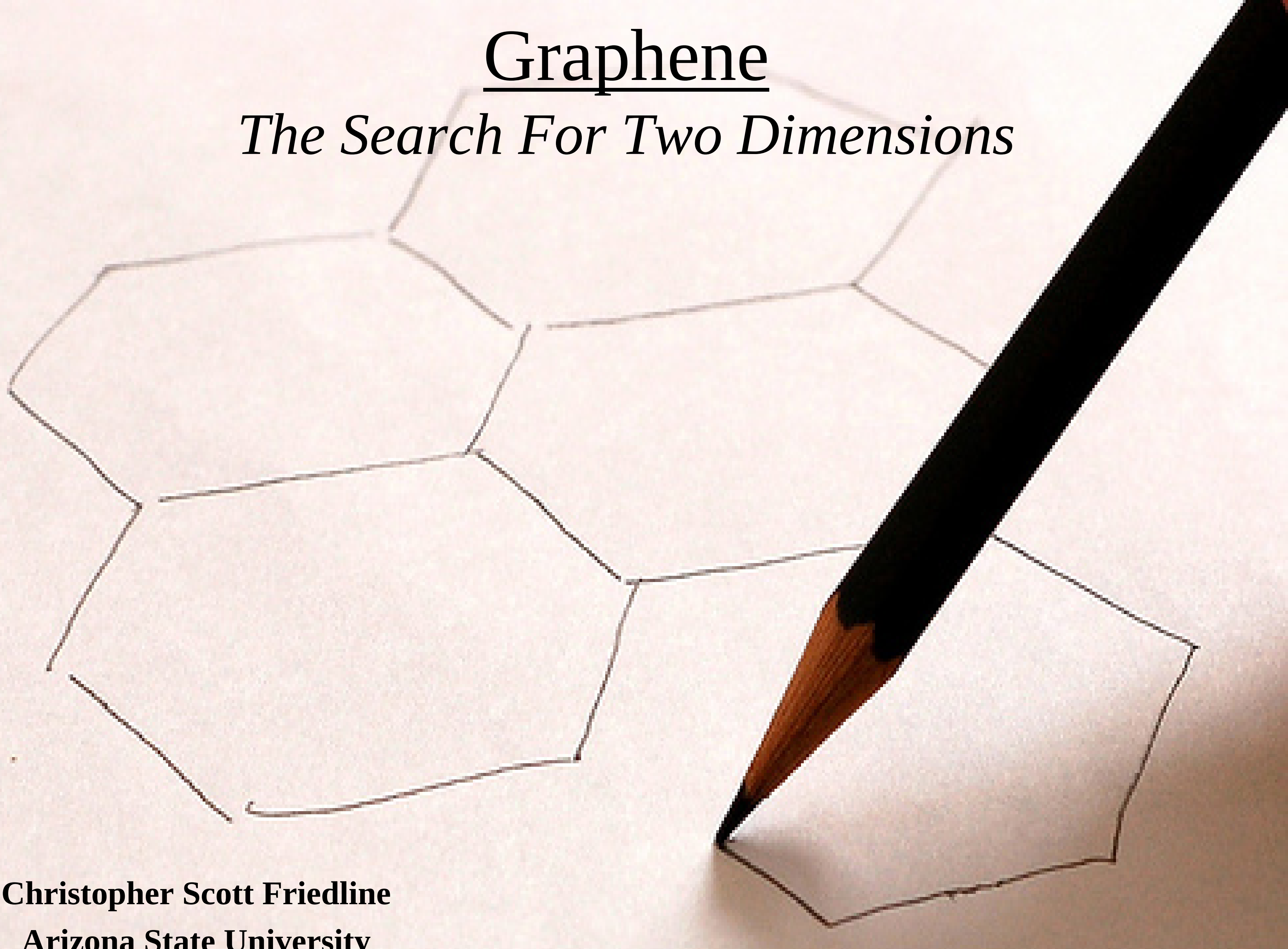
Graphene

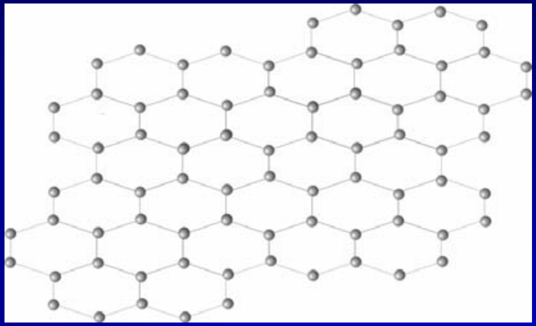
The Search For Two Dimensions



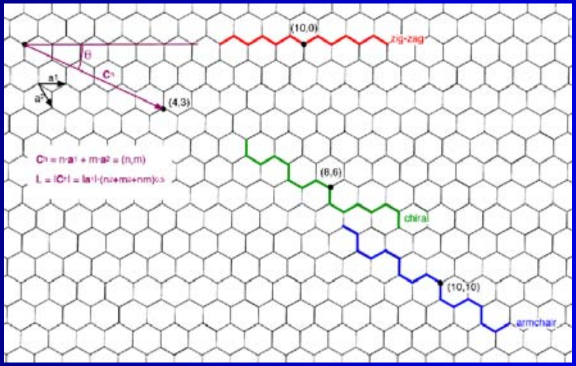
Christopher Scott Friedline
Arizona State University

What Is Graphene?

- Single atomic layer of graphite arranged in a honeycomb crystal lattice



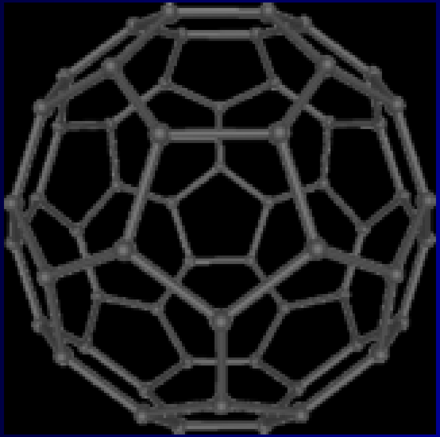
- Consists of sp^2-bonded carbon atoms with bond length approximately 1.42 angstroms



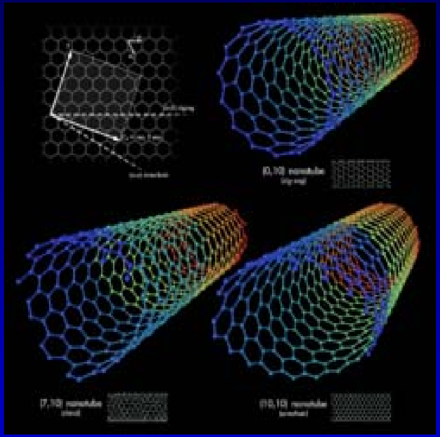
- Basic structural element for all other graphitic materials

Graphitic Materials

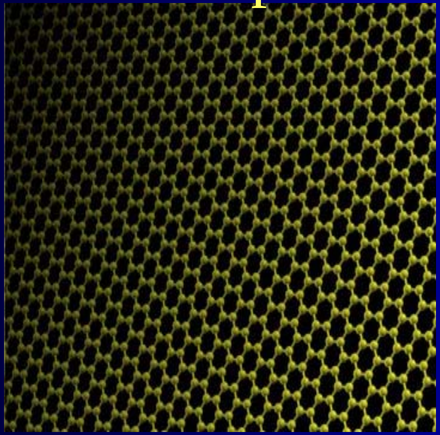
0-D Fullerenes (Buckyballs)



1-D Carbon Nanotubes



2-D Graphene



3-D Graphite

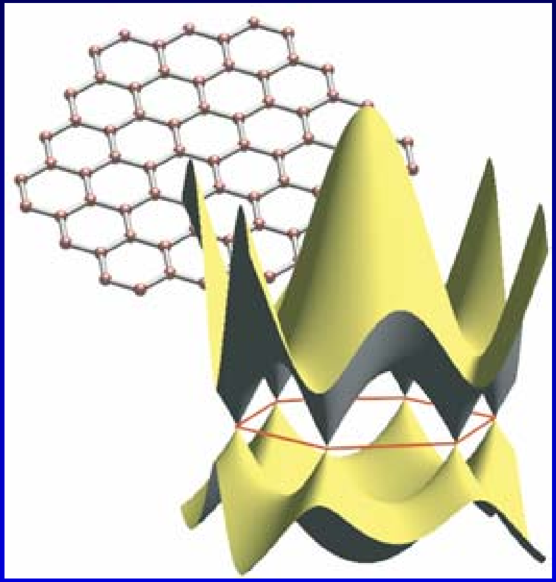
Why Study Graphene?

Graphene has many new and unusual properties that lead to the current excitement of its study.

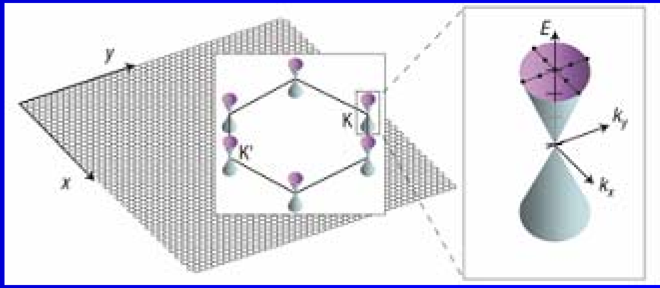
- Linear Dispersion Relation – Massless Electrons
- Electron Mobility & Minimum Conductivity
- Quantum Hall Effect
- Possibilities For New & Old Physics

Linear Dispersion Relation

- Most condensed matter electron transport is described by the Schrodinger Equation. This is not the case for Graphene.
- The energy-momentum relation is linear near the six corners in graphene's Brillouin zone.
- In this region, electrons behave like relativistic particles having zero effective mass and behave according to Dirac's Equation for spin ½ particles.
- The Fermi velocity (v_f) is 10^6m/s.



$$E = \hbar v_f \left| \vec{k} \right|$$



Electron Mobility & Minimum Conductivity

- Electron mobility in graphene is remarkably high at room temperature.

$$3.5 \times 10^{-5}(\Omega - m) \;\; vs \;\; 10^{-8}(\Omega - m)$$

- The resistivity of graphene is less than silver, the lowest substance known at room temperature.

$$1.59 \times 10^{-8}(\Omega - m)$$

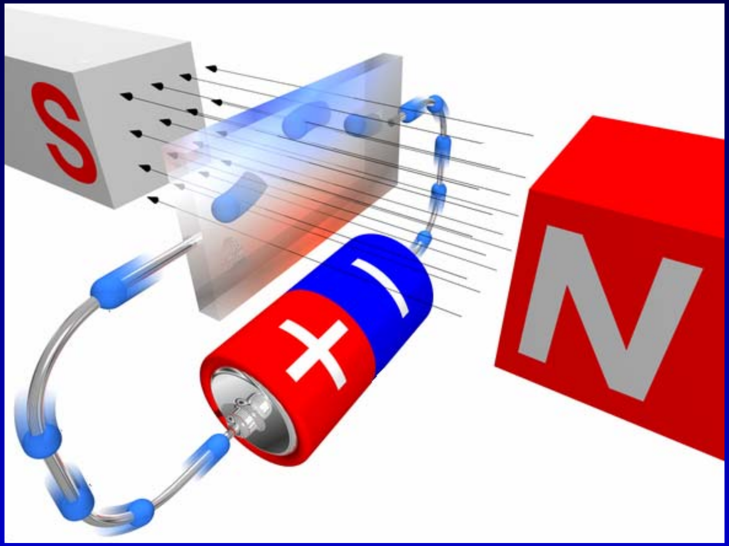
- Should be zero carrier density at Dirac points yet there exists a minimum conductivity.

$$\frac{4e^2}{h} \; ? \; \frac{4e^2}{\pi h}$$

- The origin of minimum conductivity is still unclear.

Quantum Hall Effect

- Potential difference on the opposite sides of an electrical conductor through which an electric current is flowing, created by a magnetic field applied perpendicular to the current.
- Quantum hall effect is seen in 2-D objects with quantized values of conductivity.
- Bi-layer agrees with standard effect while mono-layer has a shift of ½.
- Graphene is the only known material that sees this effect at room temperature.

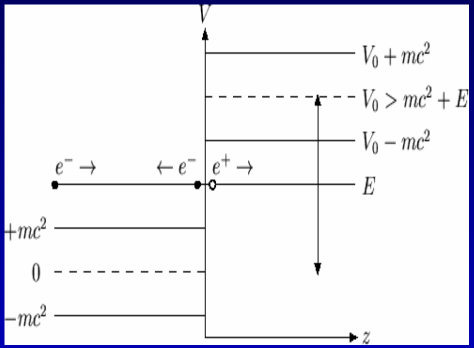


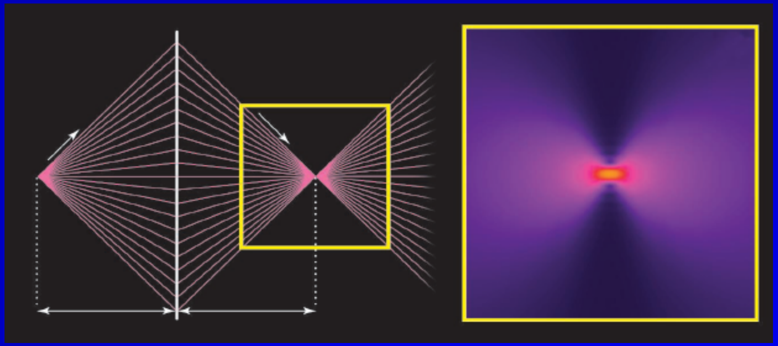
$$\sigma_{xy} = \pm \frac{4e^2}{h} N$$

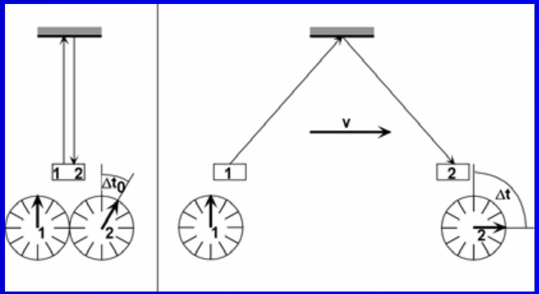
$$\sigma_{xy} = \pm \frac{4e^2}{h}\left(N + \tfrac{1}{2}\right)$$

Possibilities For New & Old Physics

- Relativistic quantum mechanics
- 2-D Dirac equations
- Klein Paradox
- Veselago Lens
- Table Top Relativity

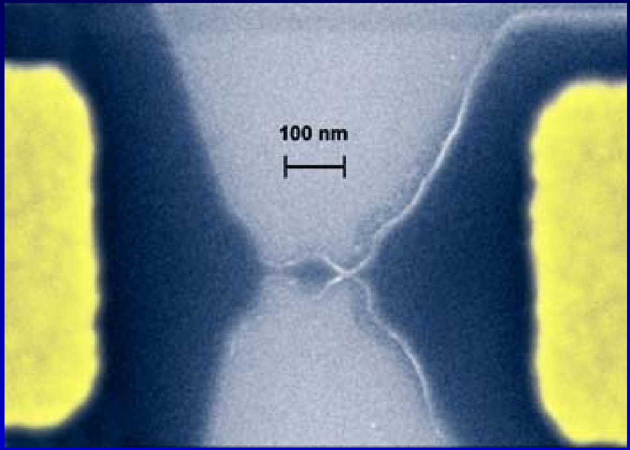


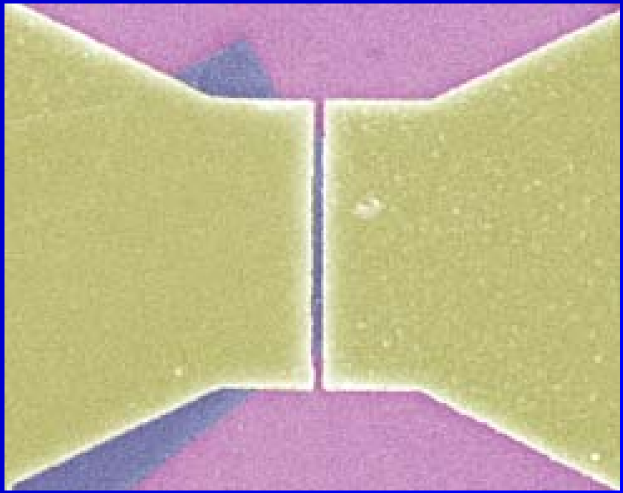




Future Applications

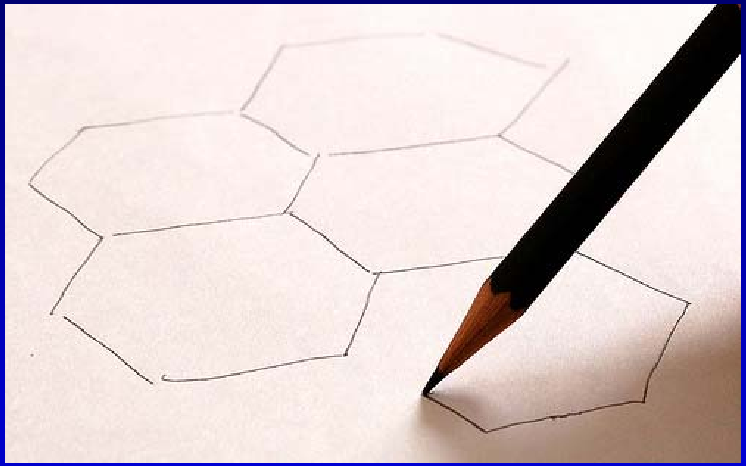
- Graphenium microprocessors – order of magnitude better than Si
- Graphene transistors – more effective the smaller they get
- Graphene powder in batteries to replace carbon nanofibers
- Optical properties allow to be used to improve plasma displays, LCDs and touch screens
- Single molecule gas detection

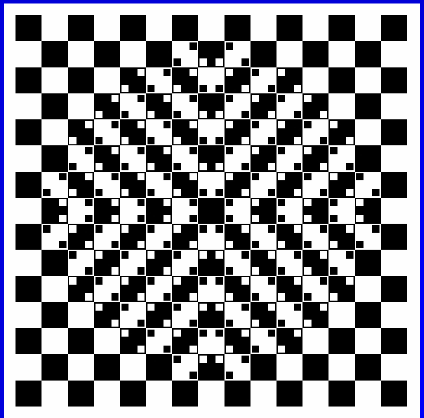




Looking For 2-Dimensions In a 3-D Universe

- Currently, graphene is the most expensive materials on earth.
- As of April, 2008 a piece of graphene the size of the cross section of a human hair cost $1,000.
- Producing graphene is easy, finding it is the real challenge.
- Visual and Atomic Force Microscopy





How is Graphene Made and Found in the Lab

One of the hardest aspects of working with graphene is being able to create and find it successfully and **consistently**.

- Preparing SiO_2 wafer
- Rubbing techniques
- Scotch tape method
- Optical microscopy
- AFM

Preparing SiO_2 Wafer

- Diamond Pen
- Acetone Sonication
- IPA Rinse
- Compressed Air
- BOE Etching
- Piranha Etching
- 280 vs. 300 nm Oxide



Rubbing Techniques

The first real challenge of depositing graphene flakes onto SiO_2 is to find a reliable technique that works consistently.

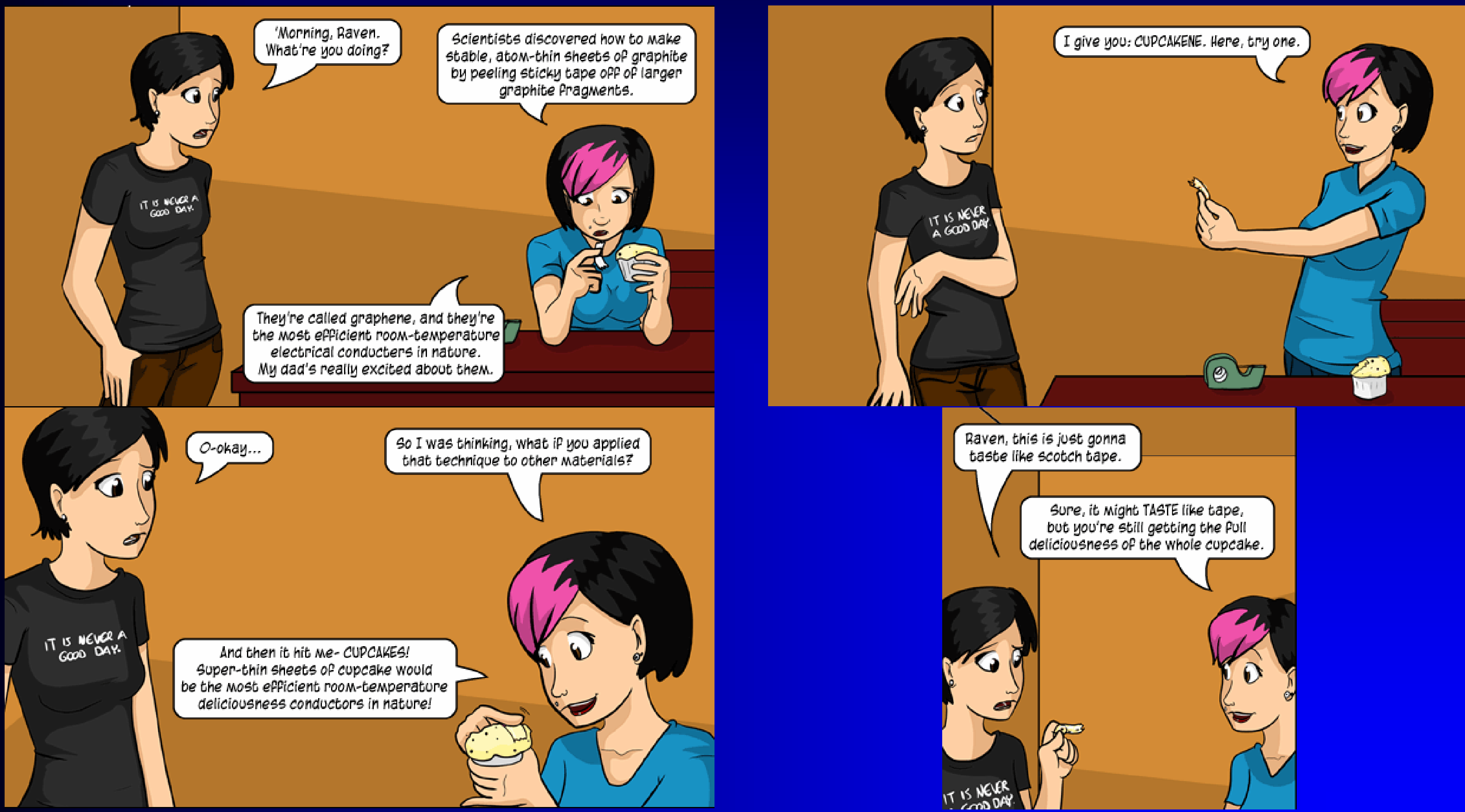
- Gentle to forceful rubbing with tweezers
- Graphite “sandwich”
- Liquid deposition – water, acetone, IPA
- Heated wafer
- Cleaving

Scotch Tape Method

- Developed by researchers at Manchester University
- Single piece of graphite cleaved multiple times quickly
- Fresh atomic layers at each graphite site
- Ability to create multiple samples with less time and material

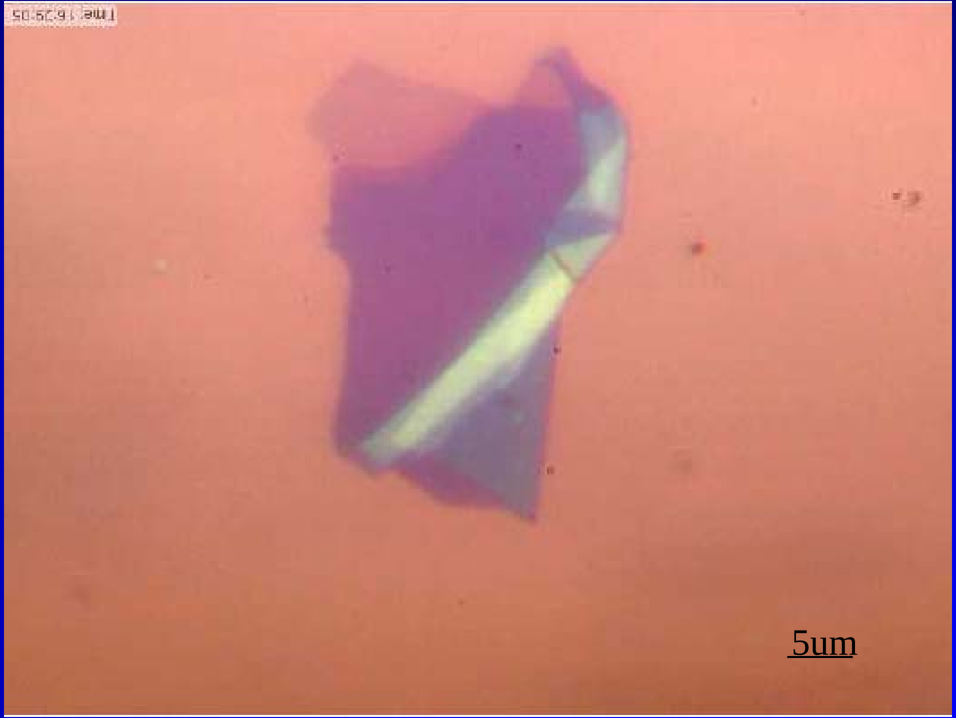



Scotch Tape Method



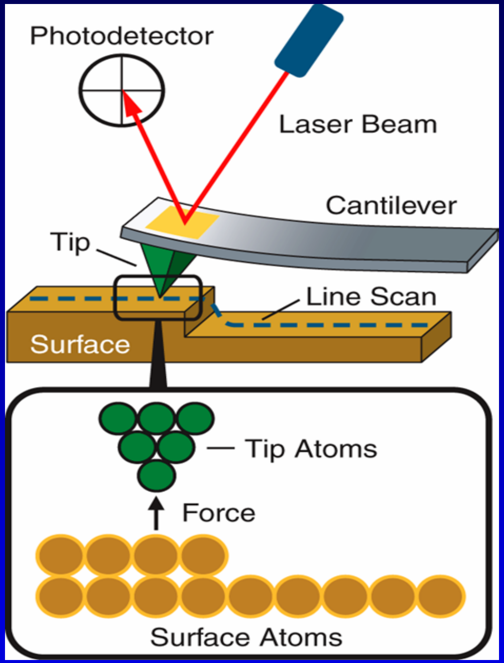
Optical Microscopy

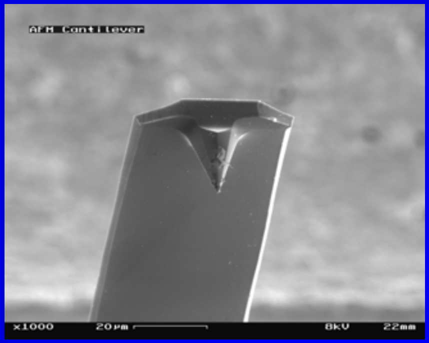
- Graphene can be viewed optically with minimal magnification
- Approximate thickness is determined by color (black, white, blue, purple, pink)
- Slow process of scanning, pictures and documenting
- 4x, 10x, 20x, 40x, 100x magnification



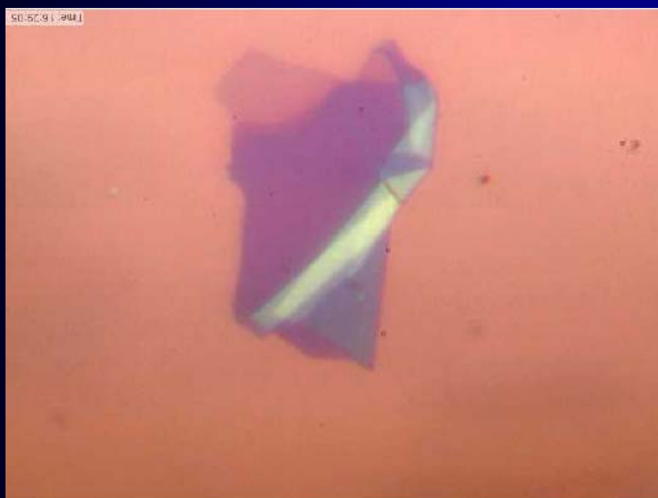
Atomic Force Microscopy

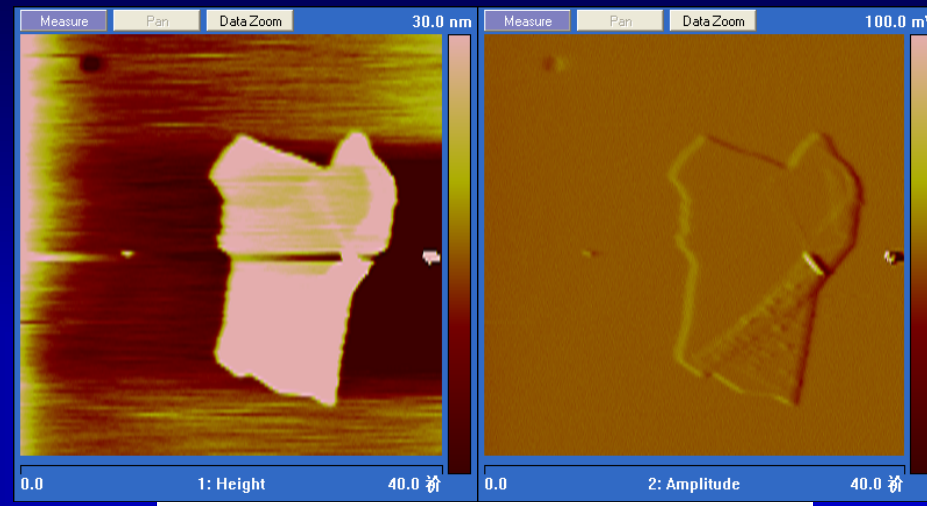
- Measures height to give a topological picture
- Derivative gives a 3-D picture of surface
- Cantilever oscillates at or near resonant frequency
- Repelled by van der Waals force
- Reflected laser off back of cantilever records data

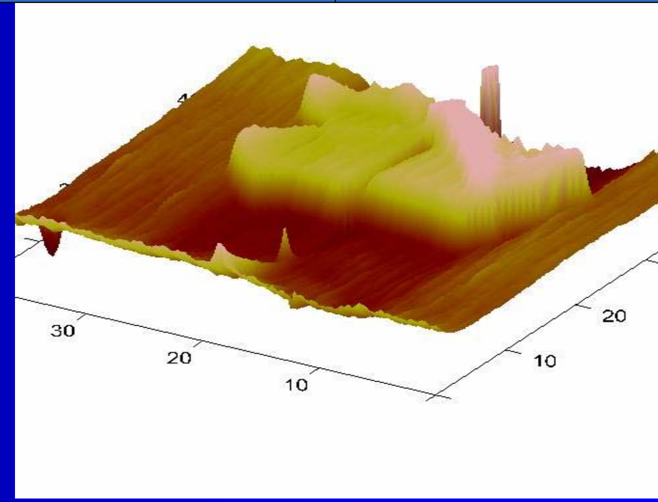




Atomic Force Microscopy

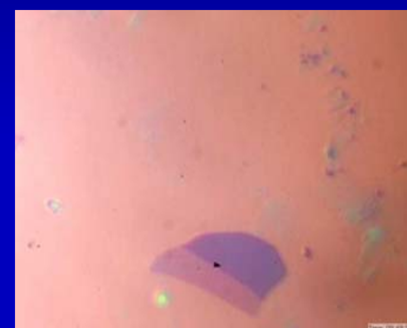


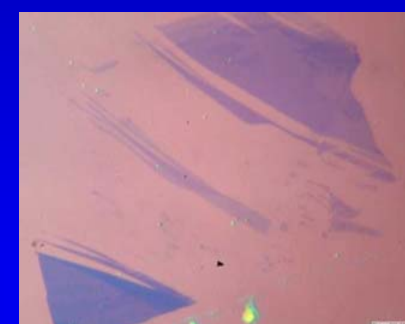




Sample 080701(1)csf

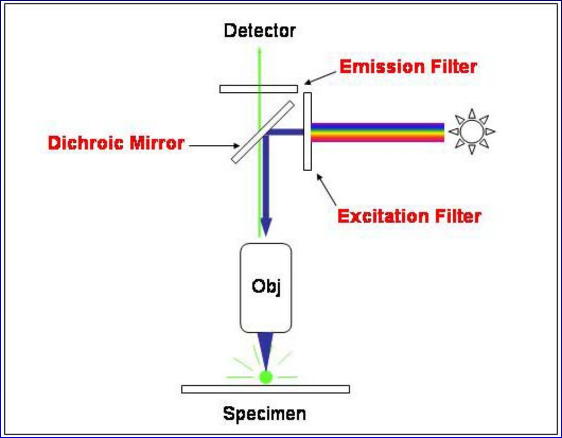
- Multiple POI's
- Varied thickness
- Possible single layer

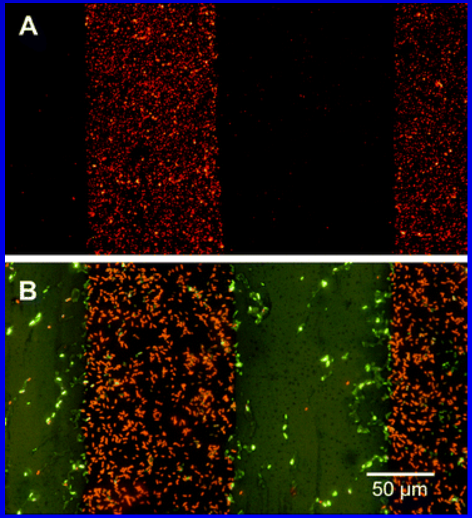




Colloidal Gold and Fluorescence Microscopy

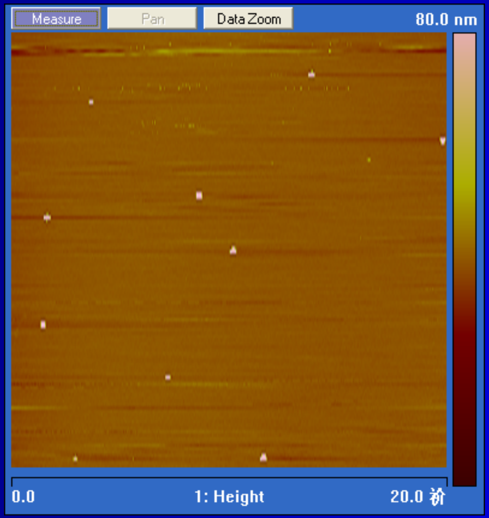
- Sample illuminated with specific wavelength of light
- Light is absorbed by gold and emits a longer wavelength
- Colloidal gold is sensitive to dielectric materials
- Should be a large difference in wavelength between single and bi-layer graphene

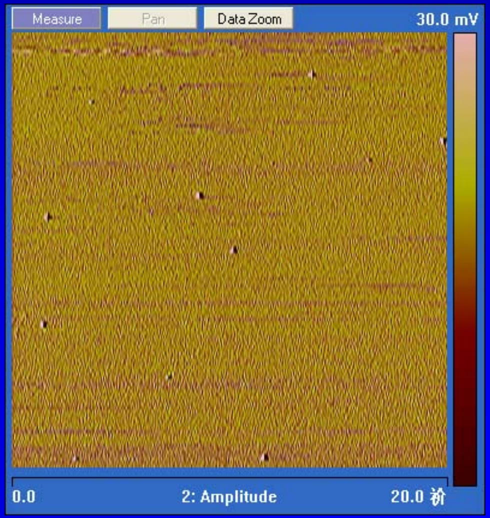




Experimenting With Gold

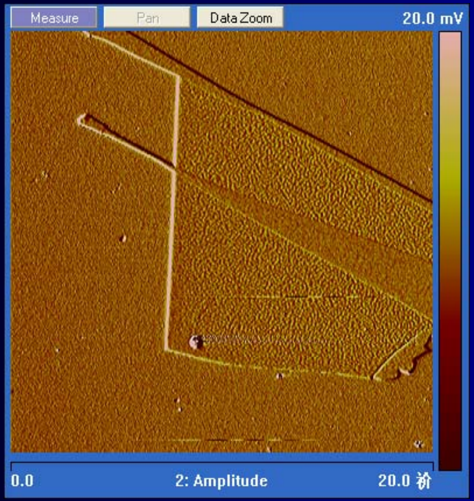
- Spun onto substrate
- Viewed with AFM
- Goal: Deposit gold on or around graphene

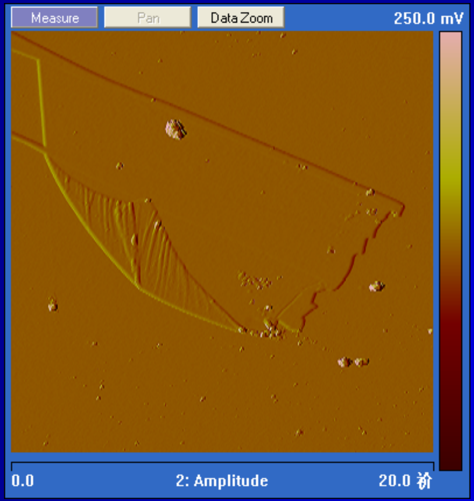


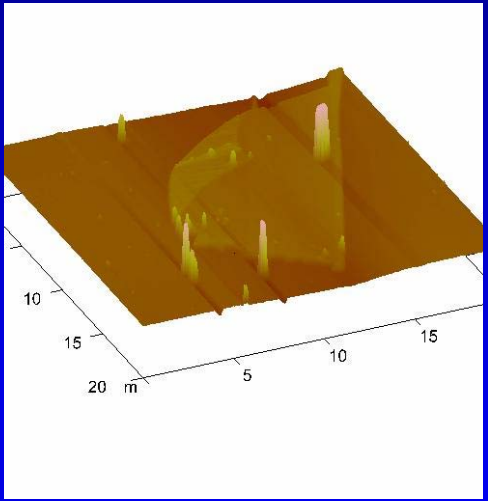


Setback → Discovery

Spinning gold colloid affects thinner pieces of graphene causing it to fold and lose its integrity.



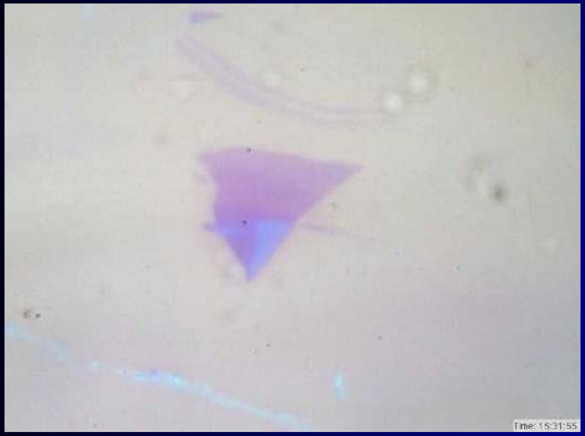


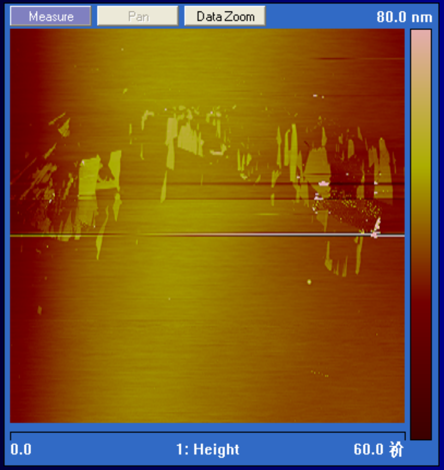


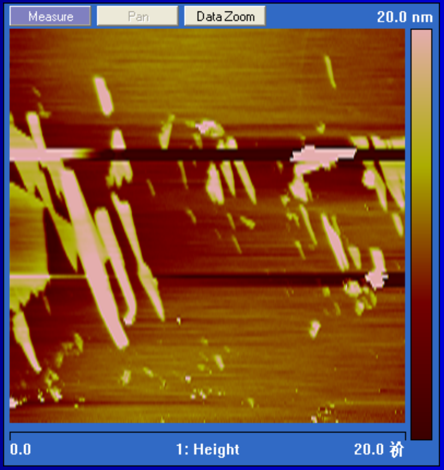
What if gold is spun first and then graphene is deposited?

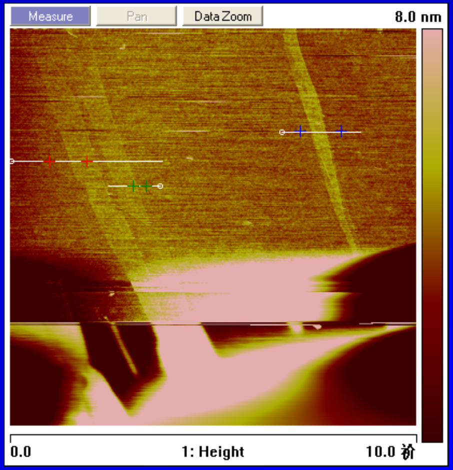
Single Layer Graphene

Initial results showed multiple POI's with confirmed single layer graphene. Gold colloid was on and around all POI's.





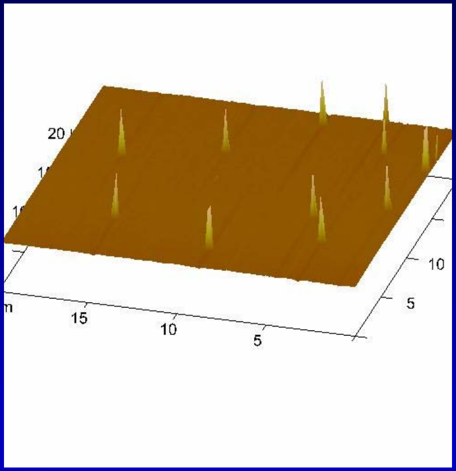


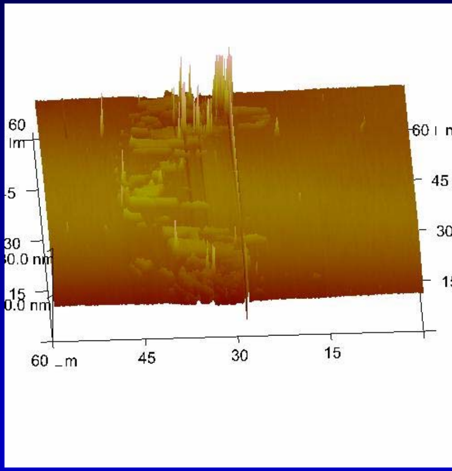


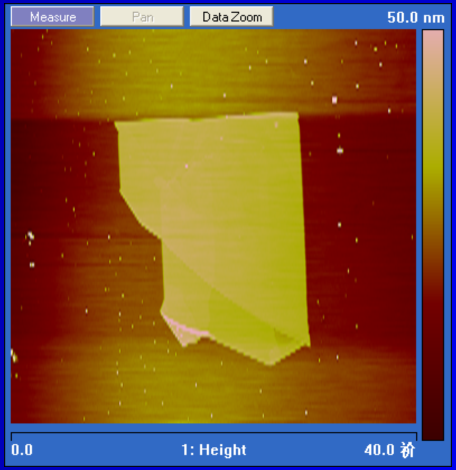
What caused this?

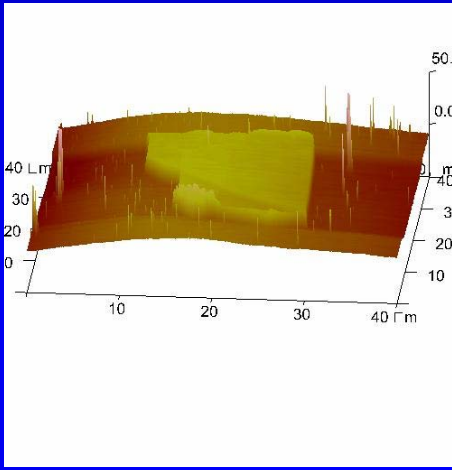
Friction & Anchors

- Gold on the substrate could act as a source of friction
- Graphite moves gold around causes them to clump
- Large enough pieces finally grab onto the substrate and anchor down large layers of graphite

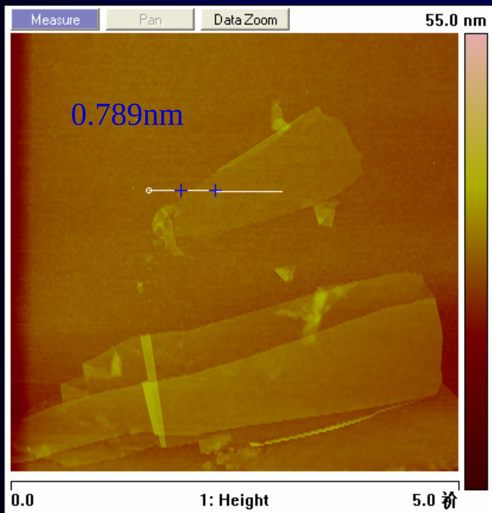


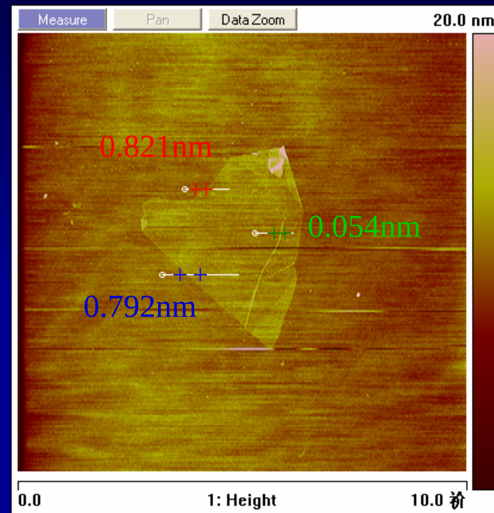






Repeatable


Measure
Pan
Data Zoom
55.0 nm
0.789nm
0.0
1: Height
5.0 祄


Measure
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0.821nm
0.054nm
0.792nm
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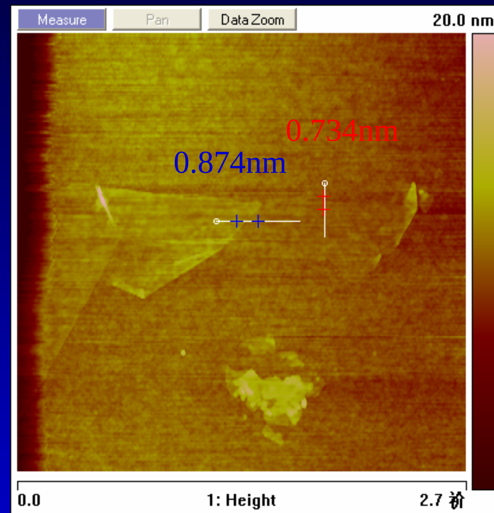
1: Height
10.0 祄


Measure
Pan
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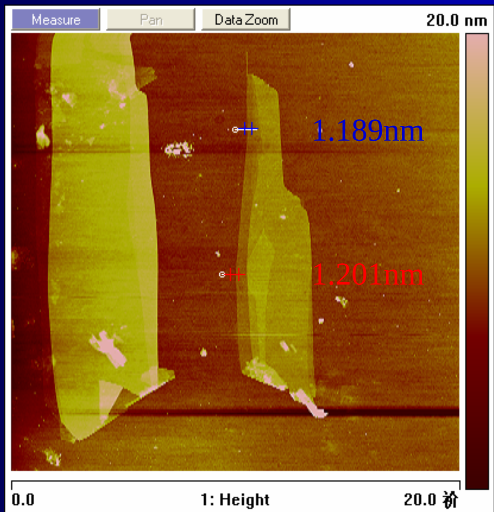
20.0 nm
0.734nm
0.874nm
0.0
1: Height
2.7 祄


Measure
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Data Zoom
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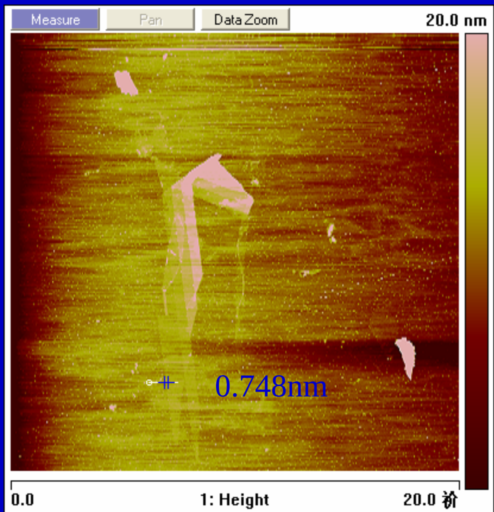
1.189nm
1.201nm
0.0
1: Height
20.0 祄


Measure
Pan
Data Zoom
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0.748nm
0.0
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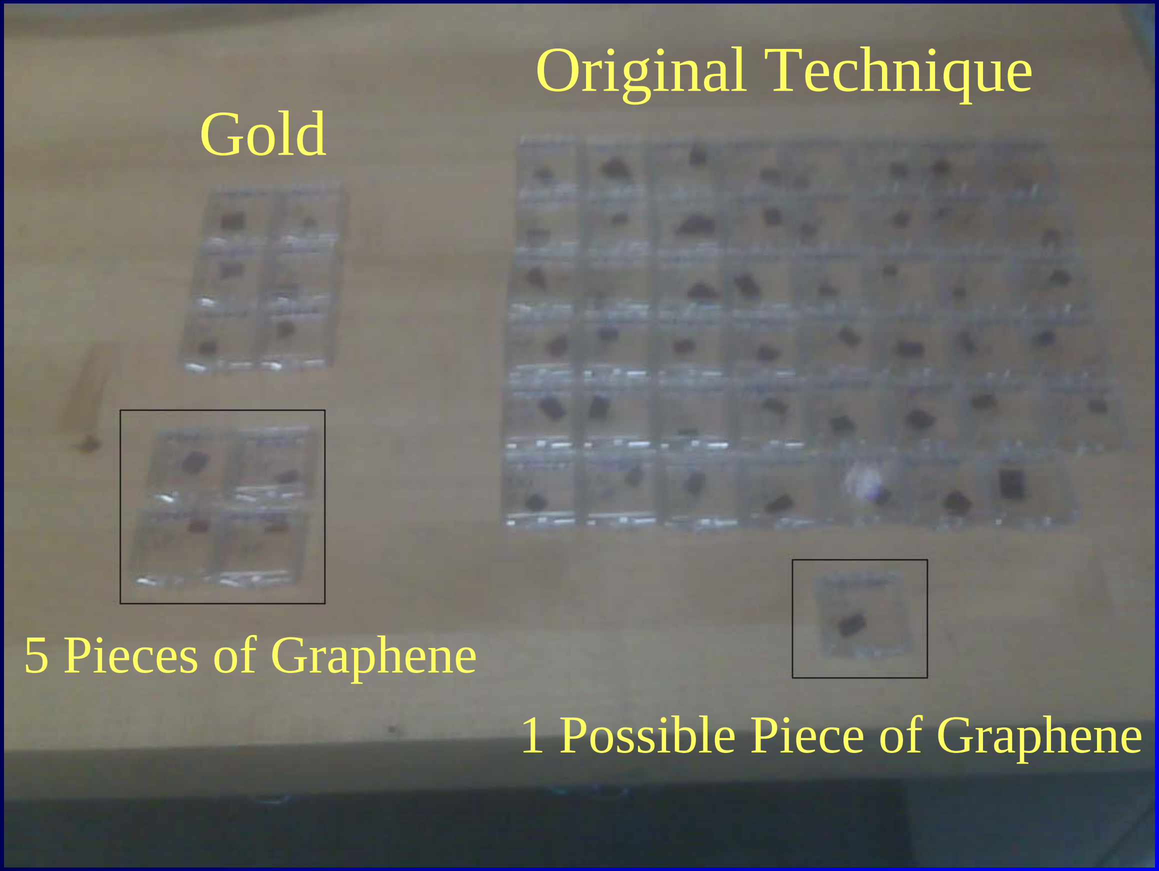
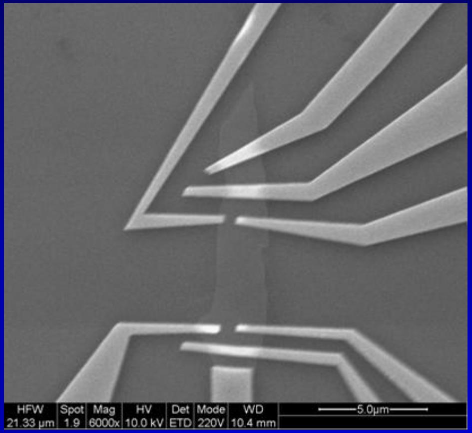
20.0 祄

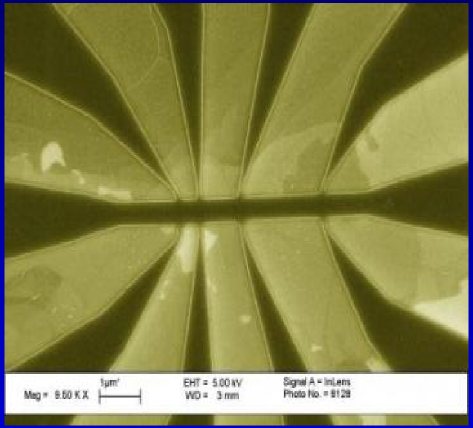
Improvement On Original Technique

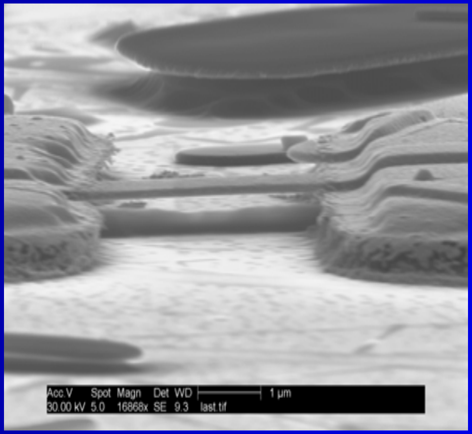


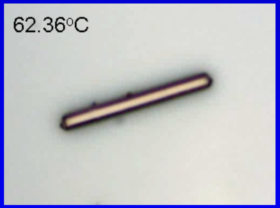
Future Research

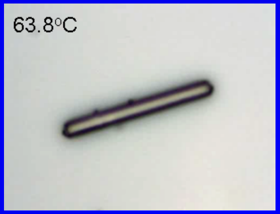
- Continued production of graphene
- Fluorescence microscopy
- Devices
- Growing VO_2 on graphene
- Using gold colloid as VO_2 seeds











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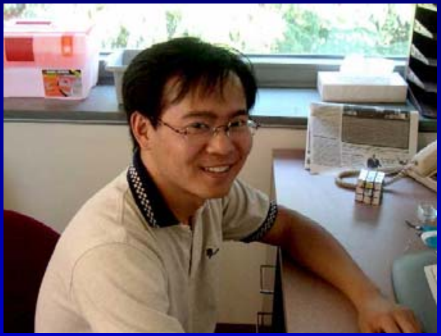
- Jacob Beedle
- Peter Morse
- Geeta Yadav (Not Pictured)


Questions ?