Nitrogen Modification of Epitaxial Graphene Formed on SiC

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The Georgia Tech Laboratory for New Electronic Materials

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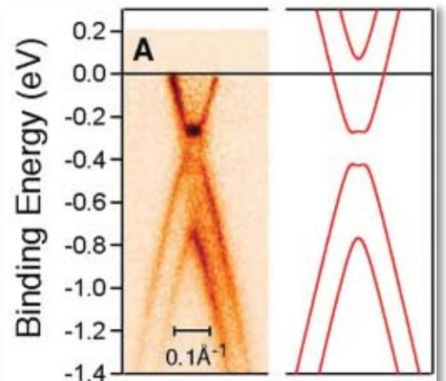
The Challenge of Graphene

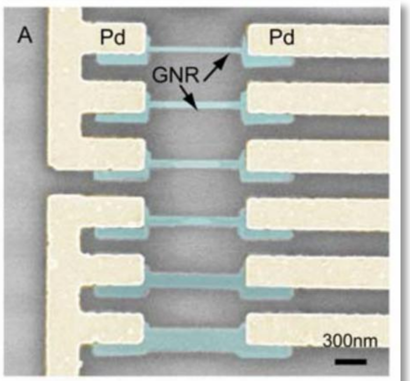
Graphene electronics requires a room temperature compatible band gap.

After more than a decade of research, producing a **significant** band gap remains the fundamental challenge

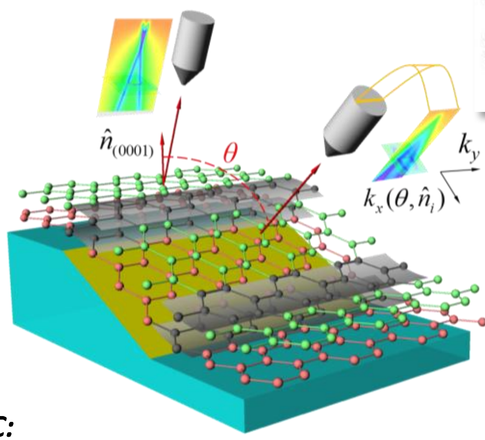
- Chemistry
- Strain
- Confinement



Ohta et al., Science 313 (2006)



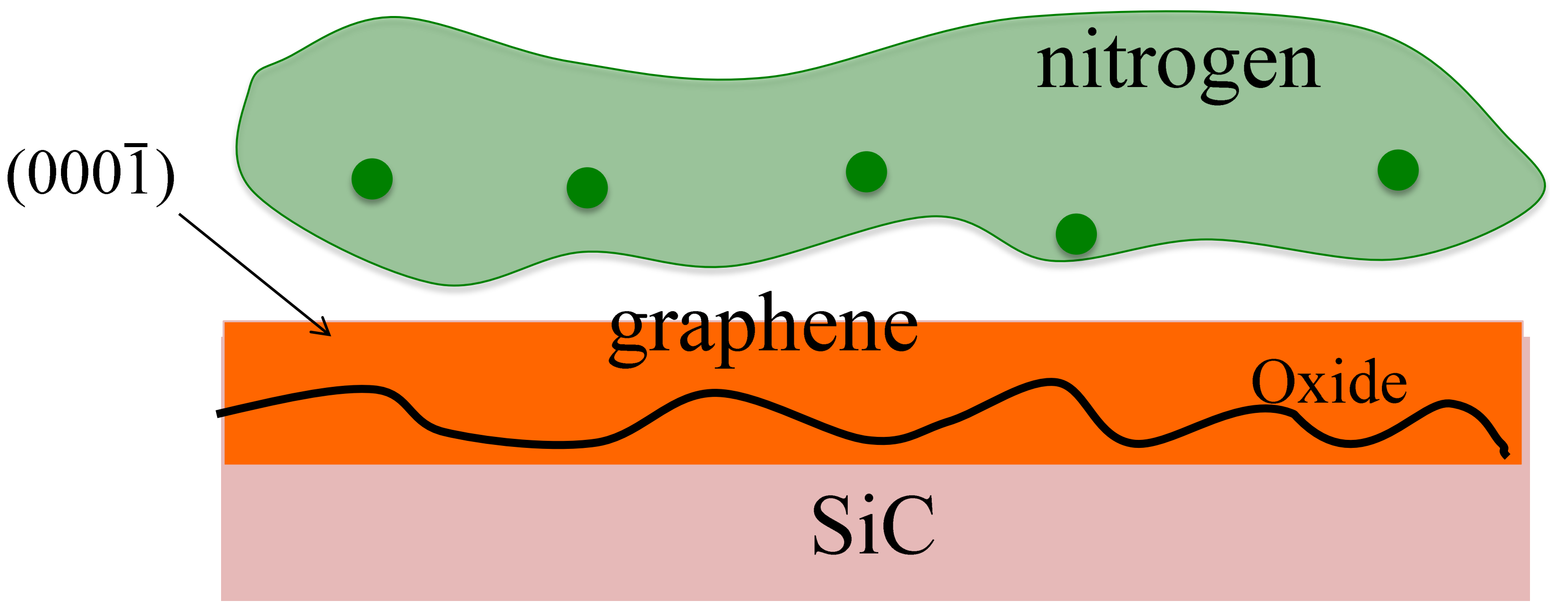
Chen et al., Physica E 40 (2007)



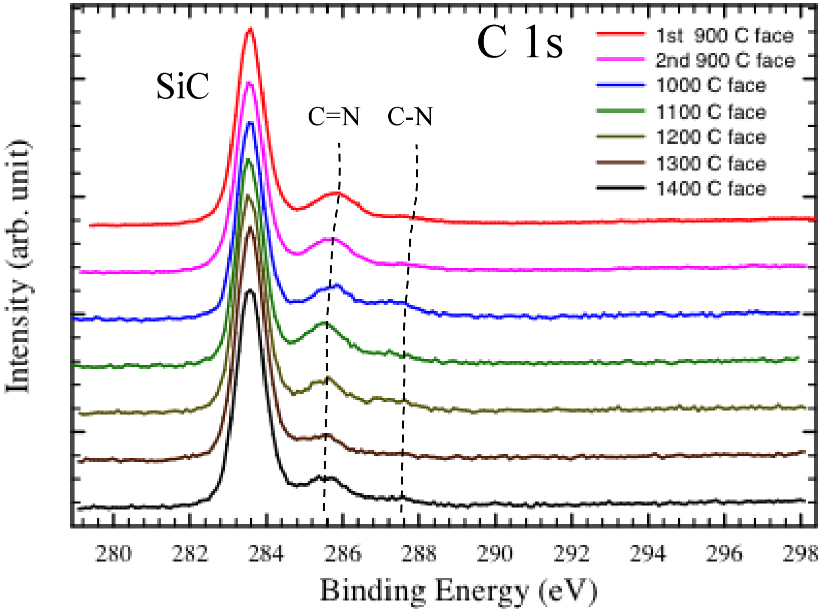
Hicks et al. Nature Phys. 9, 49 (2013).

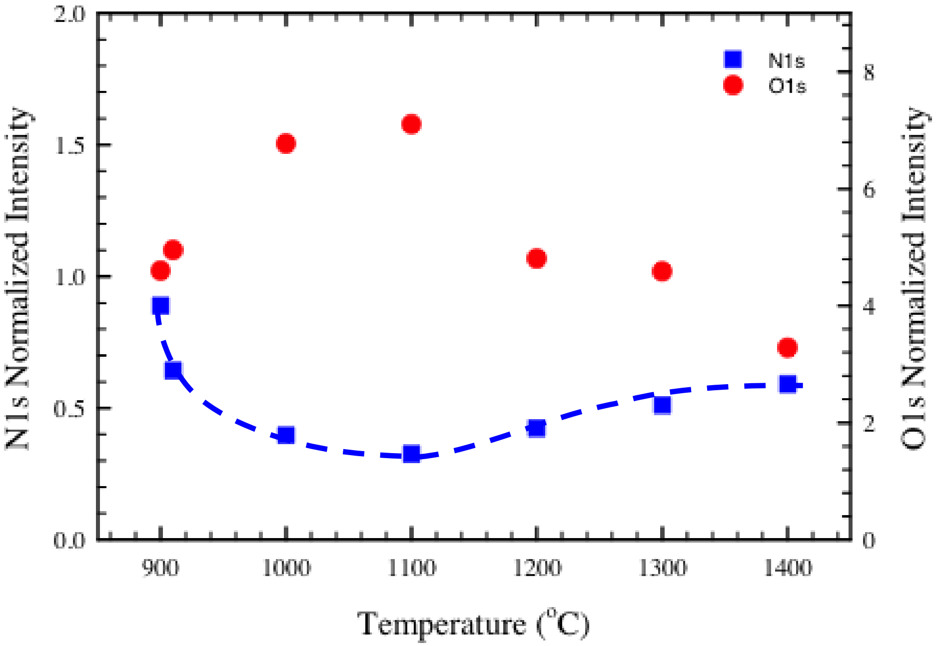
Nitrogen-Induced Strain Confined Graphene

Capable of producing large band gaps (> 0.7eV)

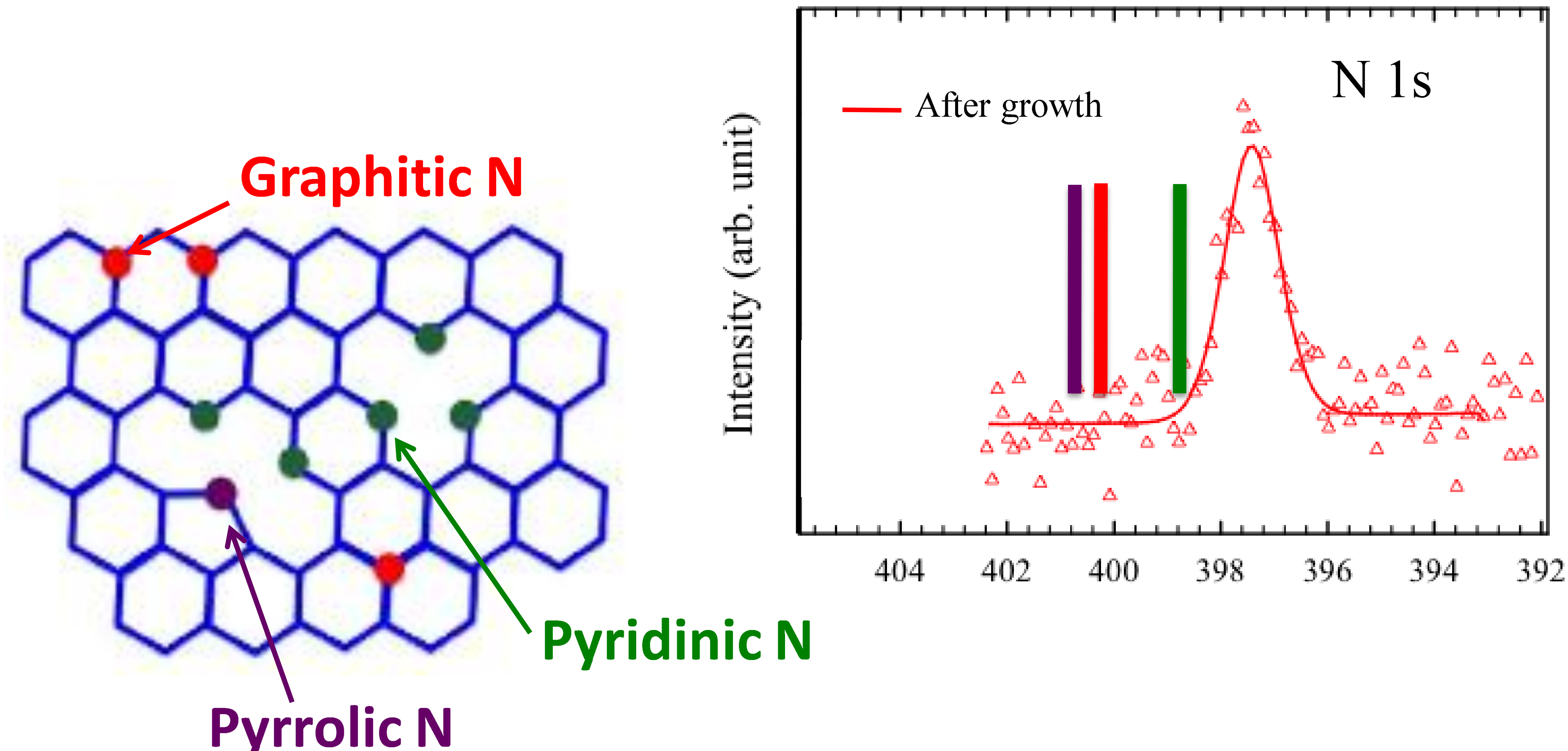


Nitrogen is stable to very high temperatures

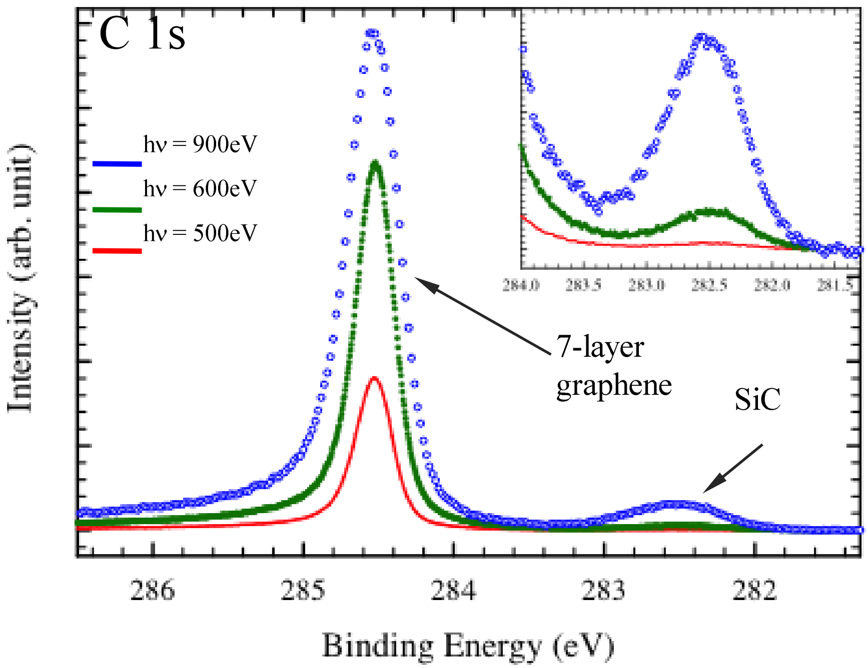


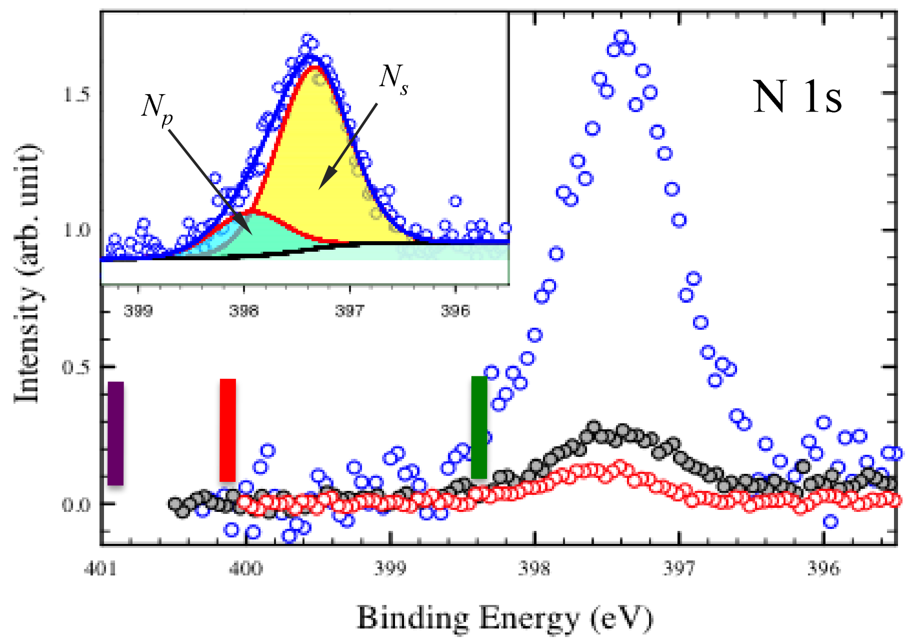


Nitrogen does not incorporate into the graphene during growth

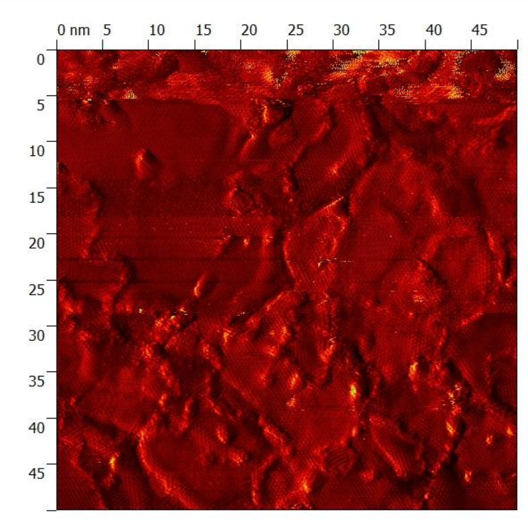


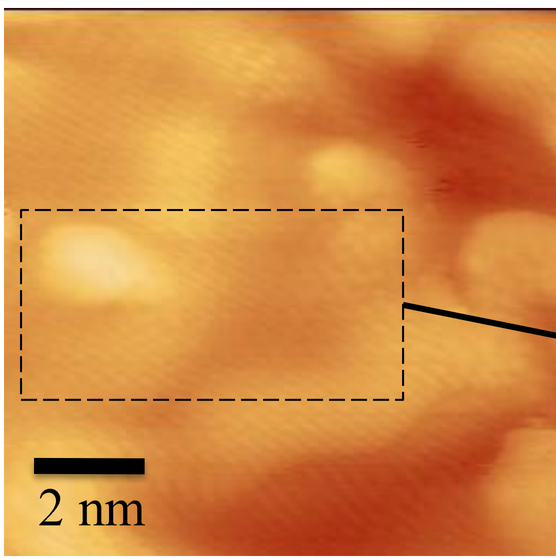
Nitrogen remains at the SiC interface after graphene growth

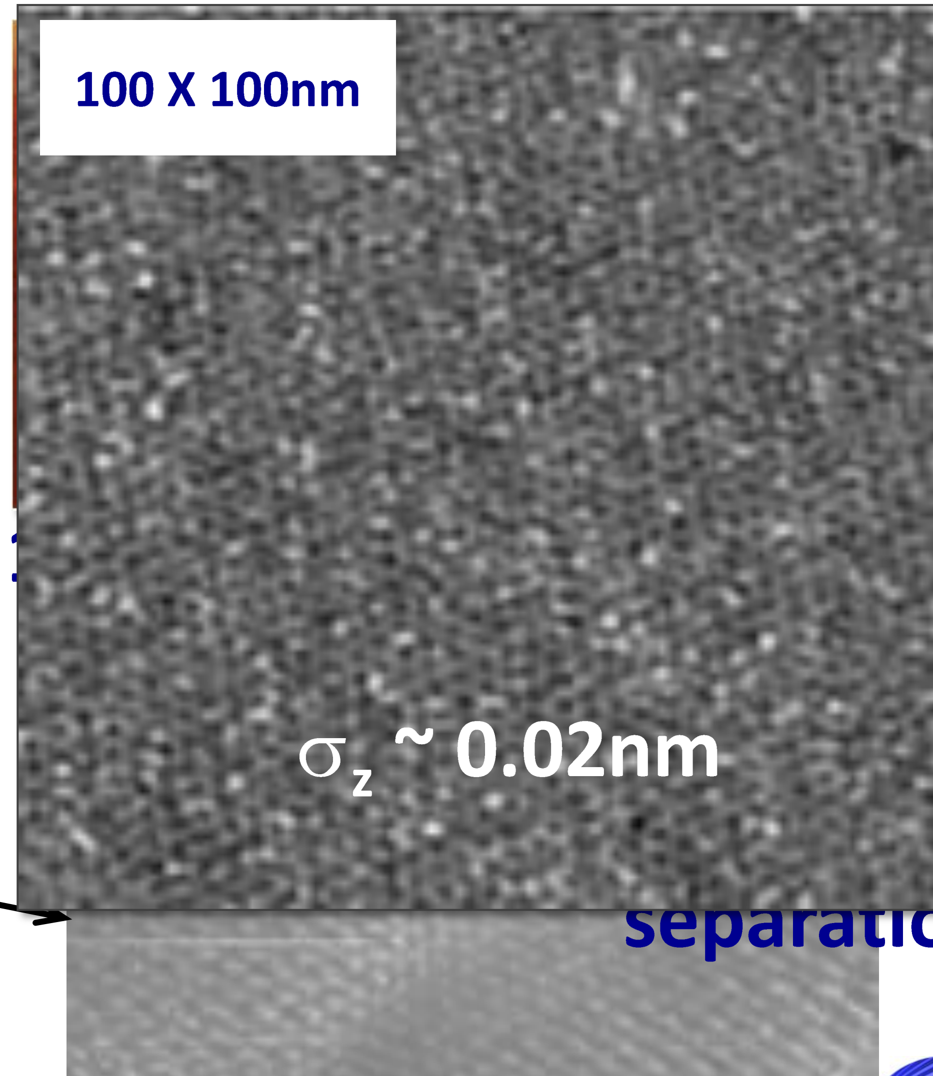




STM of Buckled Graphene

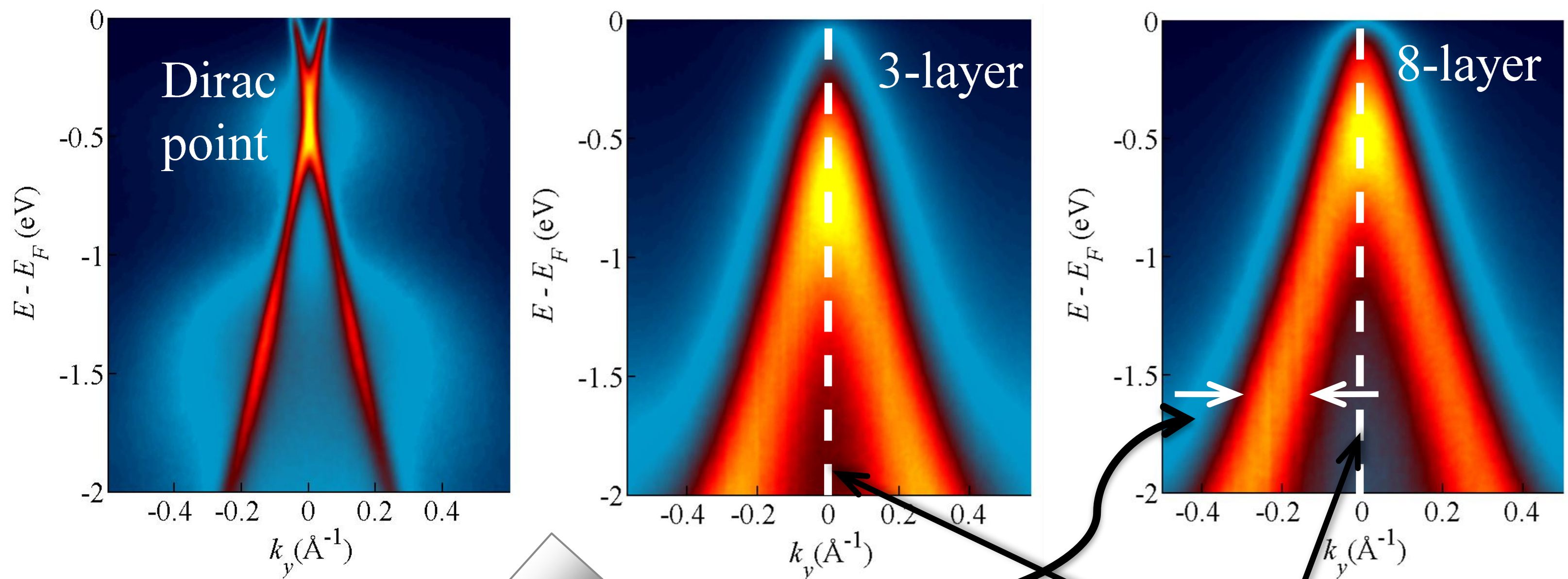




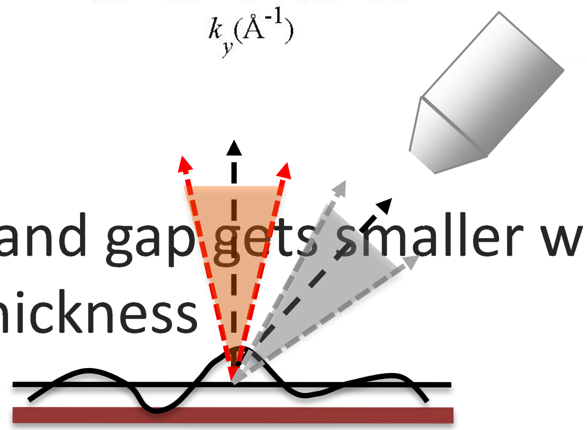


separation

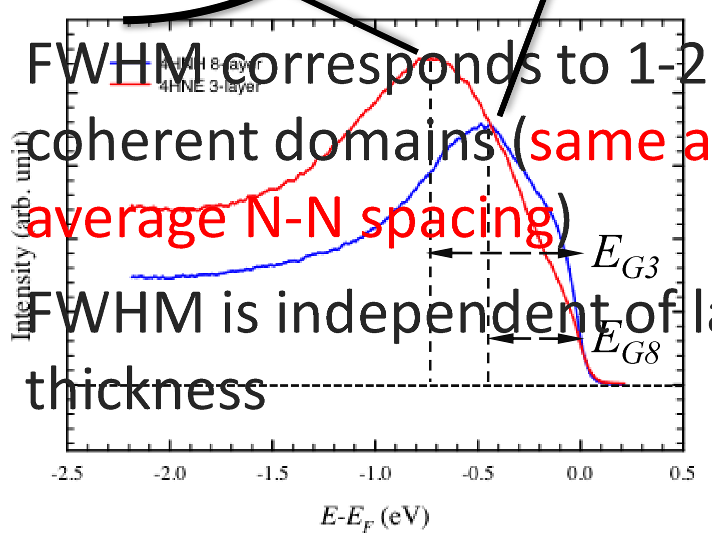
Angle resolved photoemission from buckled graphene



- Band gap gets smaller with thickness



- FWHM corresponds to 1-2nm coherent domains (same as average N-N spacing)
- FWHM is independent of layer thickness



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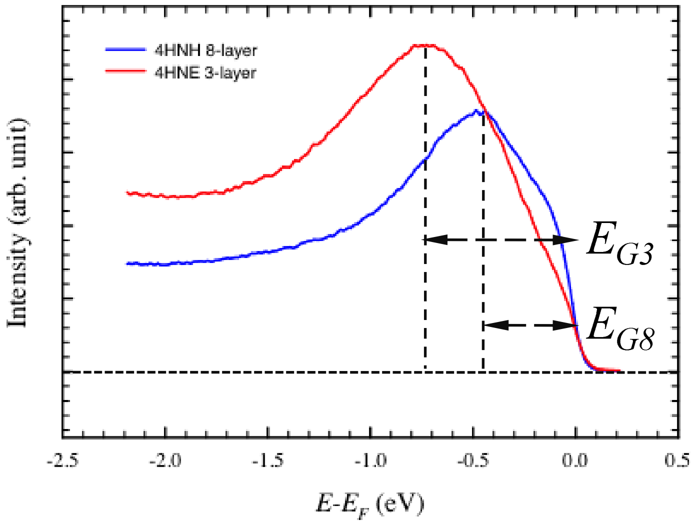
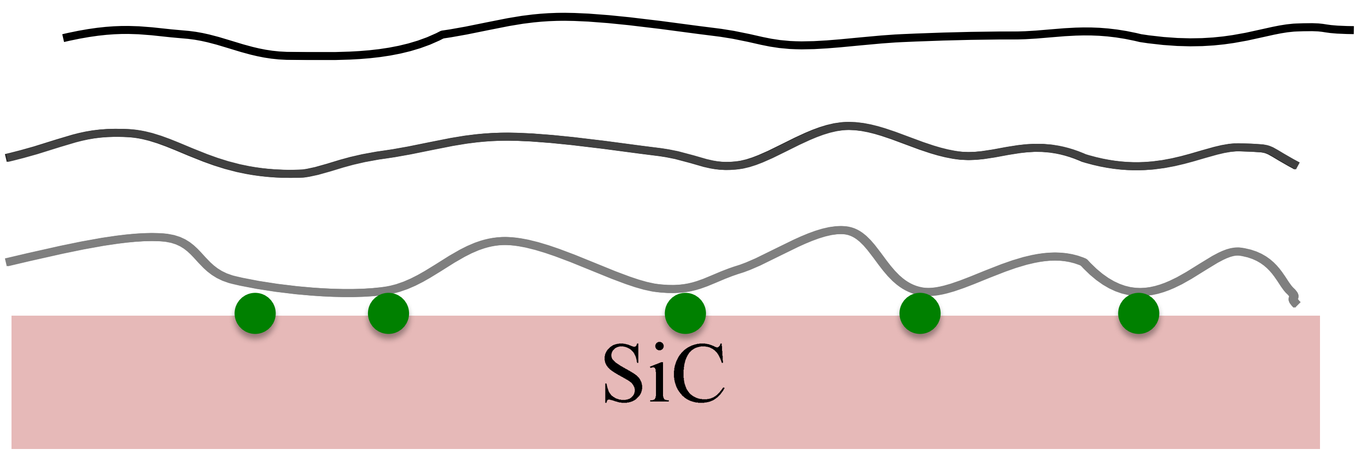
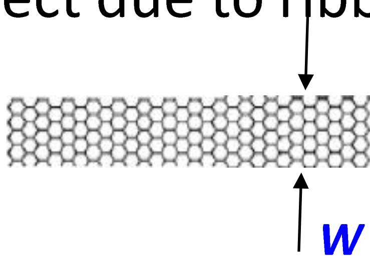
Strain gets smaller with thickness





Origin of gap

- Finite size effect due to ribbon width



$$E_{gap} \sim 1\ eV \cdot nm/W$$

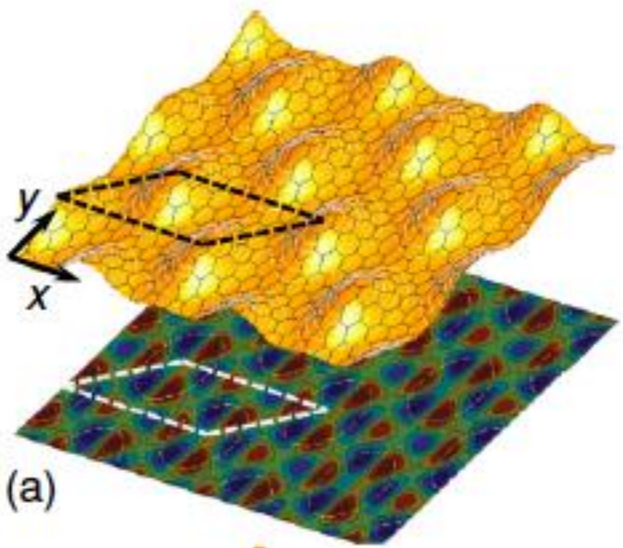
Nakada et al., PRB 54 (1996)

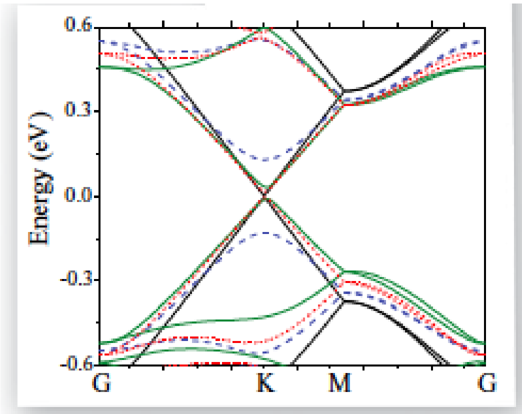
- quasi-periodic Strain

PHYSICAL REVIEW B **83**, 195436 (2011)

Gaps tunable by electrostatic gates in strained graphene

T. Low,[1,2] F. Guinea,[3] and M. I. Katsnelson[4]





Summary

- We show that sub-monolayer nitrogen on SiC can cause graphene to buckle
- The buckling opens a large bandgap (~0.7eV for 1 at% N)

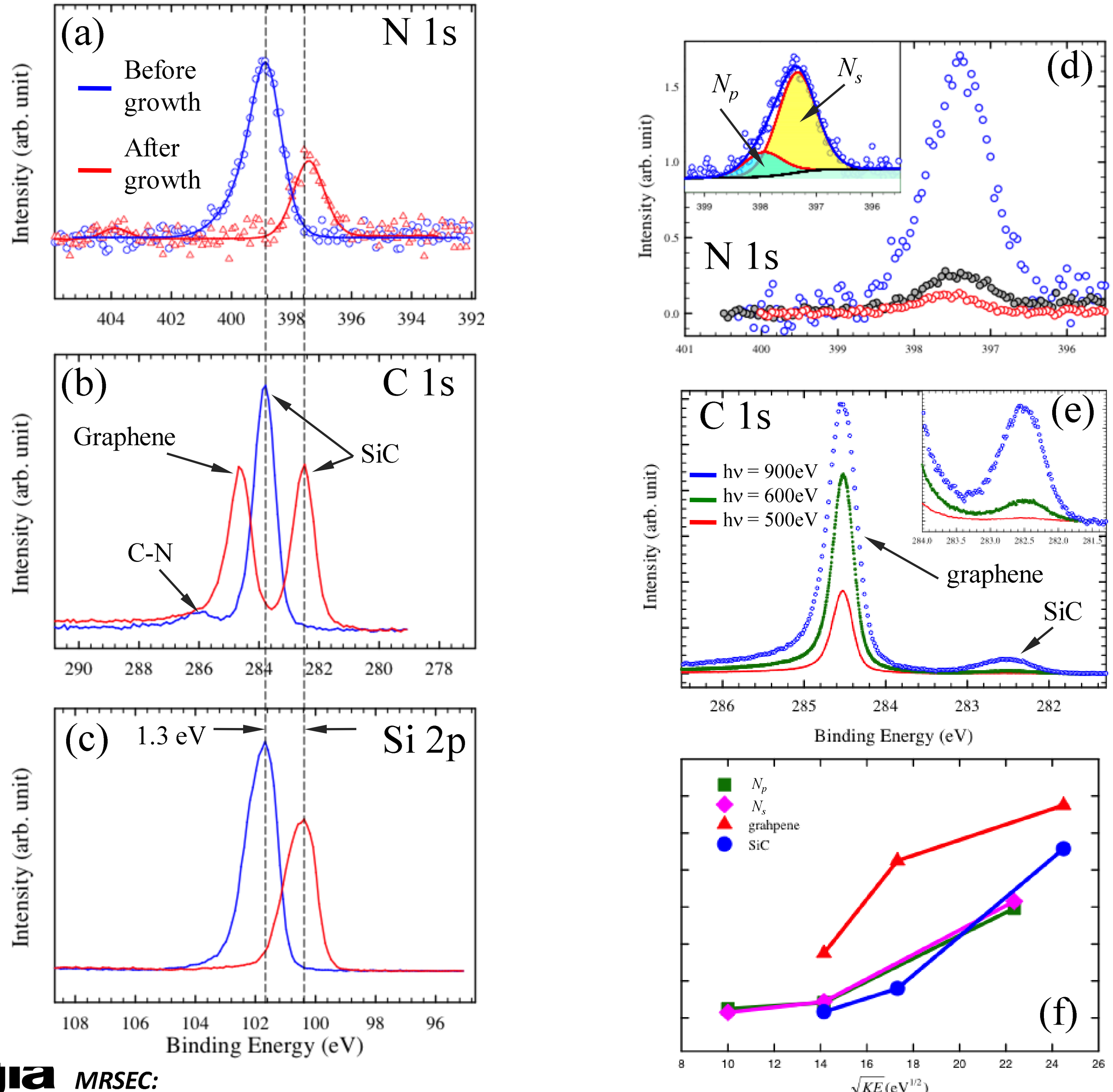
- Concentration can be adjusted to tune gap
- Nitrogen can be patterned to locally cause strain

The Cast

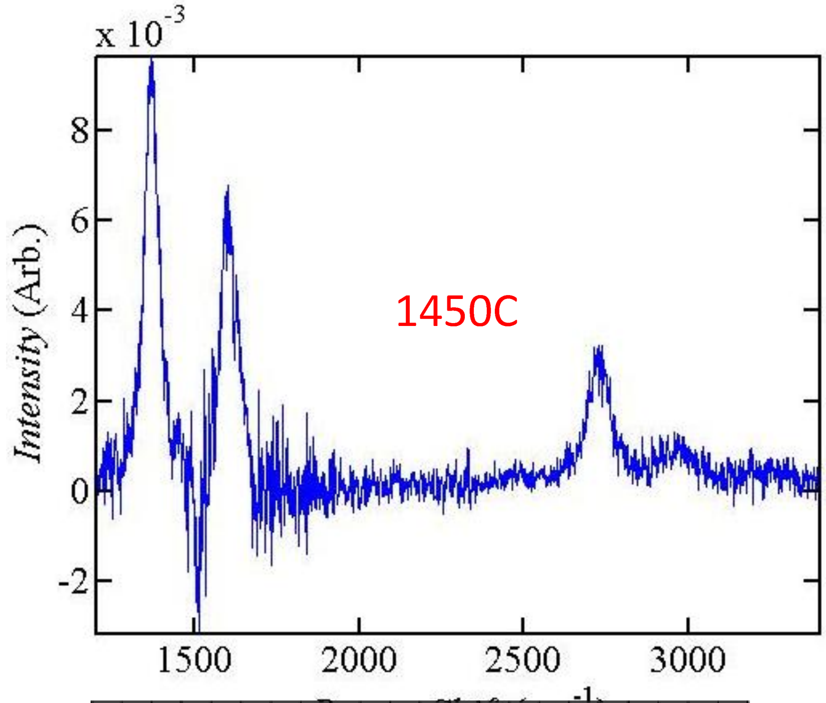
Georgia Tech	Univ. of Minnesota	Rutgers Univ.
F. Wang M. Nevius	P. Cohen S. Rothwell	L.C. Feldman G. Liu

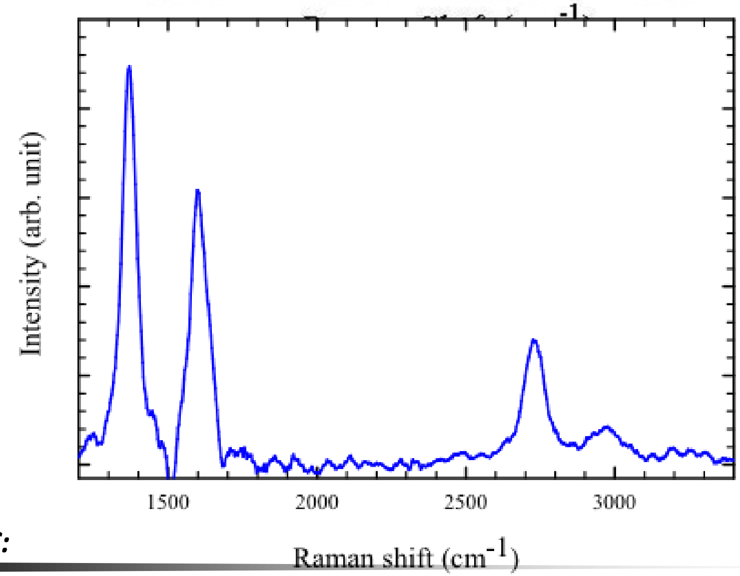
A. Tejeda	Soleil
A. Taleb-Ibrahimi	Soleil

THANKS!



(a)
N 1s
Before growth
After growth
Intensity (arb. unit)
(b)
C 1s
Graphene
SiC
C-N
(c)
1.3 eV
Si 2p
Binding Energy (eV)
(d)
N_p
N_s
N 1s
(e)
C 1s
hν = 900eV
hν = 600eV
hν = 500eV
graphene
SiC
Binding Energy (eV)
(f)
grahpene
SiC
$\sqrt{KE}$ (eV$^{1/2}$)





FWMH of D peak is 45.39

FWHM of 2D peak is 68.79

FWMH of G peak is 49.84