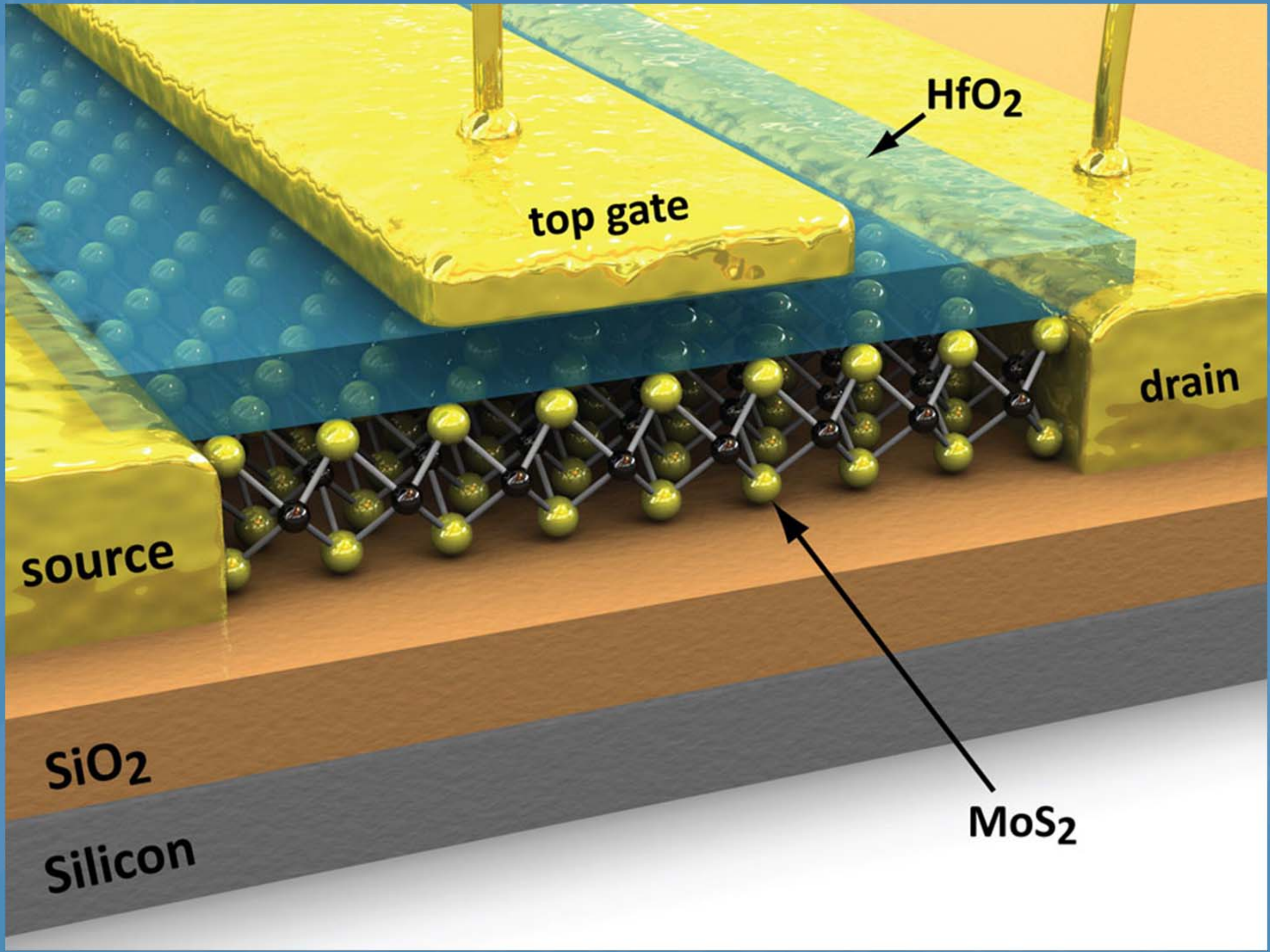
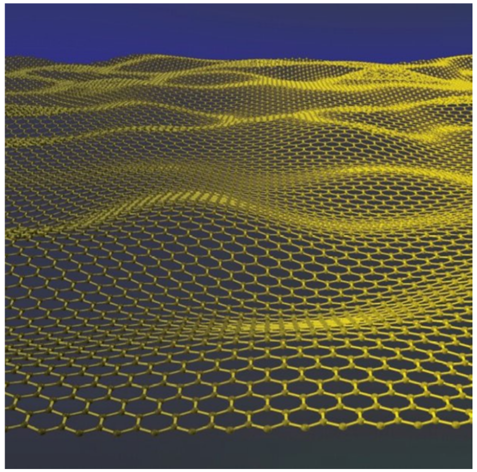
Beyond Graphene:

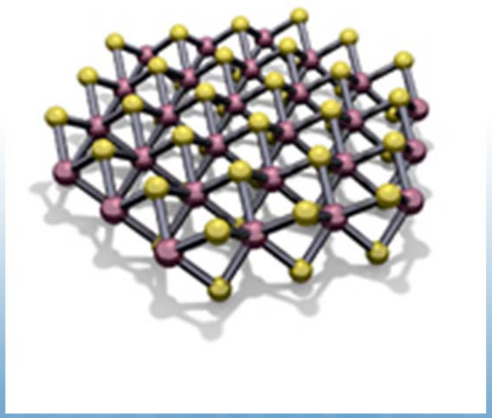


University of Massachusetts UMASS Lowell

Outline



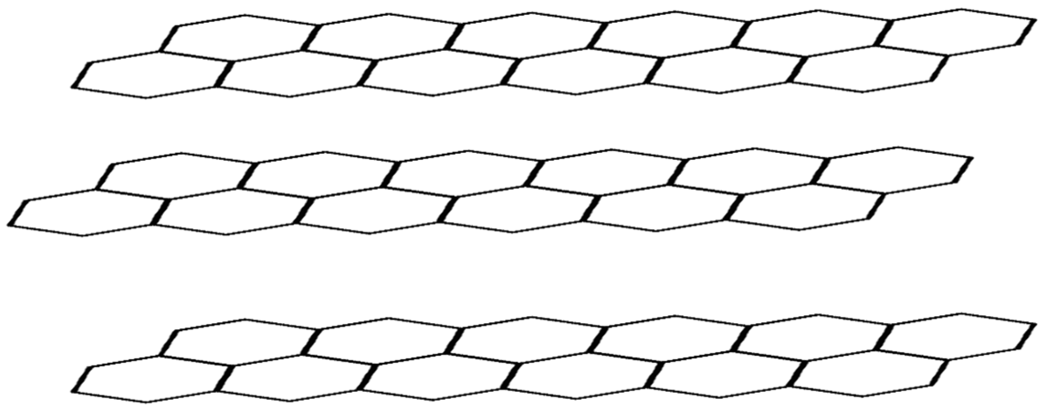
- In the beginning, there was graphene
  - The argument for 2-D
    - Beyond graphene: other 2-D materials
      - Graphitic carbon-nitride



In 2004, Andre Geim and Konstantin Novoselov “discovered graphene”

In 2010 they were awarded the Nobel prize in physics for the discovery

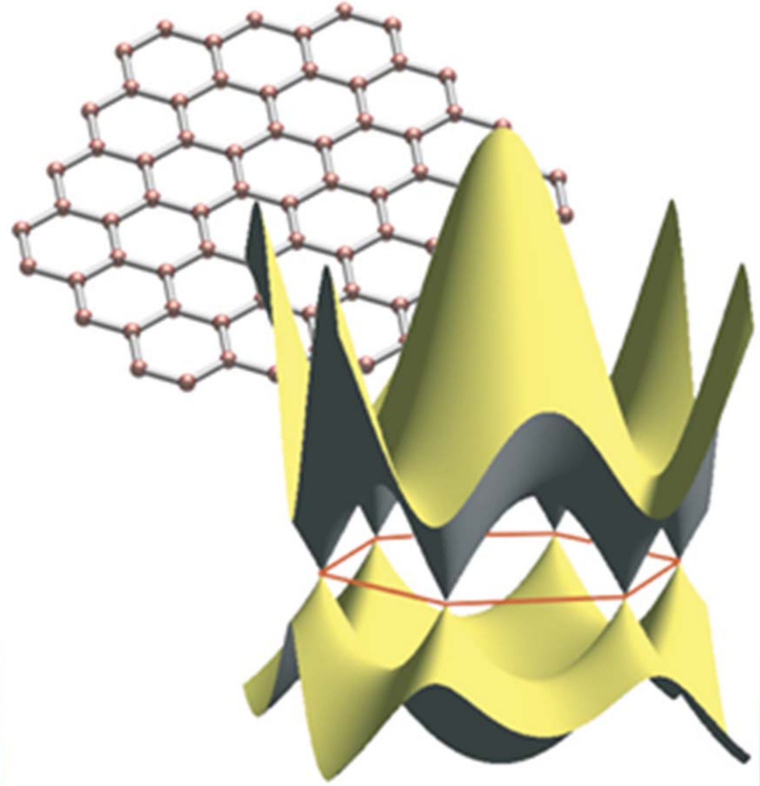
The structure of graphene can be visualized as one sheet peeled from graphite



Graphene has a number of superlatives associated with it:

- **Strongest material**
- **Most conductive material at room temp**
- **Extremely high mobility**
  - 40,000 cm^2/Vs on SiO_2
  - 200,000 suspended
- **High thermal conductivity**
- **Gas tight**
- **“relativistic” electrons**

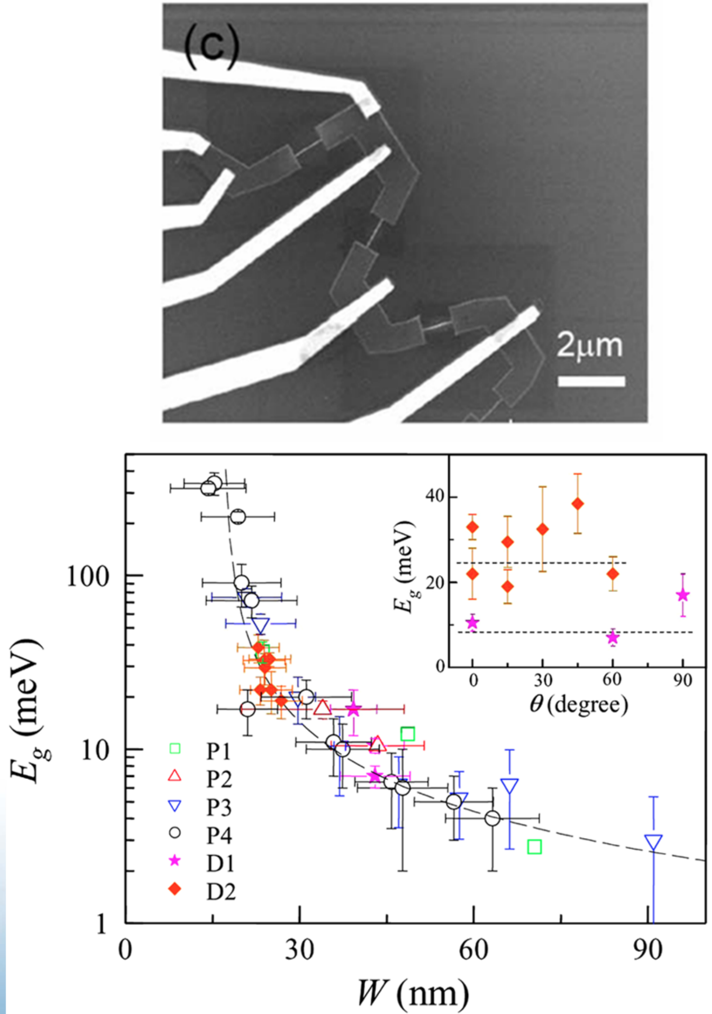
Graphene acts like a metal though it is technically a semiconductor

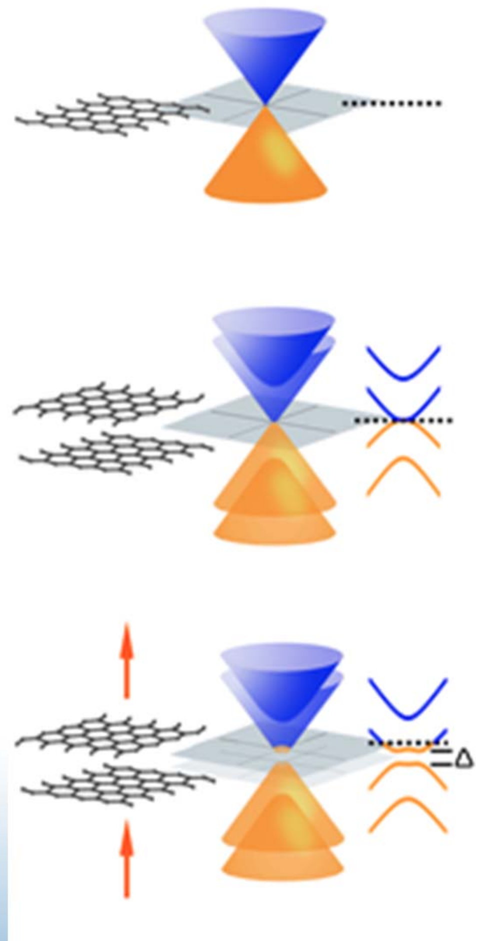


- The valence and conduction band touch at six points in the Brillouin zone
- It is a called a "zero gap" material.
- The lack of a bandgap is a problem for transistors.

Without a bandgap, control of electrons is hard.

Several techniques have been tried for opening a bandgap

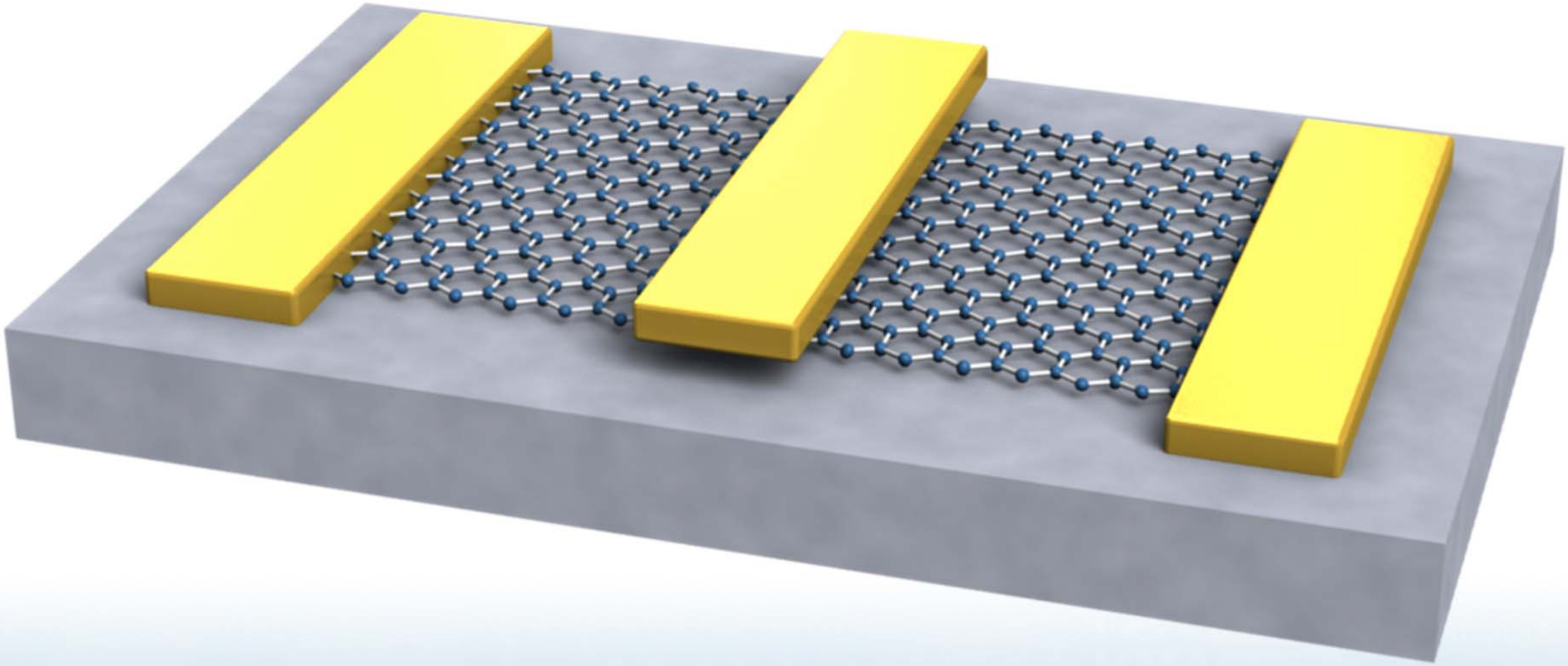




They both have issues that have led many researchers to a conclusion…

PRL 98, 206805 (2007), Nature 459, 820 (2009)

Graphene was thought to be good for transistors



The lack of a bandgap however is problematic.

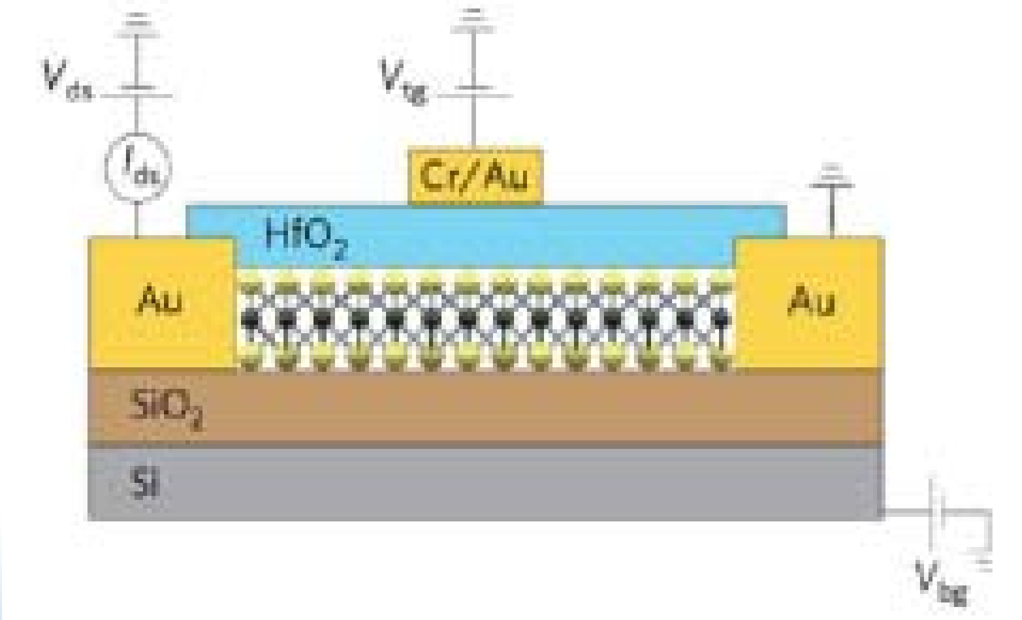
Even though graphene is looking less promising, there are compelling reasons to look at 2-D

- Very small screening length.

$$\lambda = \sqrt{\frac{\varepsilon_s d_s d_{ox}}{\varepsilon_{ox}}}$$

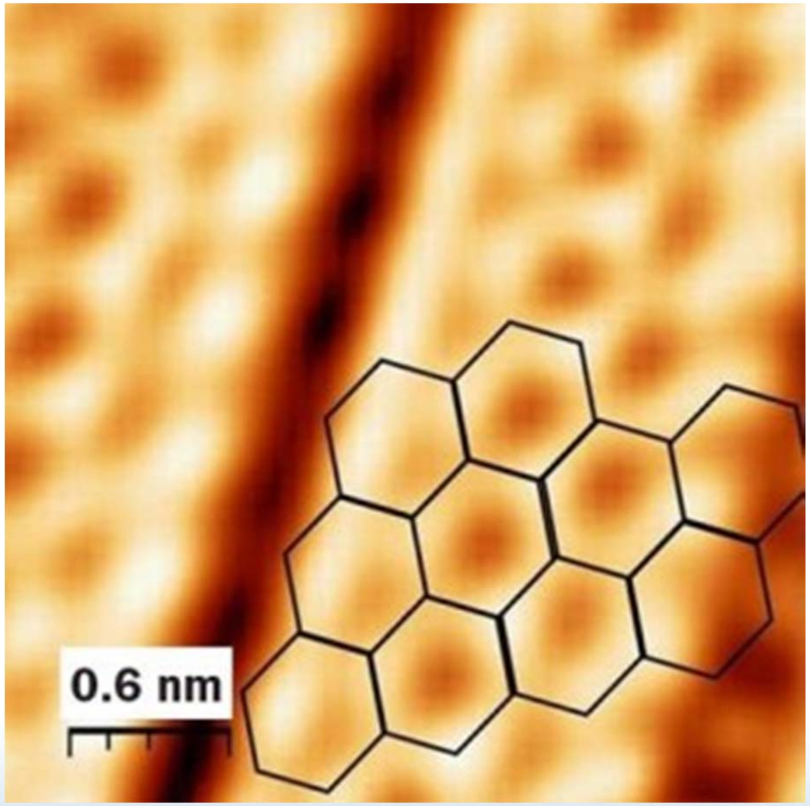
- This is needed for smaller channel lengths.
- 2-D materials can operating in the quantum capacitance limit.
- This results in less energy consumed during switching.

2-D transistors have the potential for very low power electronics.

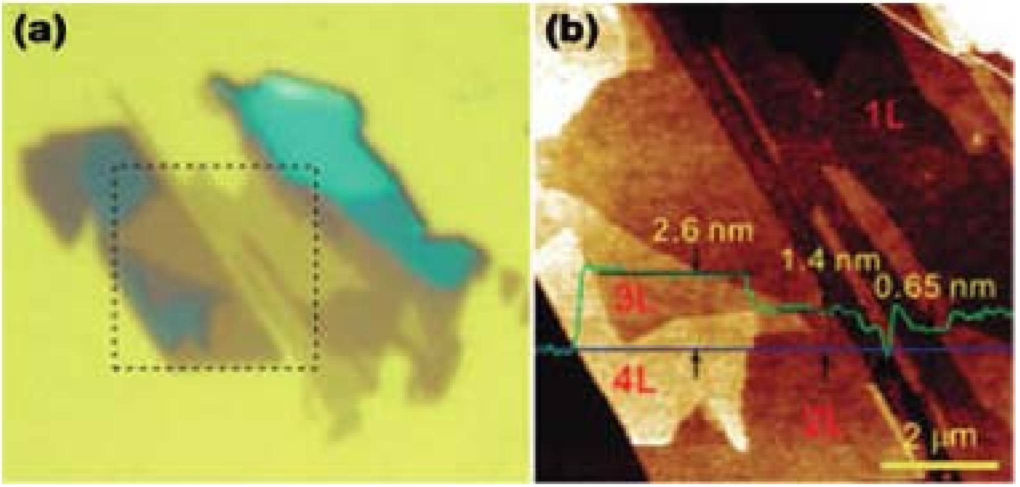


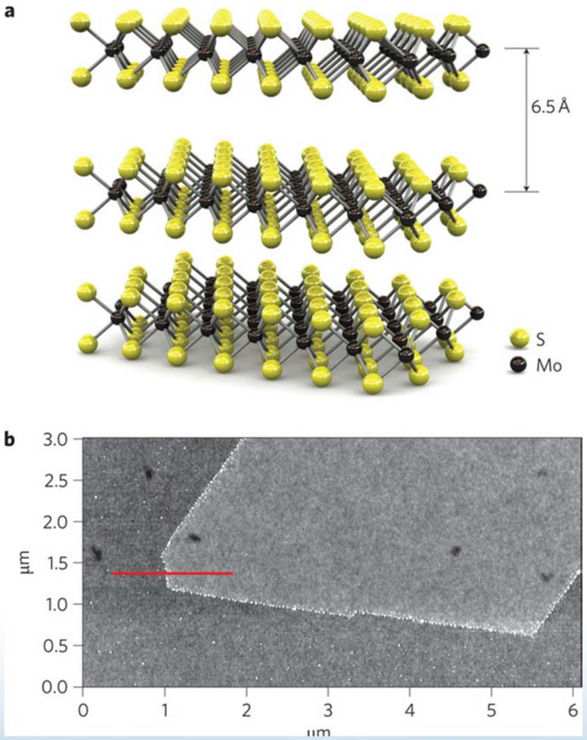
A MoS_2 transistor has shown on/off current ratios of nearly 10^{10}

Other 2-D materials: silicene

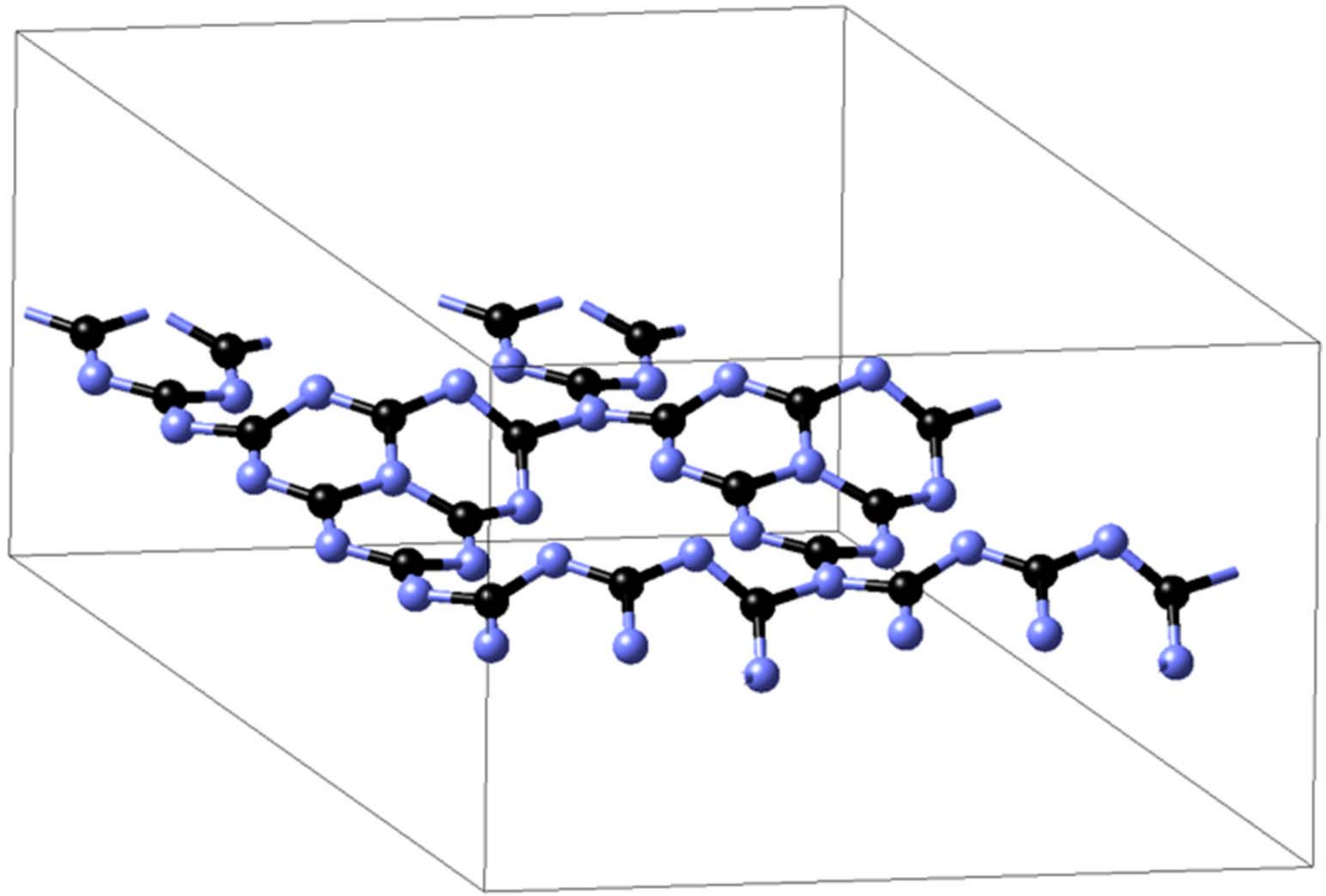


MoS_2

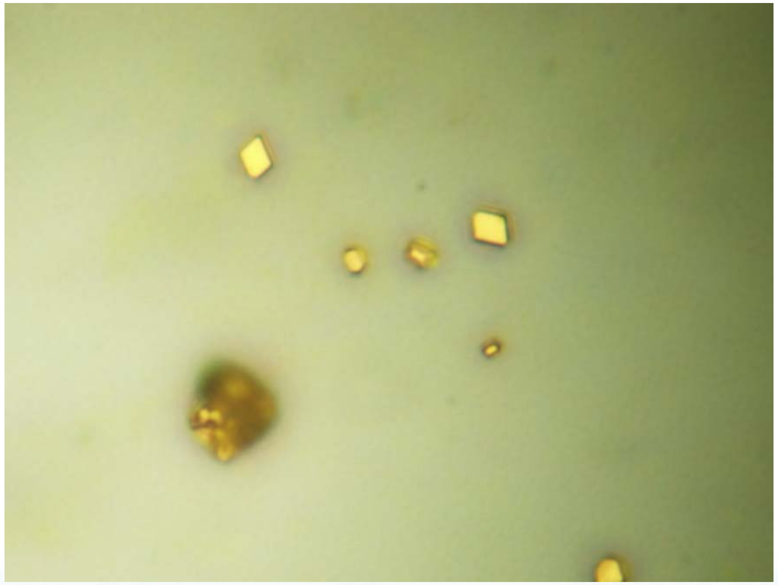

(a)
(b)
1L
2.6 nm
1.4 nm
0.65 nm
3L
4L
2 μm


a
6.5 Å
S
Mo
b
3.0
2.5
2.0
1.5
1.0
0.5
0.0
μm
0
1
2
3
4
5
6

Graphitic Carbon-Nitride



Synthesis starts with dicyandiamide…

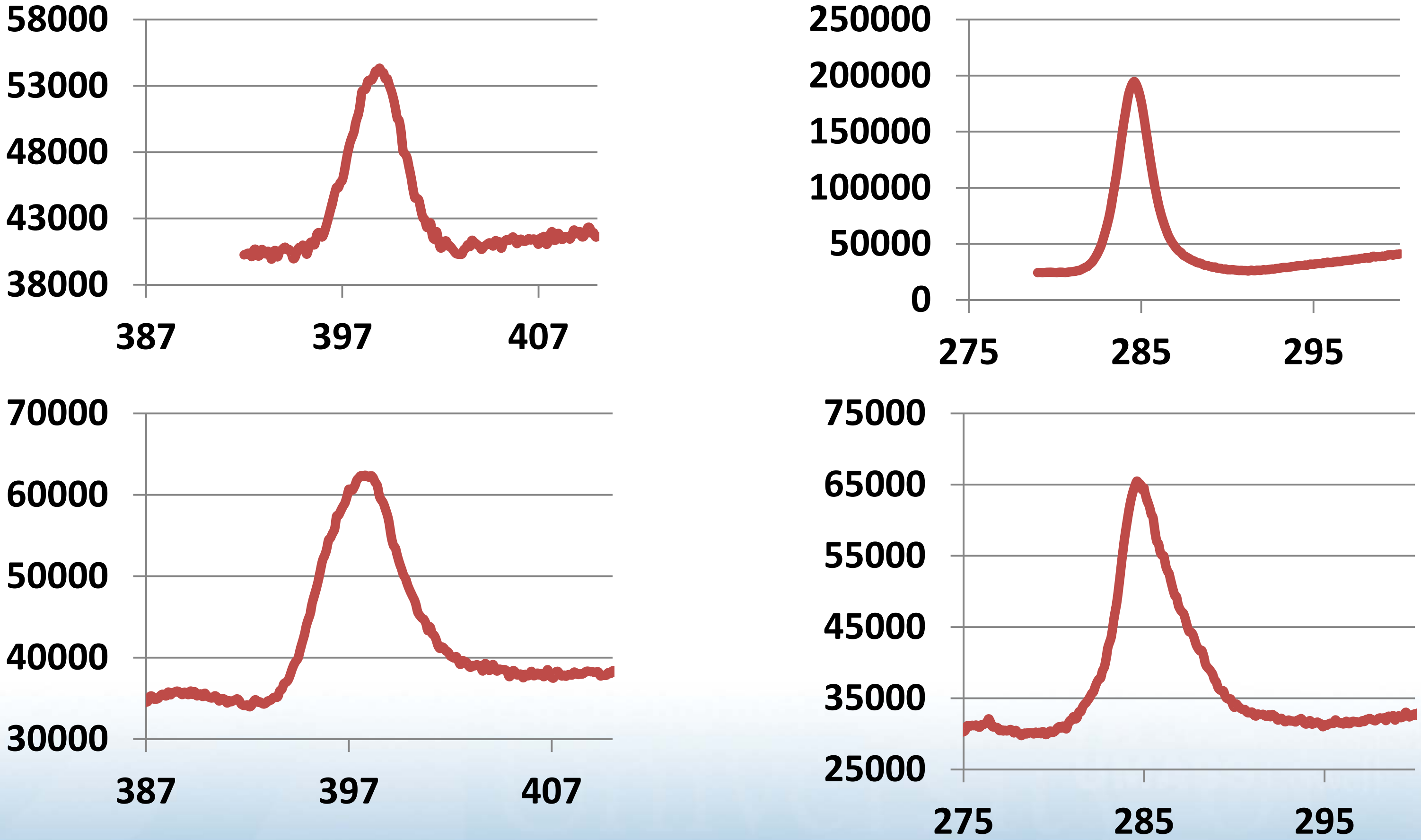


- **Dissolved in water**
- **Spin cast onto substrate**
- **Heated to 650°C for 10 hours**
- **Heating causes polymerization**
  - ↓ Dicyandiamide
  - ↓ Melamine
  - Melon

Heating beyond 700°C leads to residue free decomposition of melon

M Bojdys et. al. Chem Eur J, 14, 8177-8182

XPS was applied to the precursor and final product.

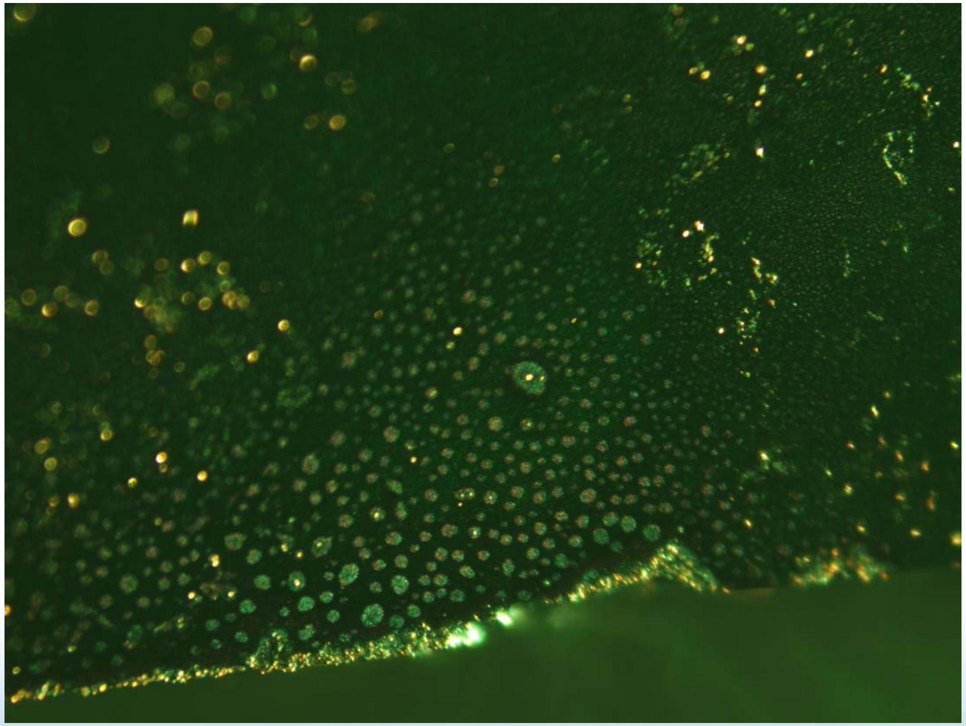


N1s

C1s

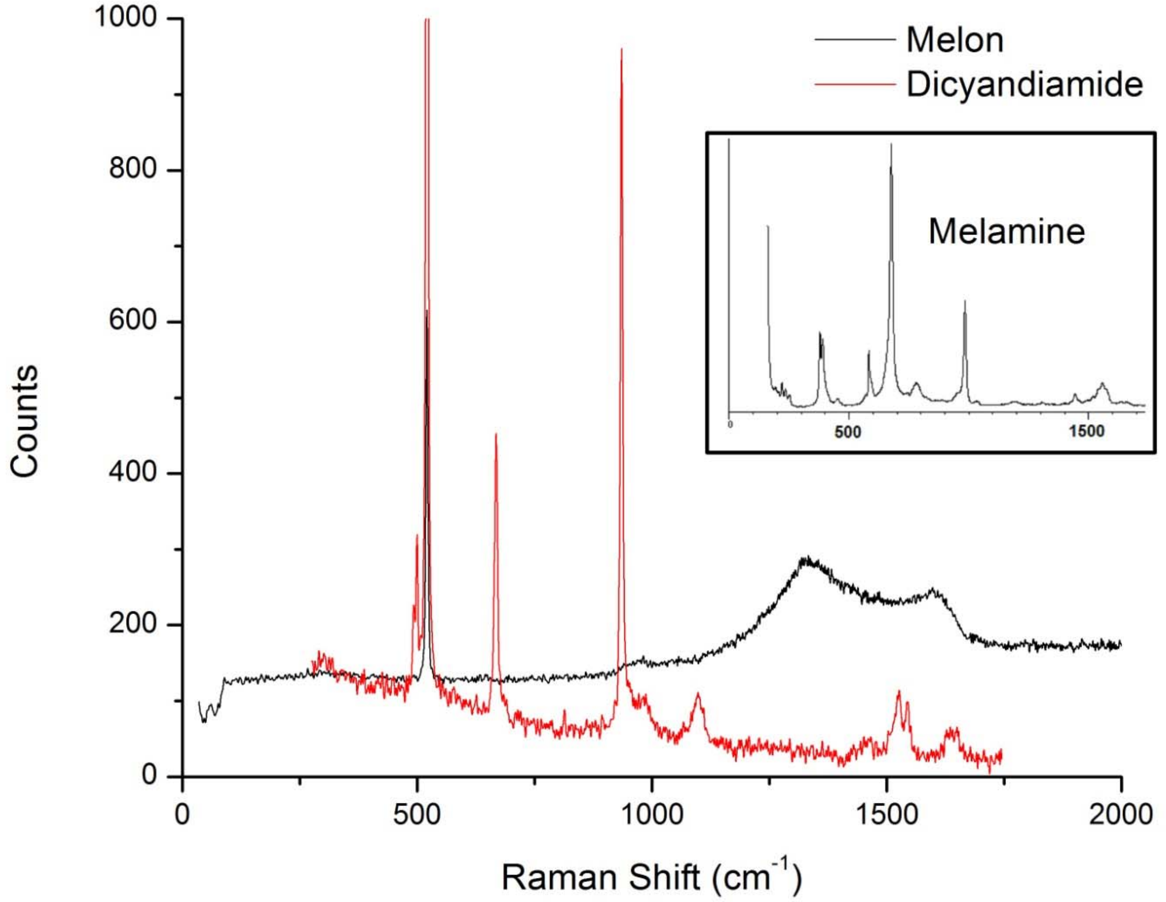
N1s and C1s peaks show change in bonding and stoichiometry

Unlike graphene, melon has an intrinsic bandgap

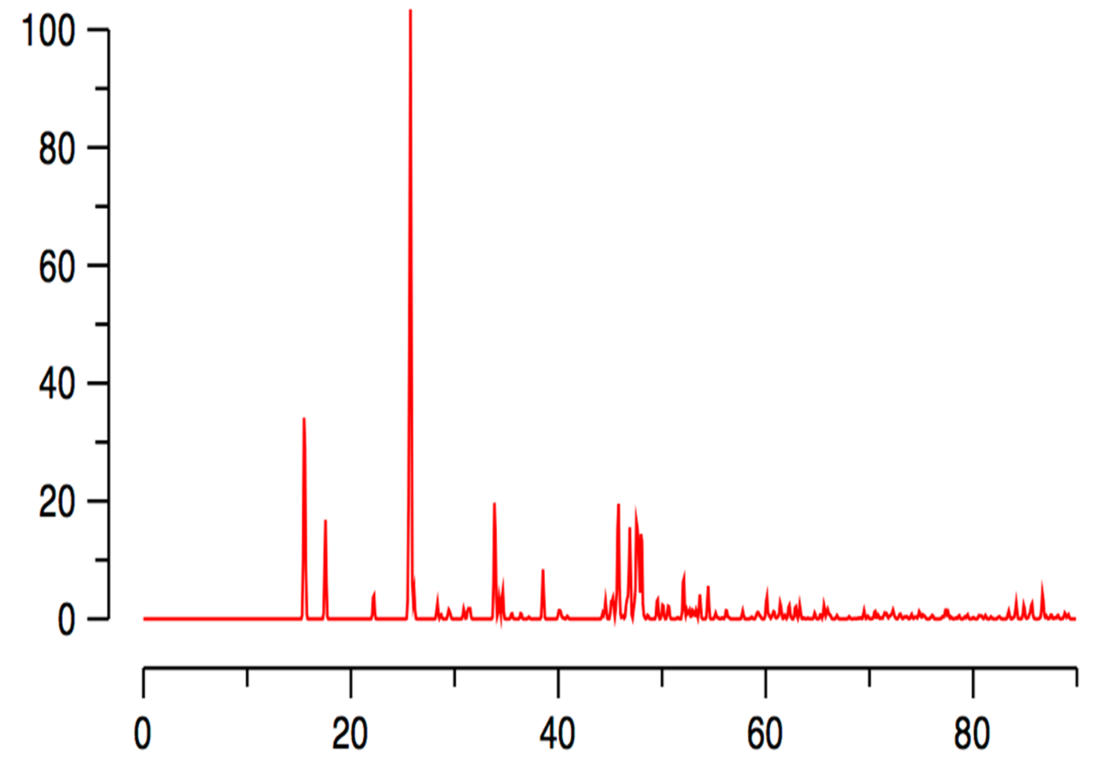


Fluoresces between blue and green when excited with UV

Raman analysis shows a material distinct from the precursor or intermediary



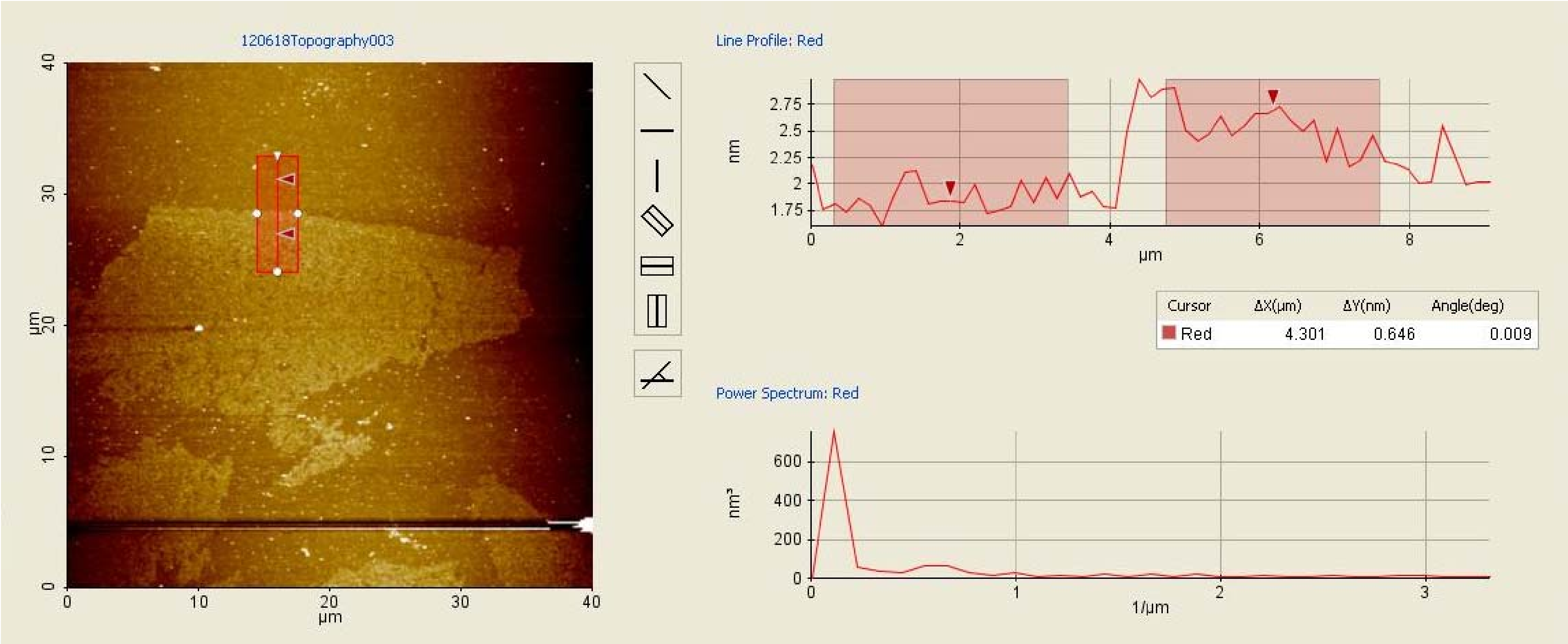
We have done XRD on the crystallites found alongside the thin layer material.



- **Several peaks show up**
- **The most important one is at 26°**
- **That one corresponds to an interlayer spacing of 3.4Å, consistent with graphite and models of the material.**

This supports the notion that this material is layered.

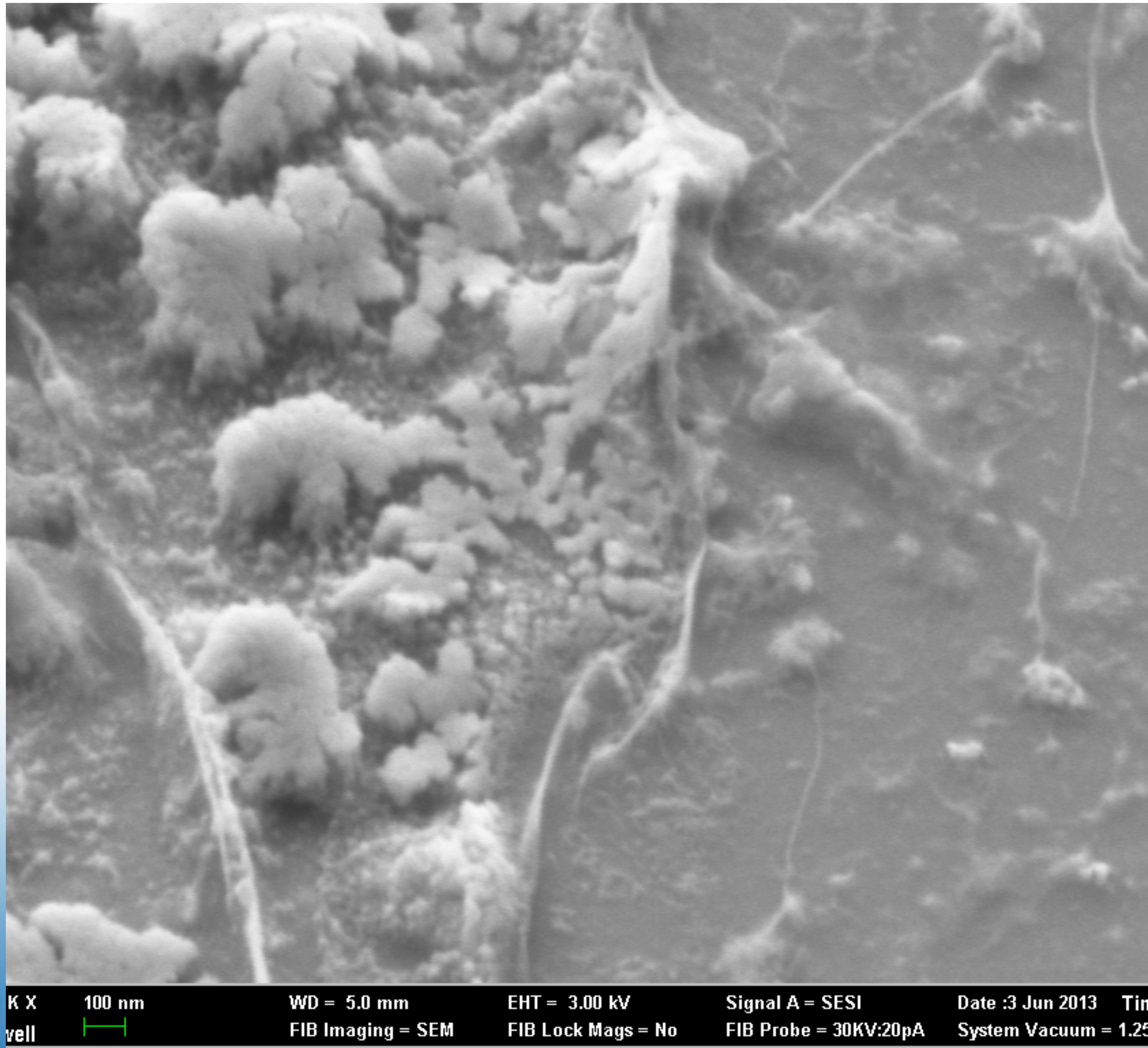
Single layer melon



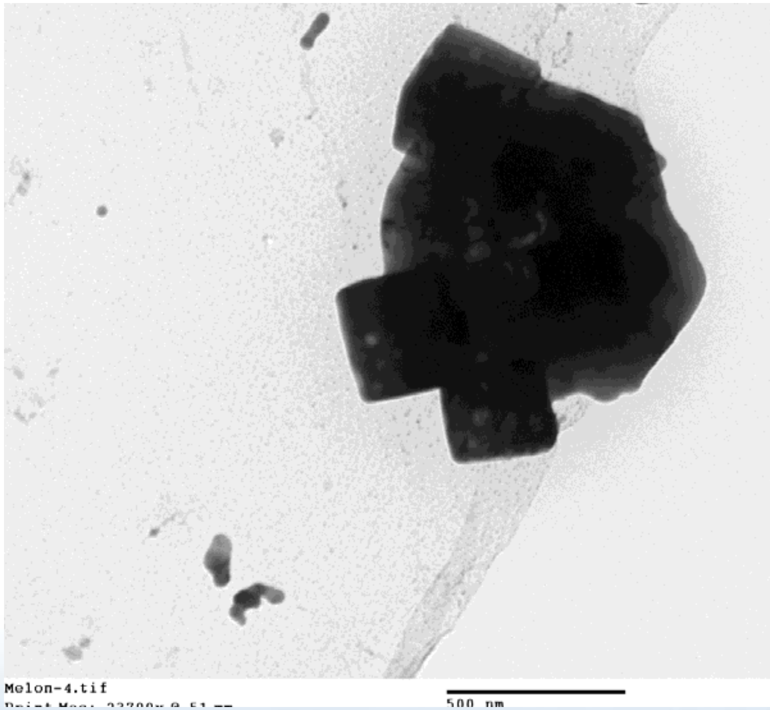
We succeeded over the summer to make single layer melon up to 40μm wide, large enough to begin optical studies.

(We are now making wafer-scale samples)

SEM imaging shows folded material after transferring to a different substrate.

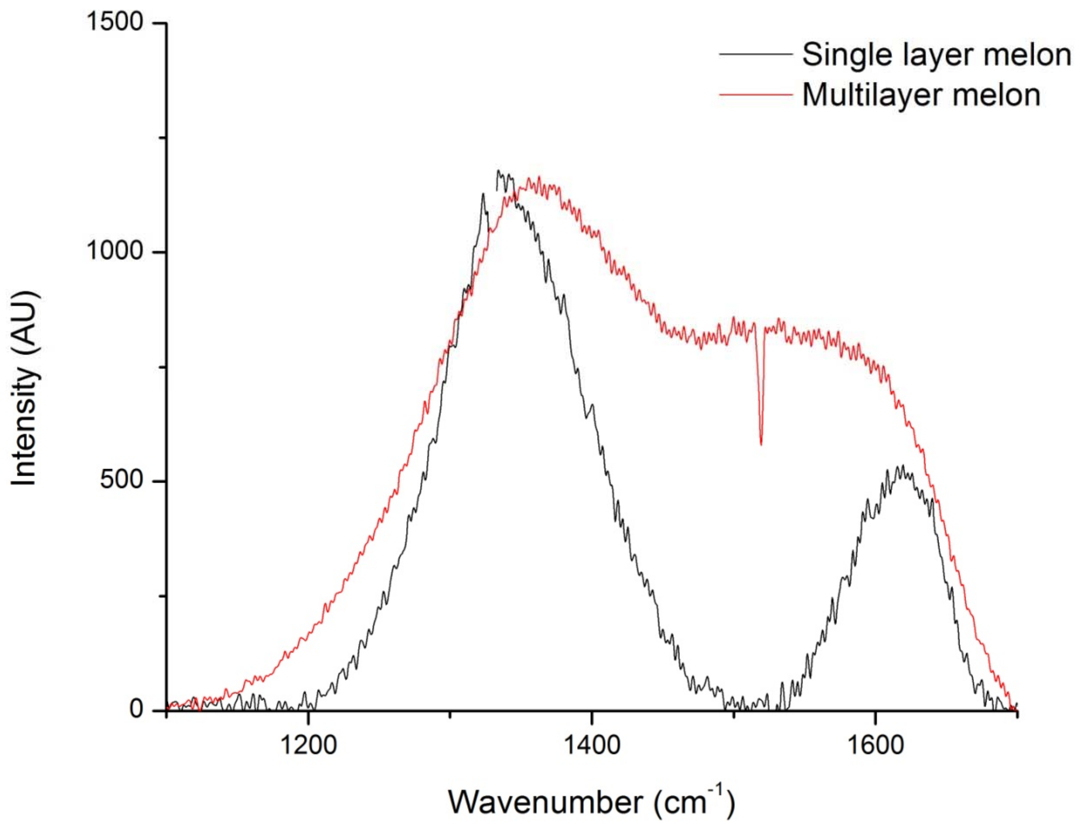


Melon has been successfully transferred to TEM grids for imaging.



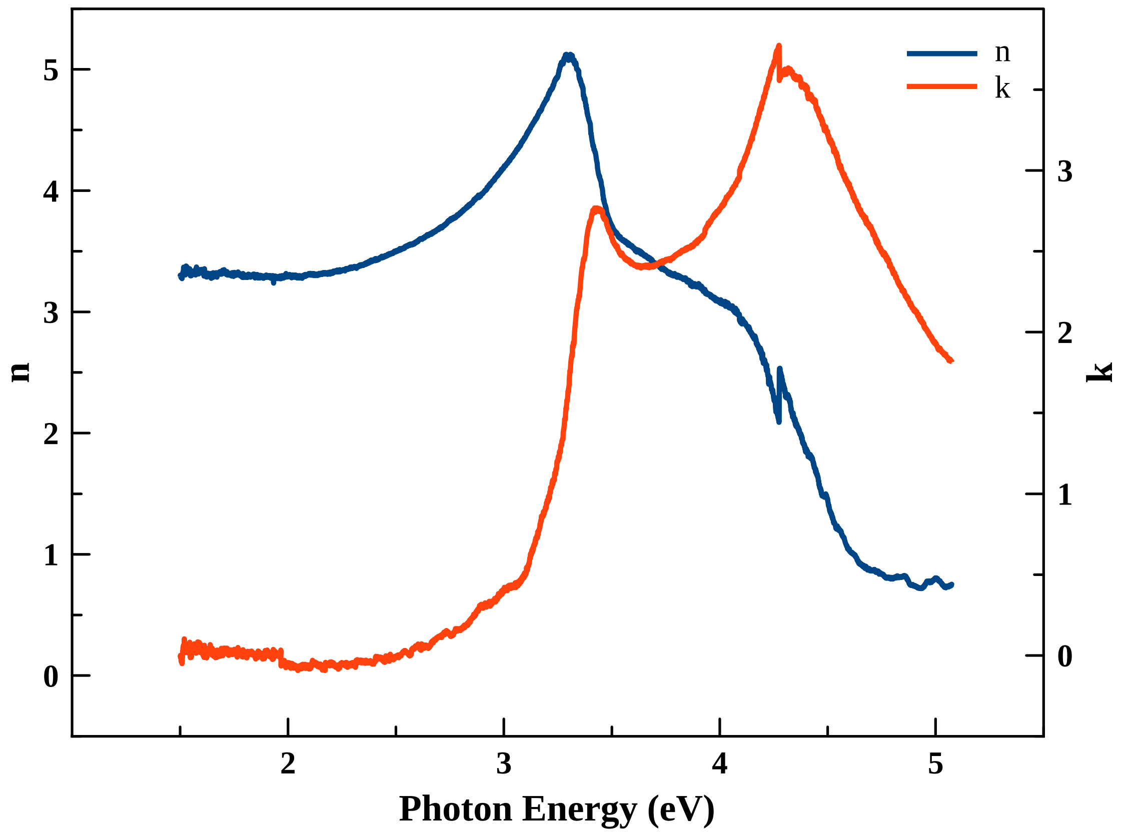
- The membrane-like nature of the material is easily seen.
- It is also highly transparent, supporting the 2D assertation.
- High thermal resistance and very strong.

Raman spectra of single layer melon is distinct from layered melon.



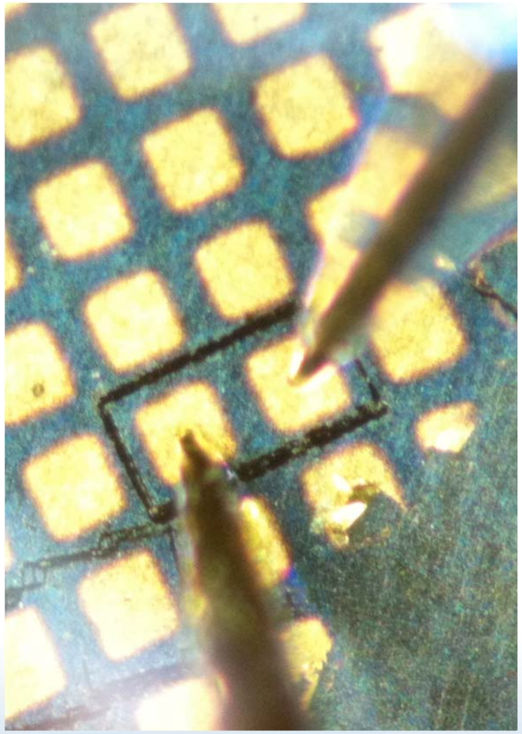
We are running simulations to determine the nature of this difference. So far they successfully predict the single layer peaks

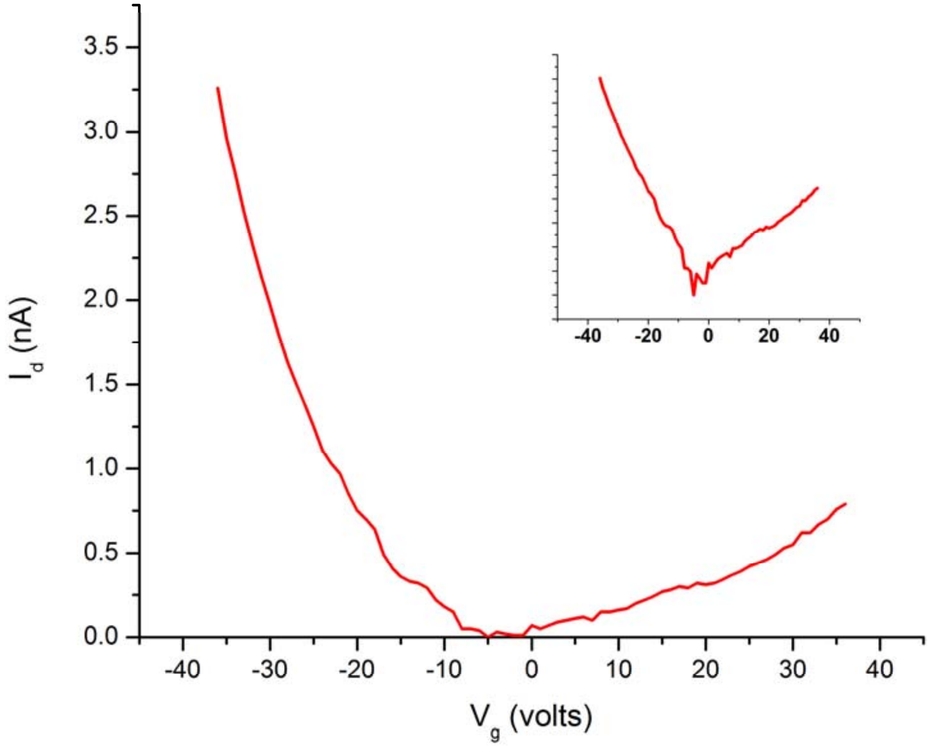
The index of refraction and extinction coefficient were found via ellipsometry



The absorption indicates this material has a direct gap of between 2.6 and 2.8eV

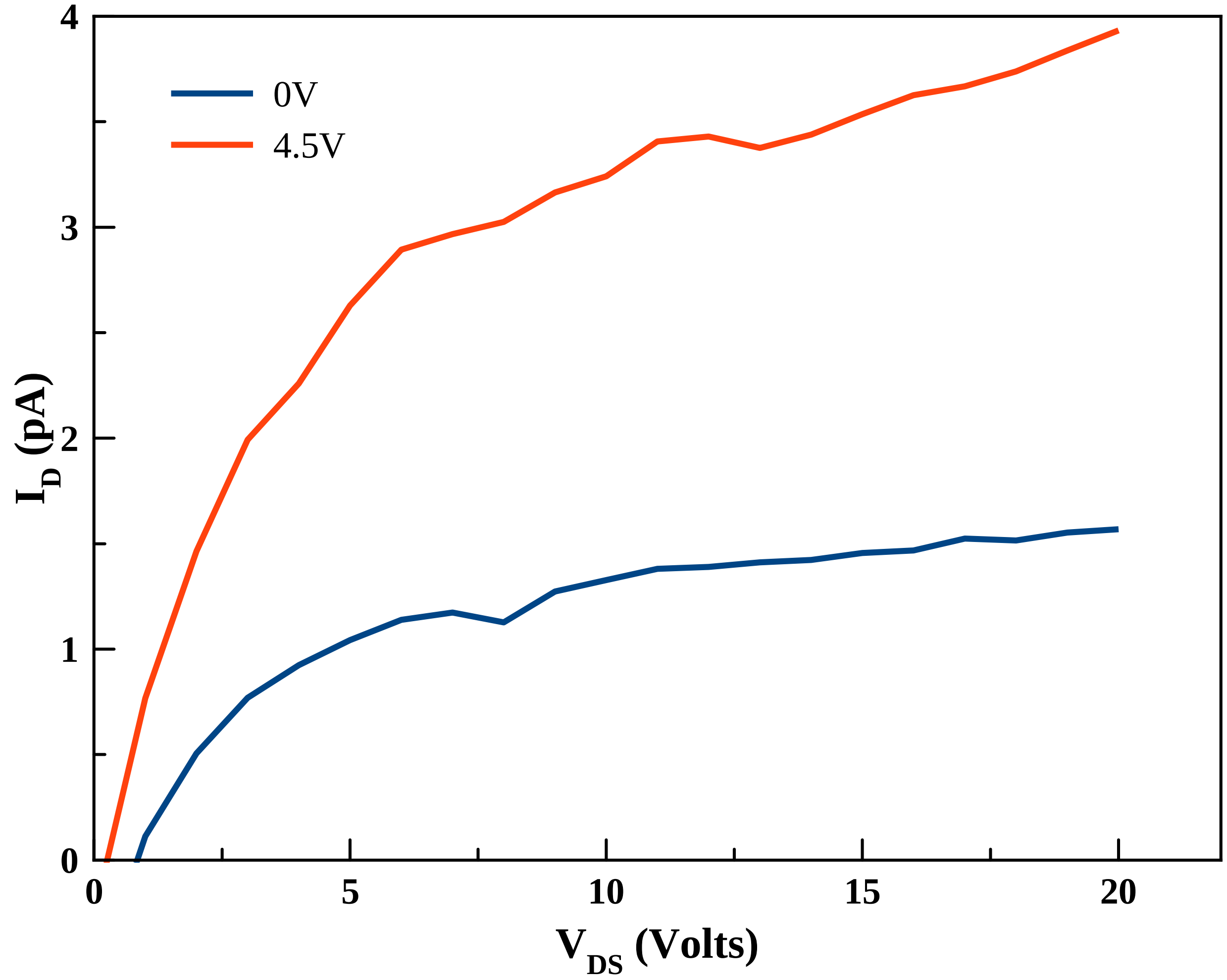
A simple field effect transistor was made



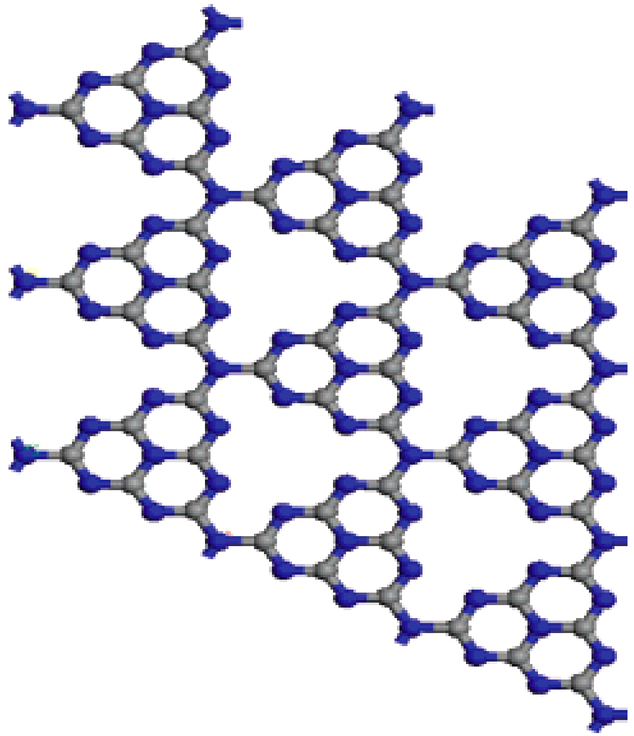


Mobility calculations were made, but the results appear too low.

Photoconductivity and FET behavior have been shown.



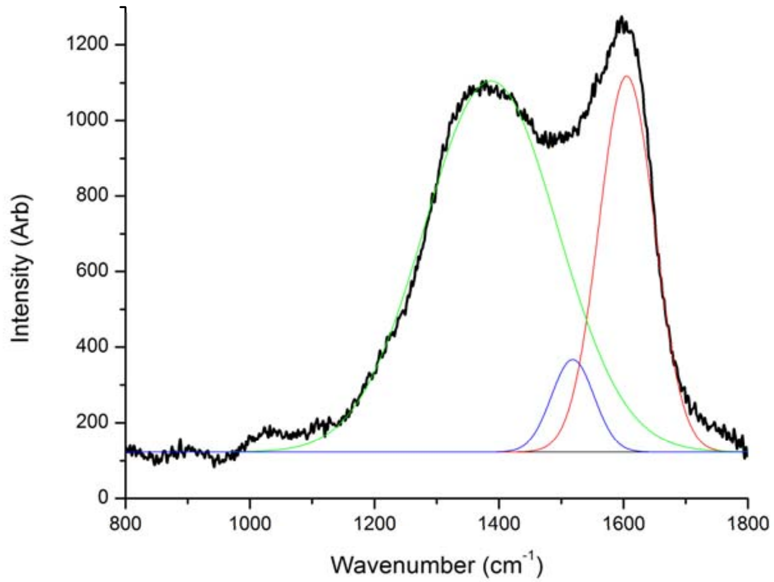
We have in mind a method for making a carbon-nitrogen alloy system of 2-D materials from graphene to melon.

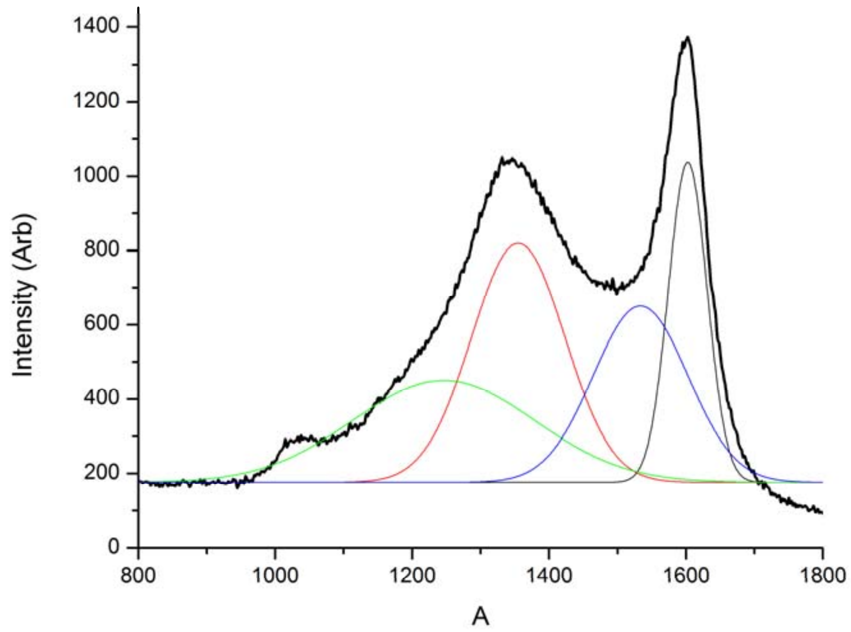


- Graphene is of course all carbon.
- Melon is C_3N_4
- We may have a means to make an alloy system of $C_XN_{1.3(1-X)}$ $(x=0\rightarrow1)$

The expectation is that one would see properties changing from graphene to that of melon.

First data on alloy





We have succeeded in making an alloy, but characterization is not complete.

듣기 주셔서 감사합니다!

Questions?