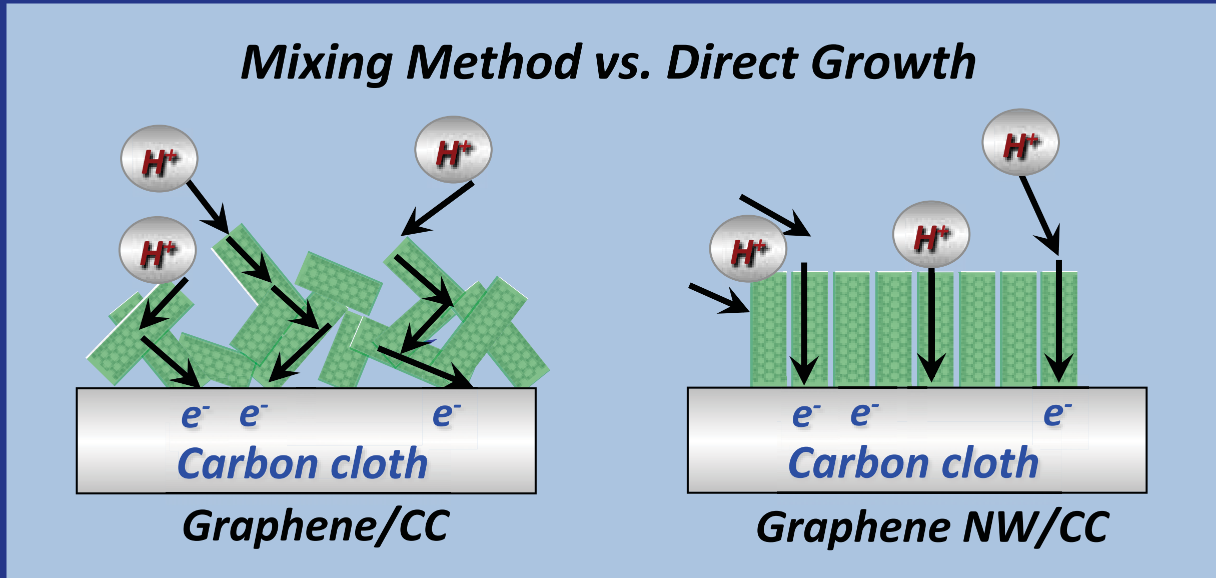
GNWs for Supercapacitors



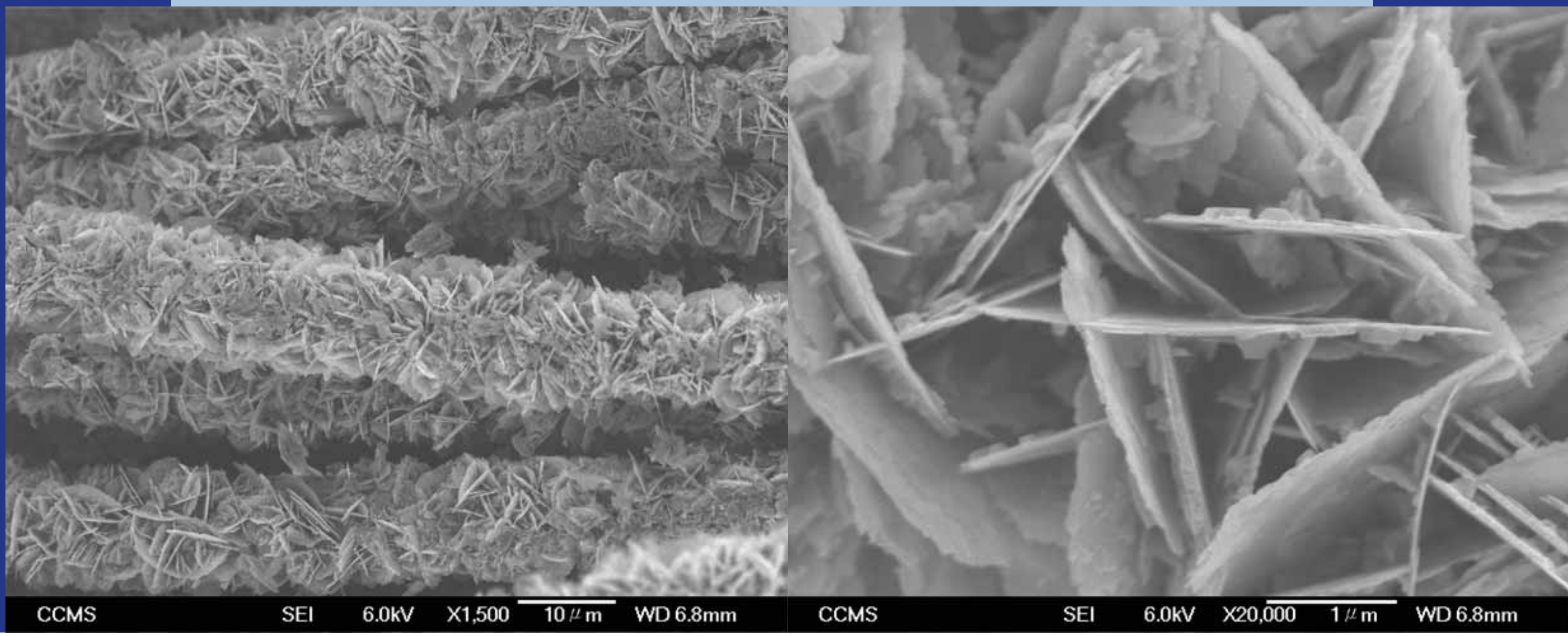
Supercapacitors



GNWs on CC

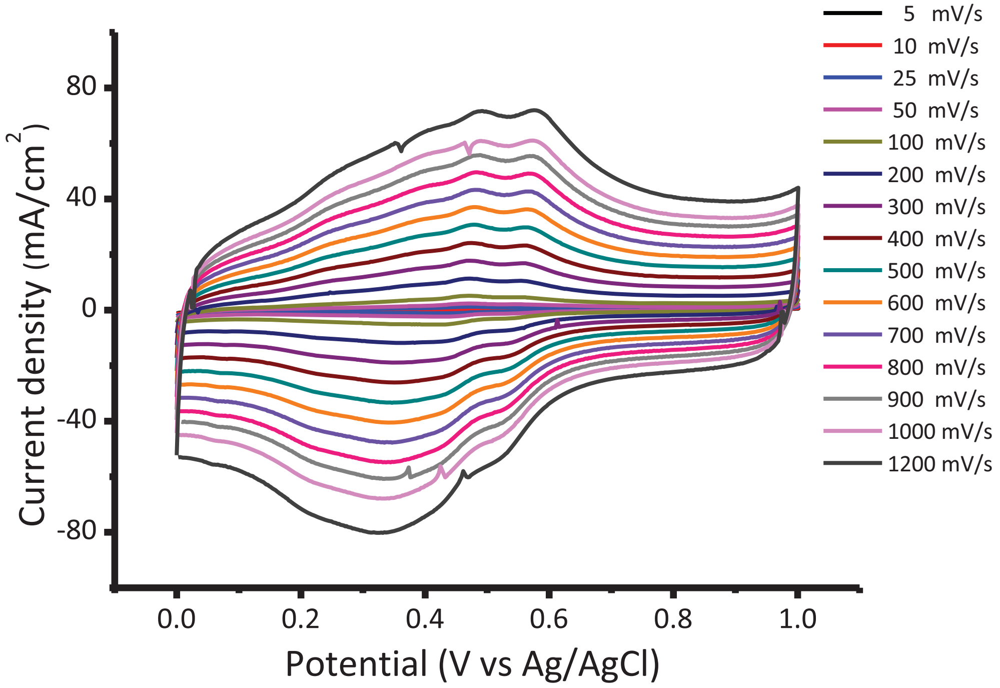


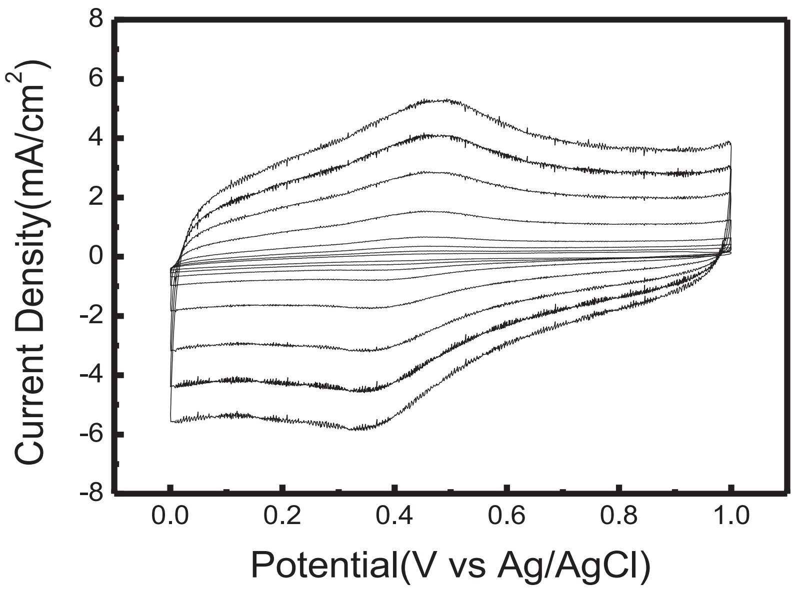
Mixing Method vs. Direct Growth
H+
e- e- e-
Carbon cloth
Graphene/CC
Carbon cloth
Graphene NW/CC



CCMS SEI 6.0kV X1,500 10 μm WD 6.8mm
CCMS SEI 6.0kV X20,000 1 μm WD 6.8mm

Capacitor Performance

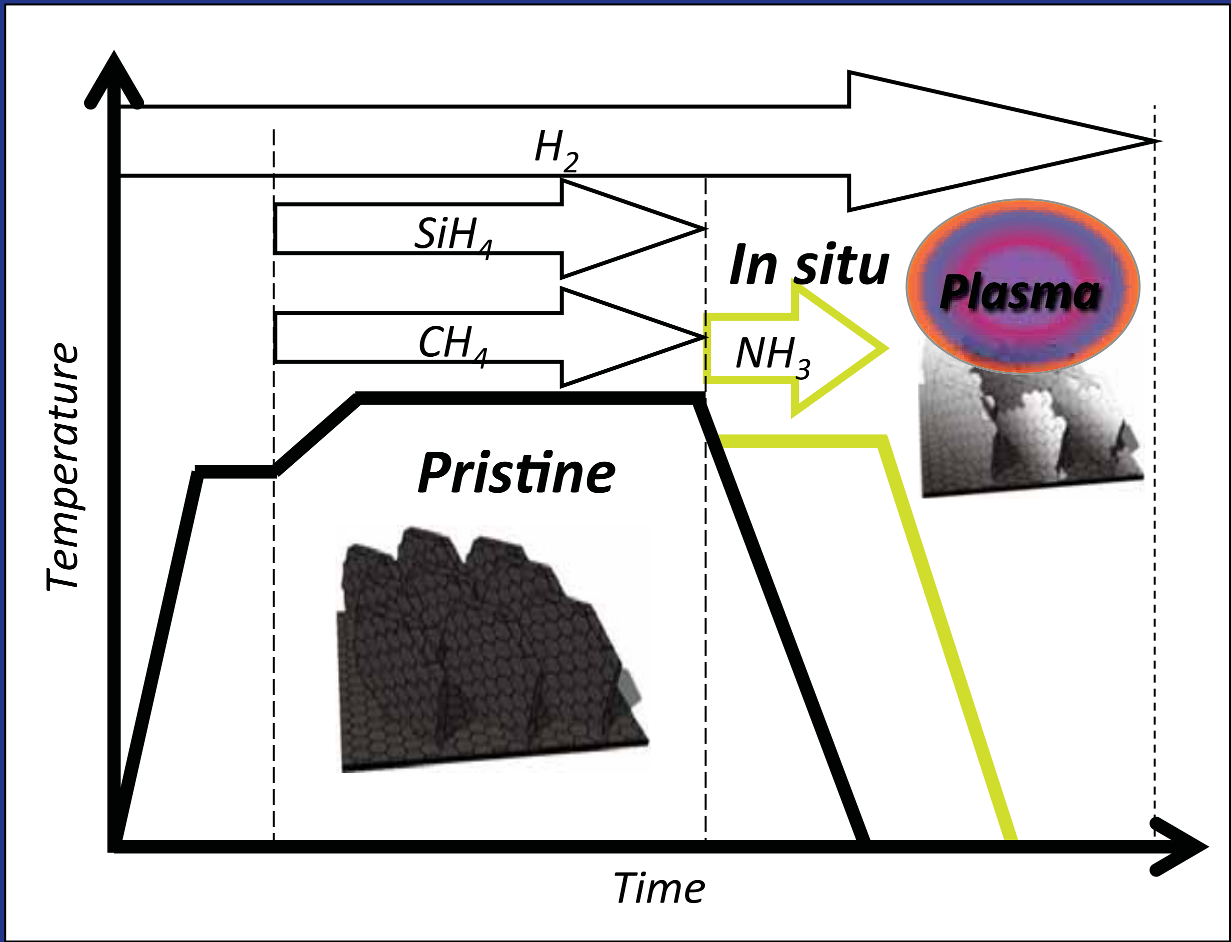


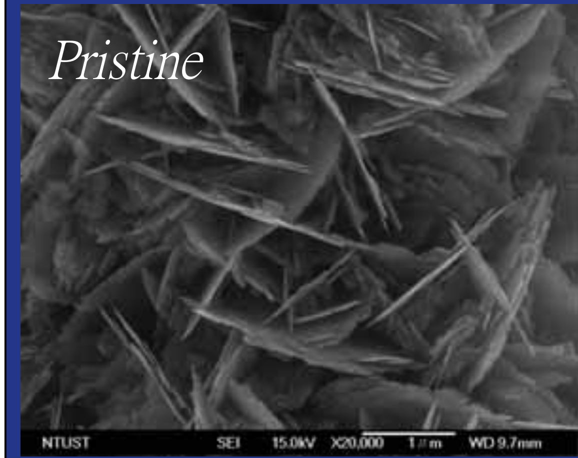


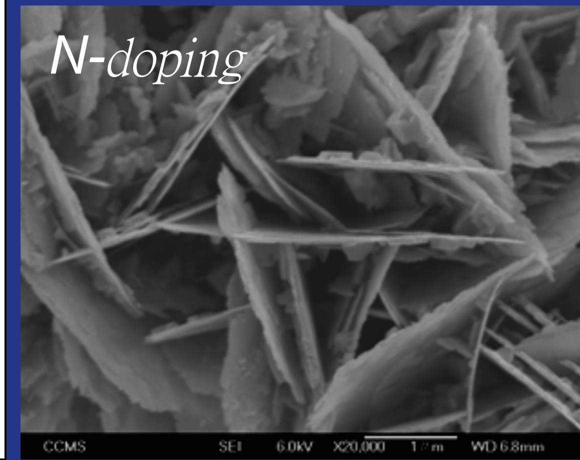
CNWs/CC

CC only

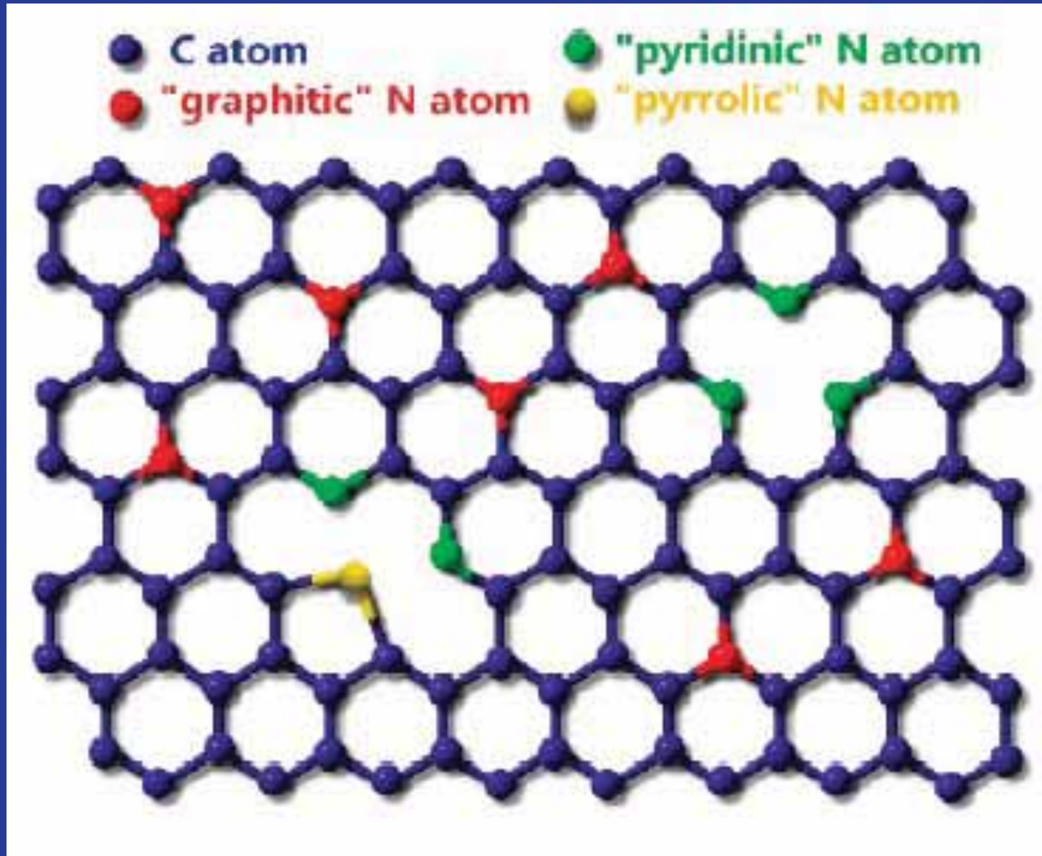
N-doped GNWs on Carbon Cloth







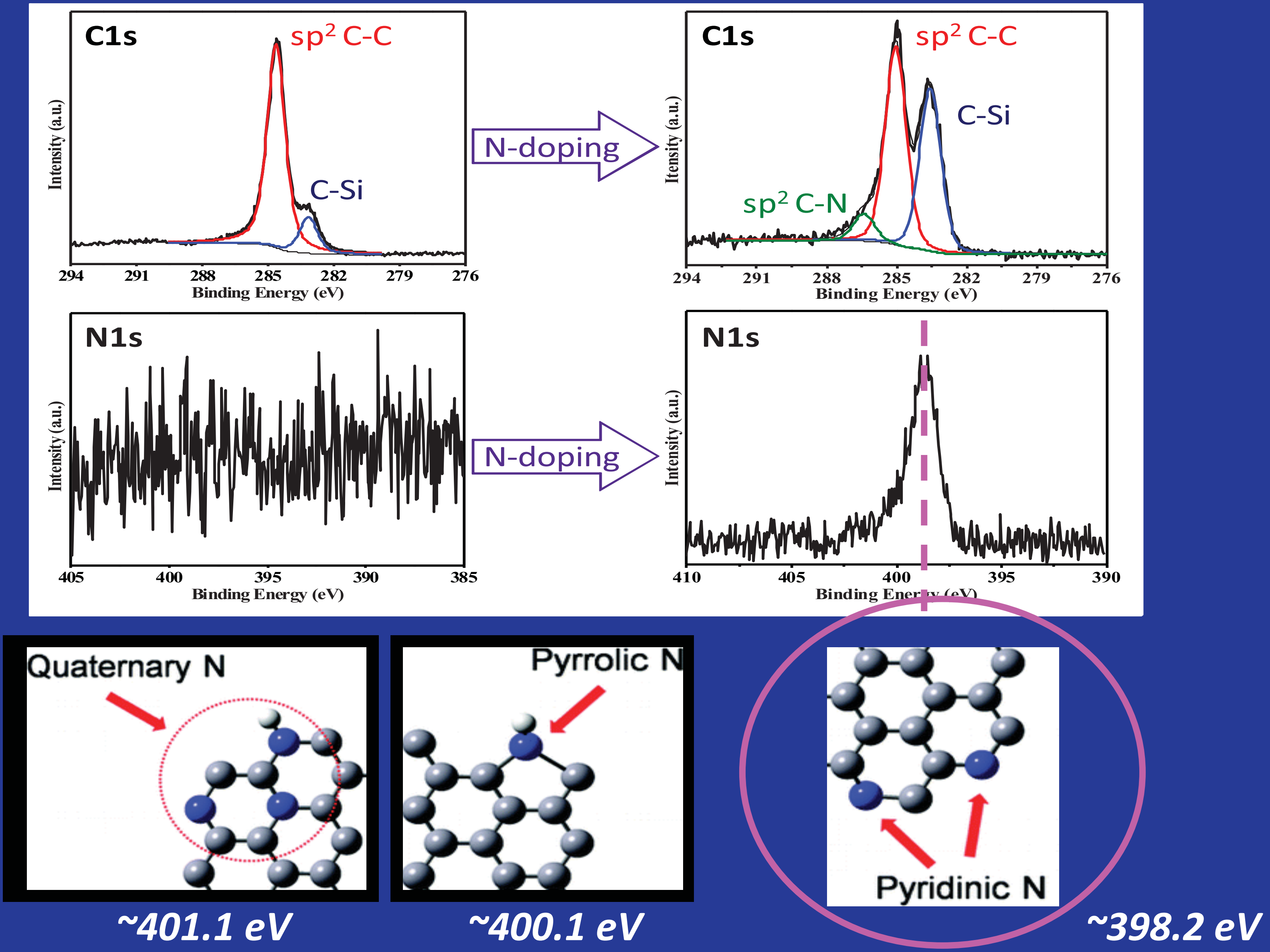
Where does N sit in graphene?



Pyridinic N (six-member ring)	*398.2 eV*
Pyrrolic N (five-member ring)	*400.1 eV*
Graphitic N	*401.1 eV*

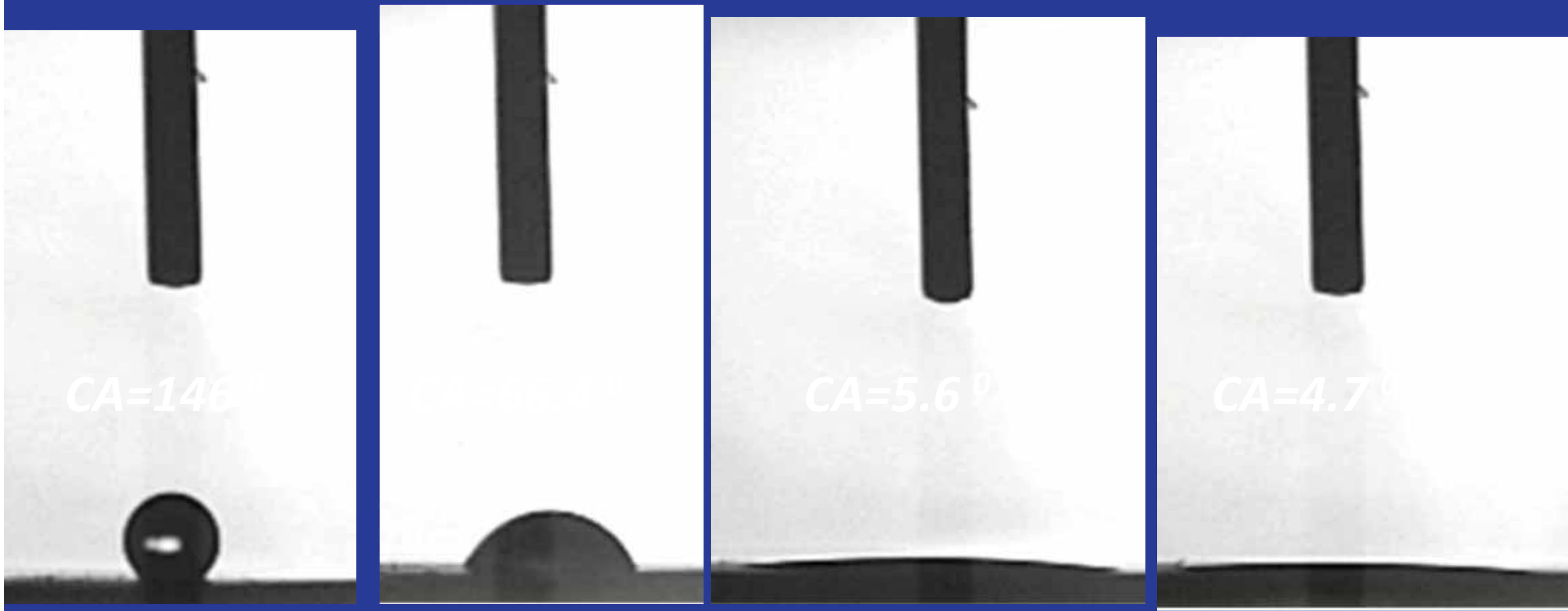
Li et al. JACS 131, 15939 (2009)
Wang et al. ACS Nano 4, 1790 (2010)

XPS: Pristine FLGs vs. N-doped FLGs



Tunable Wetting Property of Graphene:

Contact Angle vs. NH_3 Plasma Exposure Time



0 min　5 min　15 min　30 min

Hydrophobic → Hydrophilic

Ragone Plot

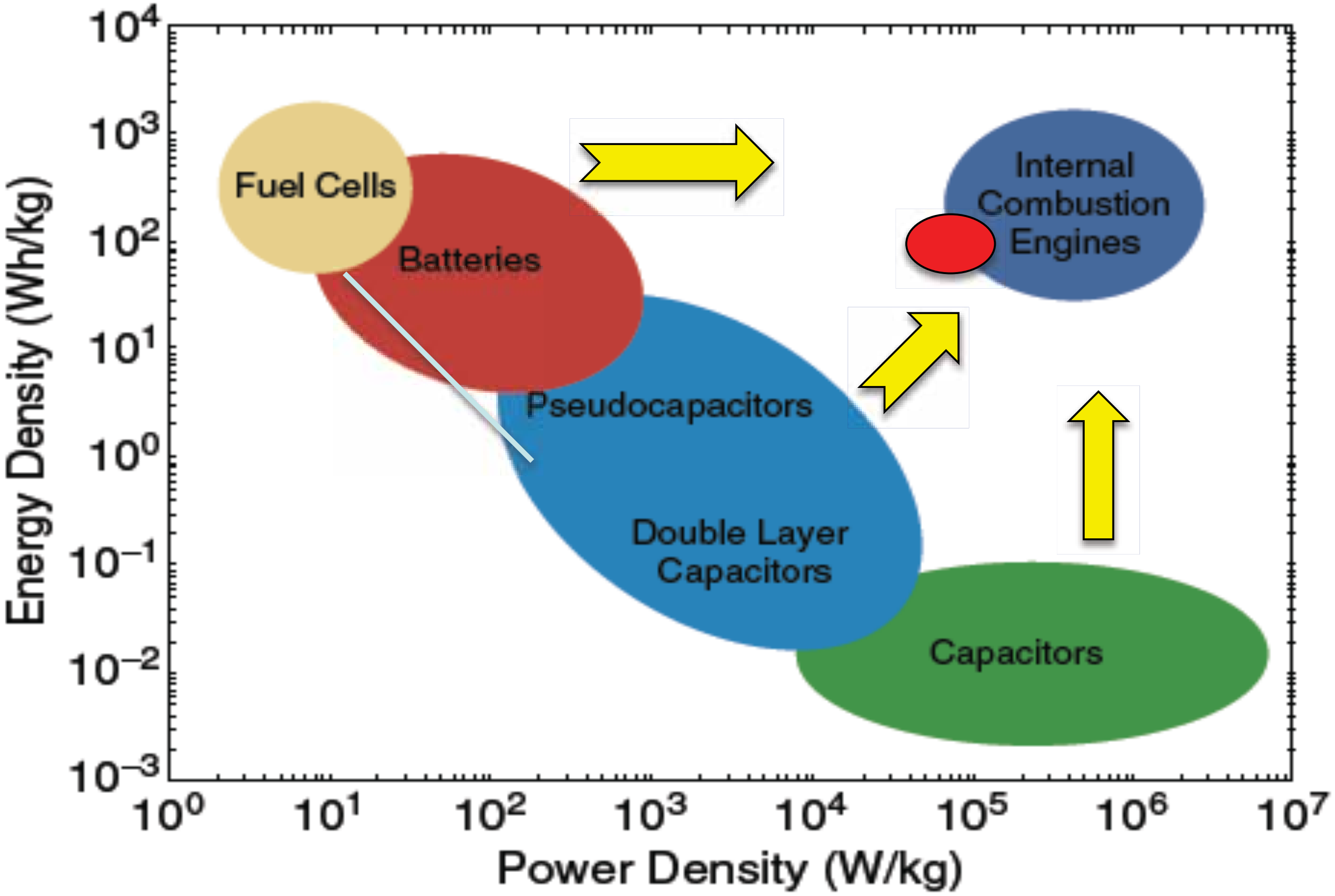


Figure 2. Comparison of the power density and energy density for batteries, capacitors, and fuel cells. (Energy is the capacity to do work; power is the rate at which work is done.)

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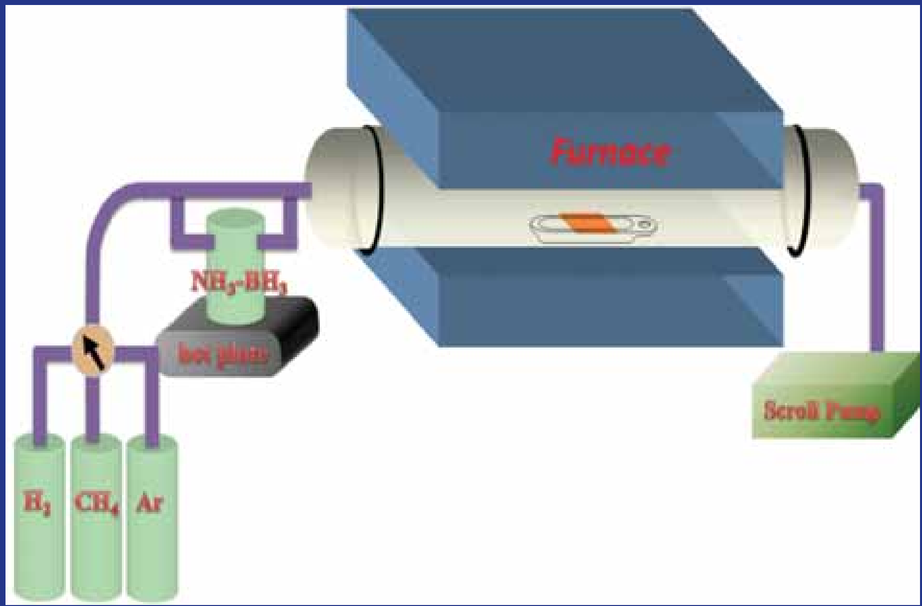
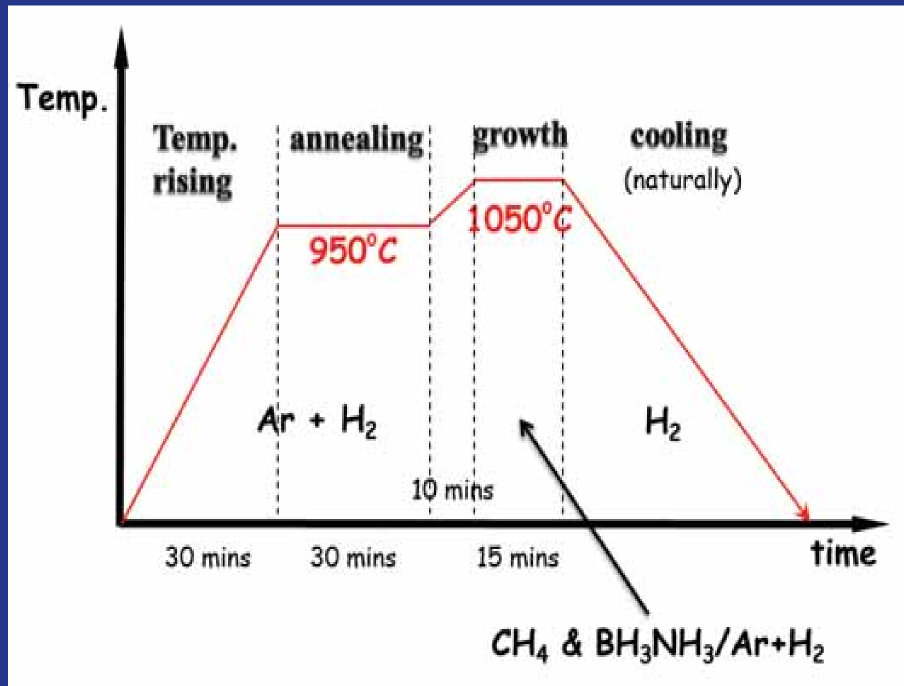
In-situ BN-doping

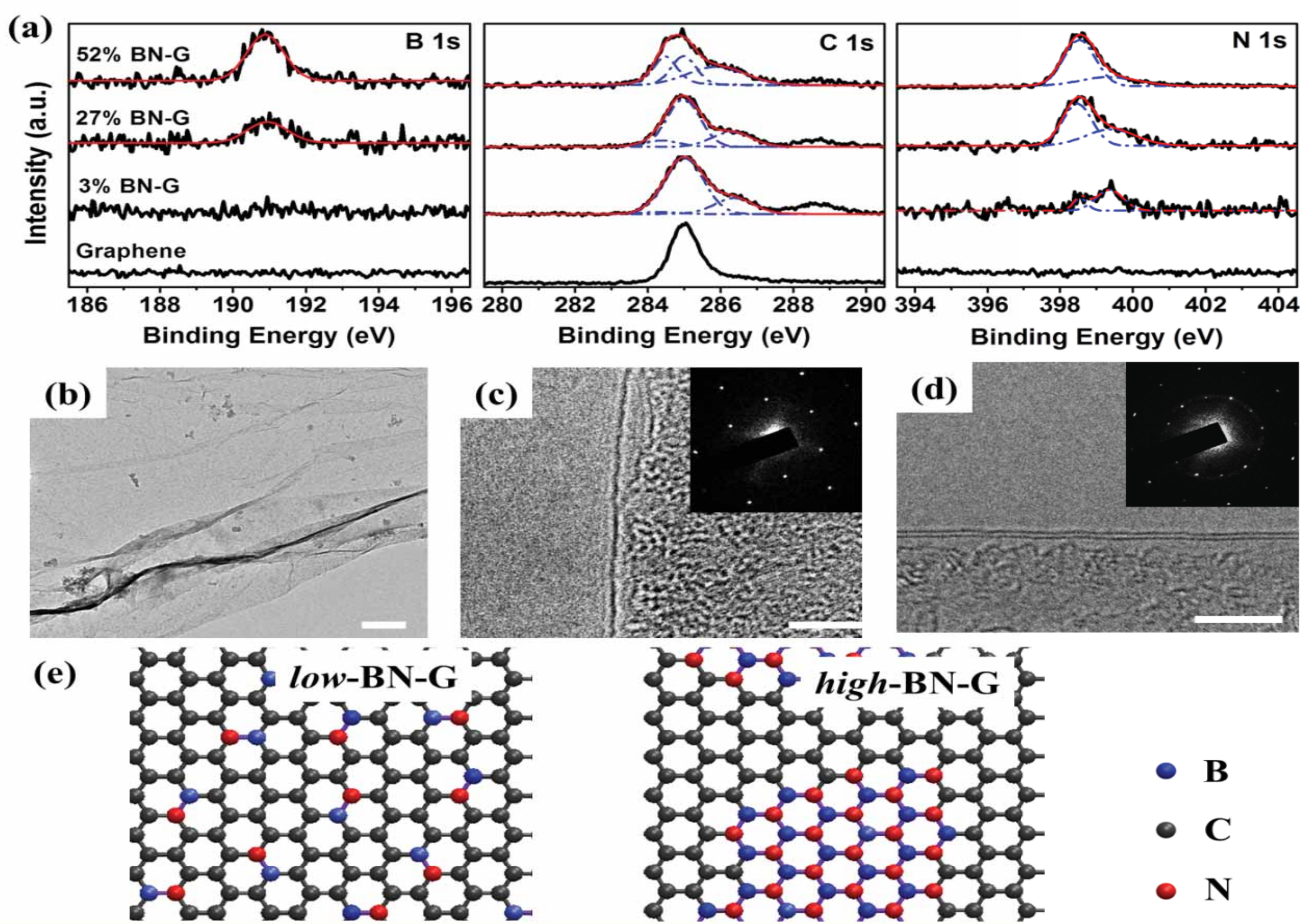




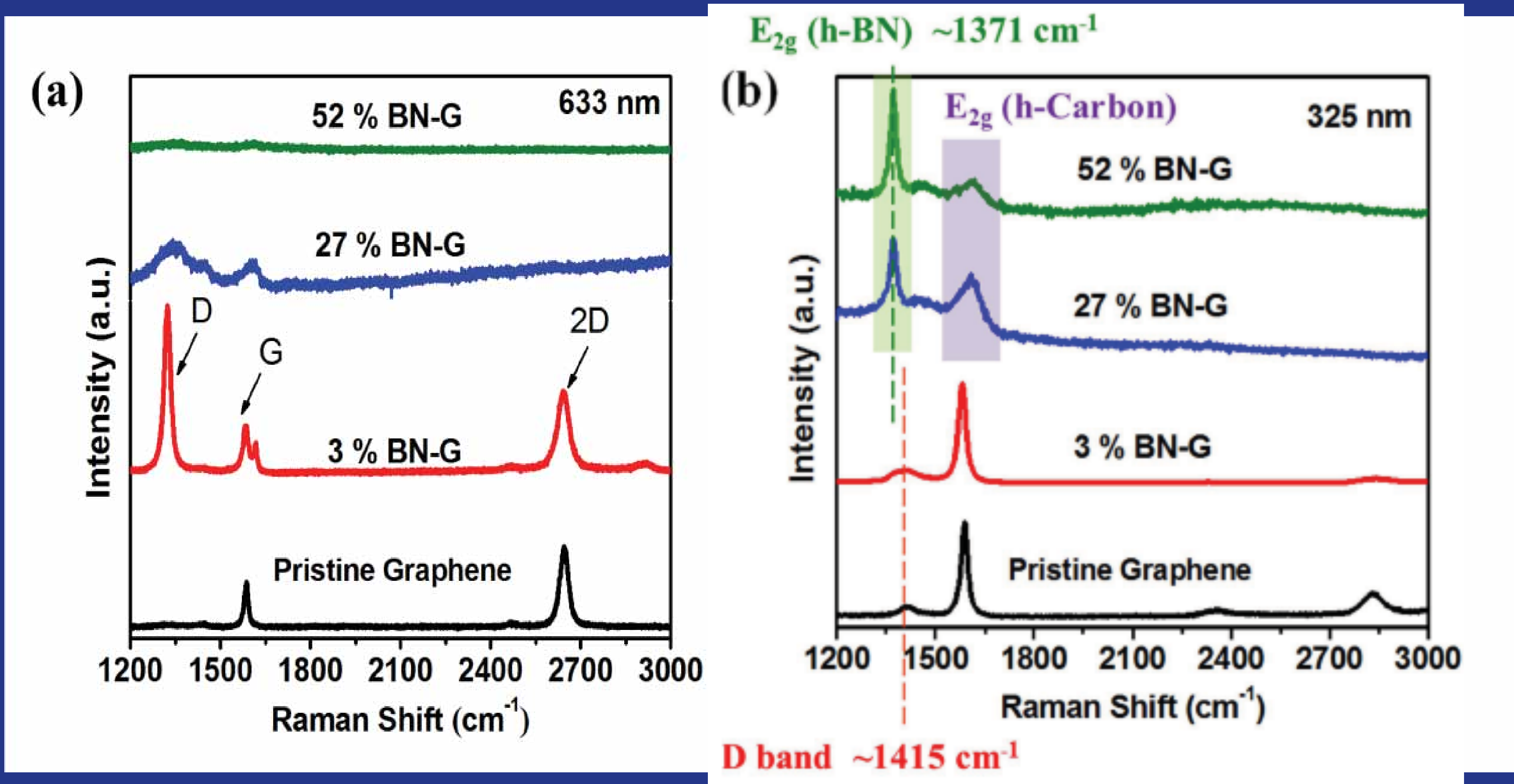
Advantages:

- *In situ BN doping*
- *Large-scaled growth*
- *Easy control of BN concentration in graphene*

XPS and TEM Analysis

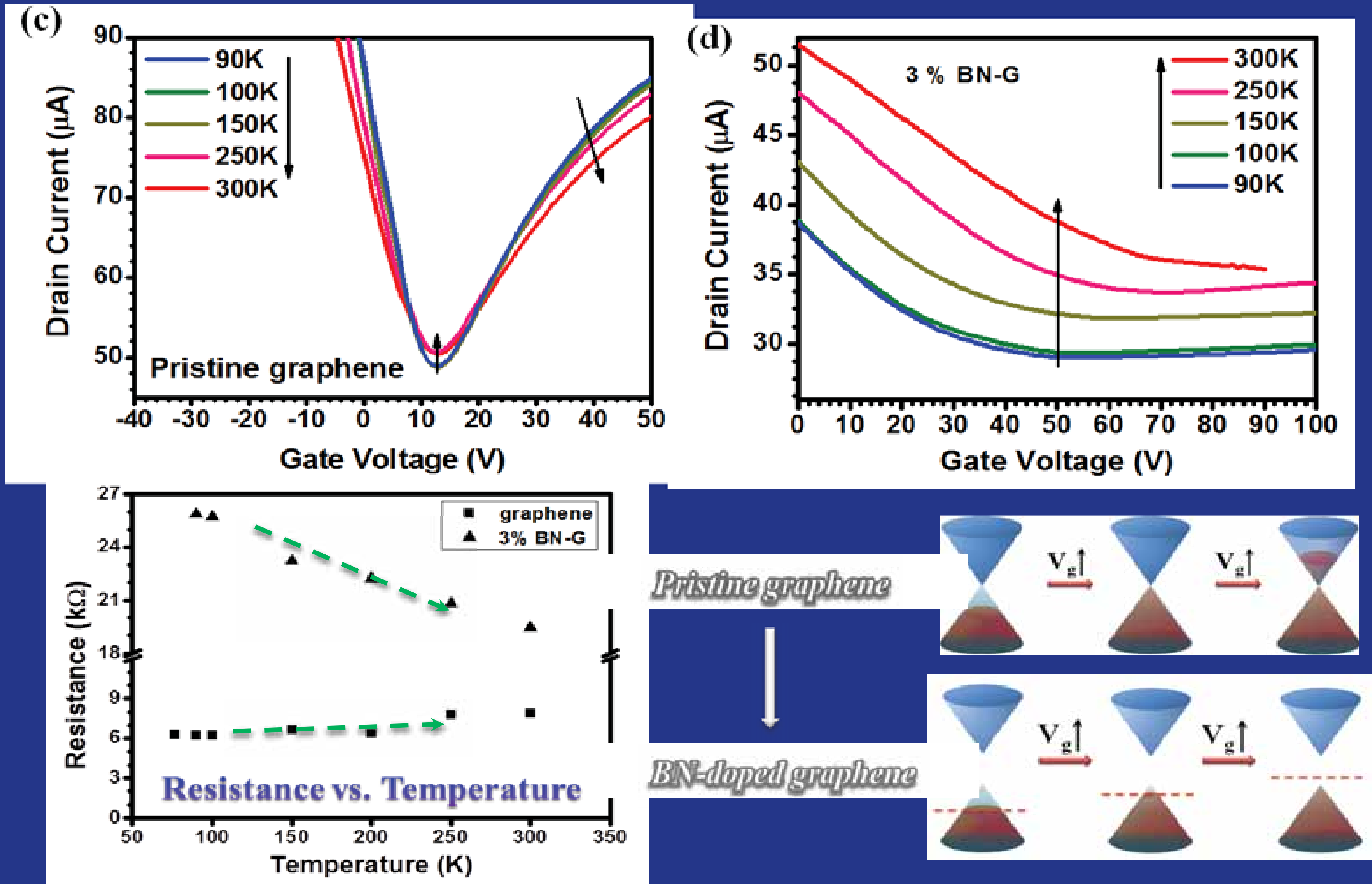


Raman Analysis



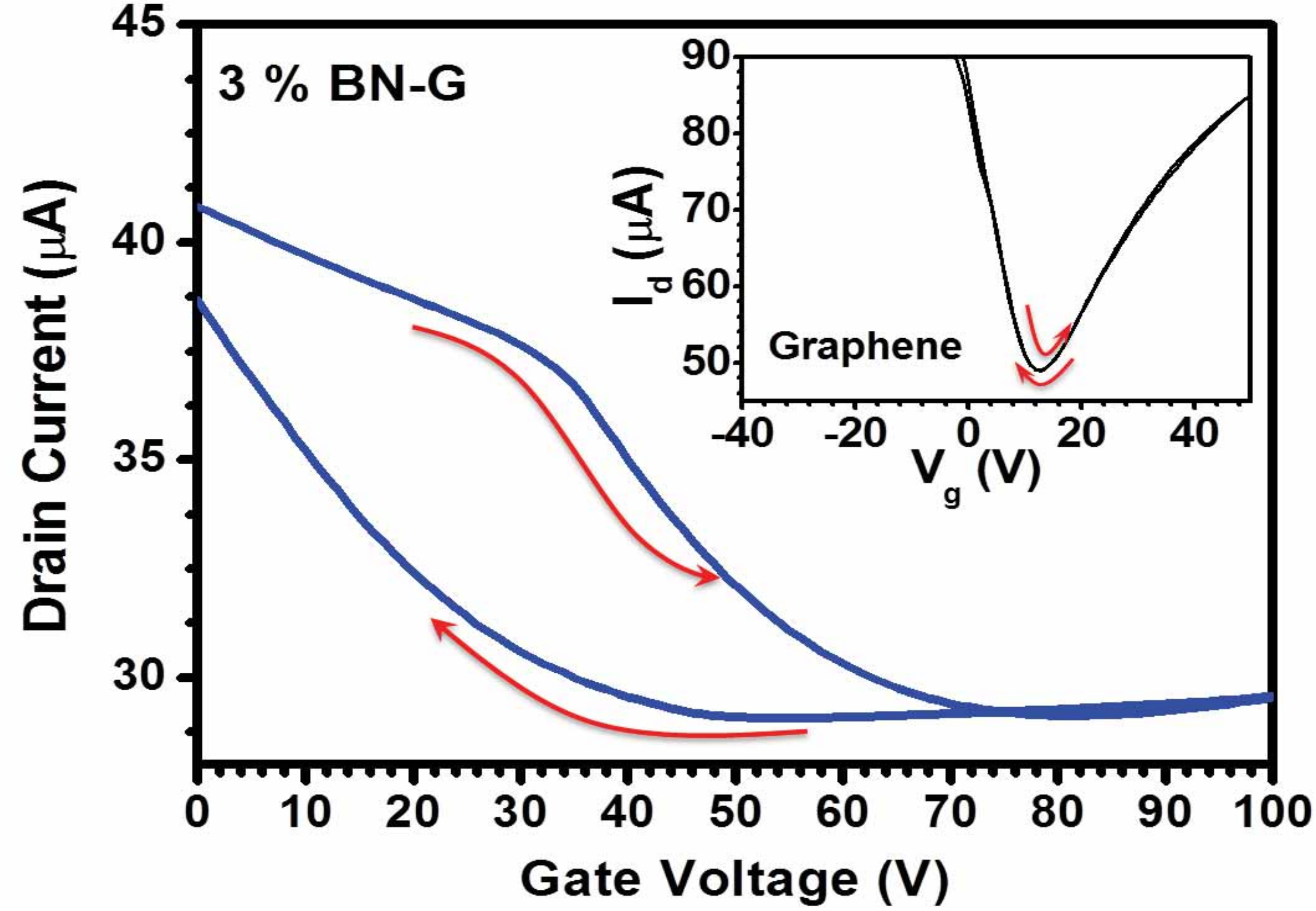
- ***Clear evidence of BN domains in high BN-doped (>27%) graphene.***

FET Analysis

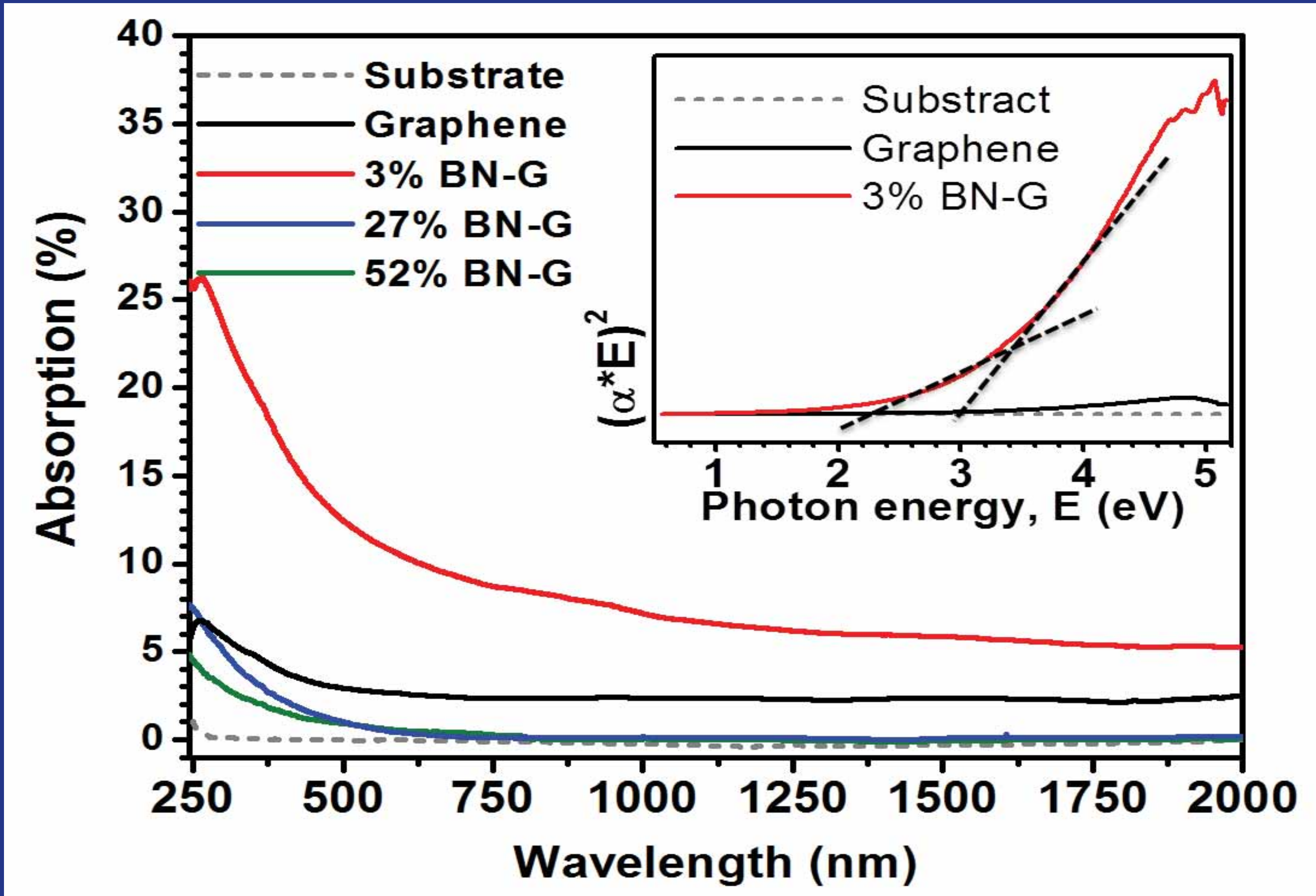


- *Semiconducting behavior is observed for 3% BN in graphene.*

FE Characteristic



Optical Absorption



Summary

- N-doped GNWs/CC provides the material for EC applications such as supercapacitor.

- Evidence of gap-opening via BN-codoping of graphene is proposed.

Acknowledgement

C.C. Kuo, C.K. Chang, Dr. S. Kataria, Dr. B.Y. Wang

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