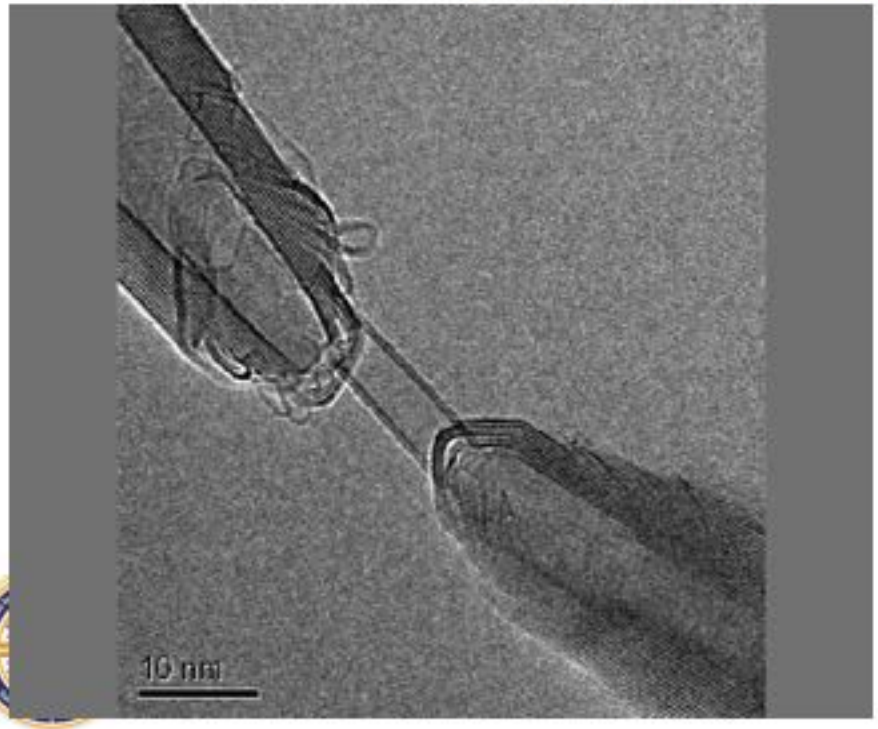
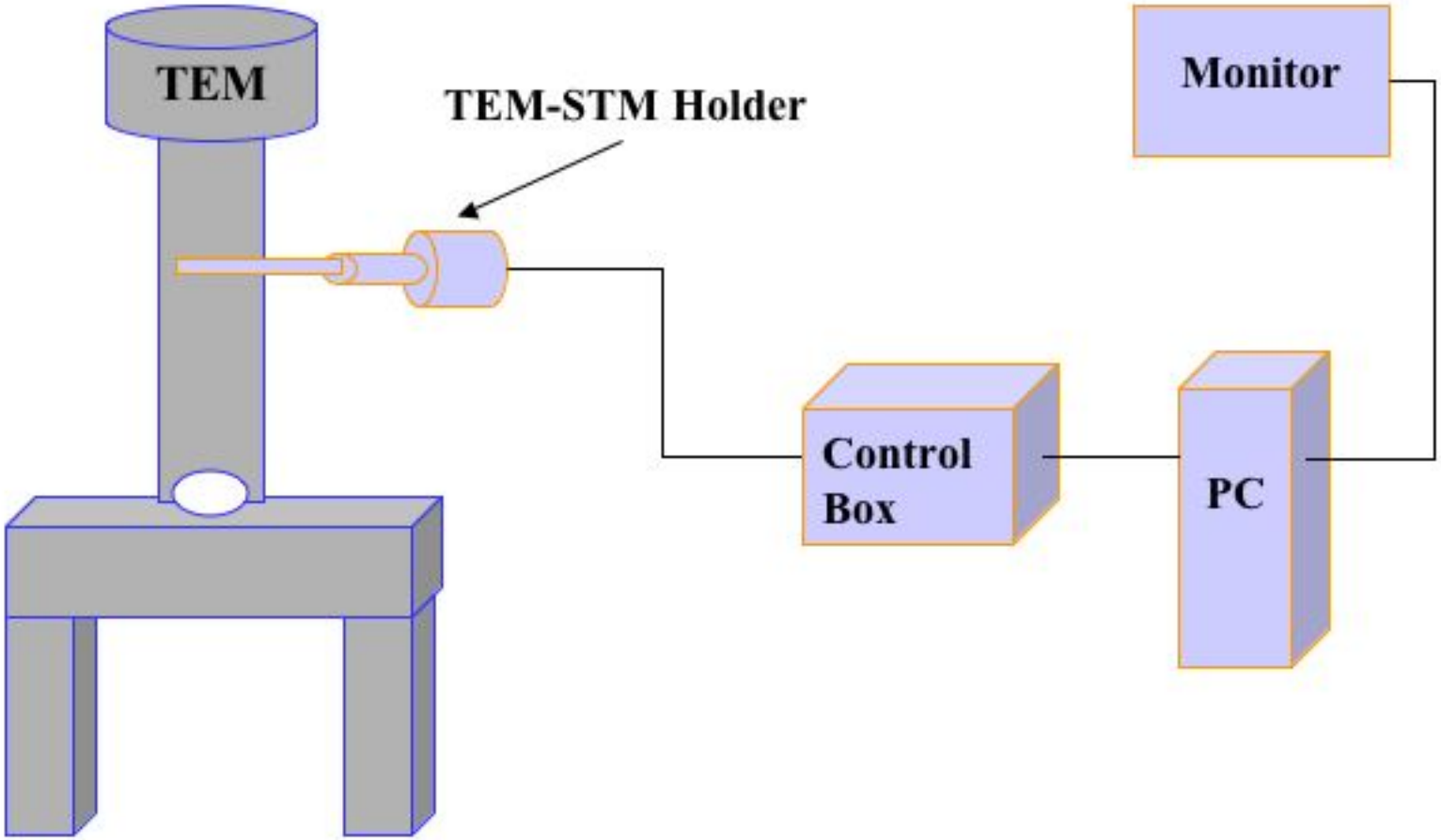
In-Situ Electron Microscopy Enabled by a TEM-SPM Platform at CINT

Jianyu Huang

Center for Integrated Nanotechnologies (CINT)
Sandia National Laboratories

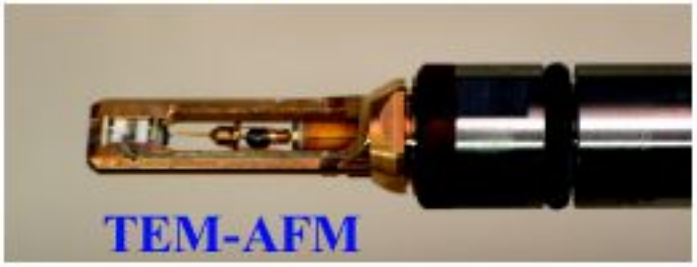


1. Introduction to the TEM-STM Platform



Sandia National Laboratories

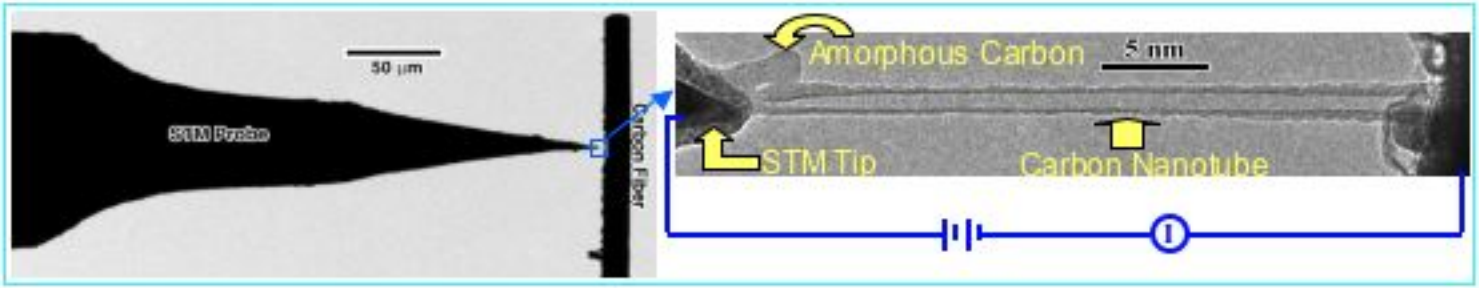
CINT TEM

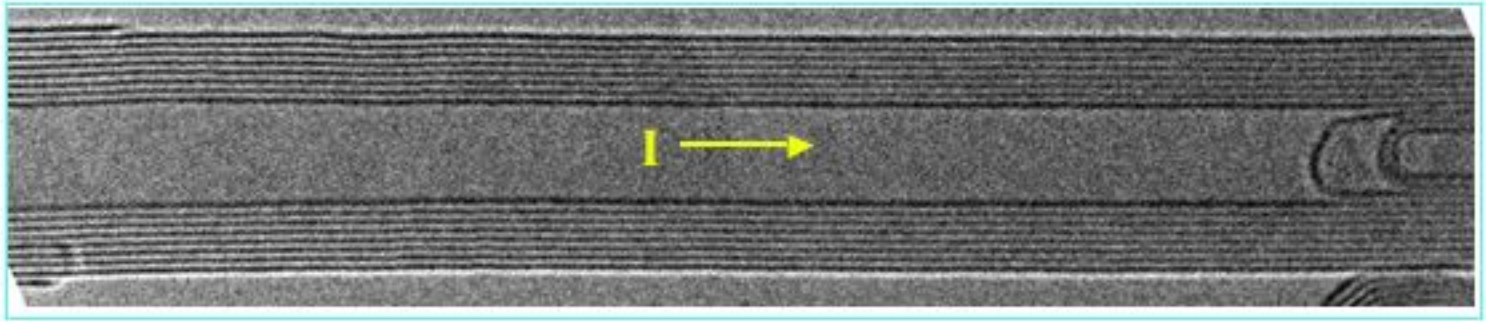


- Tecnai F30
- P-to-P: 0.2 nm
- HAADF (Z-Contrast)
- Tridiem GIF (EFTEM, EELS)
- EDAX

Sandia National Laboratories

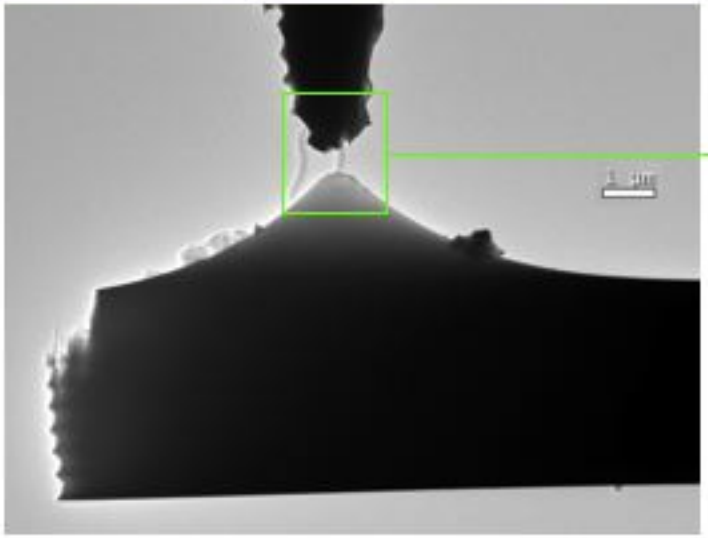
Nanofactory TEM-STM Platform

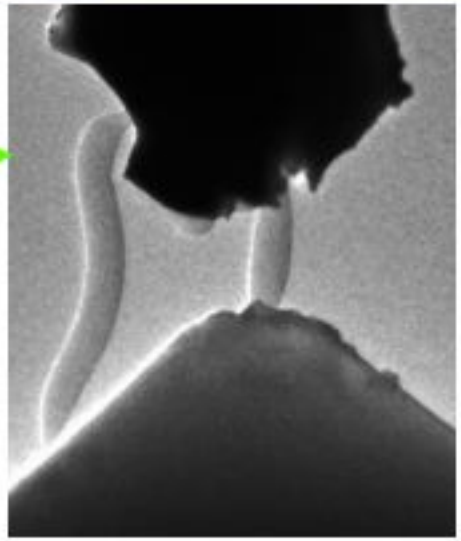


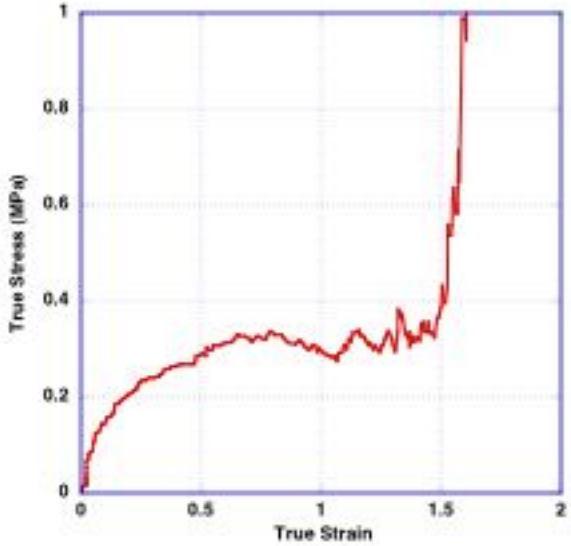


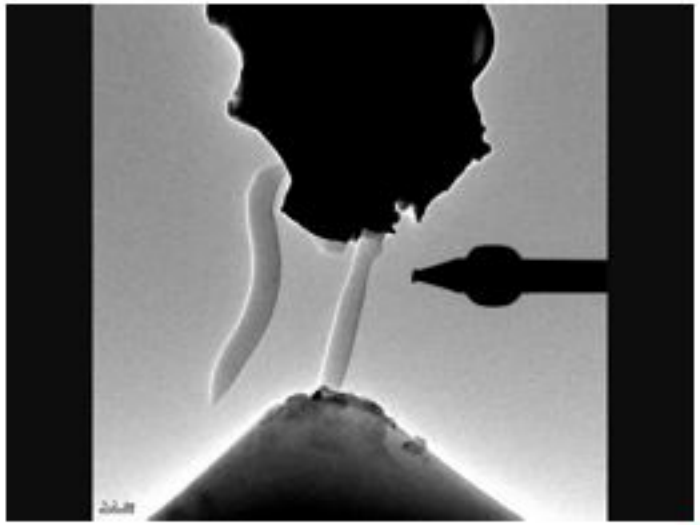
Sandia National Laboratories

Nanofactory TEM-AFM Platform







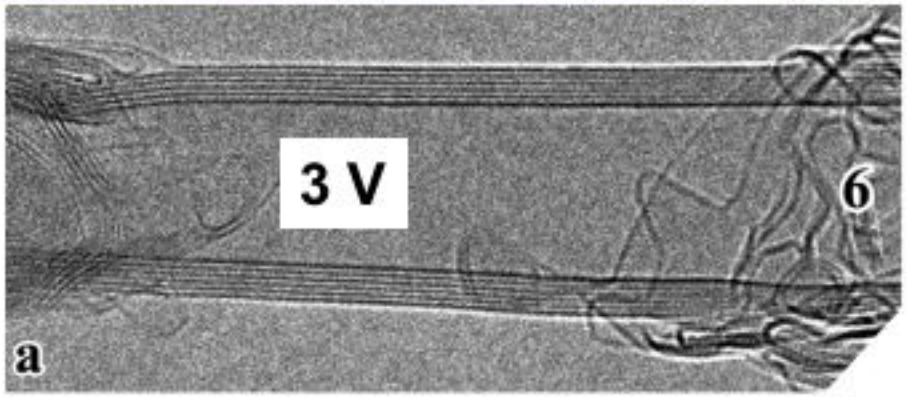


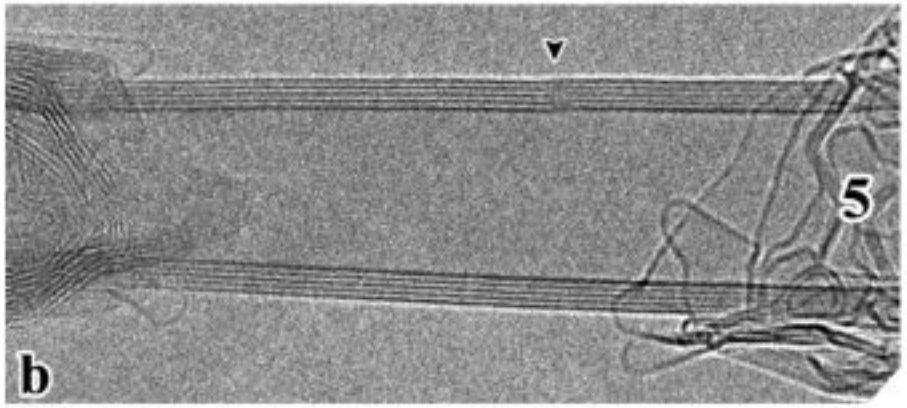
Collaborators: J.H. Luo, S.X. Mao (U. Pitts.), CINT Users

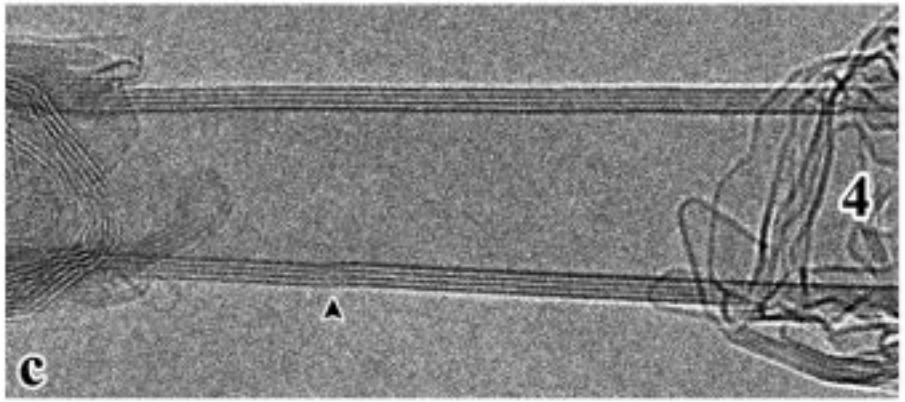
Sandia National Laboratories

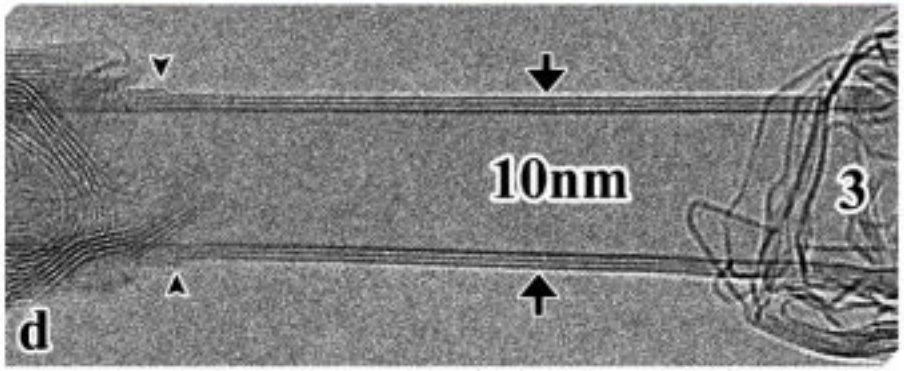
Breakdown of a 6-Walled Nanotubes

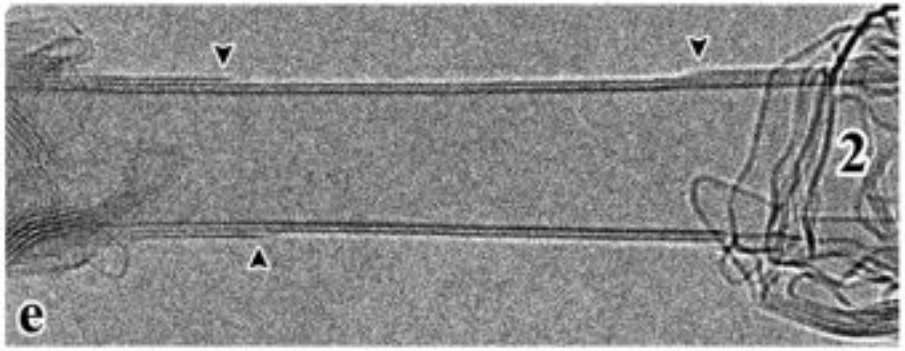
Huang *et al.*, PRL 94, 236802 (2005)

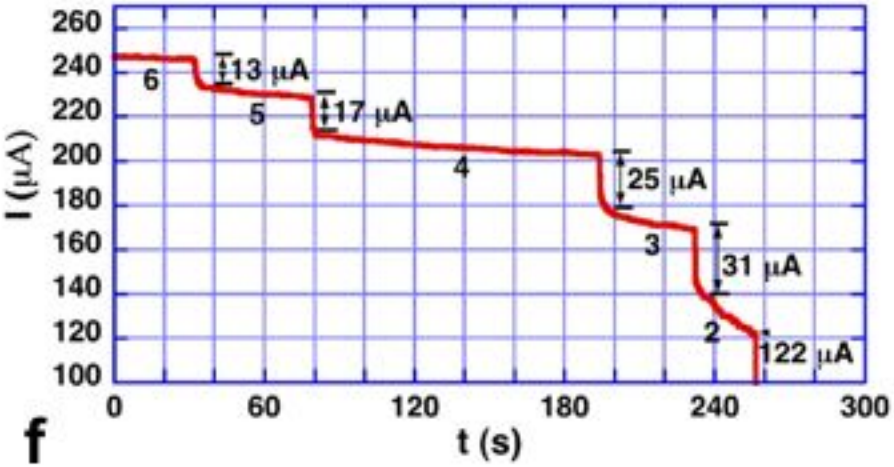






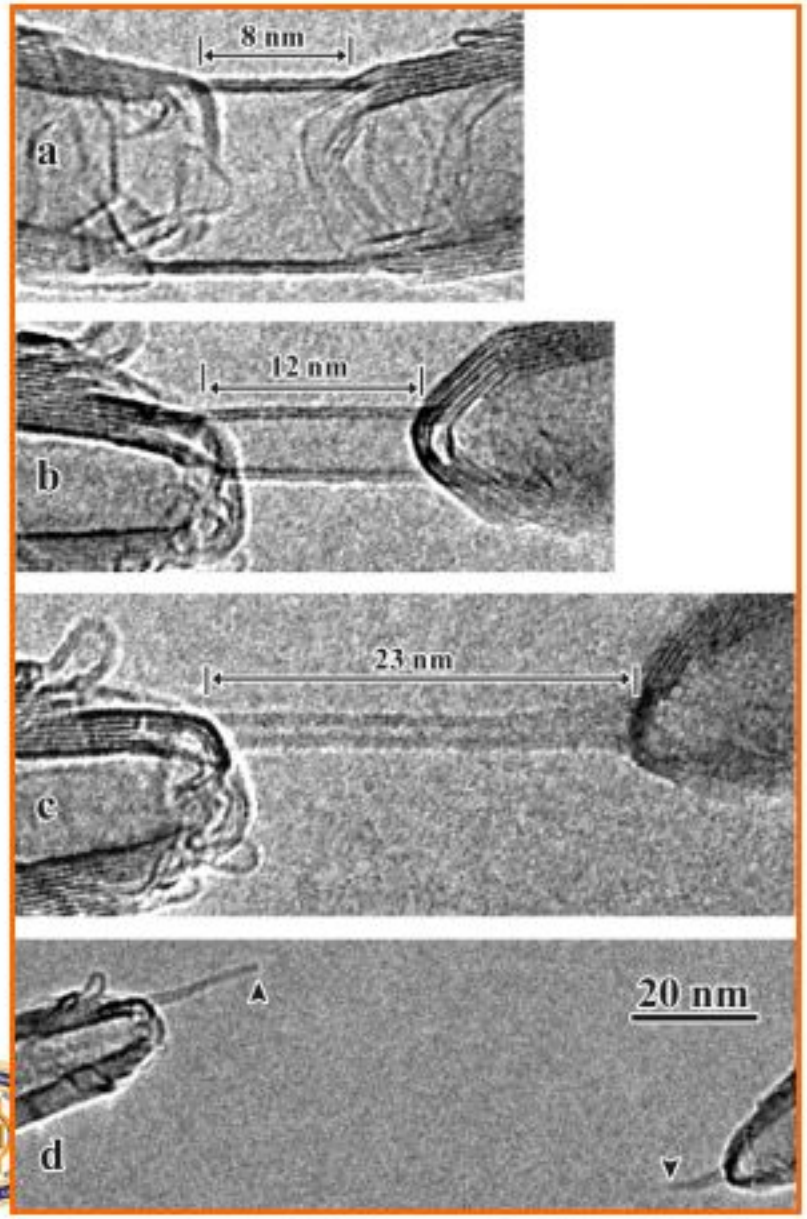


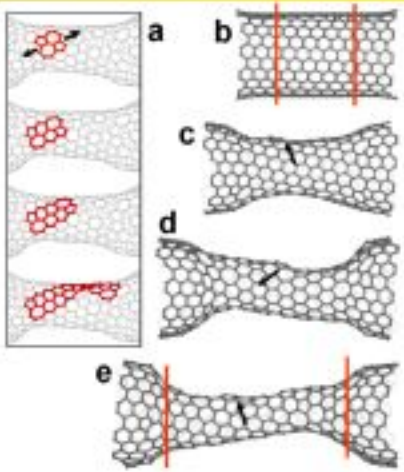


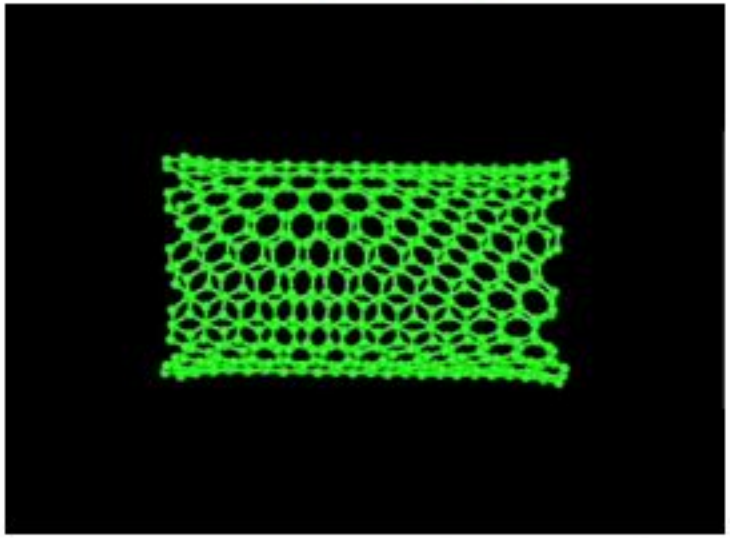


Super-Elongation of Carbon Nanotubes

Can TEAM images atomic structure of nanotubes? Chirality, point defects?



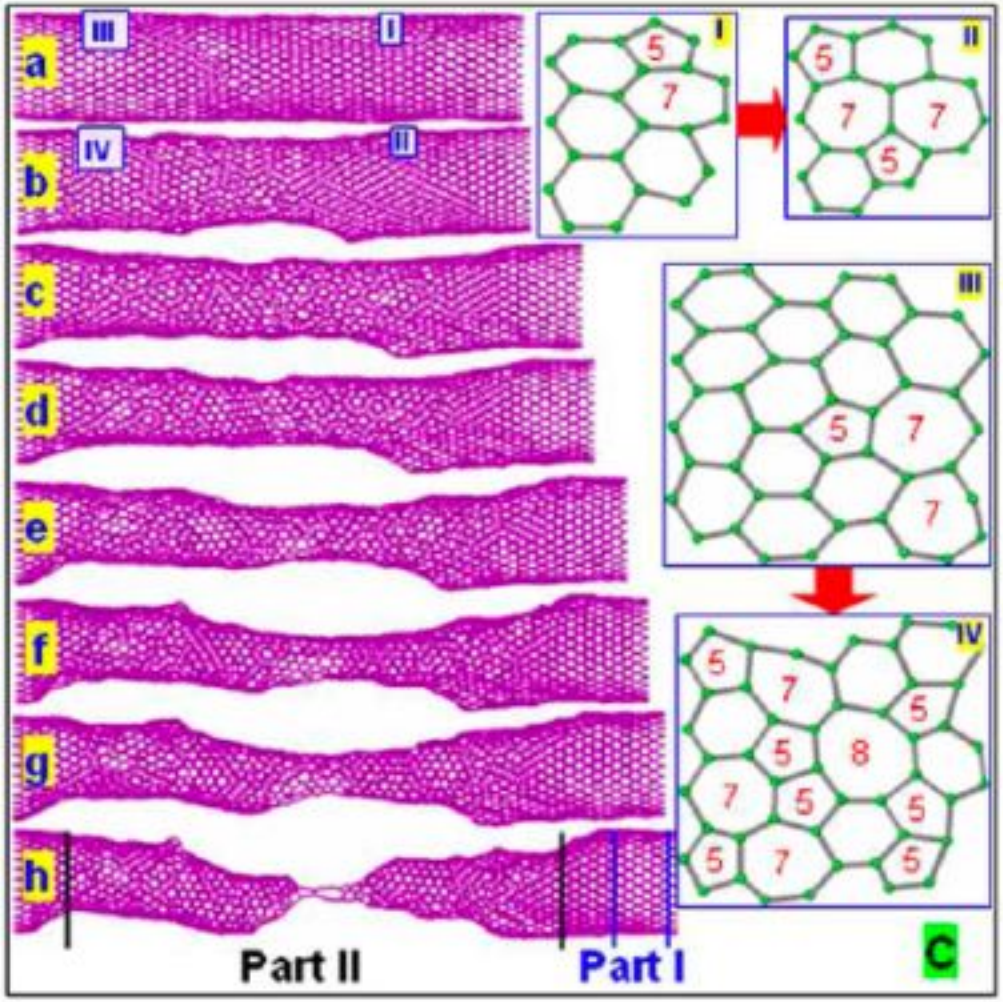




Huang *et al.*, Nature 439, 281 (2006)
Huang *et al.*, PRL 98, 185501 (2007)
F. Ding, K. Jiao, Q.M. Wu, B.I. Yakobson, PRL 98, 075503 (2007)

Super-Elongation of Carbon Nanotubes

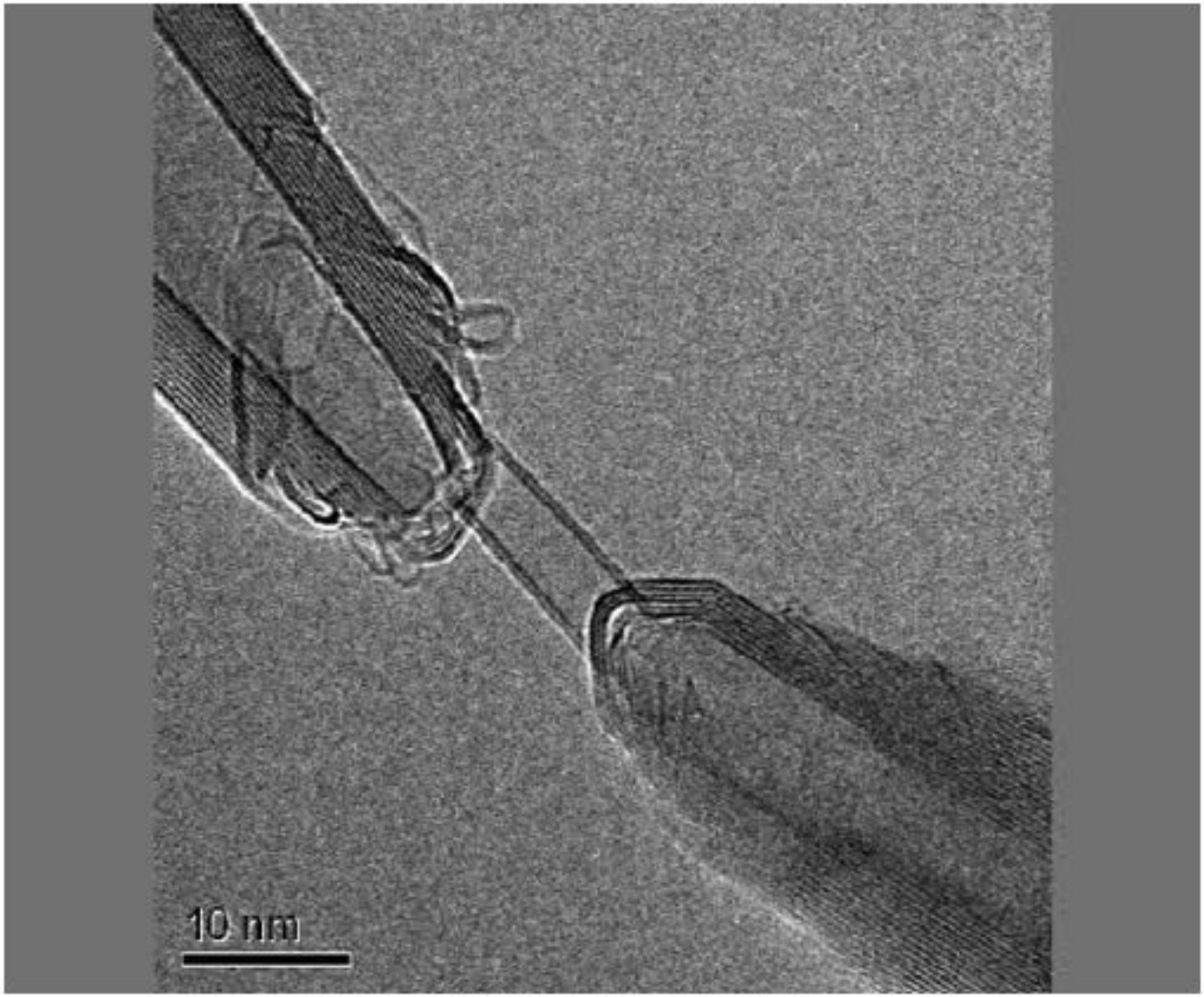
Can TEAM images atomic structure of nanotubes? Chirality, point defects?



C. Tang, W. Guo, C. Chen, PRL 100, 175501 (2008)

Sandia National Laboratories

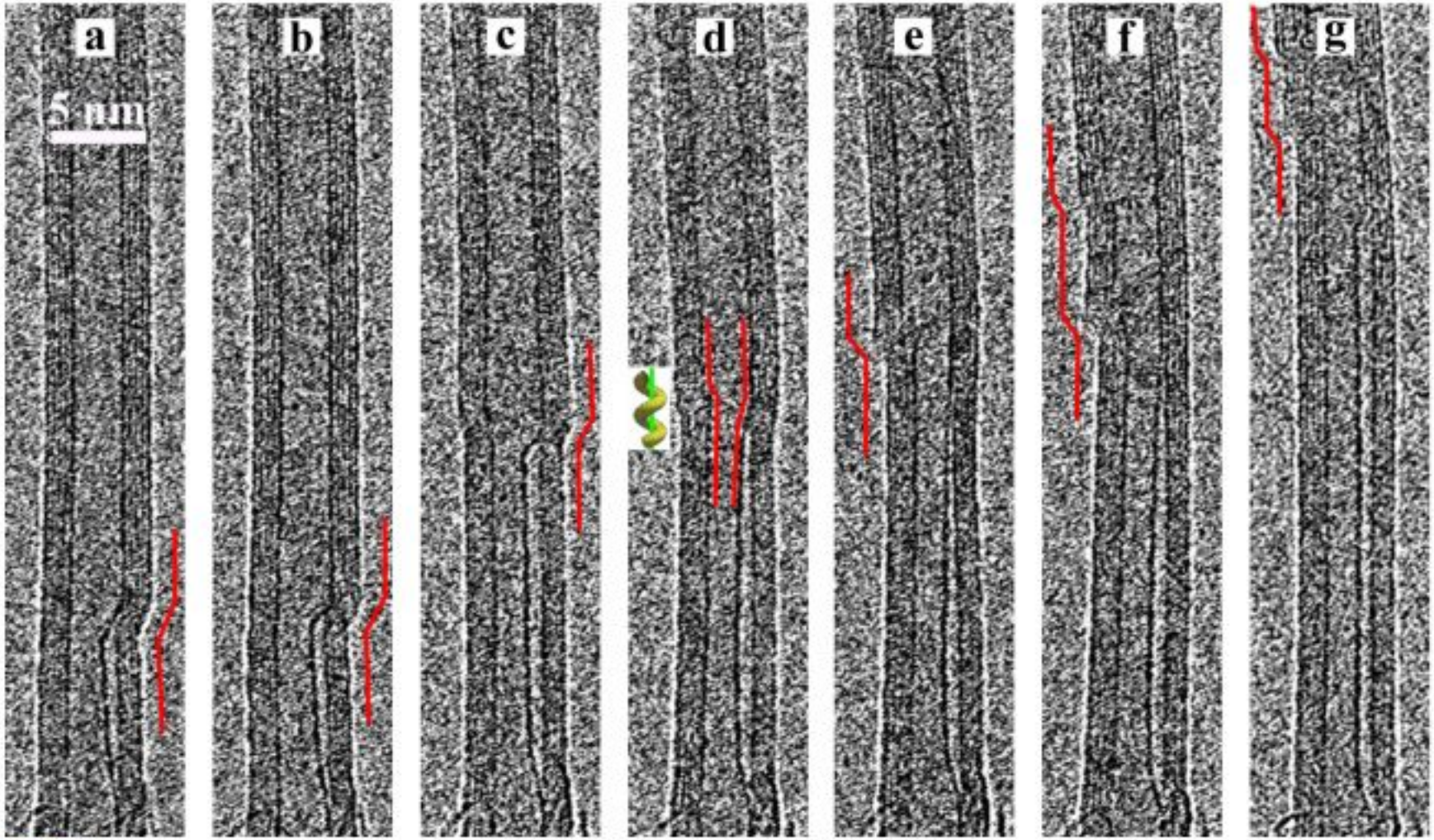
Tensile-Elongation of Individual DWCNTs



Sandia National Laboratories

Kink Motion in MWCNTs: Screw Motion

Huang *et al.*, PRL 97, 075501 (2006)

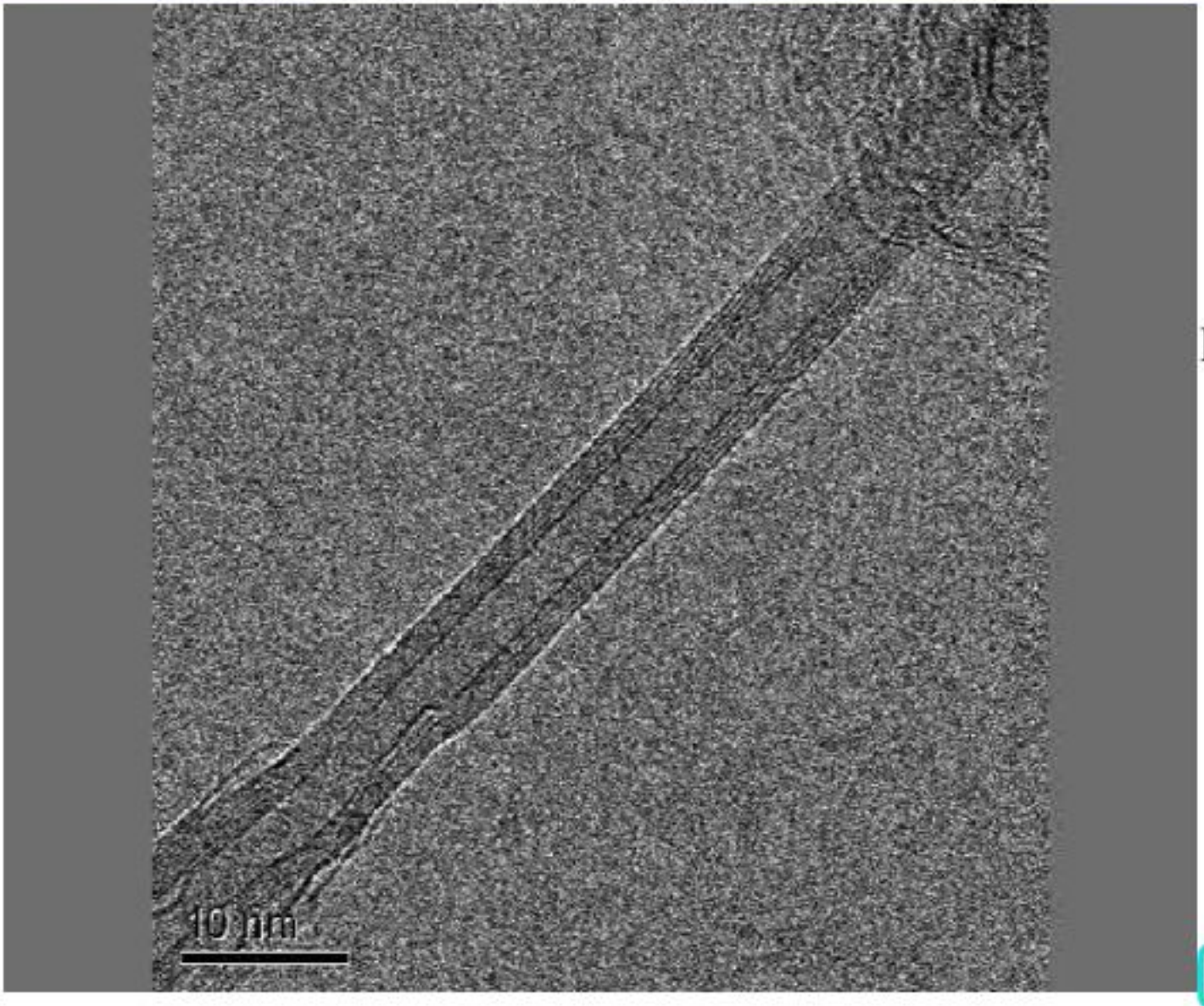


Can TEAM images atomic structure of of kinks?

The innermost wall is detached! V = 2 V, I = 100 μA, ε = 3%, v = 0.7 nm/s

Sandia National Laboratories

Kink Motion in MWCNTs

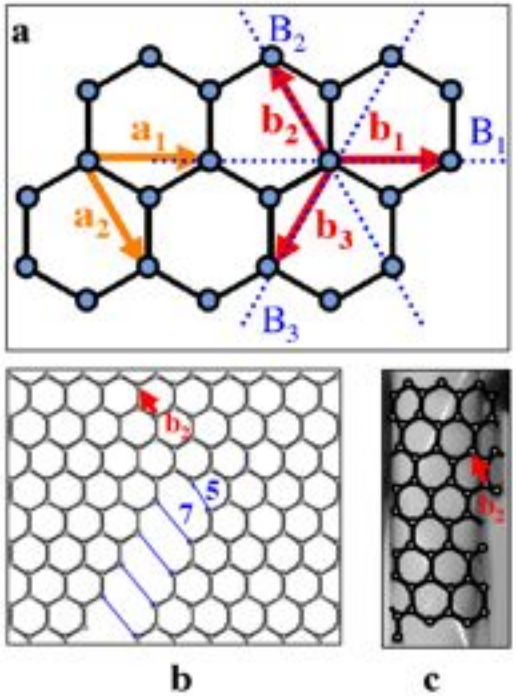


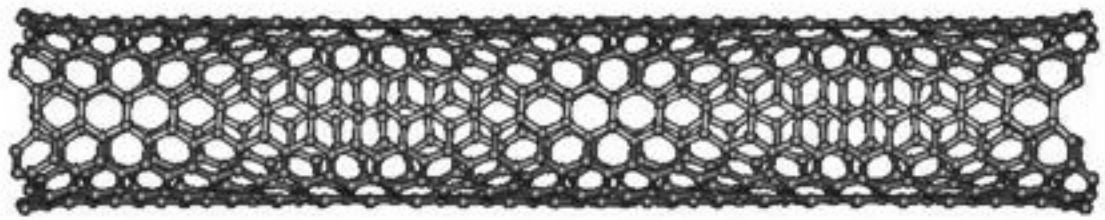
M8-5X

Sandia National Laboratories

Kink Motion Mechanism

Can TEAM images atomic structure of of dislocations in nanotubes? Core structure?





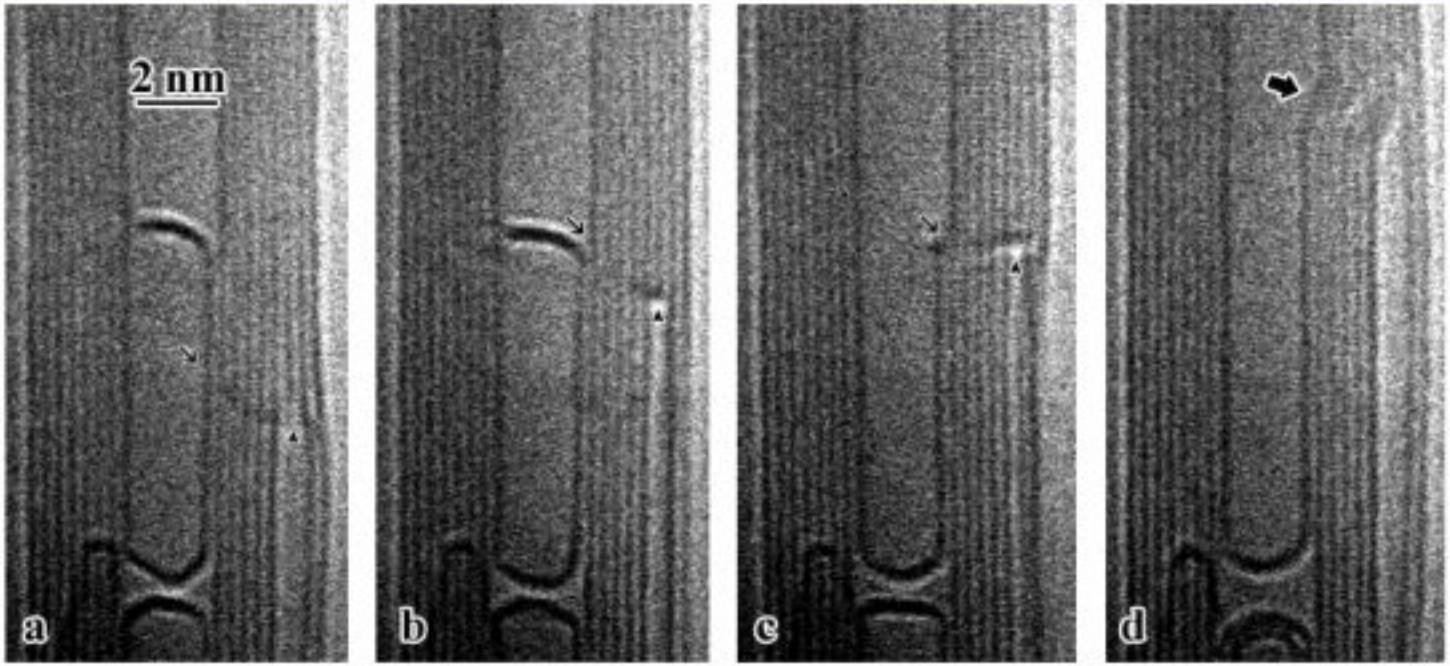
F. Ding, K. Jiao, Y. Lin, B.I. Yakobson Nano Lett. 7, 681 (2007)

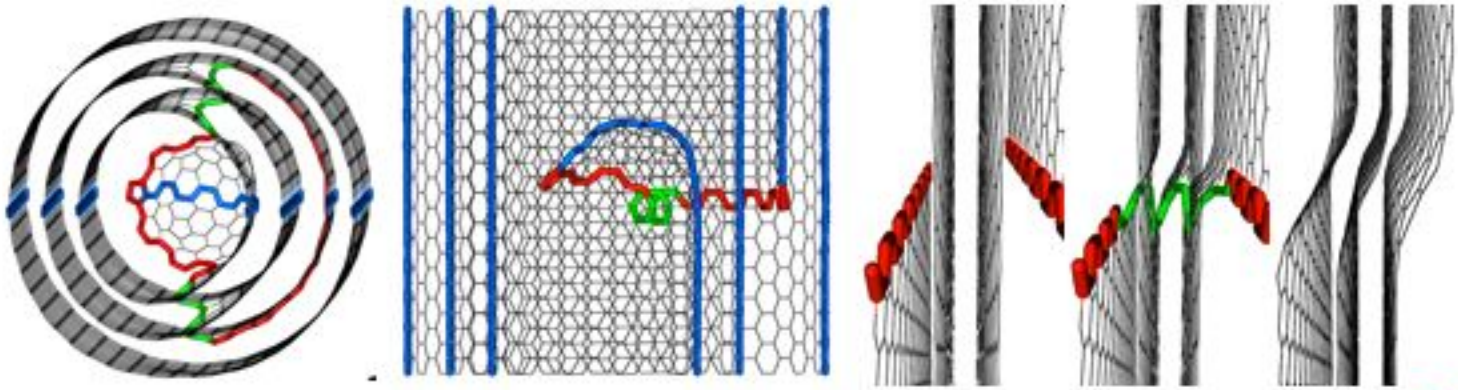
- Experiments: one kink in one direction in a straight path
- Longitudinal motion: dislocation climb
- Spiral motion: dislocation slip

Sandia National Laboratories

Dislocation in a MWCNT, b = 1/2<0001>

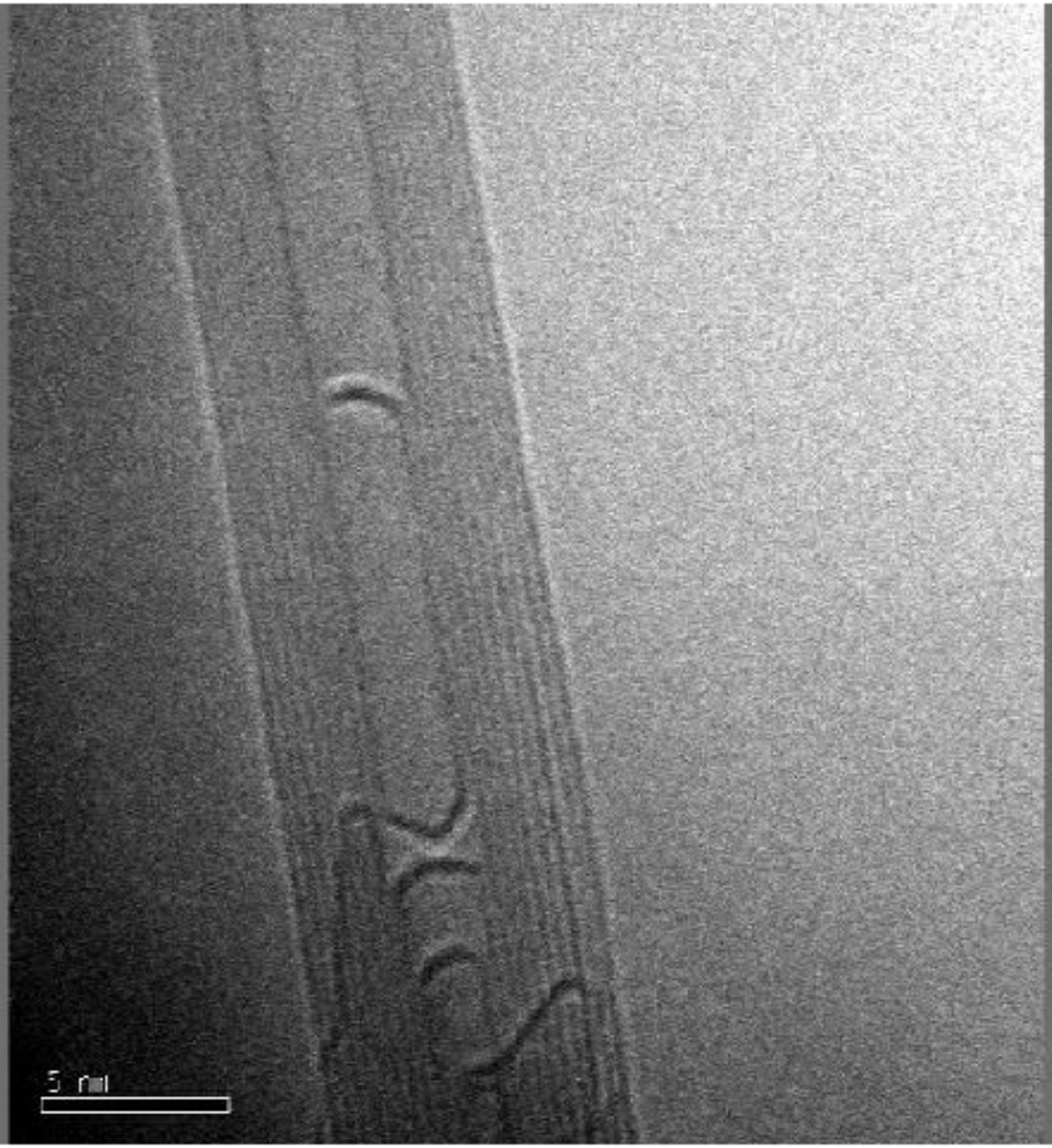
Can TEAM images atomic structure of of screw dislocations in nanotubes?





J.Y. Huang, F. Ding, B.I. Yakobson, PRL 100, 035503 (2008)

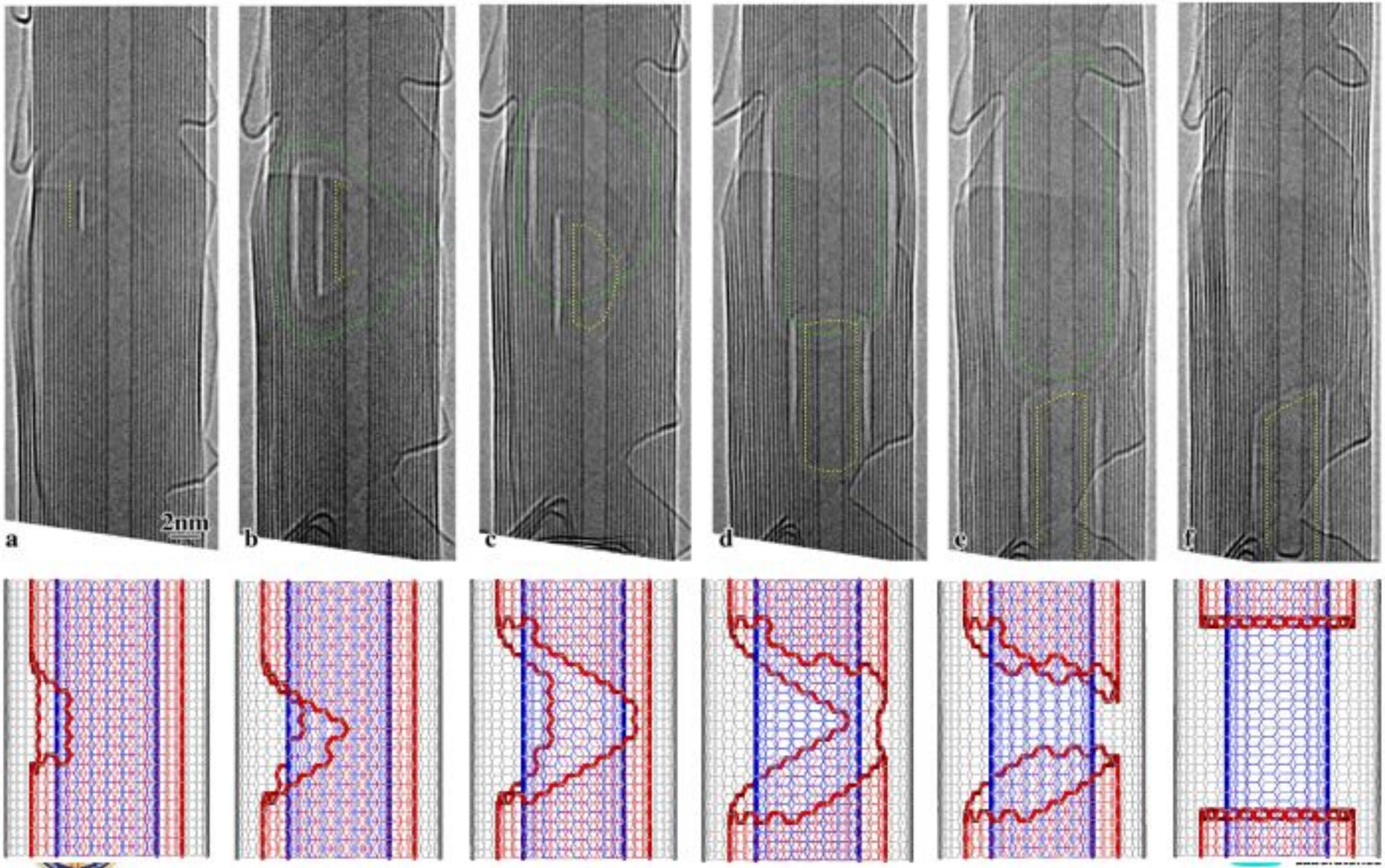
Sandia National Laboratories



Sandia National Laboratories

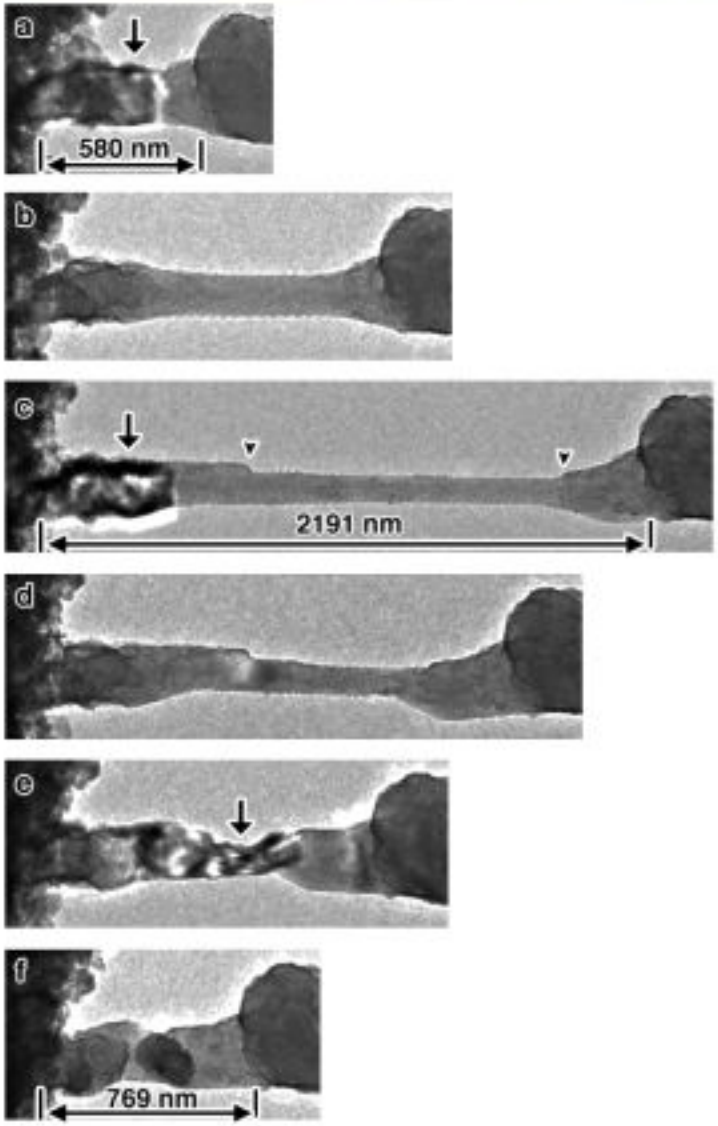
Vacancy Motion in MWCNTs

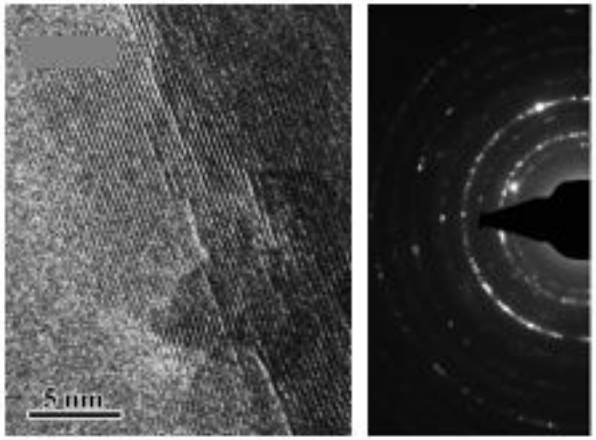
Huang, Ding, Yakobson (to be submitted)



Superelongation of Nanowires

Collaborators: J.H. Luo, S.X. Mao (U. Pitts), CINT Users; N.E. Moore, J.E. Houston (SNL)

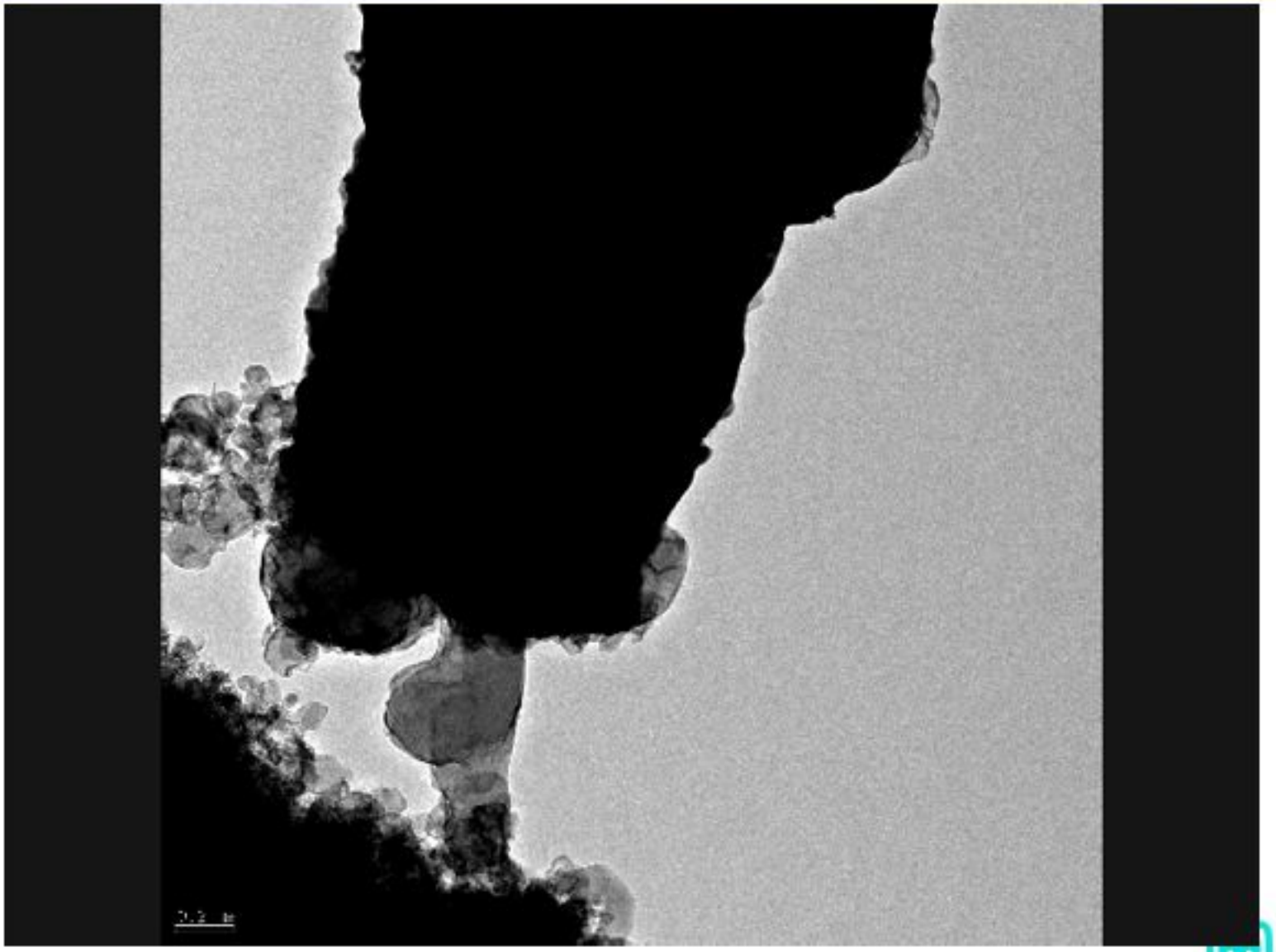




- Elongation: 278%
- Recrystallization
- No Dislocations!
- Recrystallization
- Nanocrystalline structure
- High density of defects
- High surface area
- Fast diffusion

Sandia National Laboratories

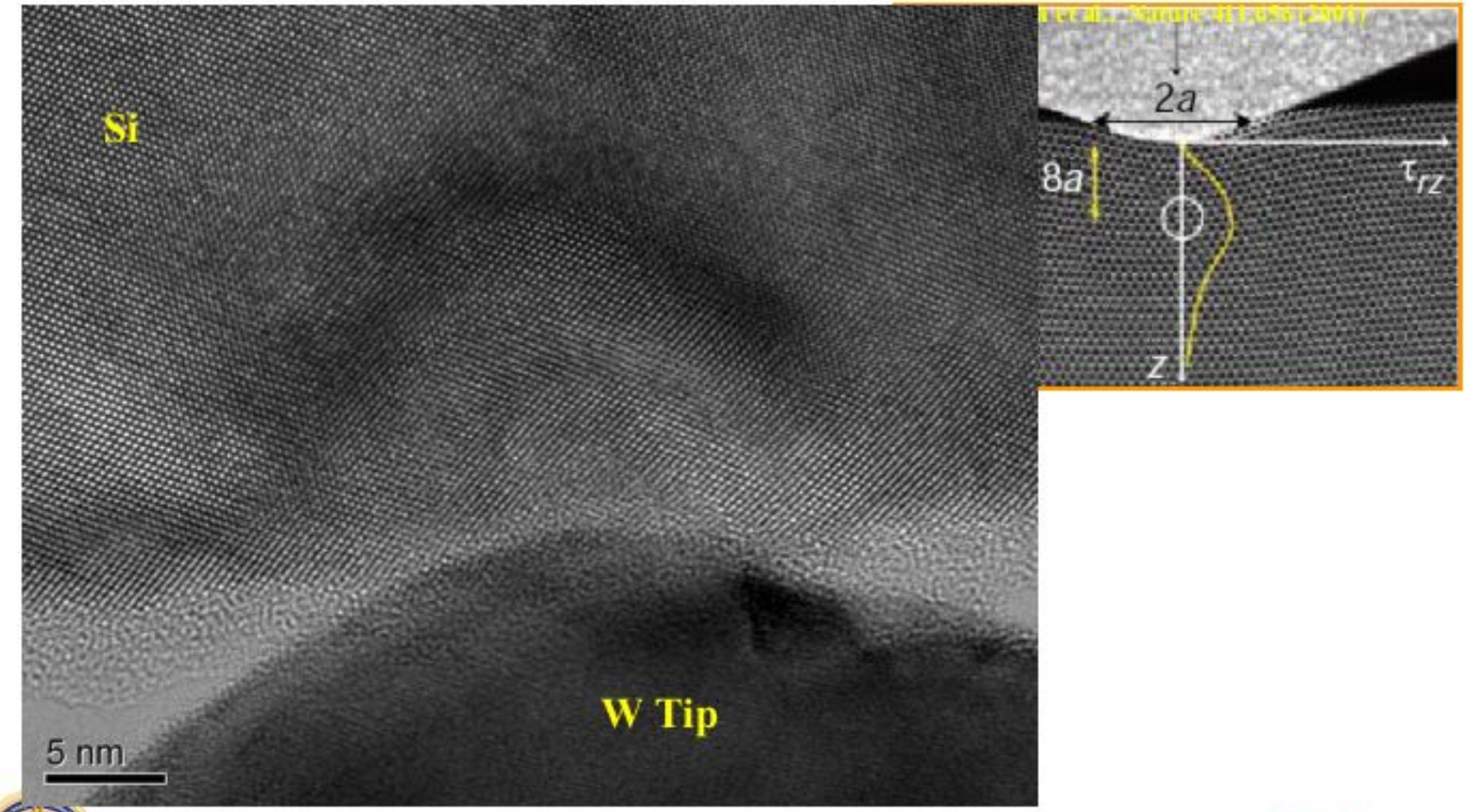
Superelongation of Nanowires

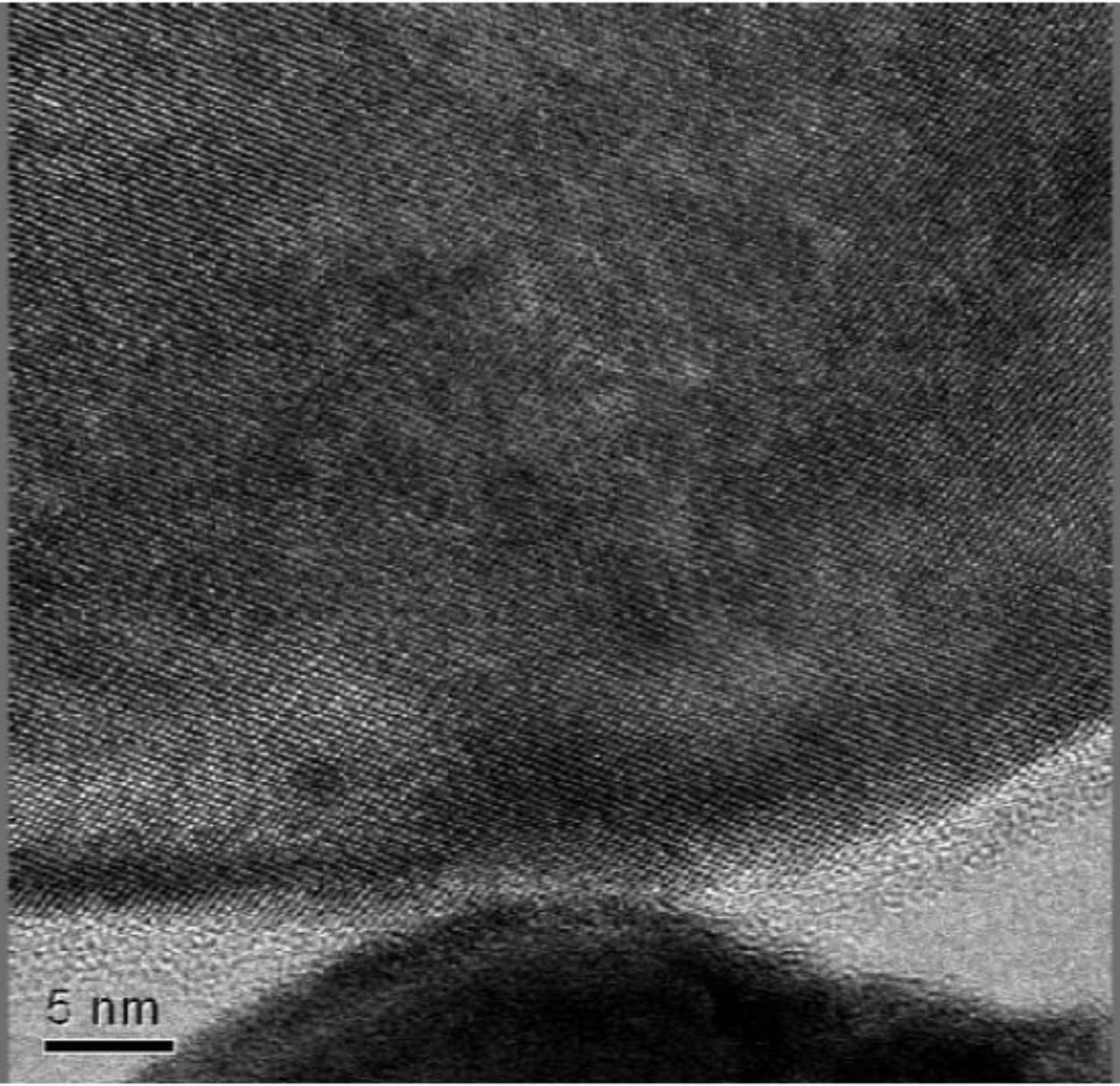


Sandia National Laboratories

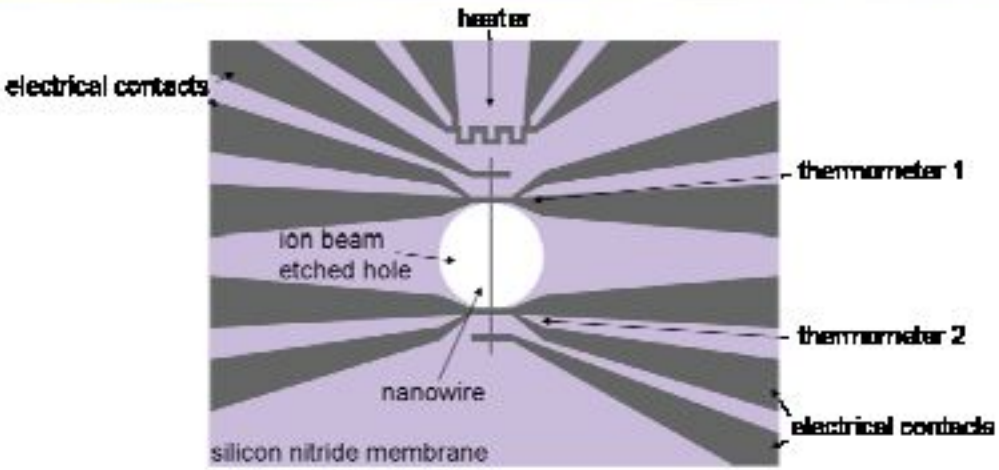
3-c. Nanoindentation of Si

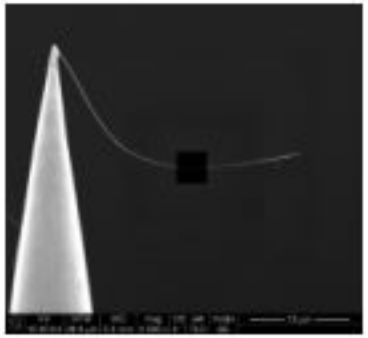
TEAM: core structure of dislocations

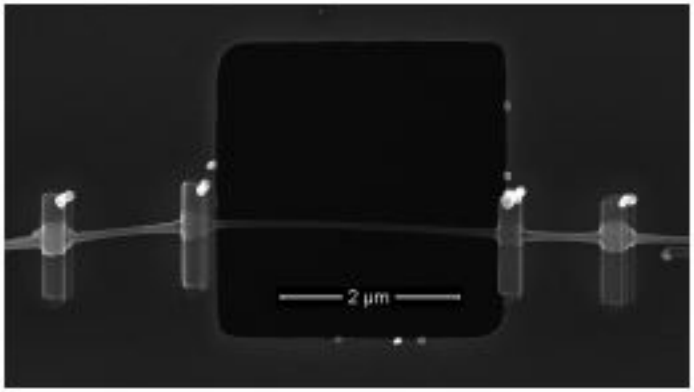


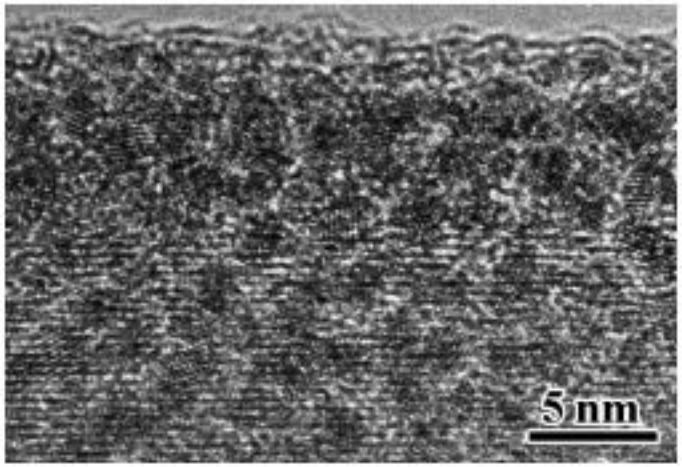

5 nm

In-Situ Thermal/Thermoelectric Properties of Individual Nanotubes/Nanowires









Allow HRTEM, thermal and electrical measurements on the same nanowire

J.Y. Huang, T.K. Kim, J.P. Sullivan, M.P. Siegel (SNL), T. Harris (student, MIT, CINT User)

Sandia National Laboratories

Summary

- TEM-SPM provides unprecedented opportunity to probe the mechanical, electrical, thermal properties in-situ and at an atomic scale of nanostructured materials.

- TEAM + TEM-SPM: improve the in-situ studies to a new level, reach a new landmark (sub Angstrom spatial resolution + less than 0.2 eV EELS resolution)!

- But when, how?

Sandia National Laboratories

Acknowledgements

Sandia National Lab.: Drs. Bob Hwang, Barney Doyle, J.P. Sullivan, M. Siegal

MIT: Profs M. Dresselhaus, G. Chen, Dr. S. Chen, Mr. C.T. Harris

Rice University: Prof. B.I. Yakobson, Dr. F. Ding

Boston College: Profs Z.F. Ren, Z.Q. Wang

Harvard: Prof. Z. Suo

University of Michigan: Prof. M. Vaziri

LLNL: Dr. Y.M. Wang

University of Pittsburgh: Prof. S.X. Mao, Mr. J.H. Luo

Supported by LDRD, DOE-BES, NSF

Sandia National Laboratories