Funded by FFG:
project 860382-VISION

VISION: Visualizing nano-mechanics of two-dimensional membranes by in-situ Atomic Force Microscopy-Scanning Electron Microscopy

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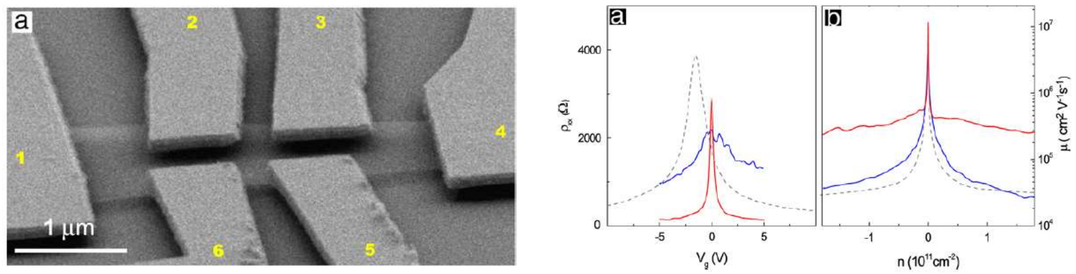
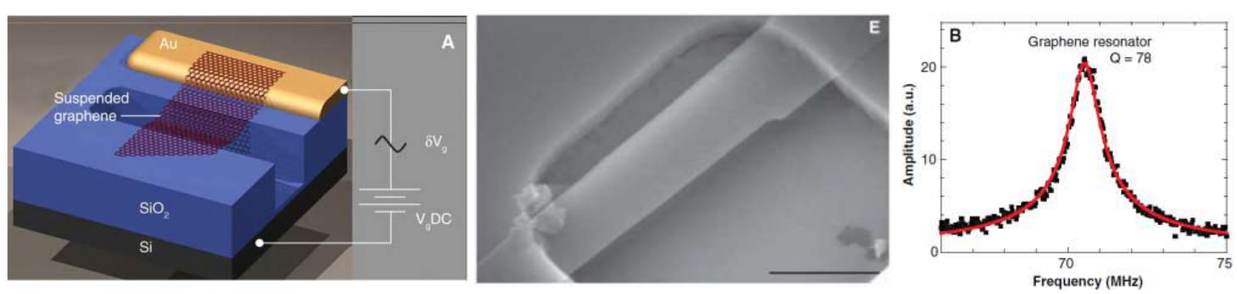
University of Vienna: Stefan Hummel, Kenan Elibol, Jannik C. Meyer et al.
GETec Microscopy GmbH: Marcel Winhold, Tobias Strunz, Chris Schwalb, Ernest Fantner et al.
Shanghai University: Dengsong Zhang et al.

Motivation: 2D membranes

- Suspended membranes of two-dimensional (2D) materials have wide technological application potential
  - Graphene, MoS_2 & other transition metal dichalcogenides etc.

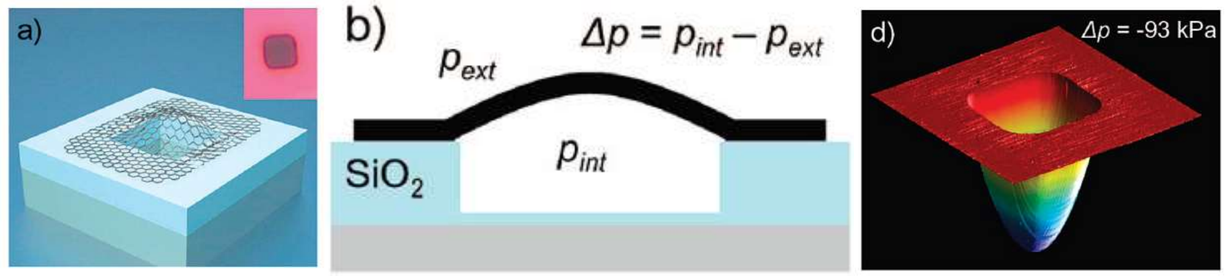


Solid State Commun., 146, 351 (2008)

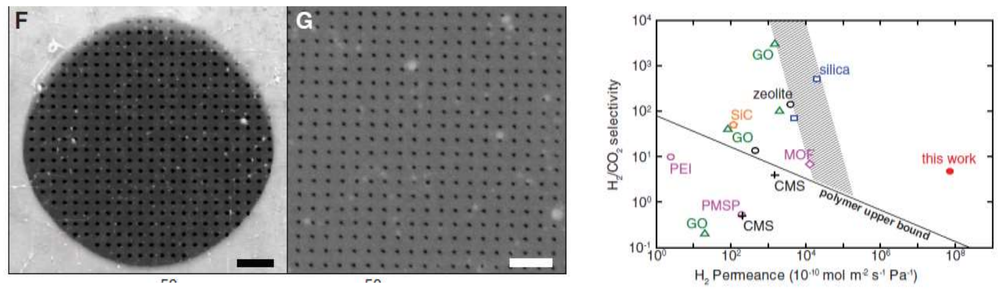


Science, 315, 490 (2007)

- Example Graphene membranes:
  - Ultrafast electronics via mitigation of substrate-related scattering
  - Nano-electro-mechanical systems (NEMS), e.g. ultrafast resonators
  - Chemical species separation, e.g. filtration or desalination



Nano Lett., 8, 2458 (2008)

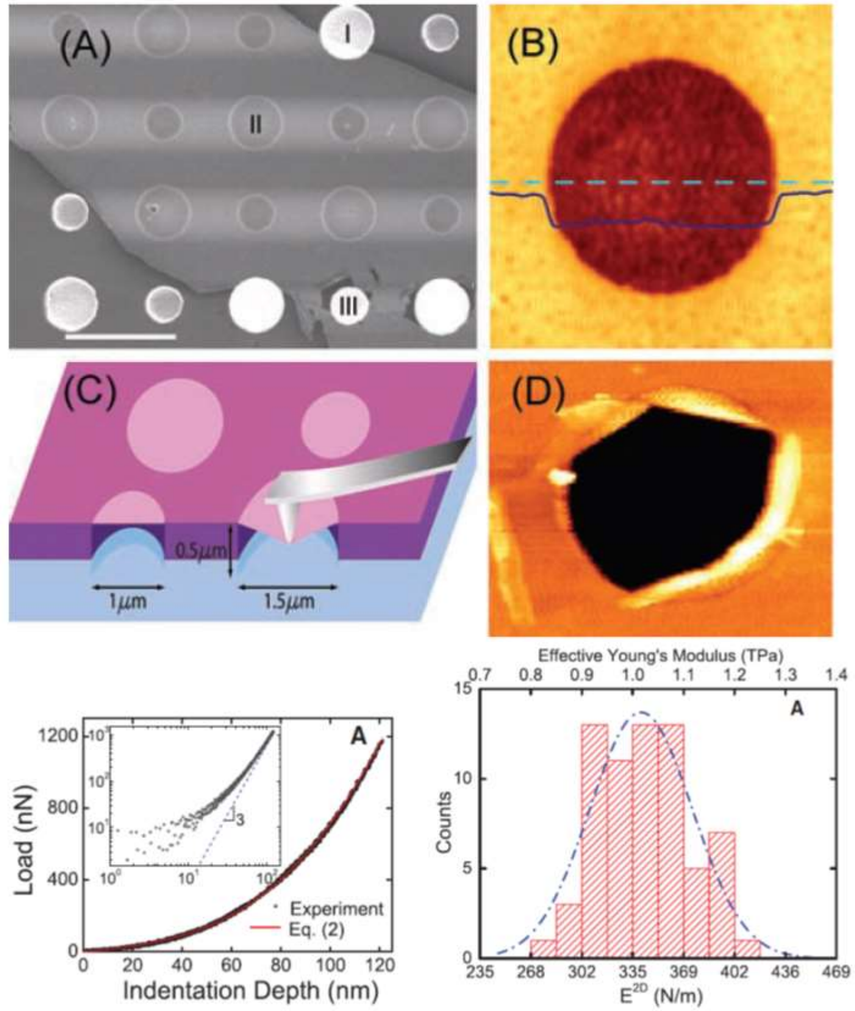


Science, 344, 289 (2014)

Challenge: 2D membrane characterisation

- Required: Understanding of 2D membrane nanomechanics → characterisation tools needed

- <u>Characterisation often employs scanning probe microscopy (SPM) techniques</u>
  - Scanning Tunnelling Microscopy (STM)
  - Atomic Force Microscopy (AFM)
  - All SPM techniques rely on a <u>sharp tip rastering accross a sample surface</u> and measuring tip-sample interaction at each point to visualize sample topography



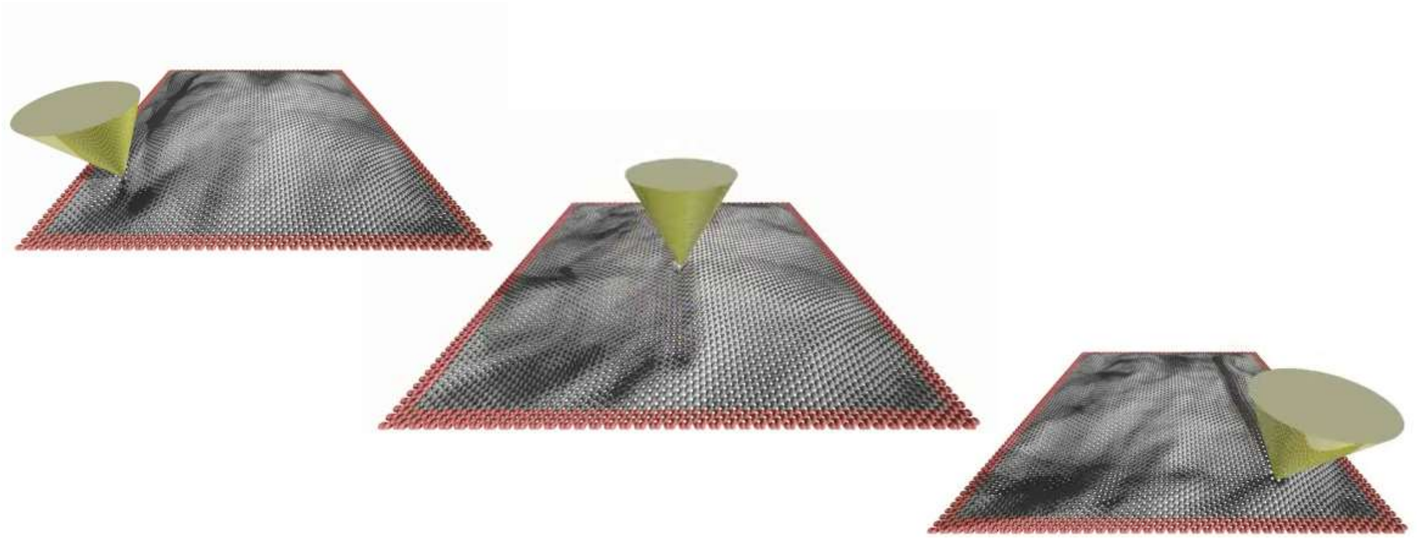
Science, 321, 385 (2008)

- Disturbance-free SPM measurements of freestanding 2D membranes are however an unsolved challenge…

Science, 336, 1557 (2012)
Nano Lett., 10, 461 (2010)
Phys. Rev. B 85, 121406 (2012)
Nano Lett. 13, 1934 (2013)
Nat Commun 5, 3720 (2014)
Carbon 77, 236 (2014)
Nat Commun 5, 4962 (2014)
Sci. Rep., 6, 28485 (2016)

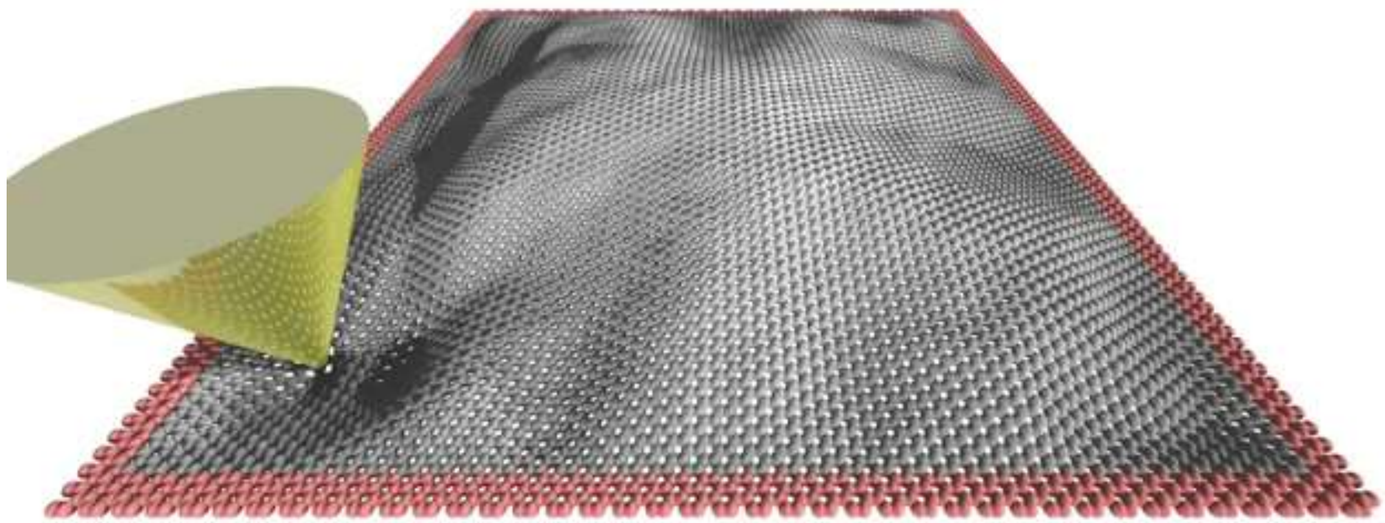
2D membranes – flexible, wrinkles & ripples

- Suspended 2D membranes highly flexible & are intrinsically wrinkled & rippled



- All SPM measurement rely on the interaction of a sharp tip with a sample surface

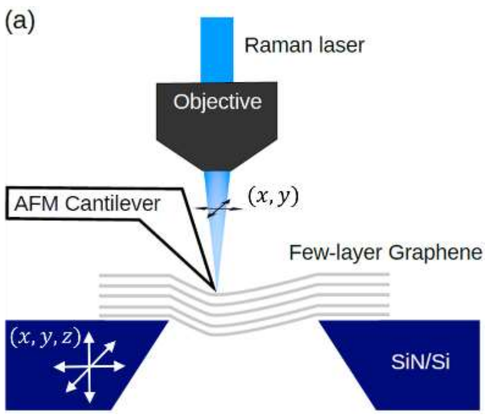
- Any SPM tip actually deforms 2D membranes' wrinkles & ripples and stretches the 2D membranes during the measurement → the measured topographies are highly probe-dependent…

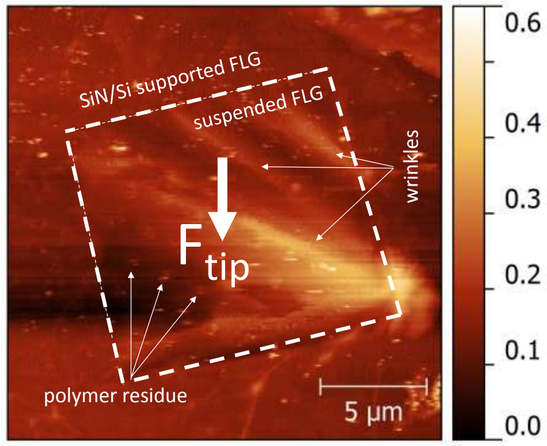


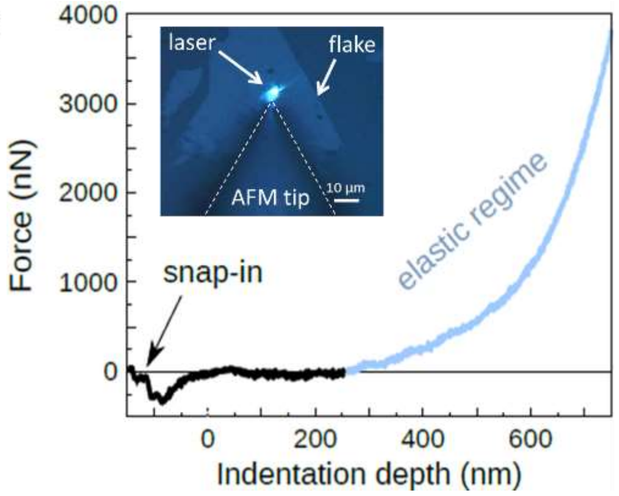
Simulation of SPM-tip induced membrane deformation (J. Kotakoski)
Nano Lett., 13, 1934, (2013)

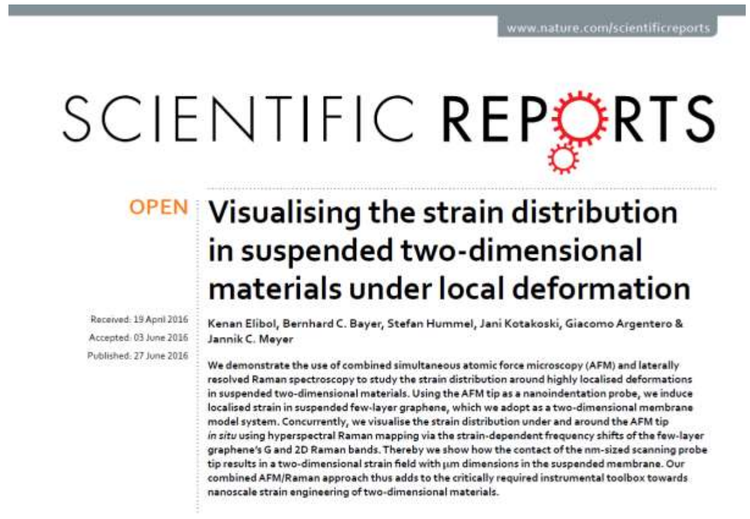
Indirect approach: Strain mapping

- Indirect approach via strain mapping using combined AFM-Raman spectroscopy
- Frequencies of Raman bands in graphene are highly strain dependent → we use Raman spectroscopy to map strain induced from AFM tip
- Actual topography of 2D membrane remains undetermined → direct approach required to visualize 2D membrane deformation from AFM tip








www.nature.com/scientificreports

SCIENTIFIC REPORTS

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Visualising the strain distribution in suspended two-dimensional materials under local deformation

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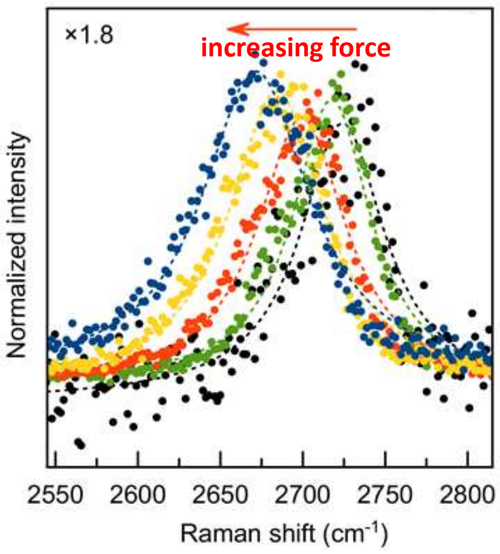
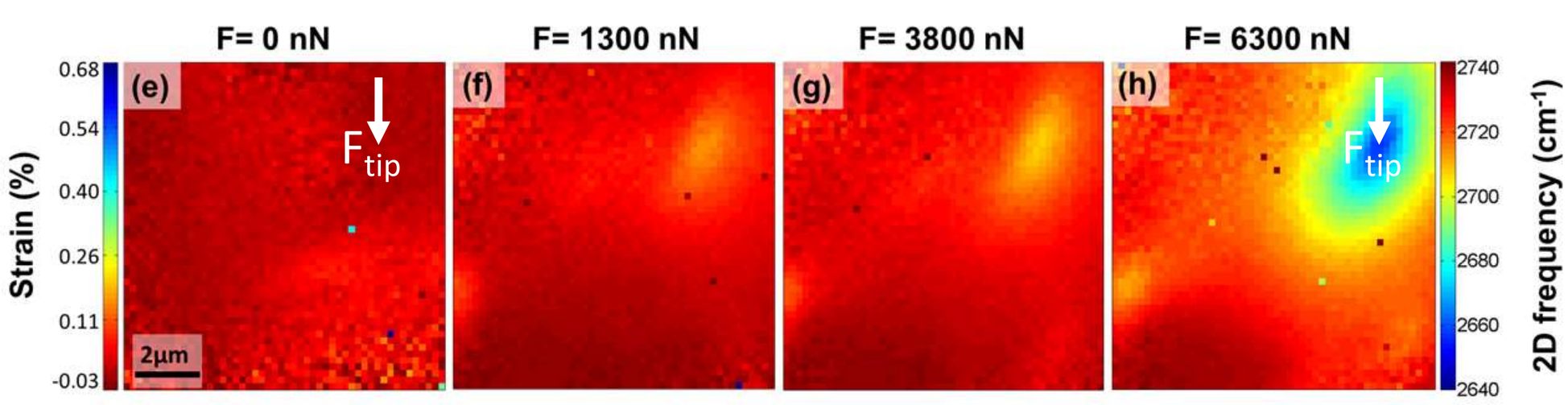
Kenan Elibol, Bernhard C. Bayer, Stefan Hummel, Jani Kotakoski, Giacomo Argentero & Jannik C. Meyer

We demonstrate the use of combined simultaneous atomic force microscopy (AFM) and laterally resolved Raman spectroscopy to study the strain distribution around highly localised deformations in suspended two-dimensional materials. Using the AFM tip as a nanoindentation probe, we induce localised strain in suspended few-layer graphene, which we adopt as a two-dimensional membrane model system. Concurrently, we visualise the strain distribution under and around the AFM tip *in situ* using hyperspectral Raman mapping via the strain-dependent frequency shifts of the few-layer graphene's G and 2D Raman bands. Thereby we show how the contact of the nm-sized scanning probe tip results in a two-dimensional strain field with μm dimensions in the suspended membrane. Our combined AFM/Raman approach thus adds to the critically required instrumental toolbox towards nanoscale strain engineering of two-dimensional materials.



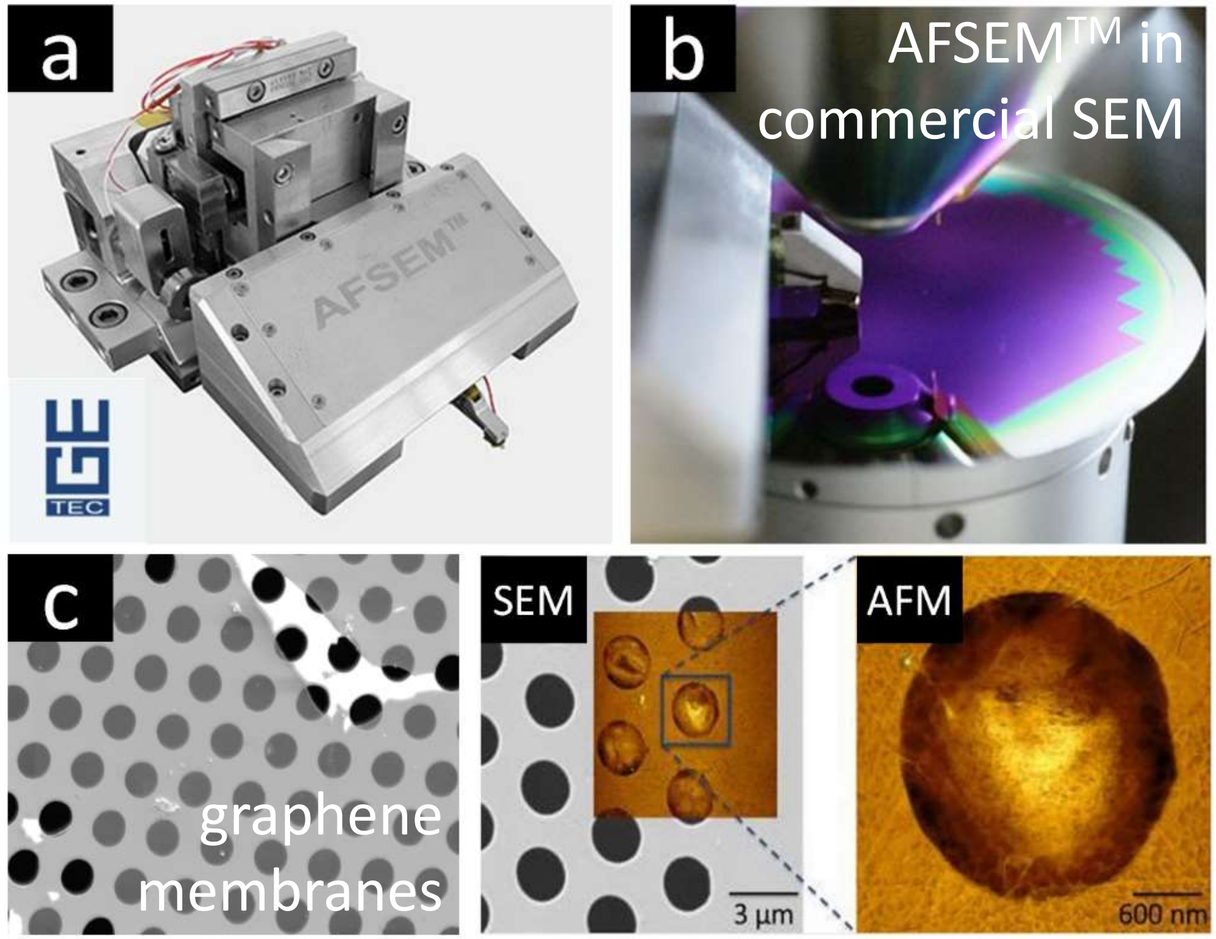


Sci. Rep., 6, 28485 (2016)

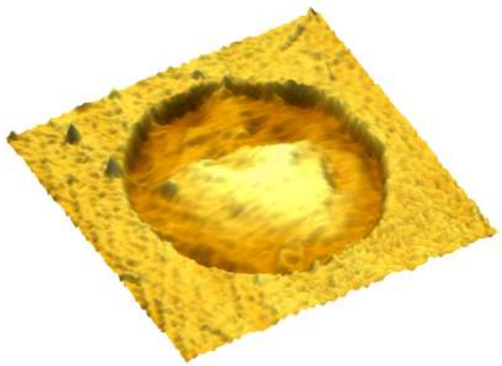
AFSEM™ from GETec

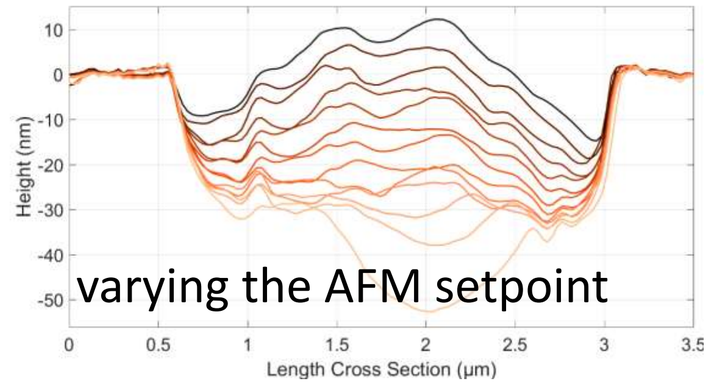
- Austrian company GETec Microscopy GmbH is world-leading in providing a uniquely compact AFM module (AFSEM™) that is readily installed in commercial scanning electron microscopes (SEMs)

- GETec's AFSEM™ allows unprecedented correlative AFM-SEM measurements (plus additionally correlative energy dispersive X-ray spectroscopy (EDX) and electrical mapping capabilities)



Correlated SEM & AFM of graphene membrane via AFSEM™





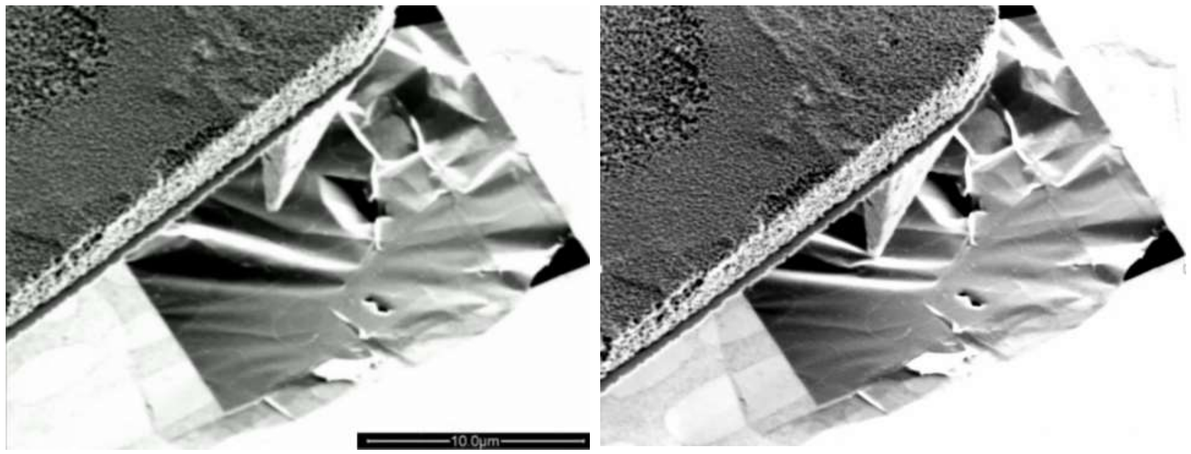
Graphene membrane in high-speed AFSEM™ AFM module: Varying AFM setpoint drastically changes measured topography of graphene membrane → What is the real topography?

www.getec-afm.com

Conclusions & Acknowledgements

- VISION develops a novel in-situ AFM-SEM capability and will thereby elucidate the nanomechanics of 2D membranes under local deformation

force/time



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Thank you!

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