Mechanical properties of nanosheets by AFM

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Journal club ,IMS group,21-02-2012

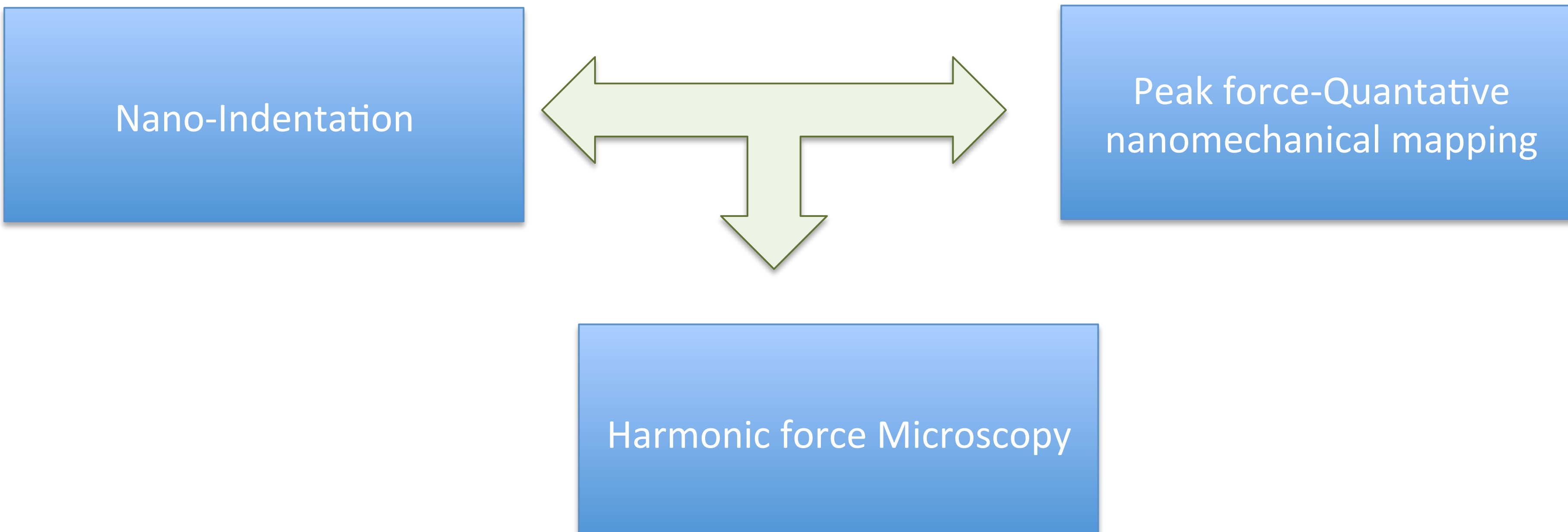
Outline

- Why mechanical properties of 2D materials ?
- Introduction
- Nano- indentation Vs Peak Force QNM
- Conclusions

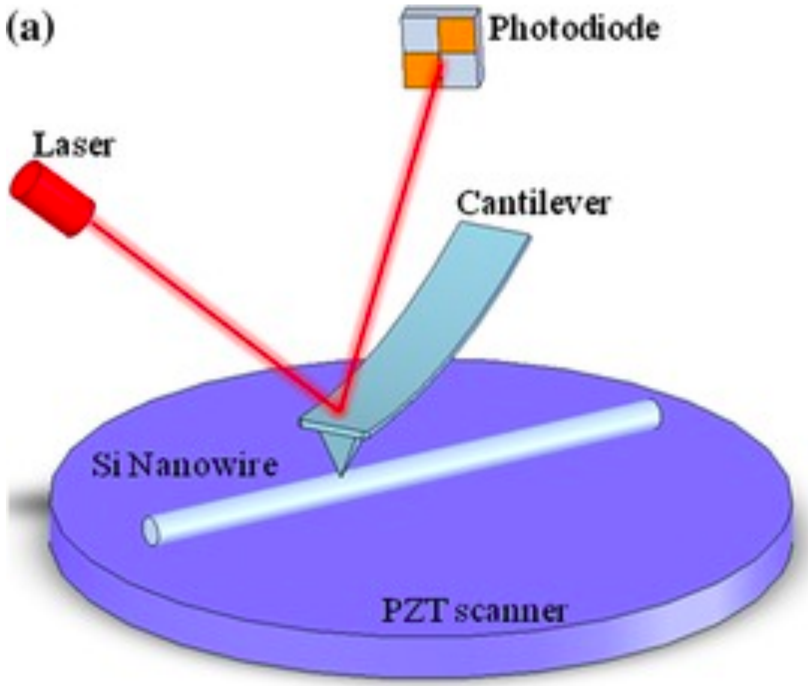
Why mechanical properties of 2D materials are important ?

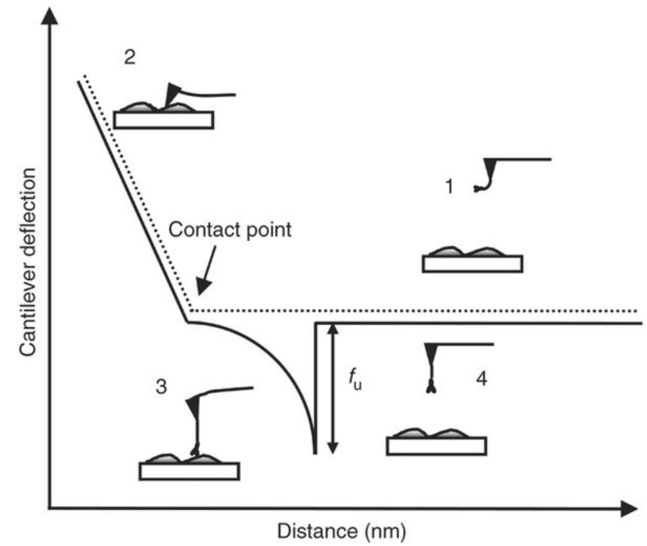
- Macroscopic materials fracture are dominated by grain boundary defect and defects
- Uncertainty in sample geometry , stress concentration and distribution , structural defects for example Nano tubes
- Applicability in flexible electronic applications ex.MoS_2 nanosheets
- Nanoelectromechanical systems(NEMS) –as resonators
- 2 D sheets geometry are precisely are defined and less sensitive to defects

Mechanical properties- Different AFM modes



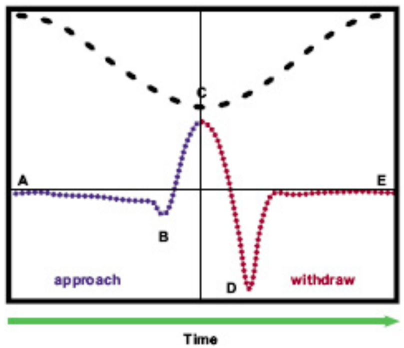
Nano-indentation

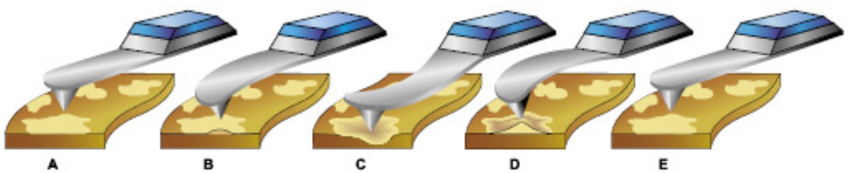


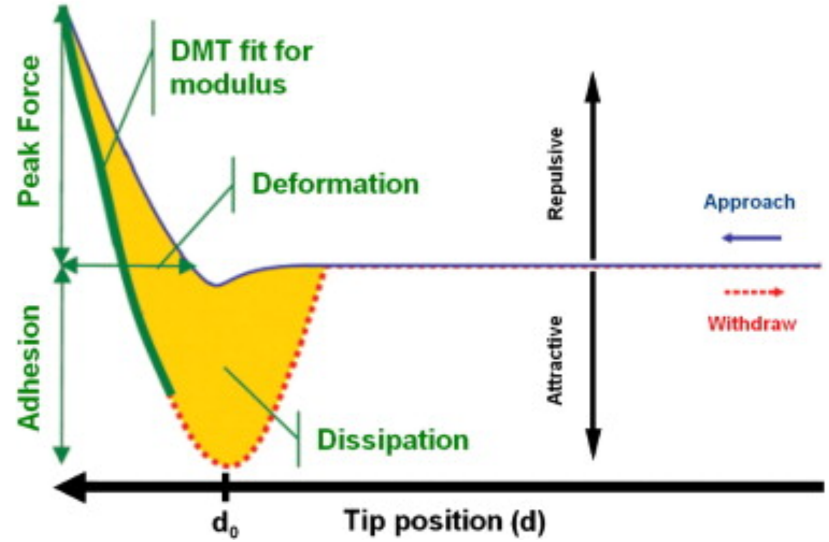


- Hertz model- Approach-retract cycle at the rate of 0.5 to 1 Hz (Very slow)
- Every pixel in an image – force Vs piezo displacement curve is obtained
- Samples :Insulin fibrils, biological substrates ,polymeric materials

Peak Force QNM

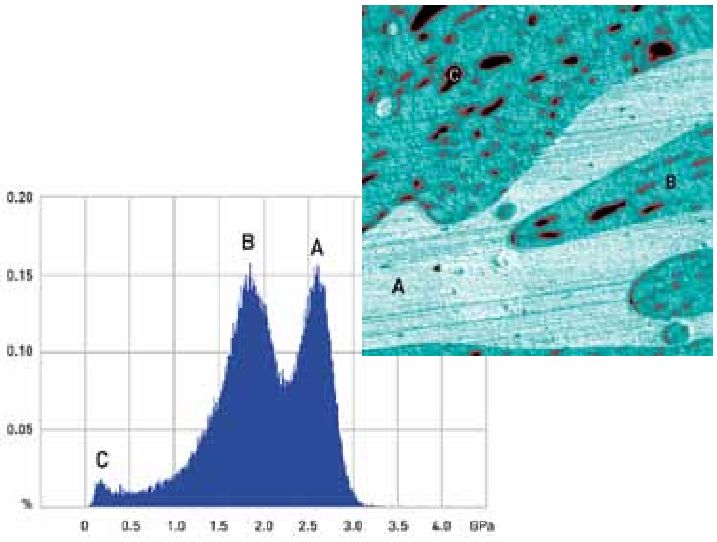






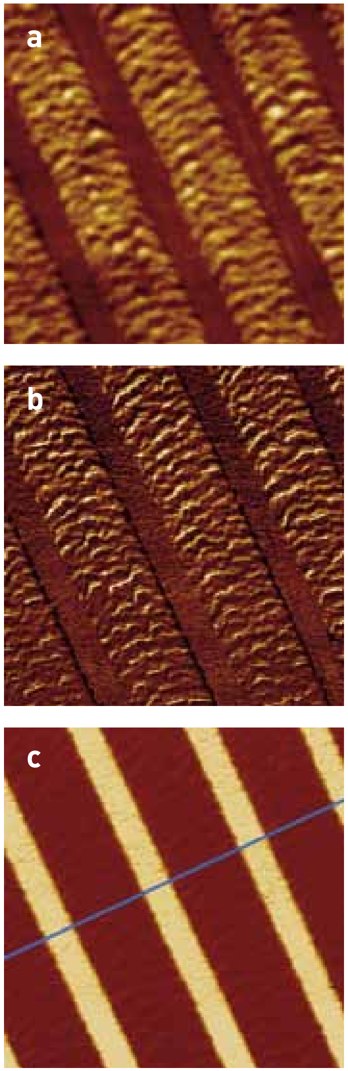
- Derjaguin–Muller–Toporov (DMT) in-built model -includes visco-elasticity and adhesion between tip and the surface
- High-Resolution Mapping of Modulus and Adhesion
- Direct Force Control Keeps Indentations Small for higher Resolution and Non-Destructive Imaging
- Widest Operating Range for Samples from Soft Gels (~1 MPa) to Rigid Polymers (>20 GPa)

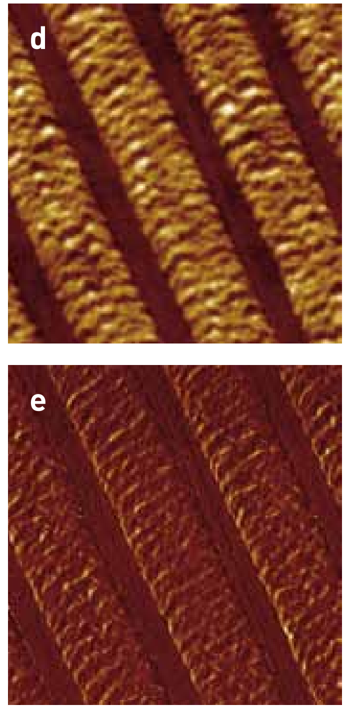
Peak Force QNM



For example. Mixture of polymer blends

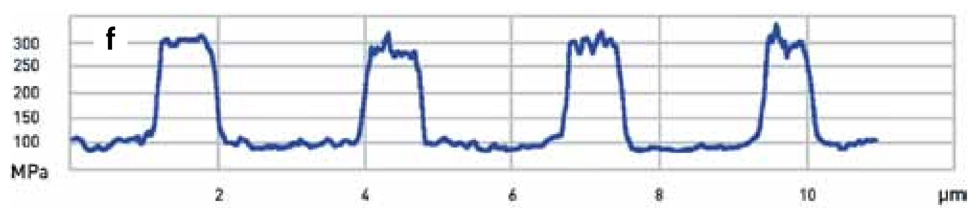
Peak Force QNM



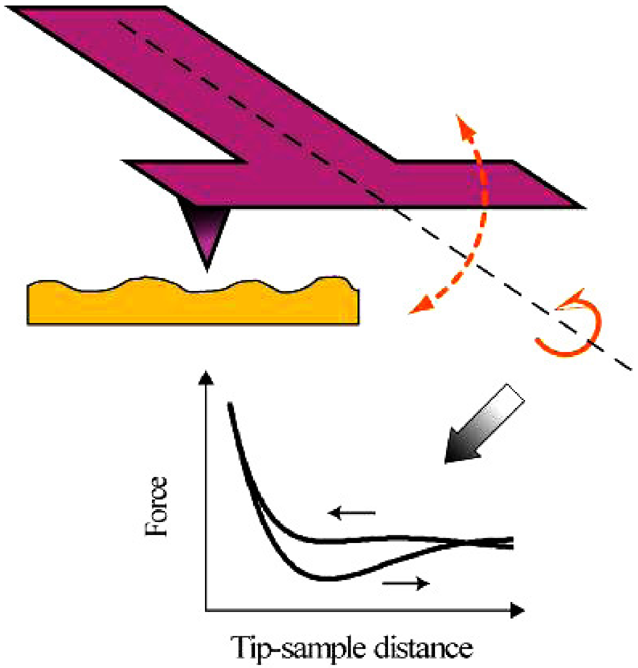


Multi-layer polymer films

a)Height
b)Adhesion
c)Modulus
d)Height
e)phase



Harmonic Force Microscopy



- T-shaped AFM cantilevers have enabled the measurement of time-varying tip–sample forces with good signal to noise ratio
- Torsional harmonic cantilevers (THC)
- Detected torsional motion is used to generate high-speed force–distance curves.

http://www.rowland.harvard.edu/rjf/sahin/pubs.html

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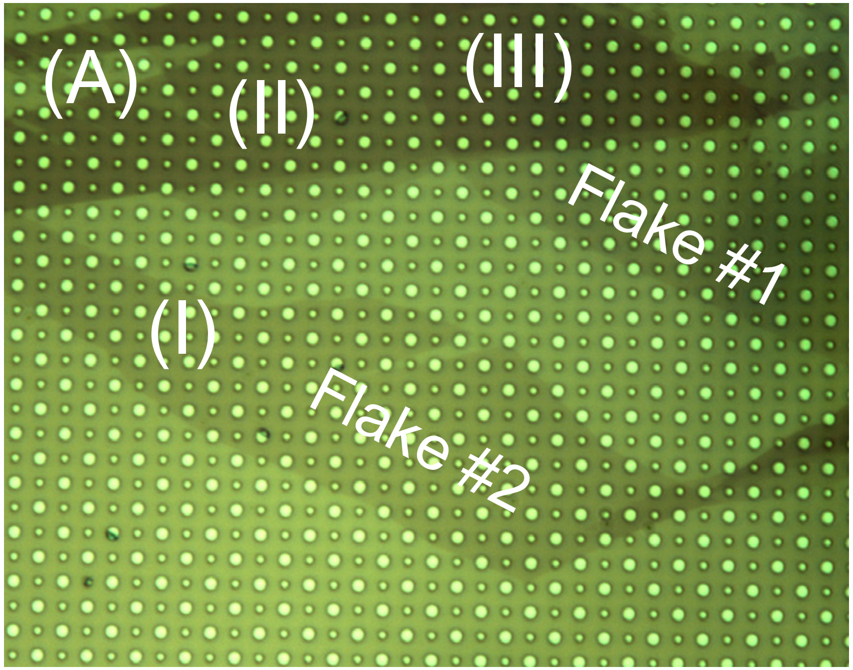
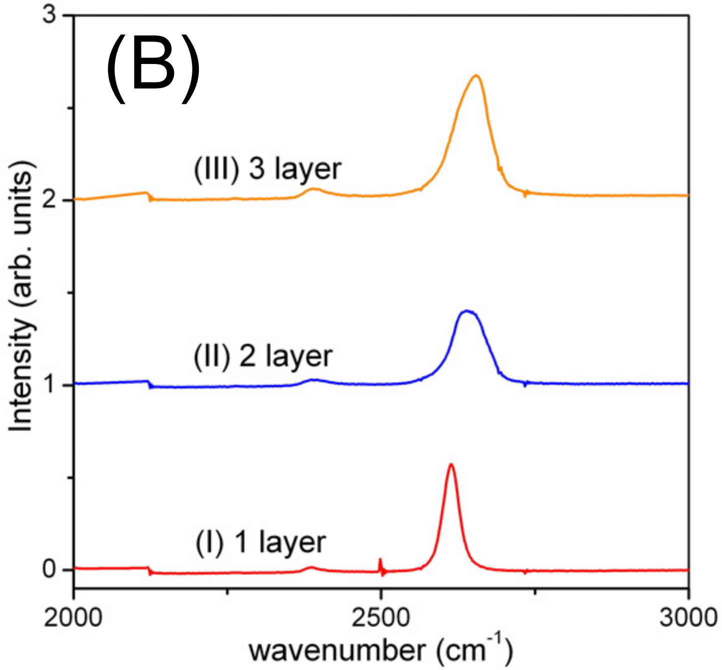
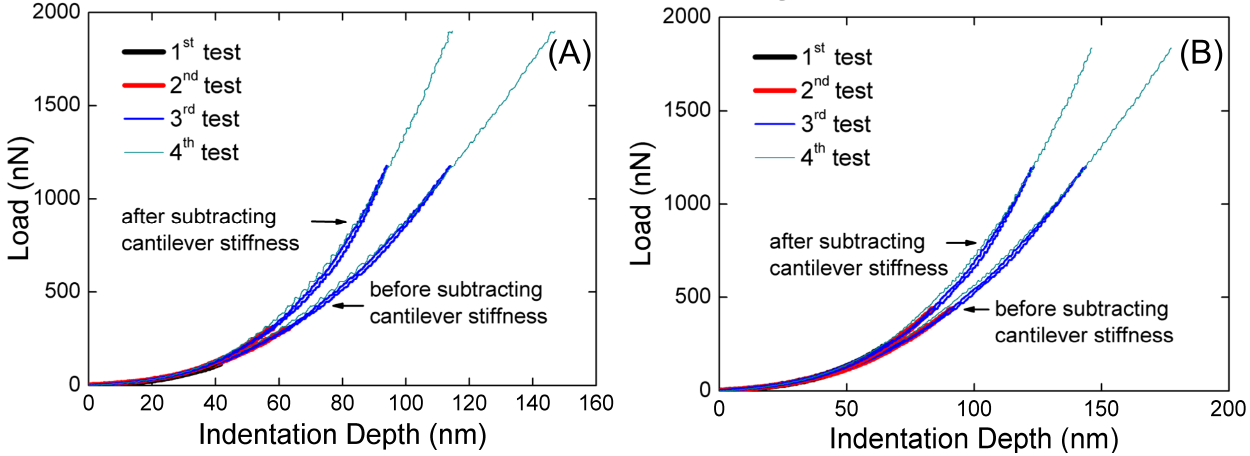
Nano-indentation of graphene monolayer





Channggu Lee et al."***Measurement of the elastic properties and Intrinsic strength of Monolayer graphene***",Science ,vol 321,385-388,2008

Nano-indentation of graphene monolayer



$$F = \sigma_0^{2D}(\pi a)\left(\frac{\delta}{a}\right) + E^{2D}(q^3 a)\left(\frac{\delta}{a}\right)^3 .$$

Assumptions:

- Bending stiffness and load of free standing film is negliglble
-

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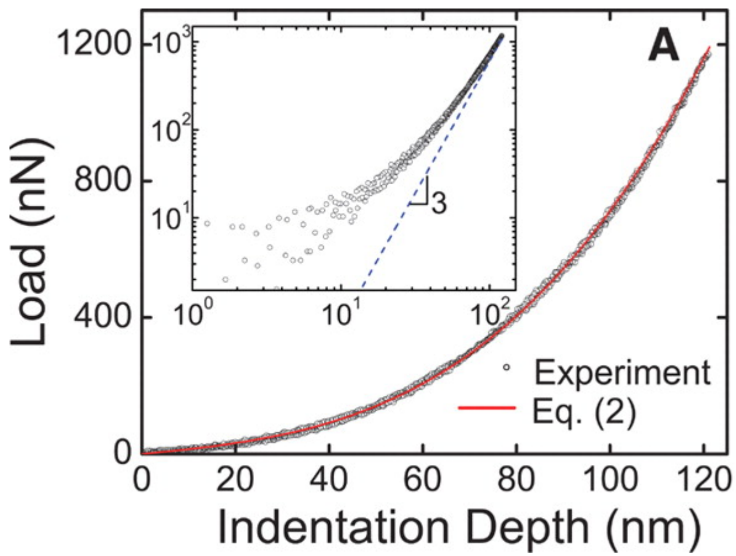
Nano-indentation of graphene monolayer



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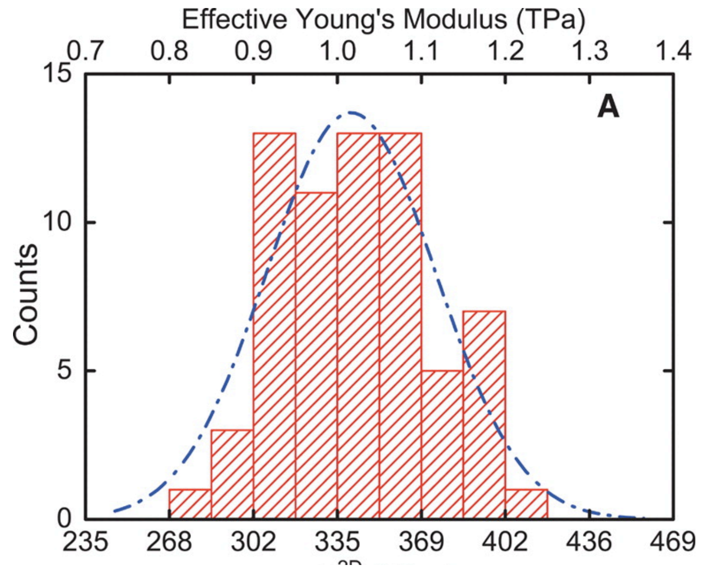

Mean value of E^{2D} is 342 N/m with the standard deviation of 30 N/m

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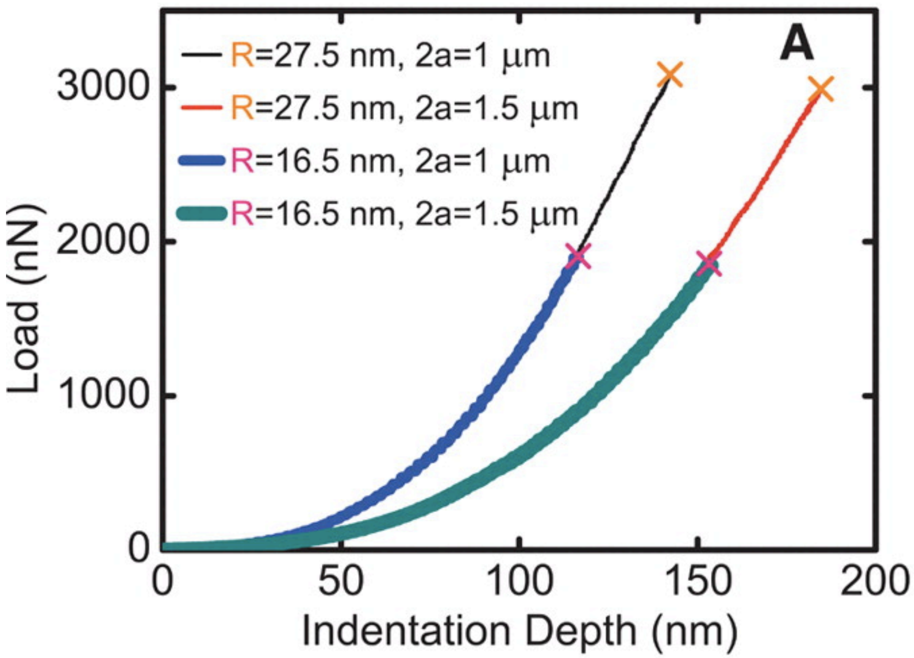
Nano-indentation of graphene monolayer



$$\sigma_{\mathrm{m}}^{\mathrm{2D}} = \left(\frac{F E^{\mathrm{2D}}}{4\pi R} \right)^{\frac{1}{2}}$$

Elastic stiffness for monolayer graphene are E^{2D} = 340 ± 50 N/ m

D^{2D} = –690 ± 120 N/m

Intrinsic strength is σ^{2D}_{int} = 42 ± 4N/m

Young's modulus E= 1.0 ± 0.1 Tpa ,

Intrinsic stress is σ_{int} = 130 ± 10 GPa at a strain of ϵ_{int} = 0.25.

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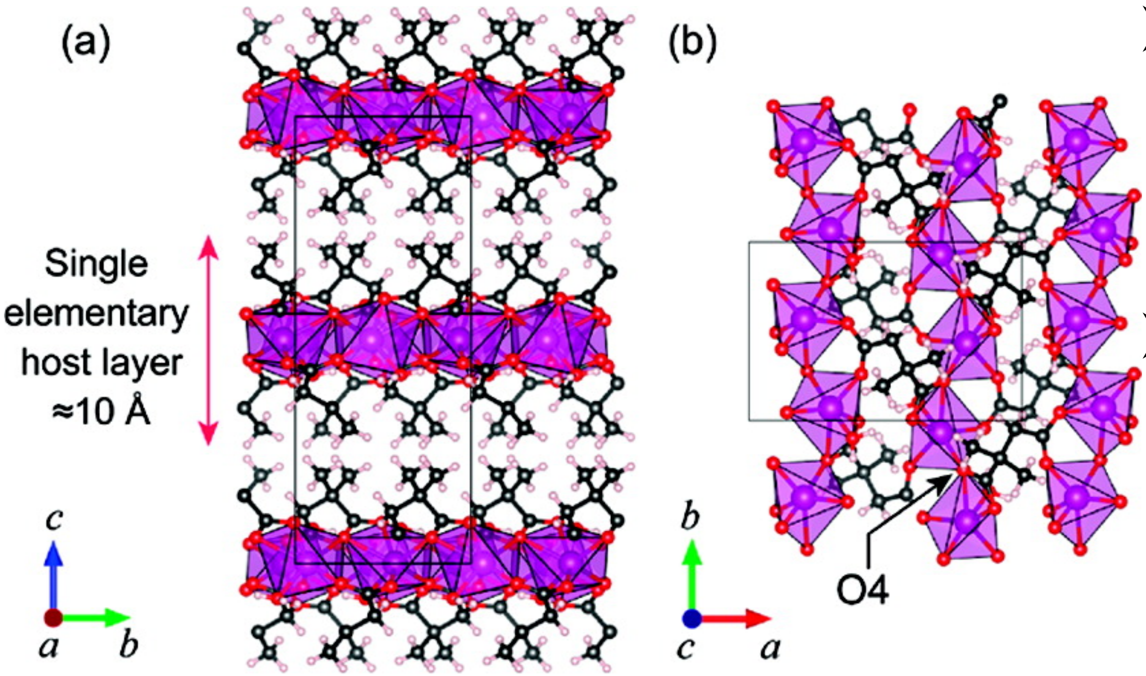
Peak Force QNM of Inorganic –organic hybrid nanosheets



- MnDMS [$Mn(C_6H_8O_4)(H_2O)$] Mn 2,2-dimethlysuccinate
- Inorganic and organic building blocks covalently bonded together having distored MnO_6 octahedra

Jin-Chong Tan etal,***"Hybrid nanosheets of an inorganic –Organic framework Material",***ACS Nano ,Vol 6,No.1,615-621,2012

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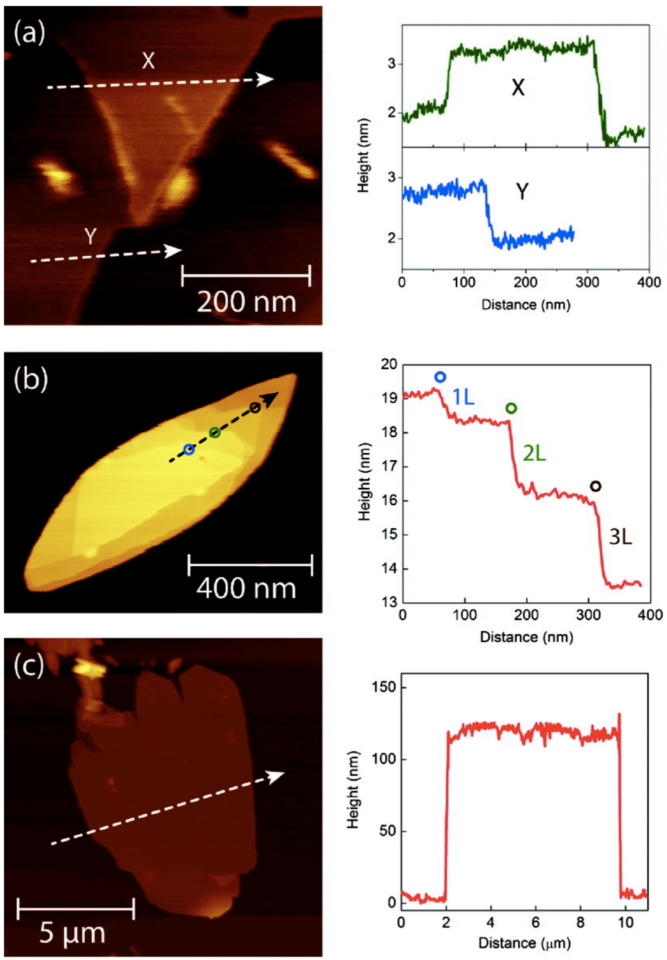

Two fully exfoliated nanosheets

Partially exfolaited nanosheets

Multi-layer films

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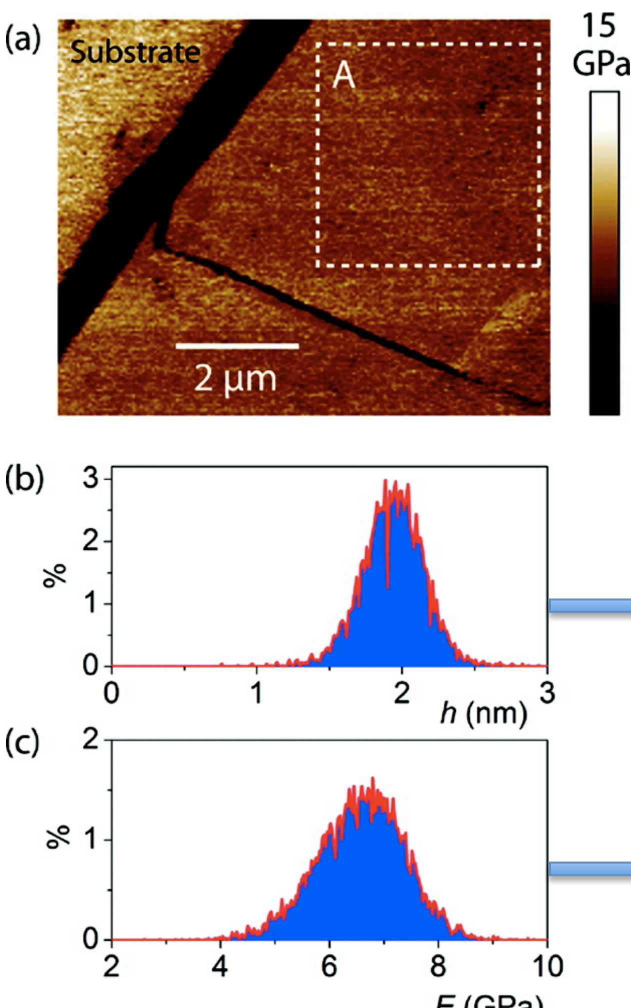

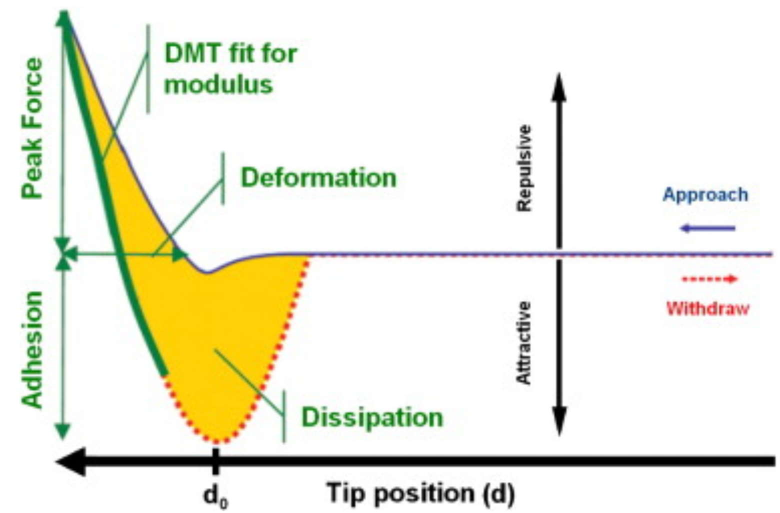

Deformation of the tip (Vertical displacement) 2,5 nm

Elastic or young's modulus- 6-7 GPa from the histogram

Jin-Chong Tan etal,*"Hybrid nanosheets of an inorganic –Organic framework Material"*, ACS Nano ,Vol 6,No.1,615-621,2012

Nano-Indentation Vs Peak force QNM-comparsion

	Nano indentation	Peak force QNM
Model	Model varies for each system	In built model
Data analysis	Time consumuing	Less time
Measured valve	More precise	quantative
Sample preparation	Tedious	Flat substrate should be sufficient
Probe tip	Investigate before and after the measurement	Proper selection of the tip according to the system
Speedy of the experiement	Time consumption	Not as Nano-indentation

Conclusions

Nanoindentation by AFM technique is very useful technique to precisely measure the mechanical properties of 2D structures compared to conventional test where their values are dominated by the defects, stalking faults and grain boundary in the 3D structures or nano tubes

Peak Force QNM is an useful technique for samples where there are two or three mixtures of components for example a bio-molecule between two nanosheets, mixtures of nanosheets , multi-layer films or surface termination in pervoskites etc