2011 is the 20th ‘Anniversary’ of the Nanotube.

Will a recent discovery made at Jefferson Lab revolutionize the field?

<u>NASA</u>
<u>Langley Research Center</u>

Michael W. Smith
Peter Lillehei
Joycelyn Harrison (now AFOSR)
Sheila Thibeault
Sharon E. Lowther
William Humphreys
Catharine Fay
Joseph Lee
Peter Gnoffo
Ken Wright
Rob Bryant
Dennis Bushnell

<u>Thomas Jefferson National Accelerator Facility</u>

Kevin C. Jordan
Steve Benson
Michelle Shinn
George Neil
Gwyn Williams
George Biallas
Matt Marchlick
Kandice Carter
Fred Dylla (now director, AIP)

<u>W&M</u>

Brian Holloway (now DARPA)

<u>National Institute of Aerospace</u>

Cheol Park
Jae-Woo Kim
Roy Crooks
Godfrey Sauti
Jin Ho Kang
Luke Gibbons (VA Tech)

<u>Old Dominion University</u>

Wei Cao

image: moonrise from the ISS, http://spaceflight.nasa.gov

image: moonrise from the ISS, http://spaceflight.nasa.gov

Boron Nitride Nanotubes

The Most Interesting ‘Stuff’ You May Have Barely Heard of...

NOVAWEDNESDAYS

Making Stuff: Series Overview

Technology reporter David Pogue hosts a four-part special series exploring the materials that will shape our future. **Premiering January 19, 2011** on PBS

Posted 07.29.10

NOVA

Watch Making Stuff: Series Overview

Premiering January 19, 2011 on PBS

EDITORS' PICKS

What's This Stuff?

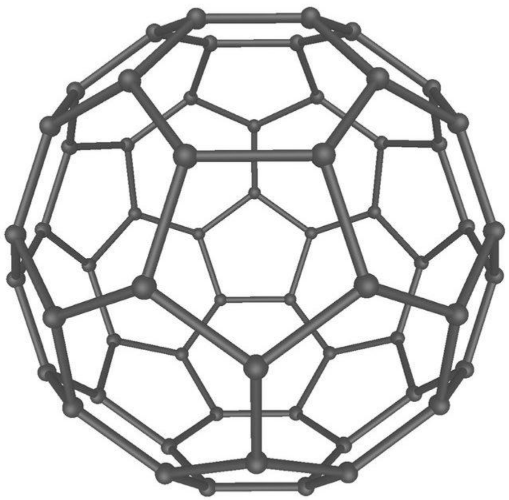
Think you know your stuff? Identify 10 mystery materials from a set of clues.

Making Stuff: Stronger

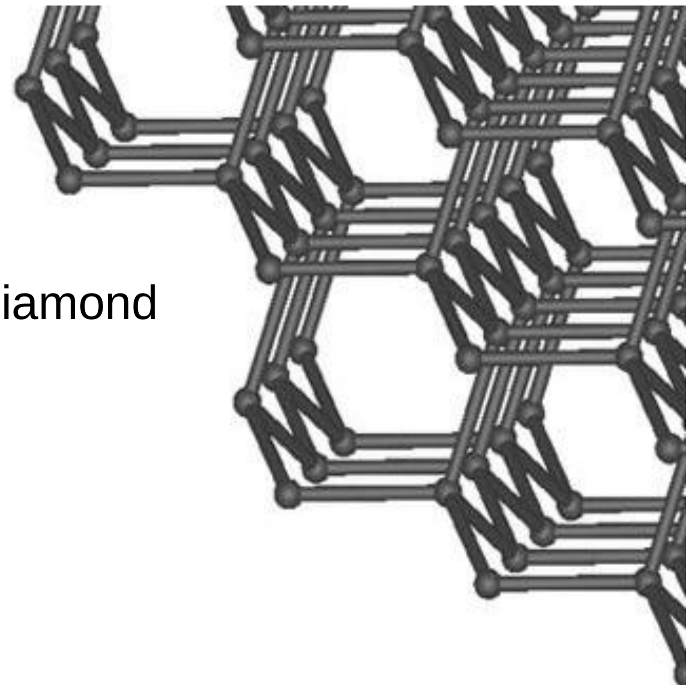
David Pogue tests his mettle against the world's strongest stuff, from steel and Kevlar to bioengineered silk.

www.pbs.org

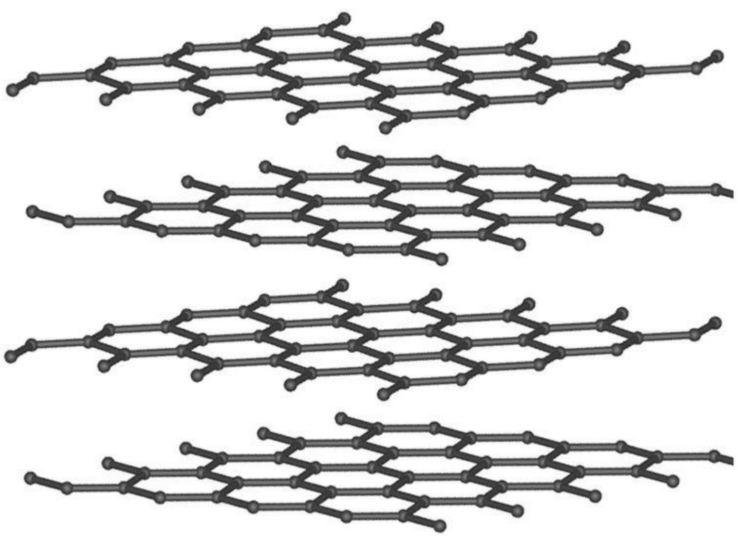
Forms (Allotropes) of Carbon



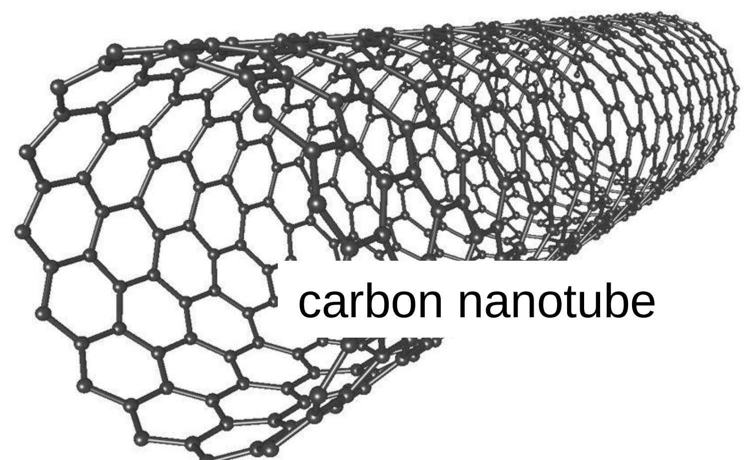
buckyball



diamond



graphite



carbon nanotube

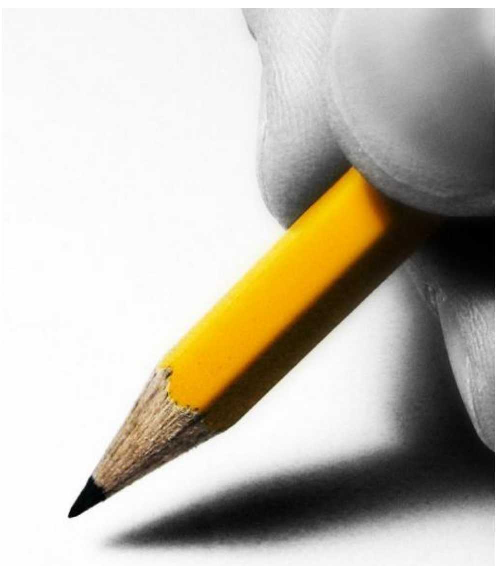
Images: wikipedia.org

Macro Forms of Carbon

From left to right: **C60, C70, C76/C78, C84** in solution.

buckyballs

diamond

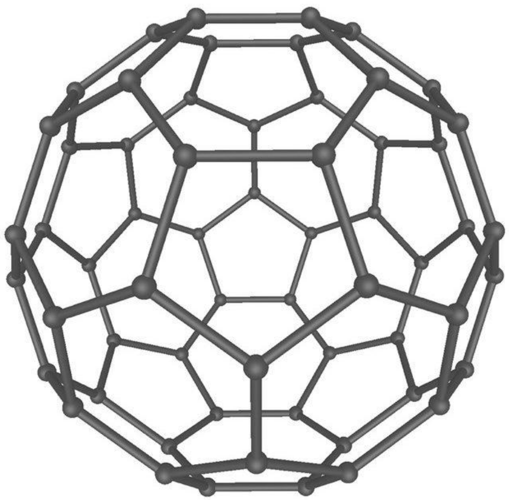


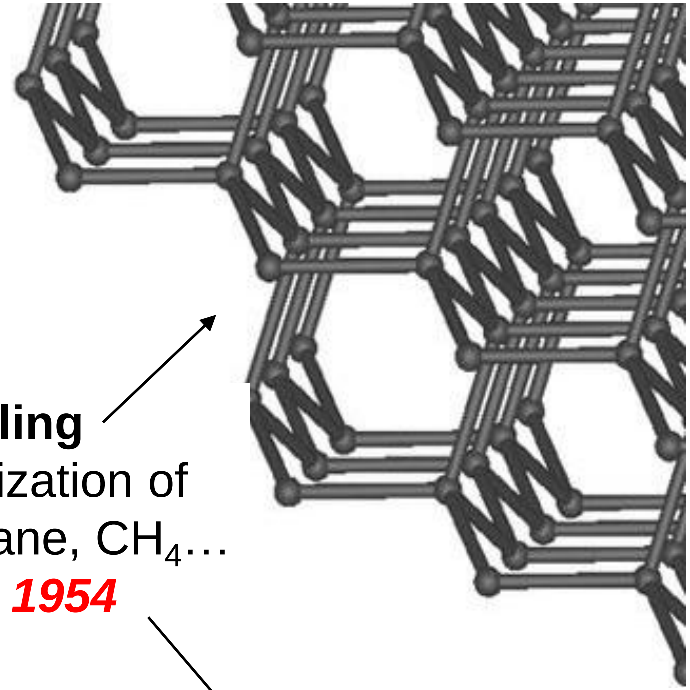
graphite

carbon nanotubes

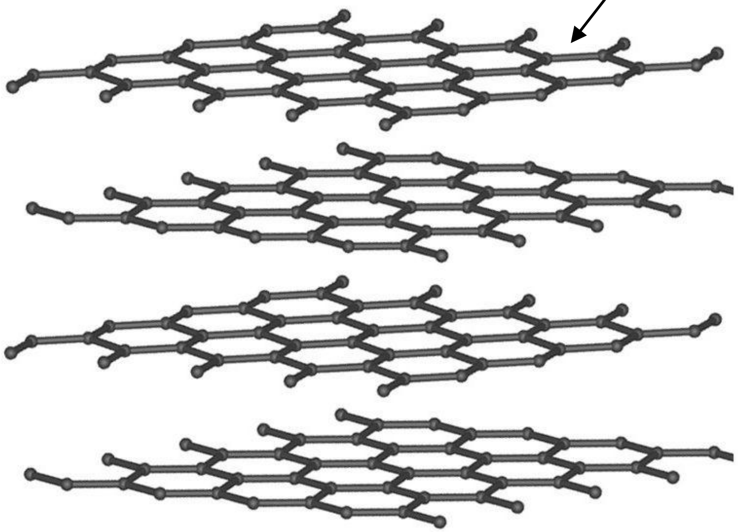
Images: www.nano-c.com www.megaexecutive.com www.diamondvues.com www.teamdeltax.com

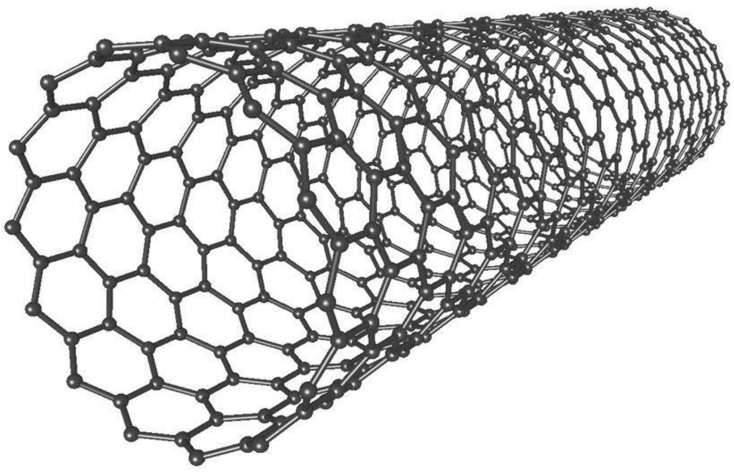
Allotropes of Carbon



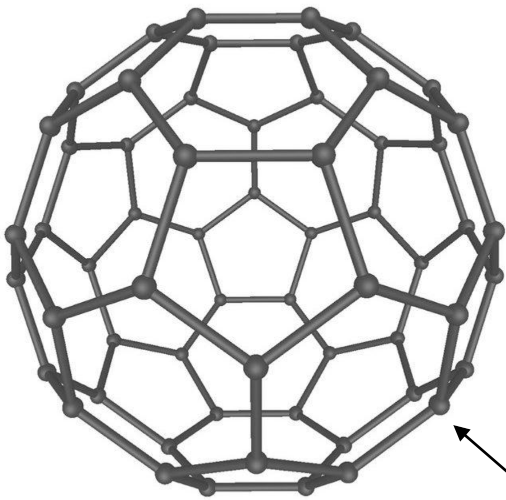


Linus Pauling
proposed hybridization of
sp bonds in methane, CH_4…
Nobel Prize 1954

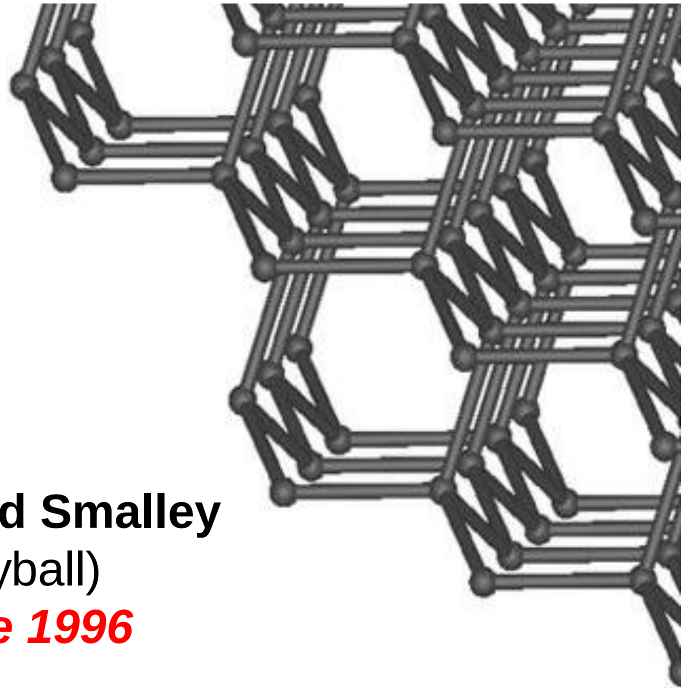


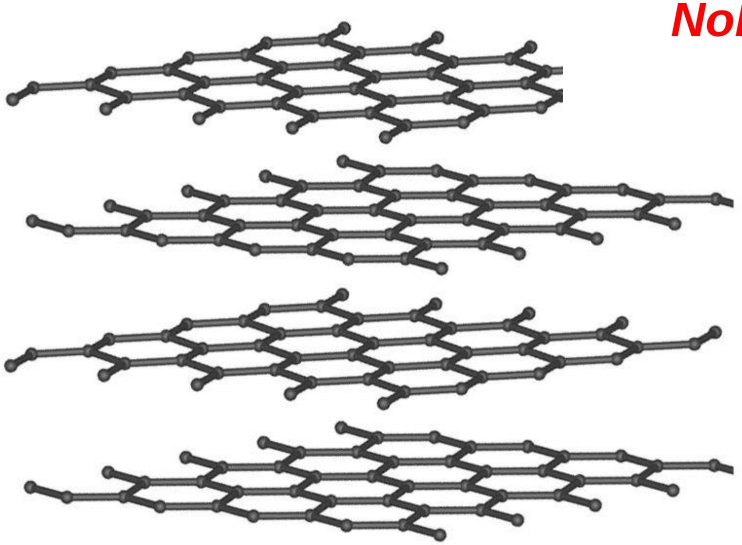


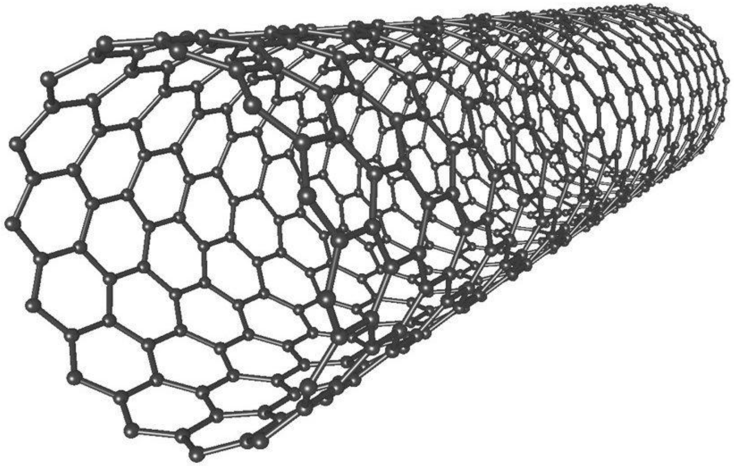
Allotropes of Carbon



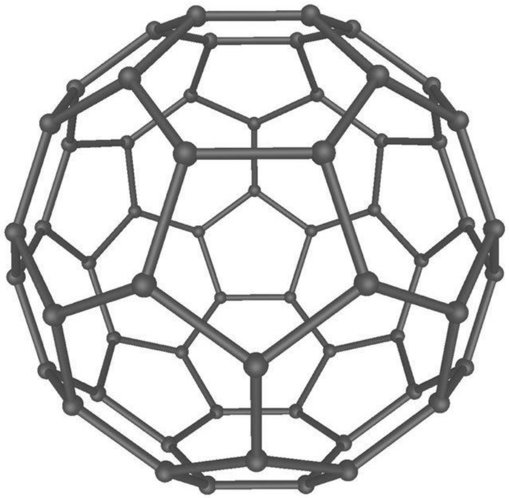
Kroto, Curl, and Smalley
C60 (buckyball)
Nobel Prize 1996

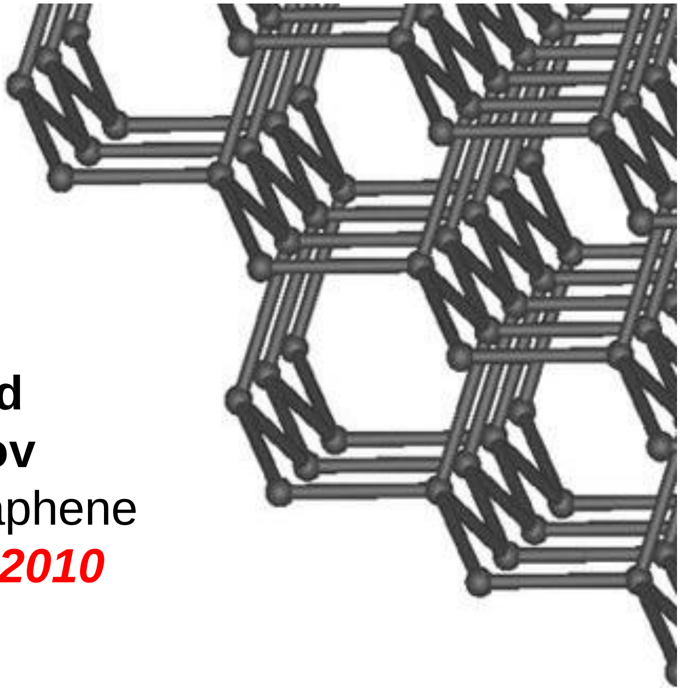






Allotropes of Carbon

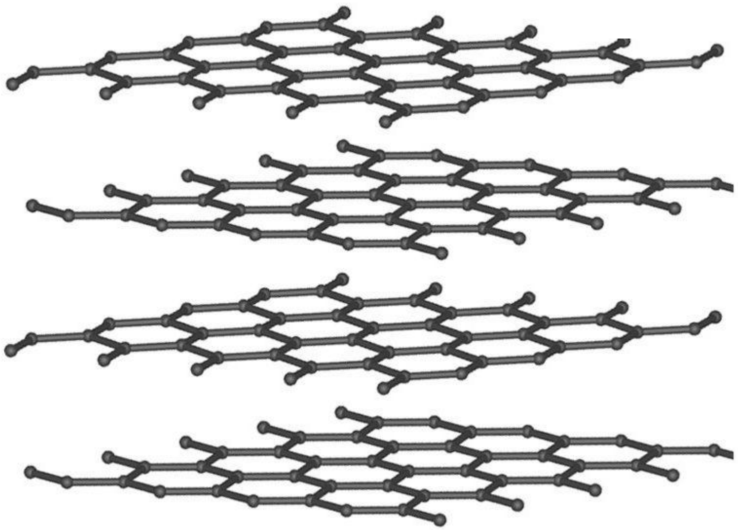


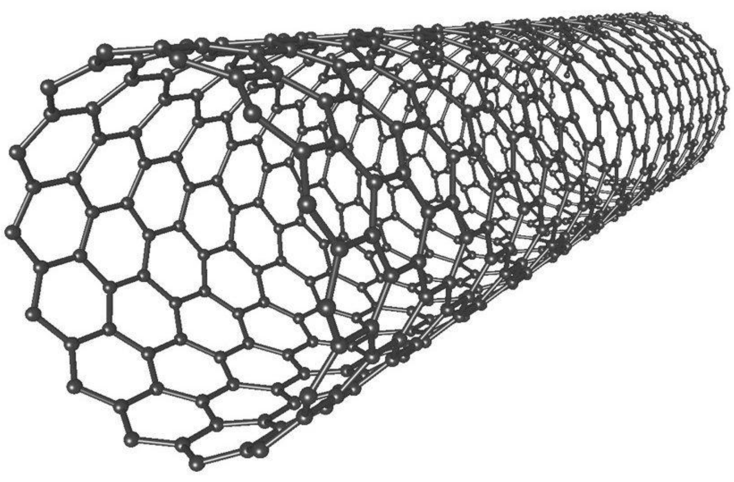


Geim and Novoselov

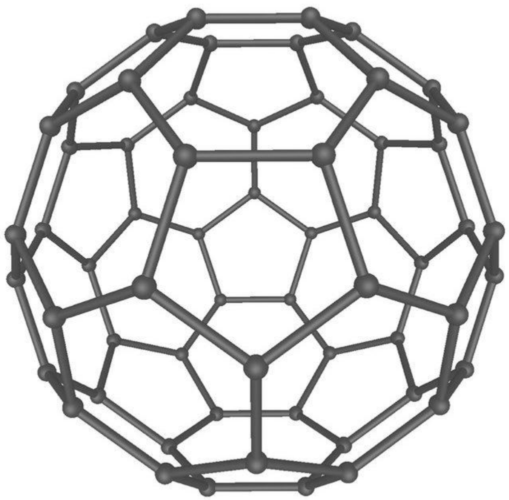
Isolation of graphene

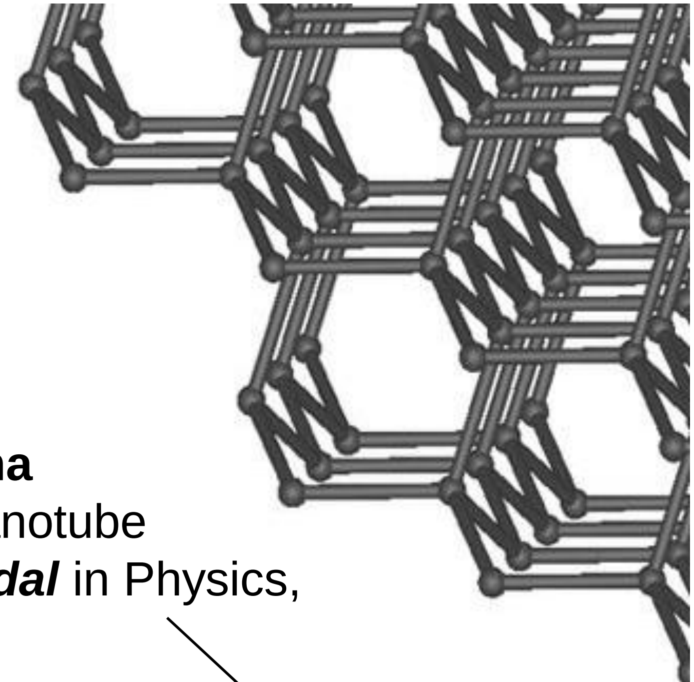
Nobel Prize 2010



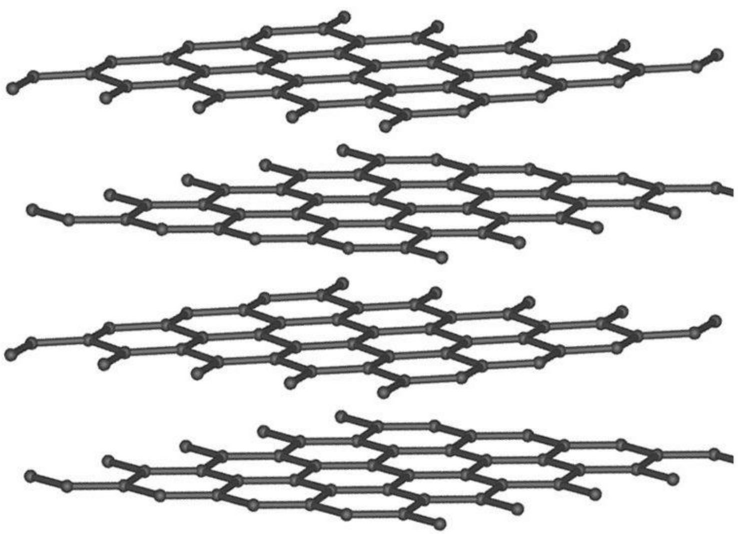


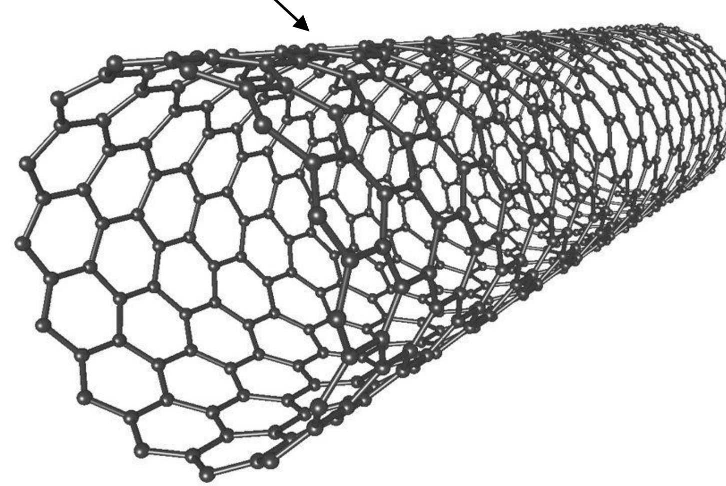
Allotropes of Carbon

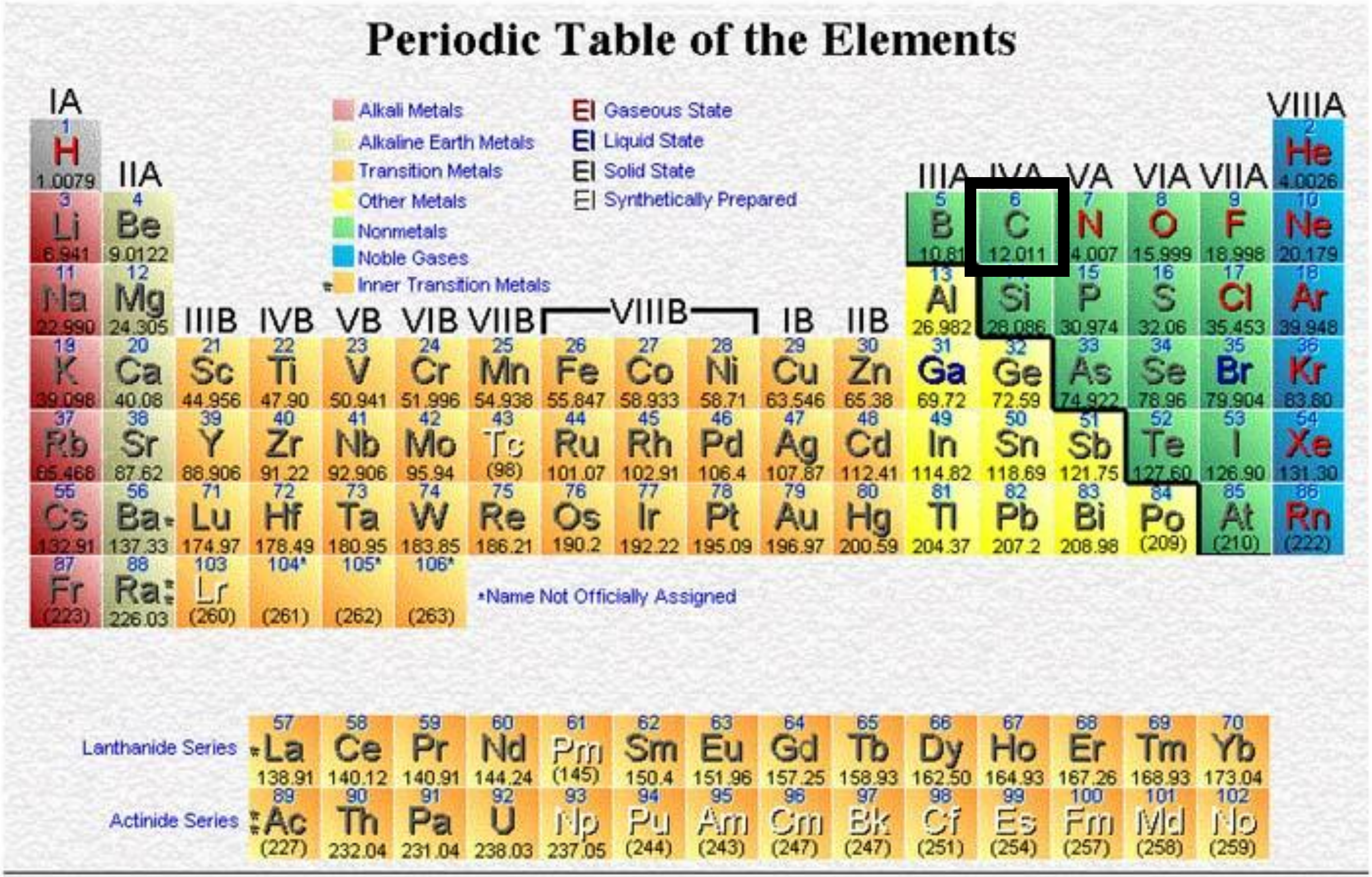




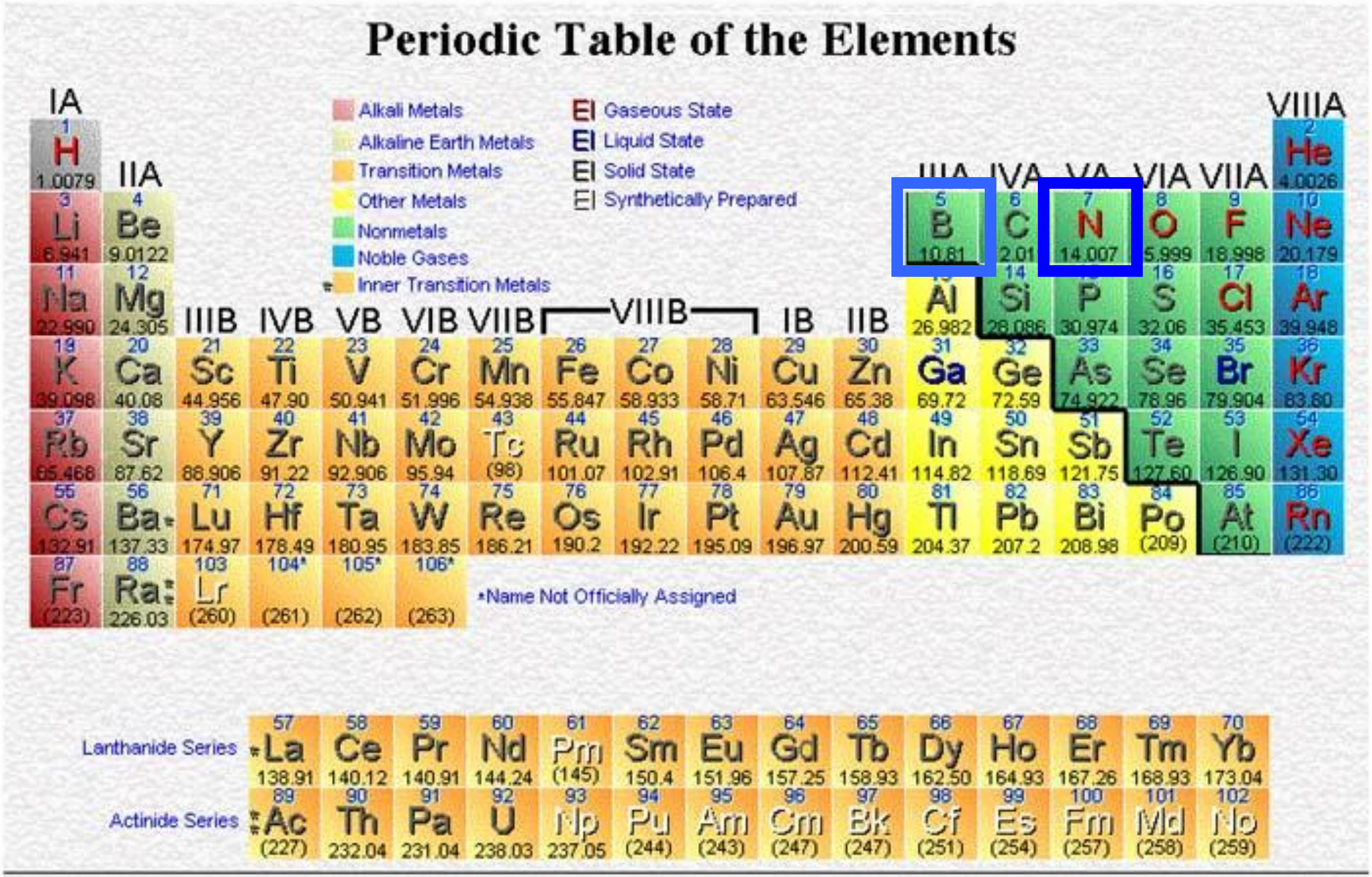
Sumio Ijima
2002 Carbon Nanotube
Benjamin Franklin Medal in Physics,







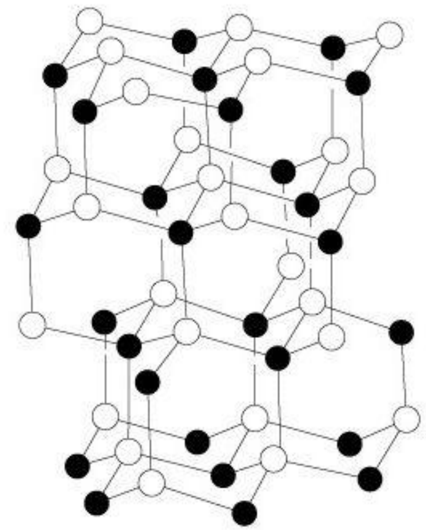
morrisonlabs.com


Periodic Table of the Elements
IA
IIA
IIIB IVB VB VIB VIIB VIIIB IB IIB
IIIA IVA VA VIA VIIA
VIIIA
Alkali Metals
Alkaline Earth Metals
Transition Metals
Other Metals
Nonmetals
Noble Gases
Inner Transition Metals
El Gaseous State
El Liquid State
El Solid State
El Synthetically Prepared
1 H 1.0079
2 He 4.0026
3 Li 6.941
4 Be 9.0122
5 B 10.81
6 C
7 N 14.007
8 O
9 F 18.998
10 Ne 20.179
11 Na 22.990
12 Mg 24.305
Al 26.982
14 Si 28.086
P 30.974
16 S 32.06
17 Cl 35.453
18 Ar 39.948
19 K 39.098
20 Ca 40.08
21 Sc 44.956
22 Ti 47.90
23 V 50.941
24 Cr 51.996
25 Mn 54.938
26 Fe 55.847
27 Co 58.933
28 Ni 58.71
29 Cu 63.546
30 Zn 65.38
31 Ga 69.72
32 Ge 72.59
33 As 74.922
34 Se 78.96
35 Br 79.904
36 Kr 83.80
37 Rb 85.468
38 Sr 87.62
39 Y 88.906
40 Zr 91.22
41 Nb 92.906
42 Mo 95.94
43 Tc (98)
44 Ru 101.07
45 Rh 102.91
46 Pd 106.4
47 Ag 107.87
48 Cd 112.41
49 In 114.82
50 Sn 118.69
51 Sb 121.75
52 Te 127.60
53 I 126.90
54 Xe 131.30
55 Cs 132.91
56 Ba 137.33
71 Lu 174.97
72 Hf 178.49
73 Ta 180.95
74 W 183.85
75 Re 186.21
76 Os 190.2
77 Ir 192.22
78 Pt 195.09
79 Au 196.97
80 Hg 200.59
81 Tl 204.37
82 Pb 207.2
83 Bi 208.98
84 Po (209)
85 At (210)
86 Rn (222)
87 Fr (223)
88 Ra 226.03
103 Lr (260)
104* (261)
105* (262)
106* (263)
*Name Not Officially Assigned
Lanthanide Series
57 La 138.91
58 Ce 140.12
59 Pr 140.91
60 Nd 144.24
61 Pm (145)
62 Sm 150.4
63 Eu 151.96
64 Gd 157.25
65 Tb 158.93
66 Dy 162.50
67 Ho 164.93
68 Er 167.26
69 Tm 168.93
70 Yb 173.04
Actinide Series
89 Ac (227)
90 Th 232.04
91 Pa 231.04
92 U 238.03
93 Np 237.05
94 Pu (244)
95 Am (243)
96 Cm (247)
97 Bk (247)
98 Cf (251)
99 Es (254)
100 Fm (257)
101 Md (258)
102 No (259)

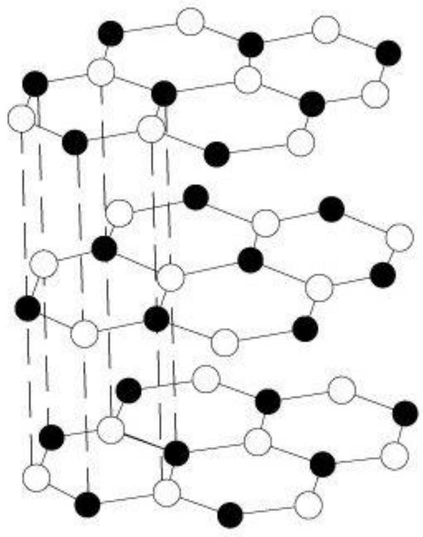
Forms of Boron-Nitrogen

BN ball

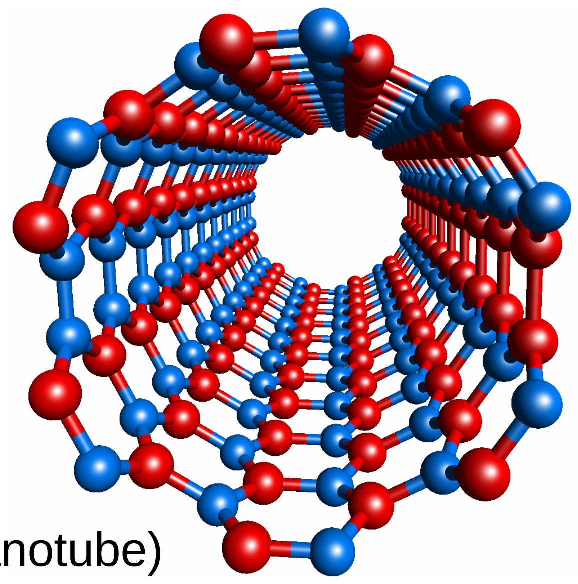
?



Cubic BN (cBN)



Hexagonal BN (hBN)

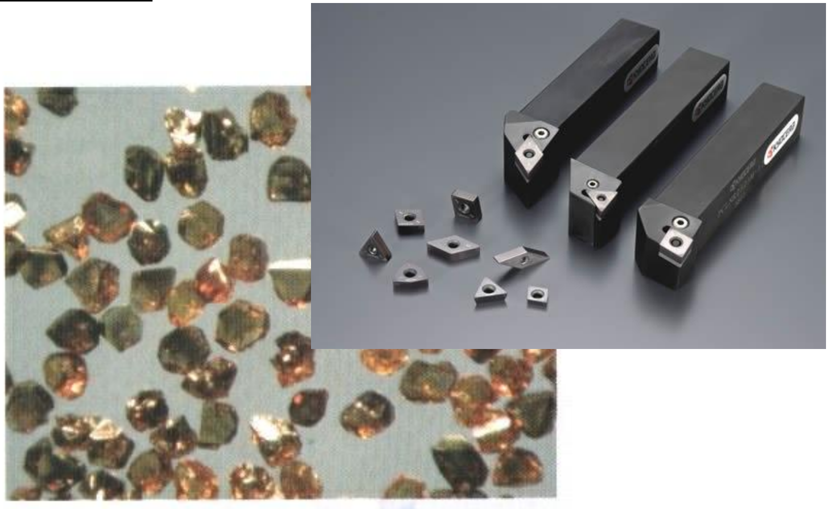


BNNT
(BN nanotube)

Images: www.mext.go.jp http://nano-bio.ehu.es

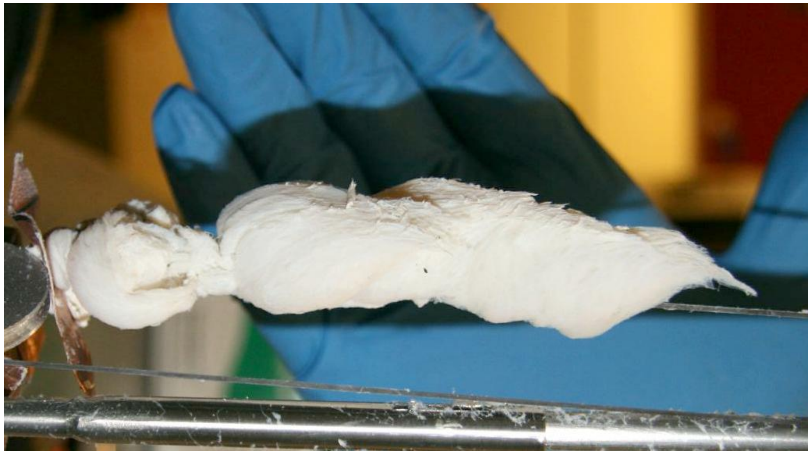
Macro Forms of BN

X



Diamond-like cubic BN

White ‘graphite’



Boron nitride nanotubes

Images: www.cybelesays.com www.kyocera.com.sg www.momentive.com

Boron Nitride Nanotubes (BNNTs)…

Are just as strong as carbon nanotubes
and are good thermal conductors too, but…

Have double the service temperature,
Are highly electro-active (due to polar bond),
Are good neutron shields (due to boron content),
Have more active surface chemistry,
Are white (you can dye them!).
Are non-cytotoxic (to human cells, so far),

But, BNNTs were much harder to make than CNTs.

…until now.

Structural similarities and differences, BNNT vs CNT…

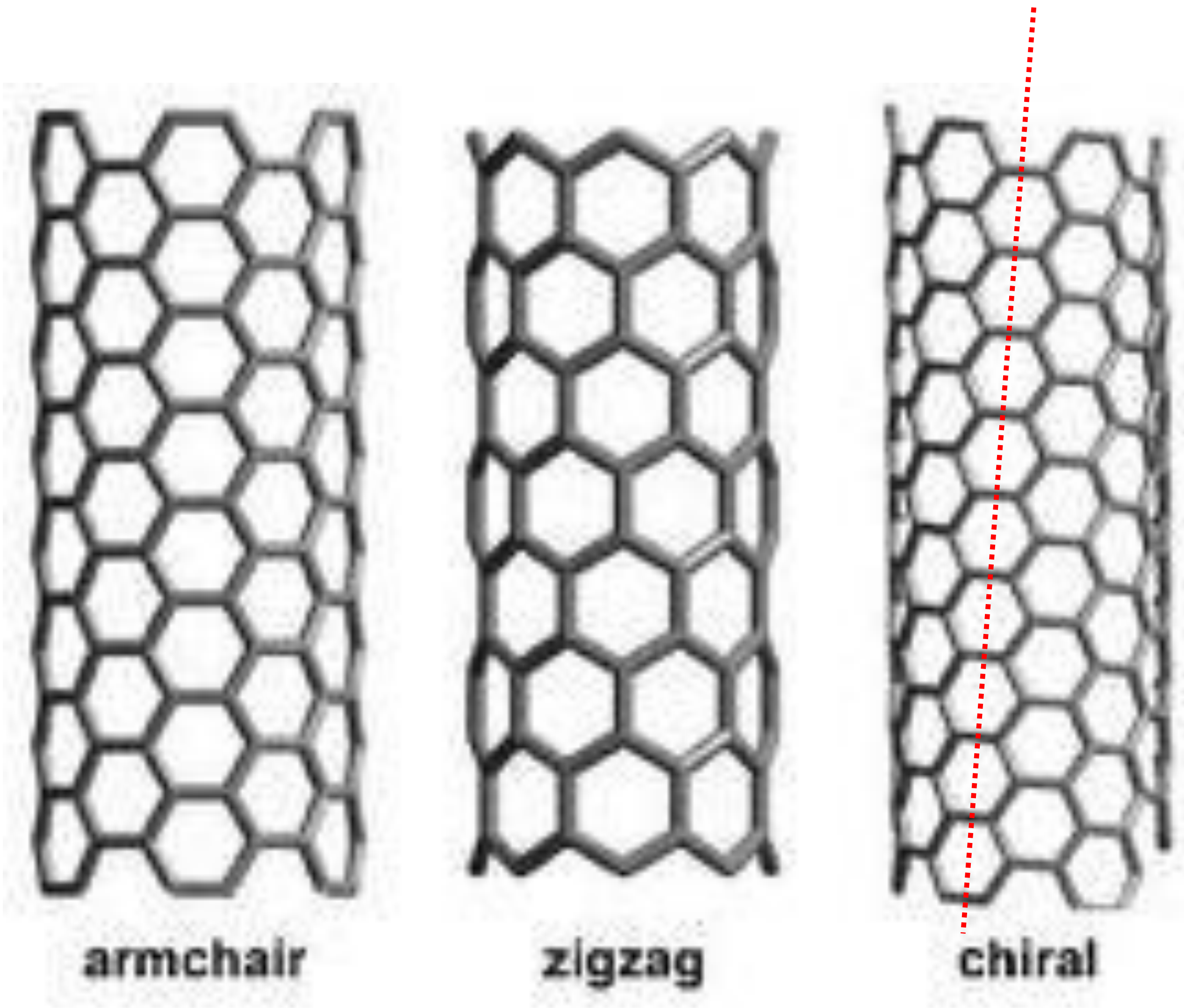
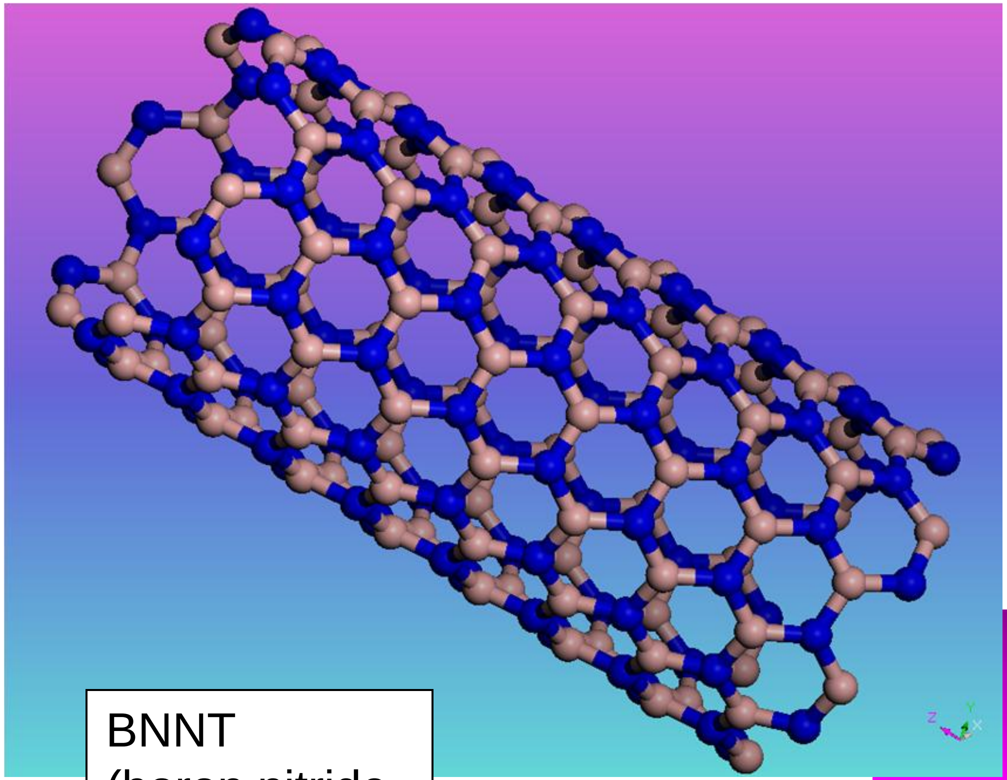
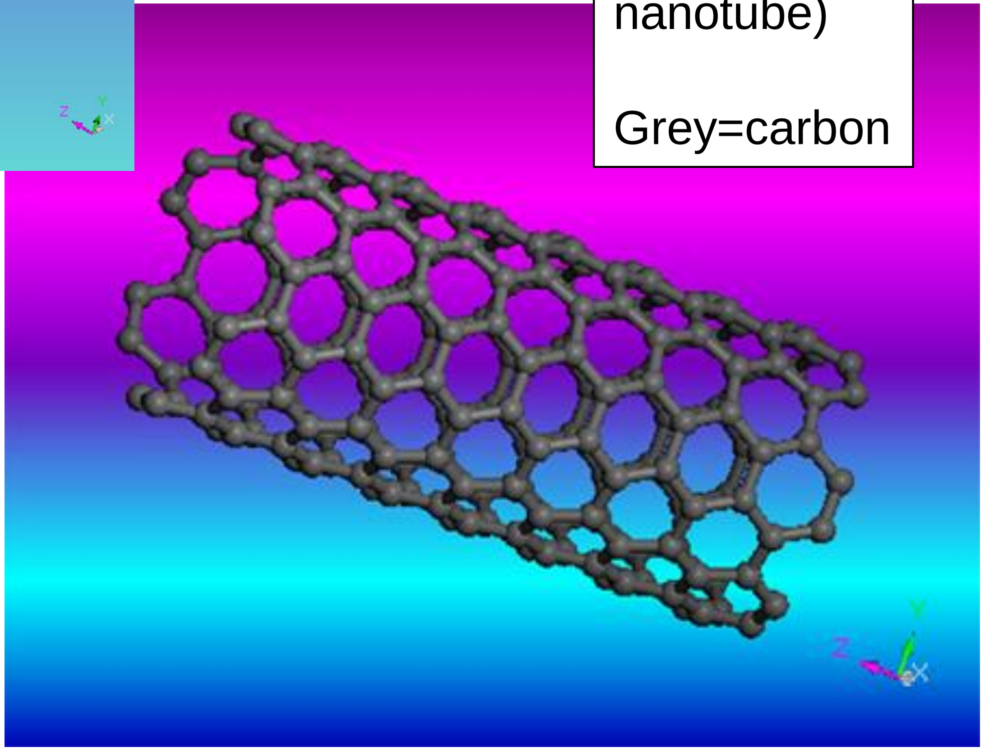


Image: coecs.ou.edu



BNNT
(boron nitride nanotube)

Blue=boron
Grey=nitrogen



CNT
(carbon nanotube)

Grey=carbon

images: www.computenano.com

Chiral BNNT

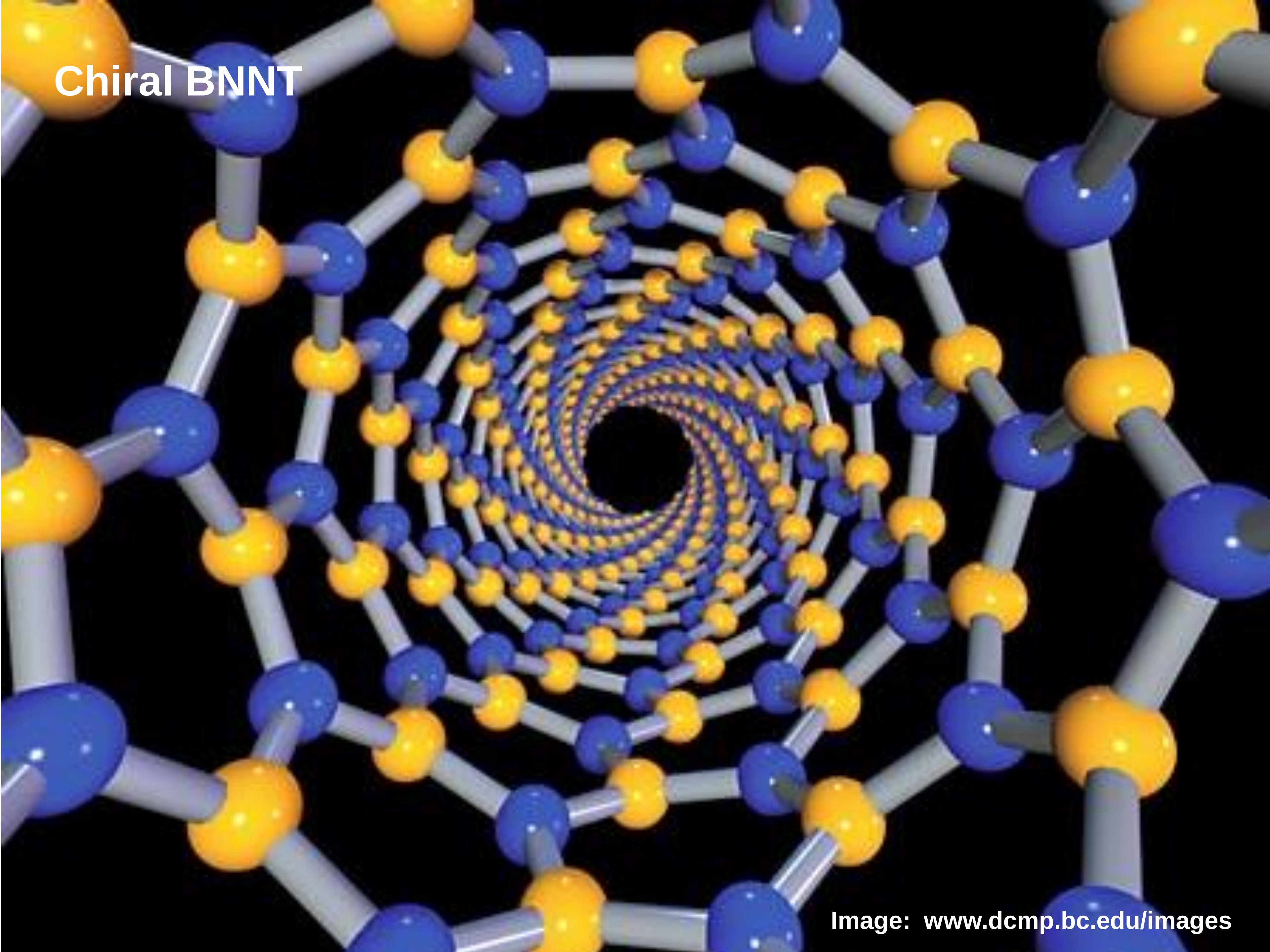


Image: www.dcmp.bc.edu/images

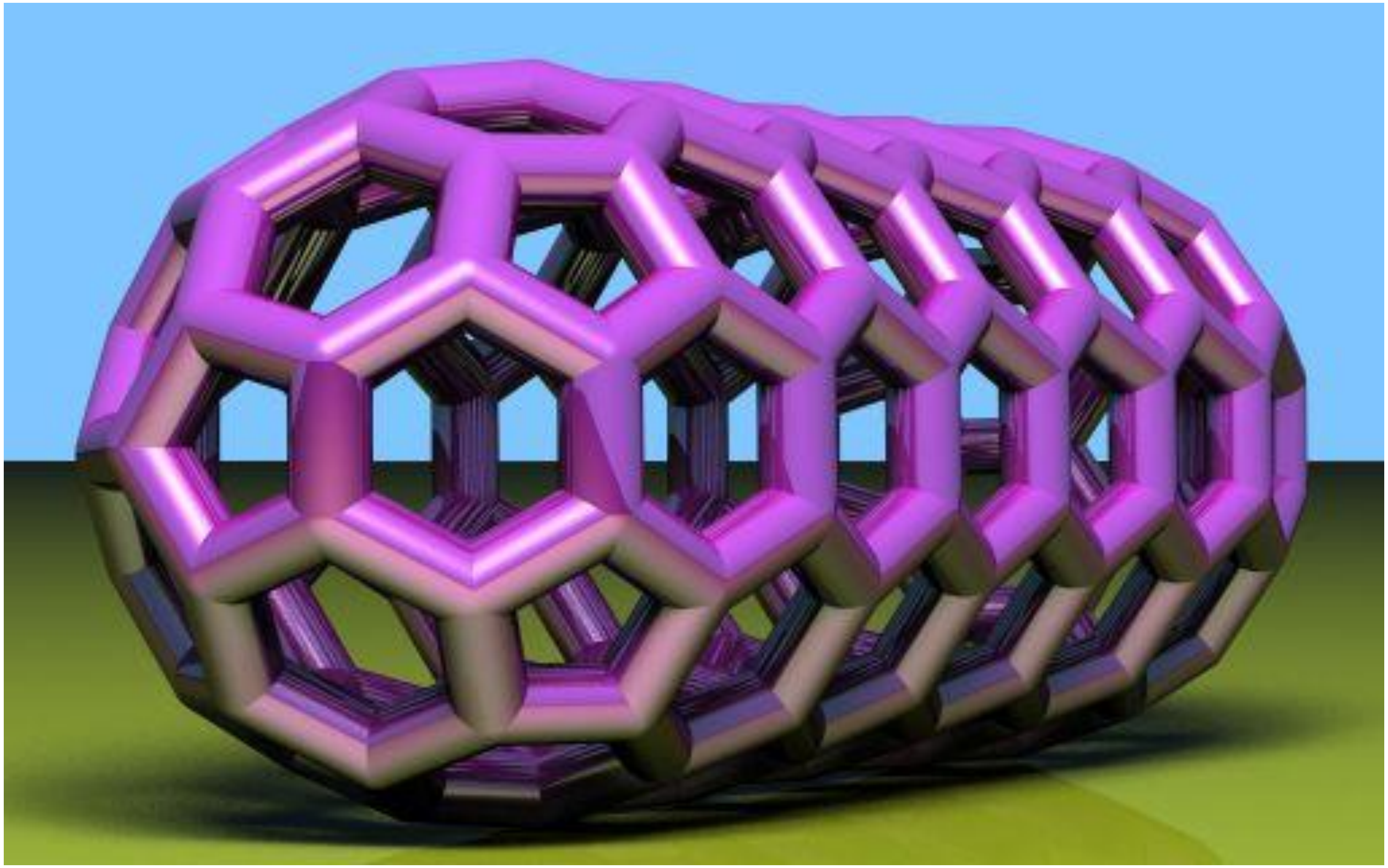
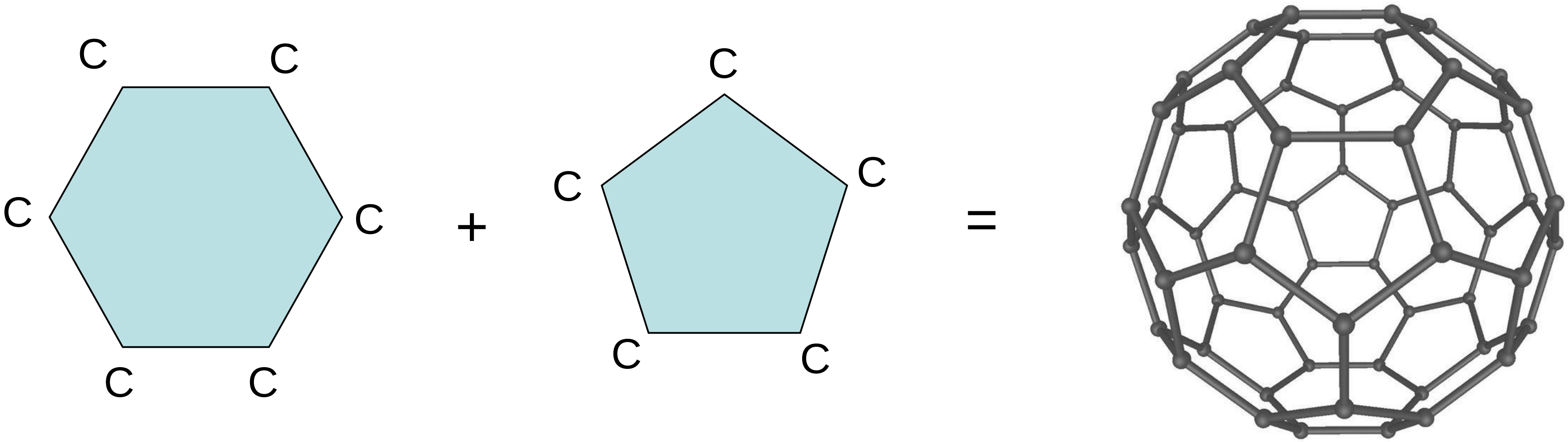
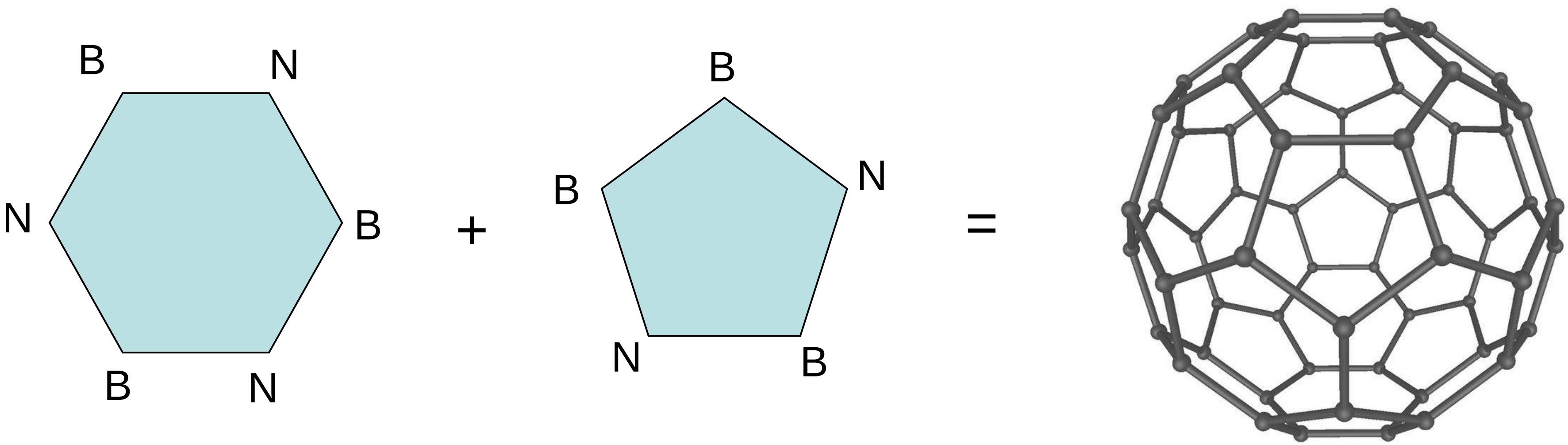


Image: http://home.icpf.cas.cz



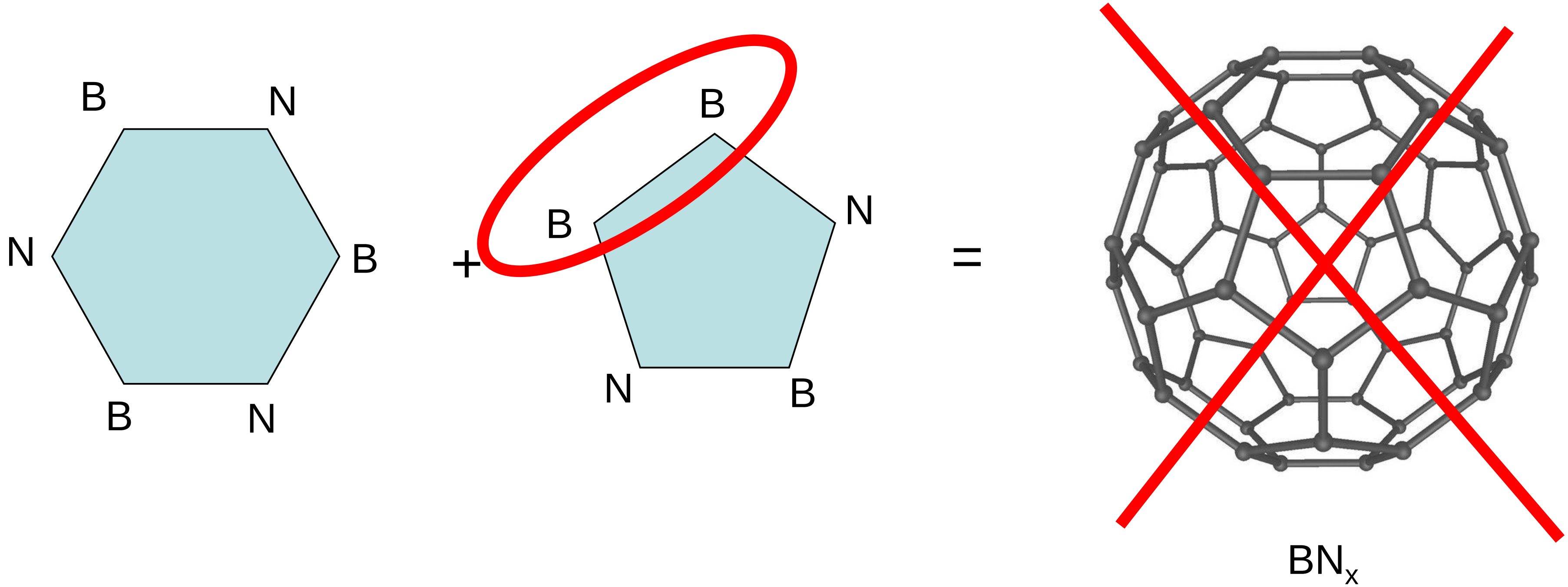
C_{60}

Images: wikipedia.org



BN_x

Images: wikipedia.org



Images: wikipedia.org

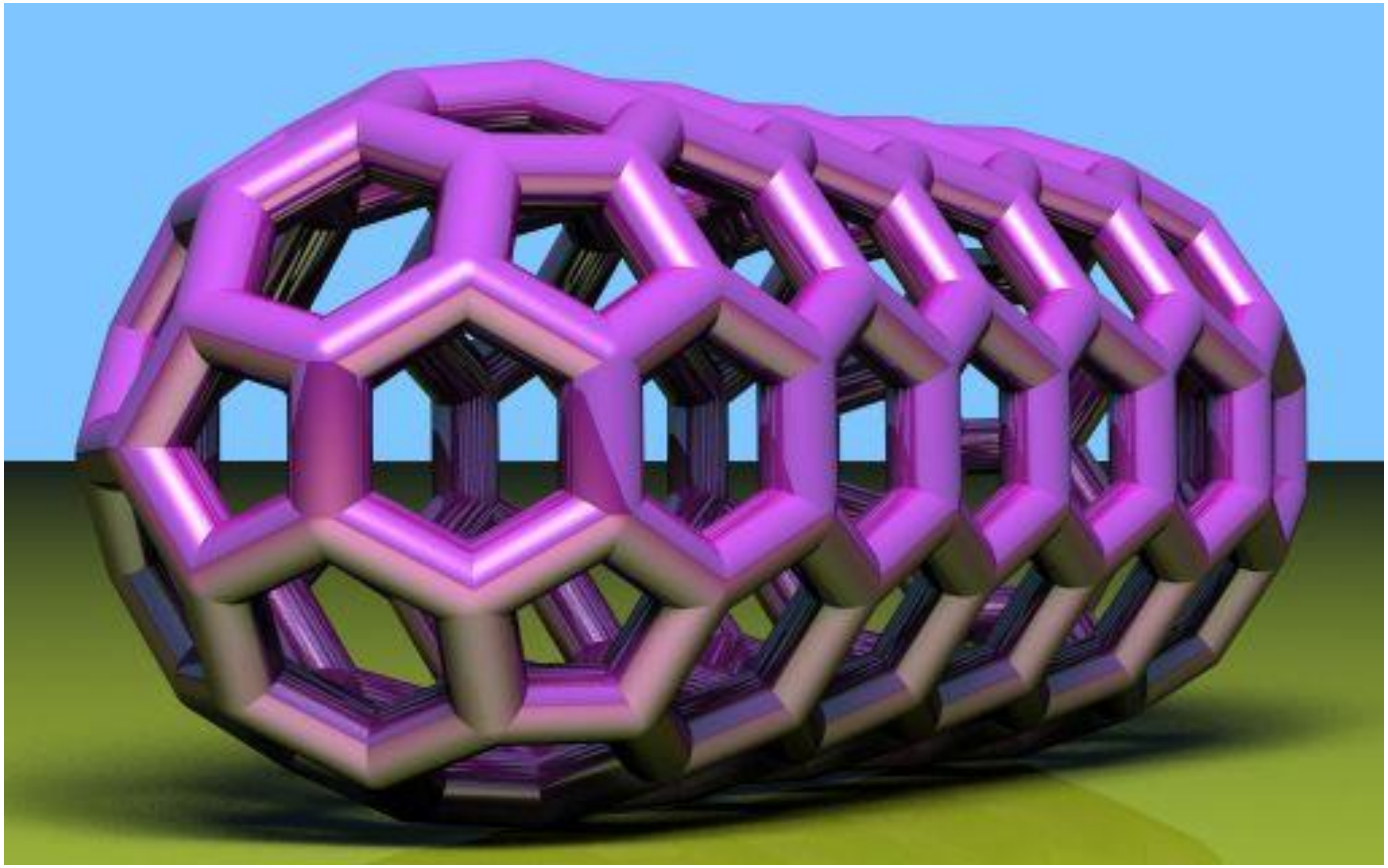
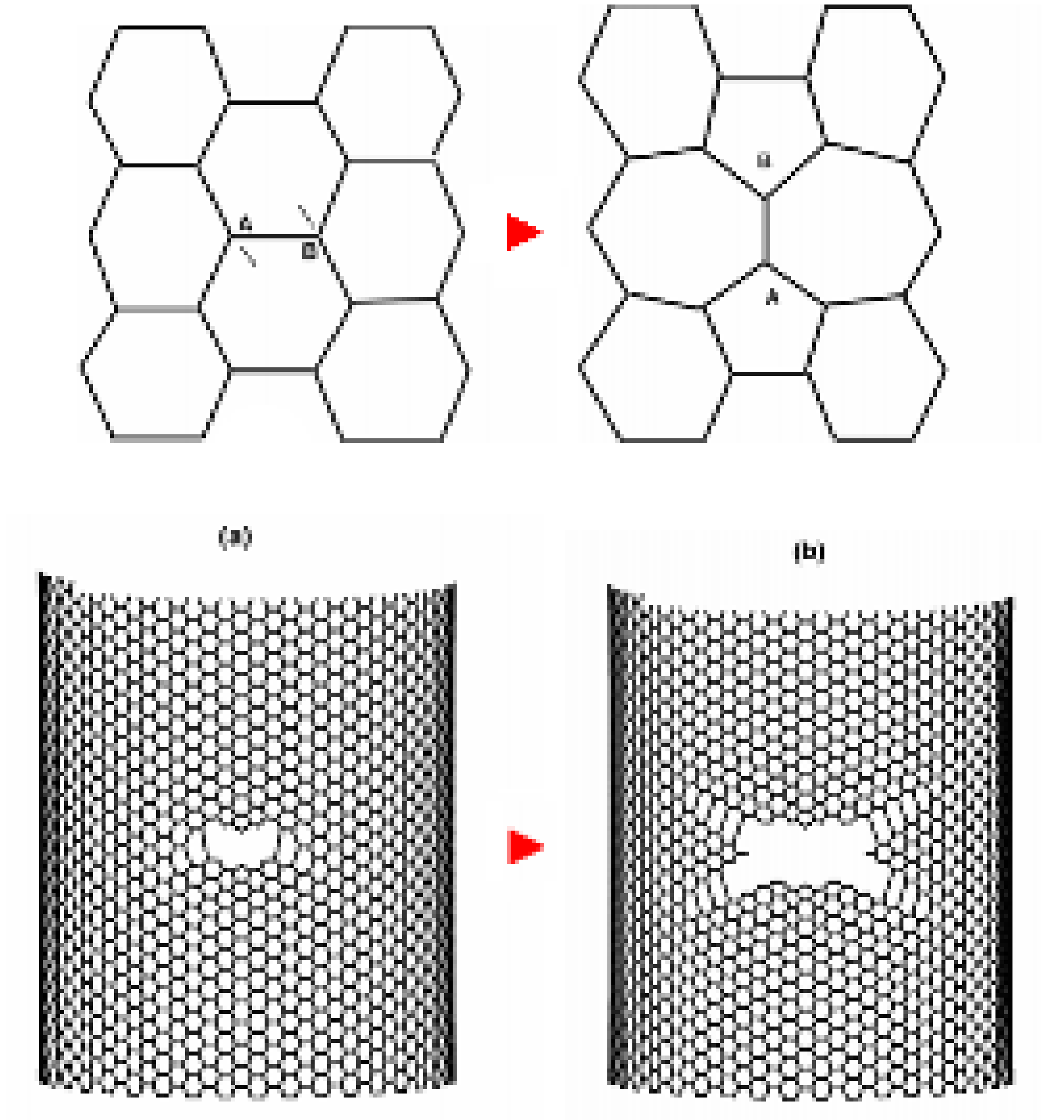


Image: http://home.icpf.cas.cz

‘Stone Wales’
Defects in
Carbon Nanotube
Under tensile stress



http://www.spaceward.org

Four-wall carbon nanotube

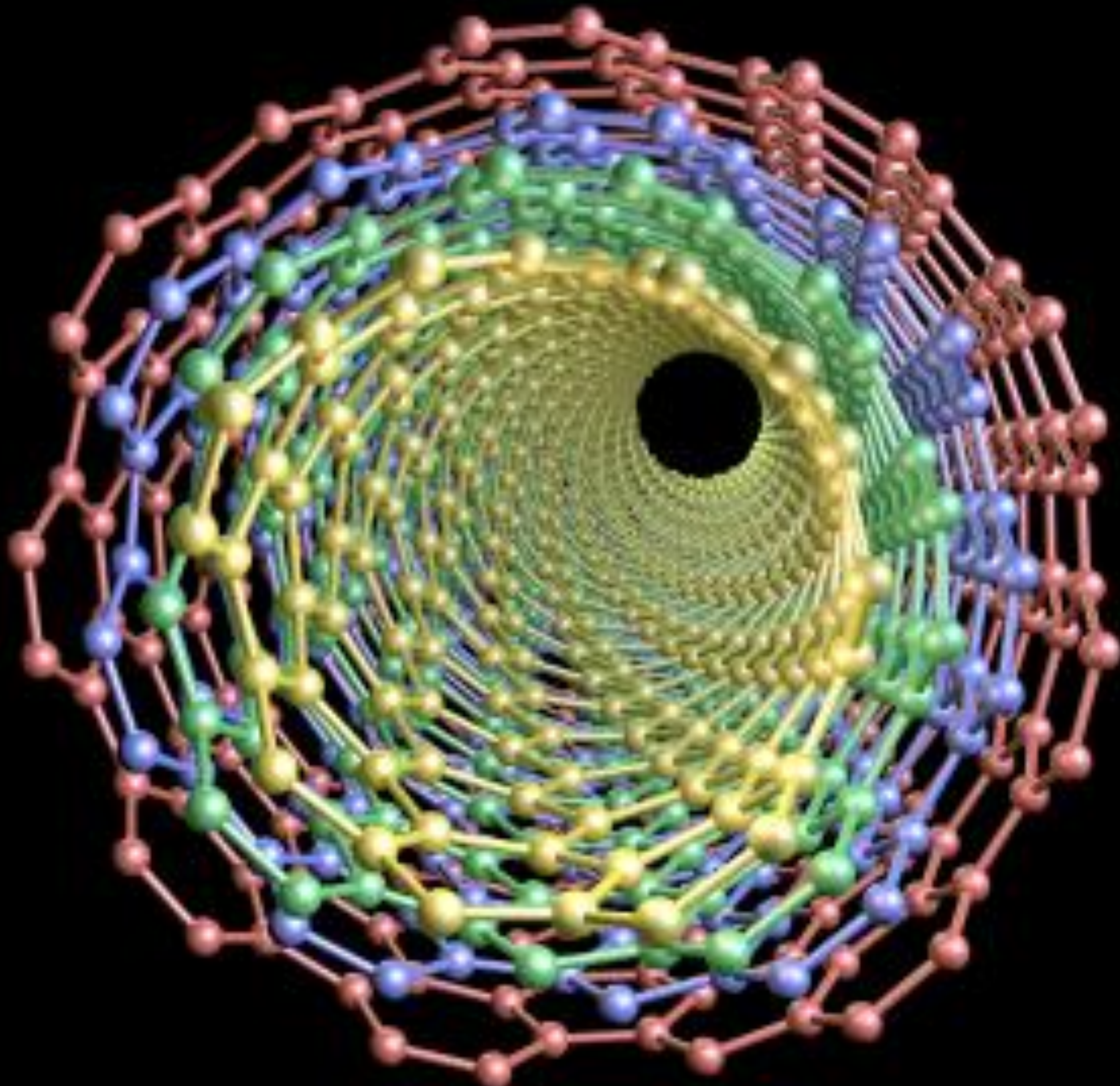
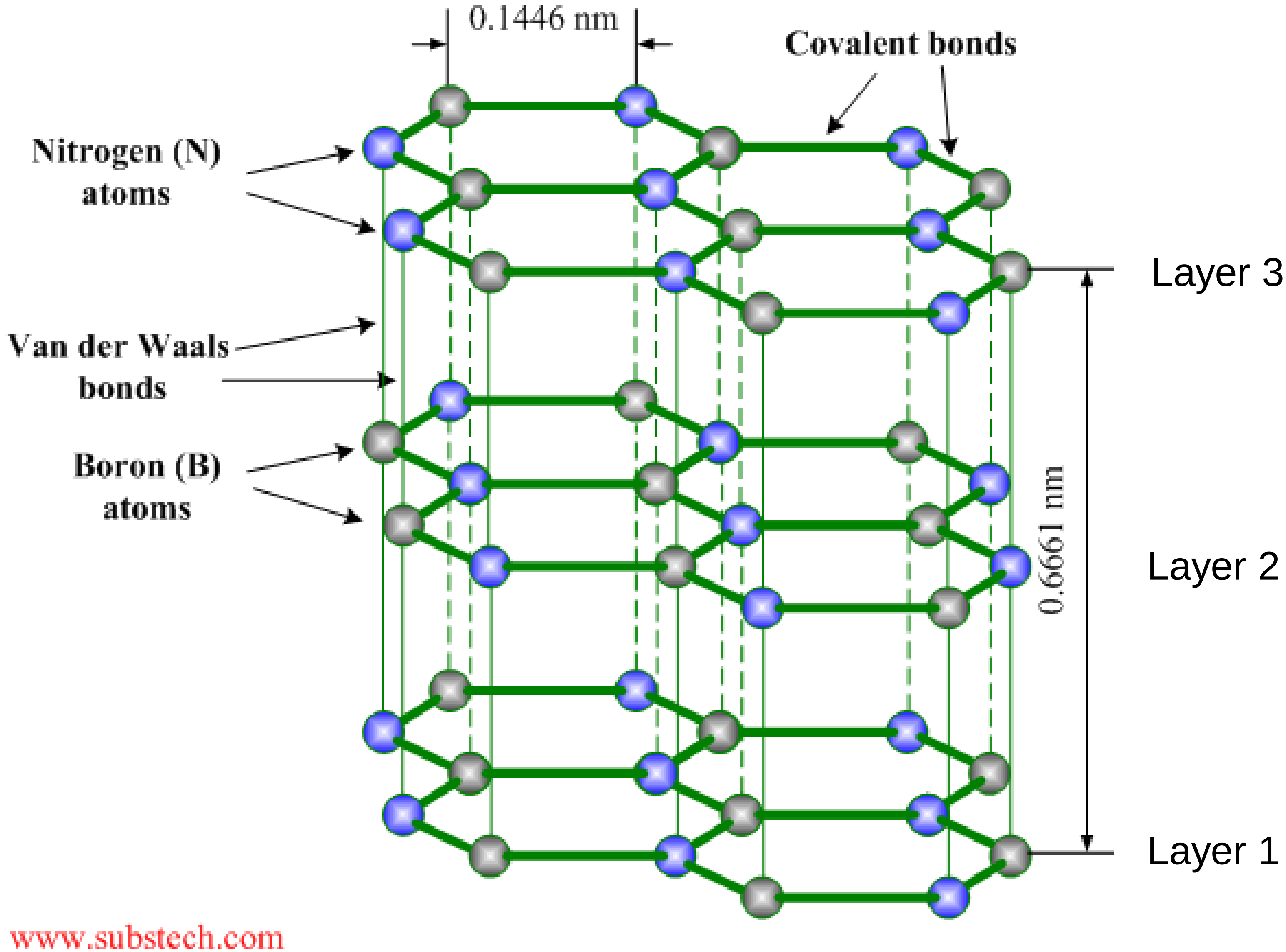


Image: http://nanogloss.com

Three layers of graphite-like hBN, showing stacking structure



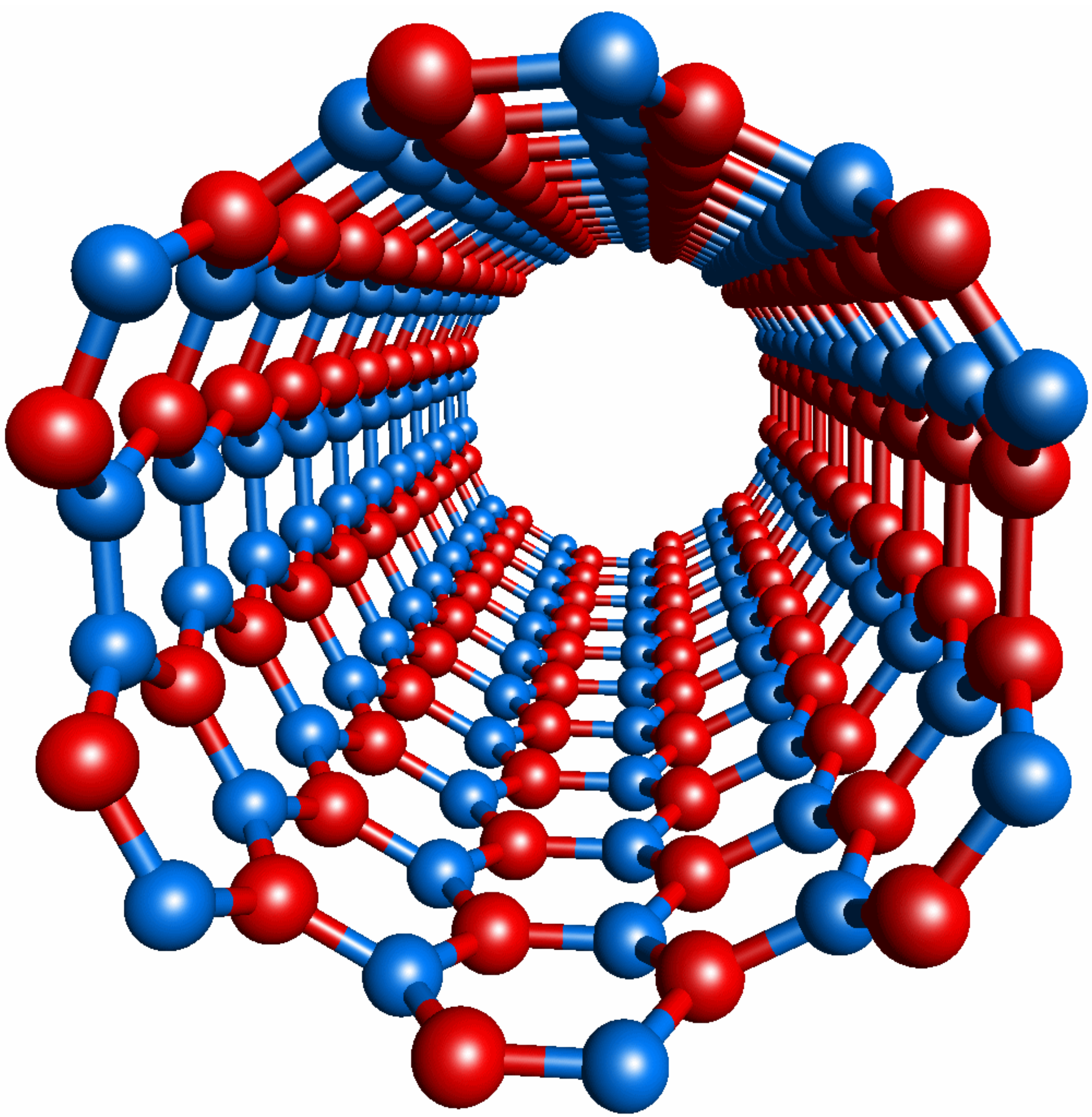
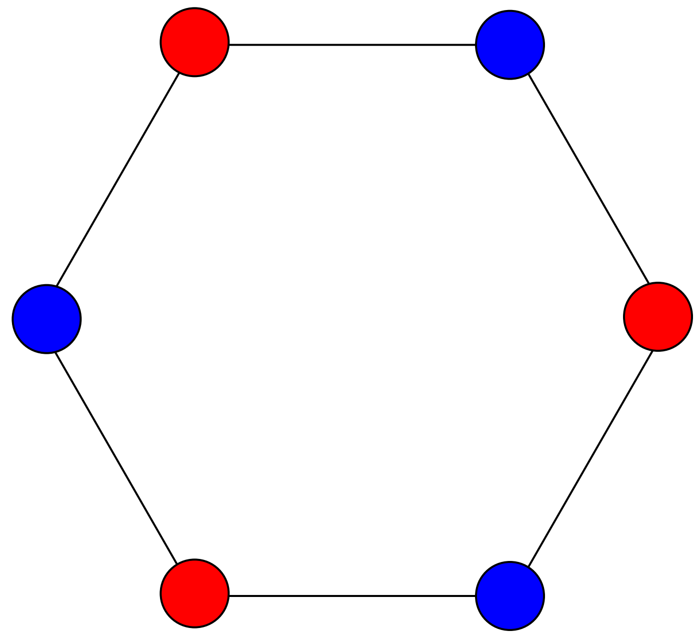
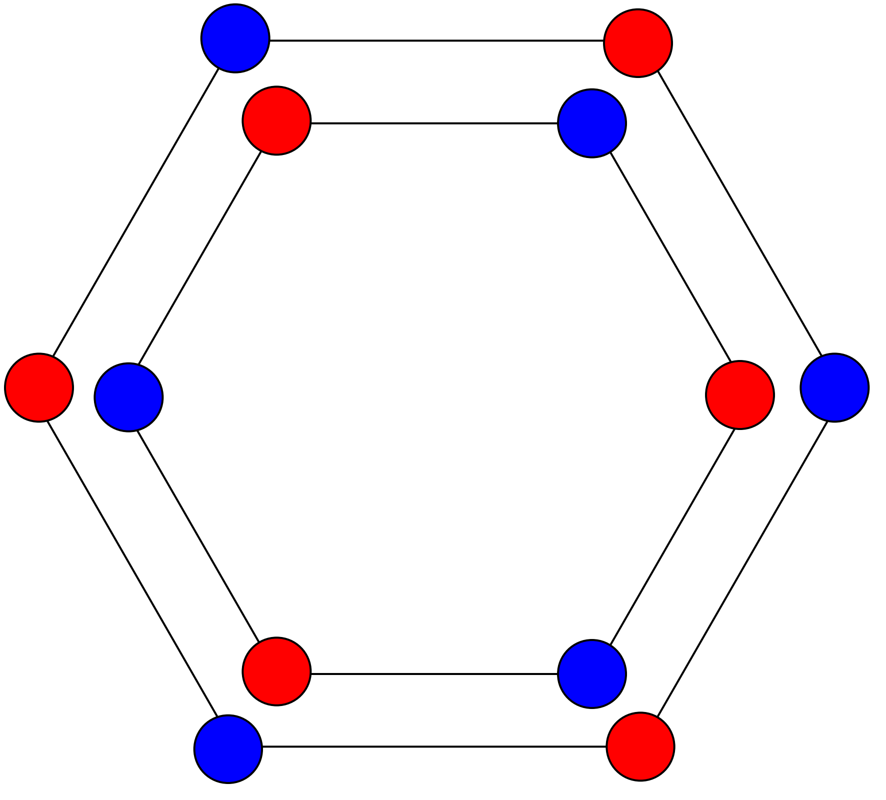


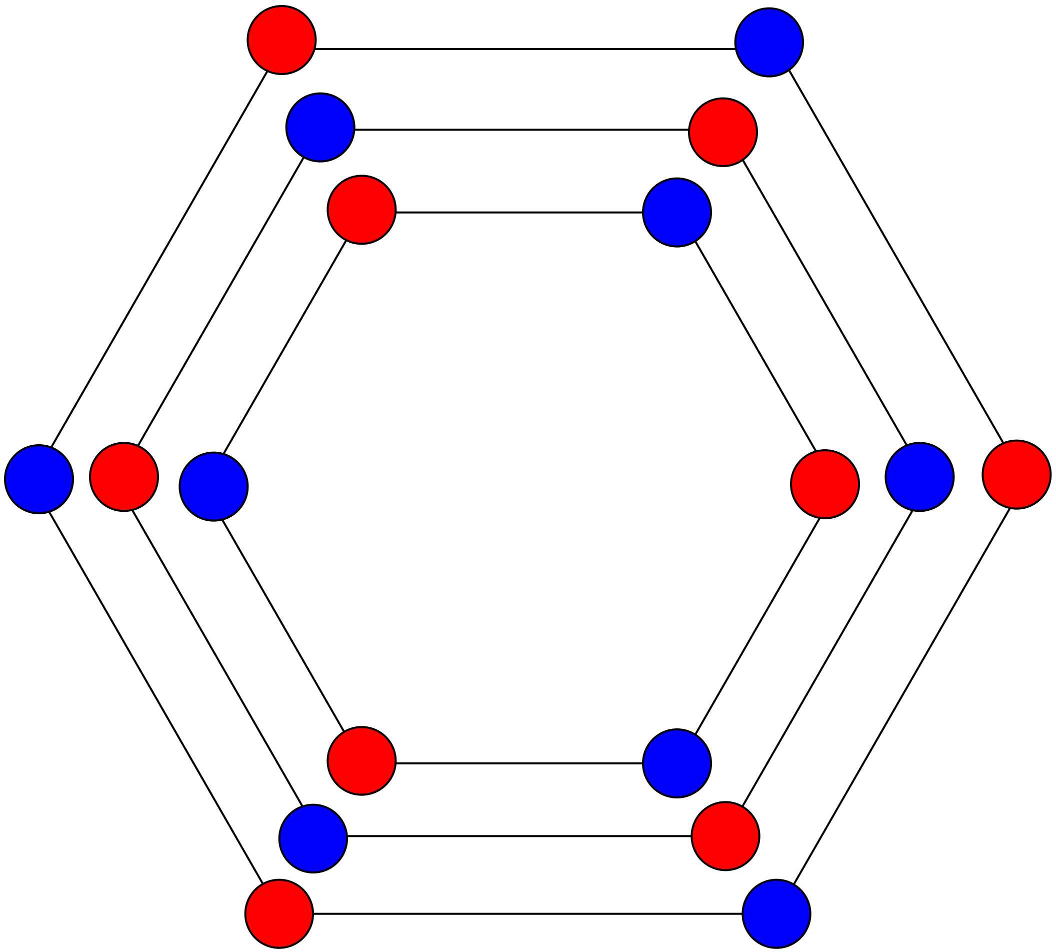
Image: http://nano-bio.ehu.es



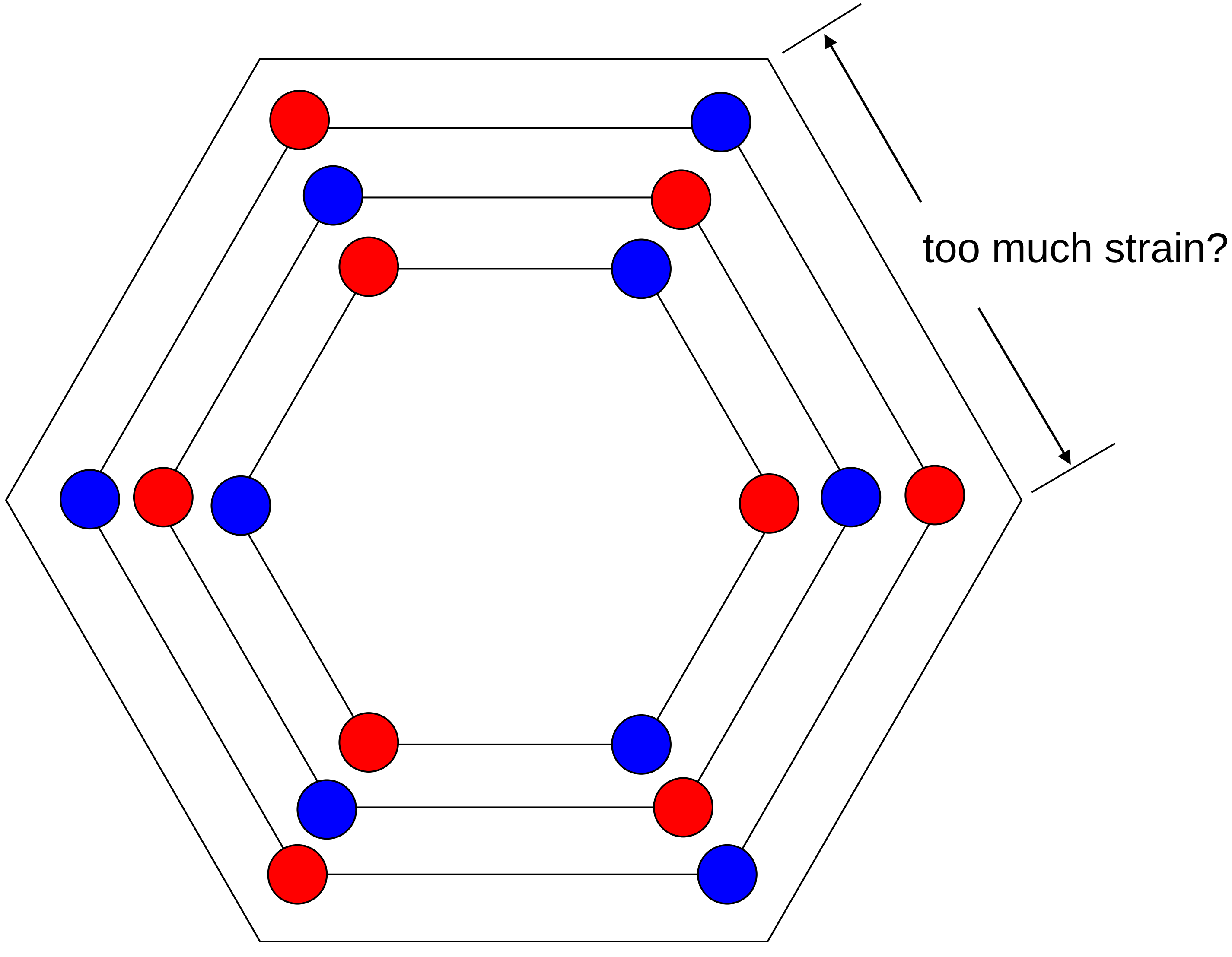
Cross-section, one-wall BNNT



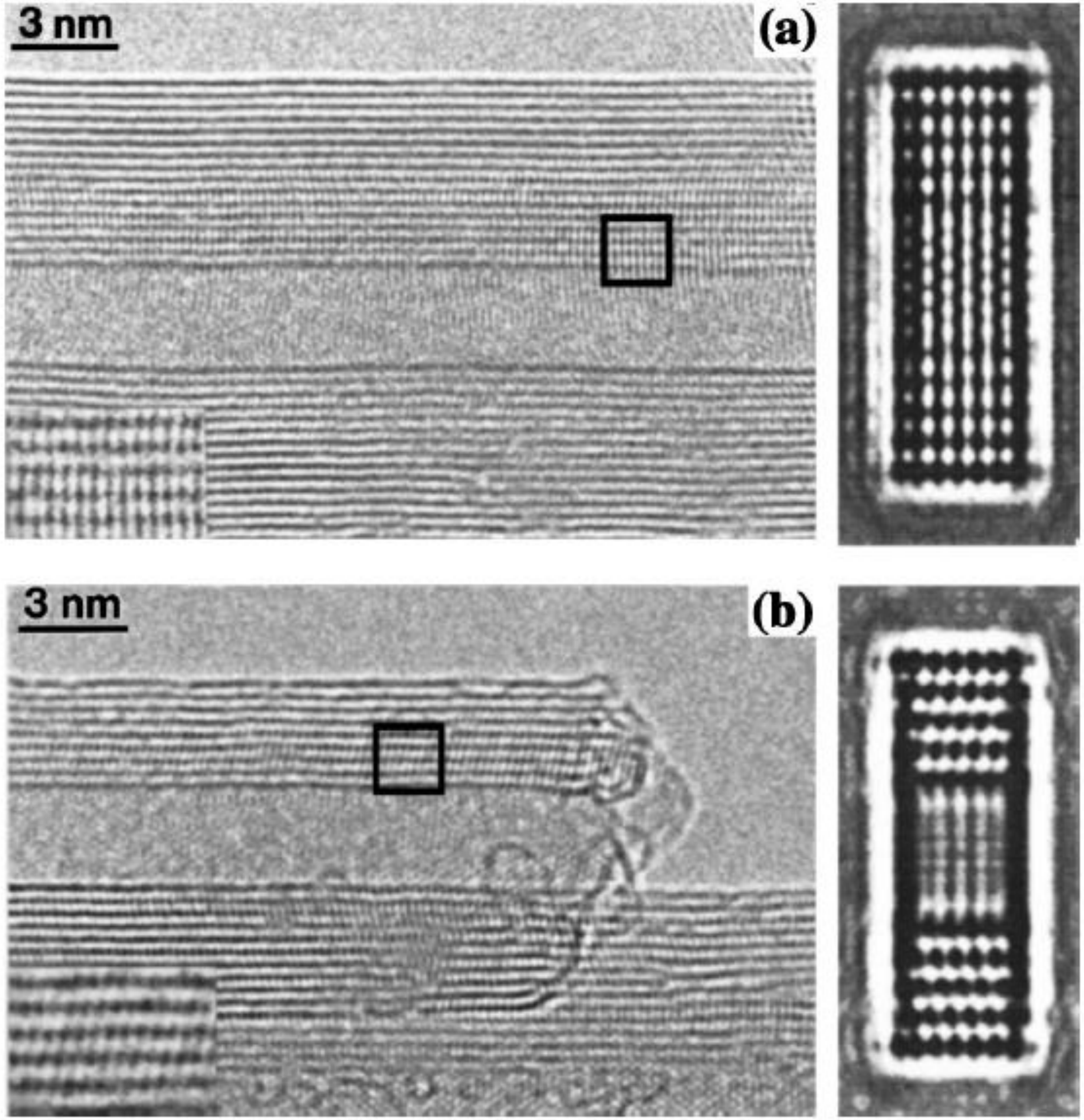
Cross-section, two-wall BNNT



Cross-section, three-wall BNNT



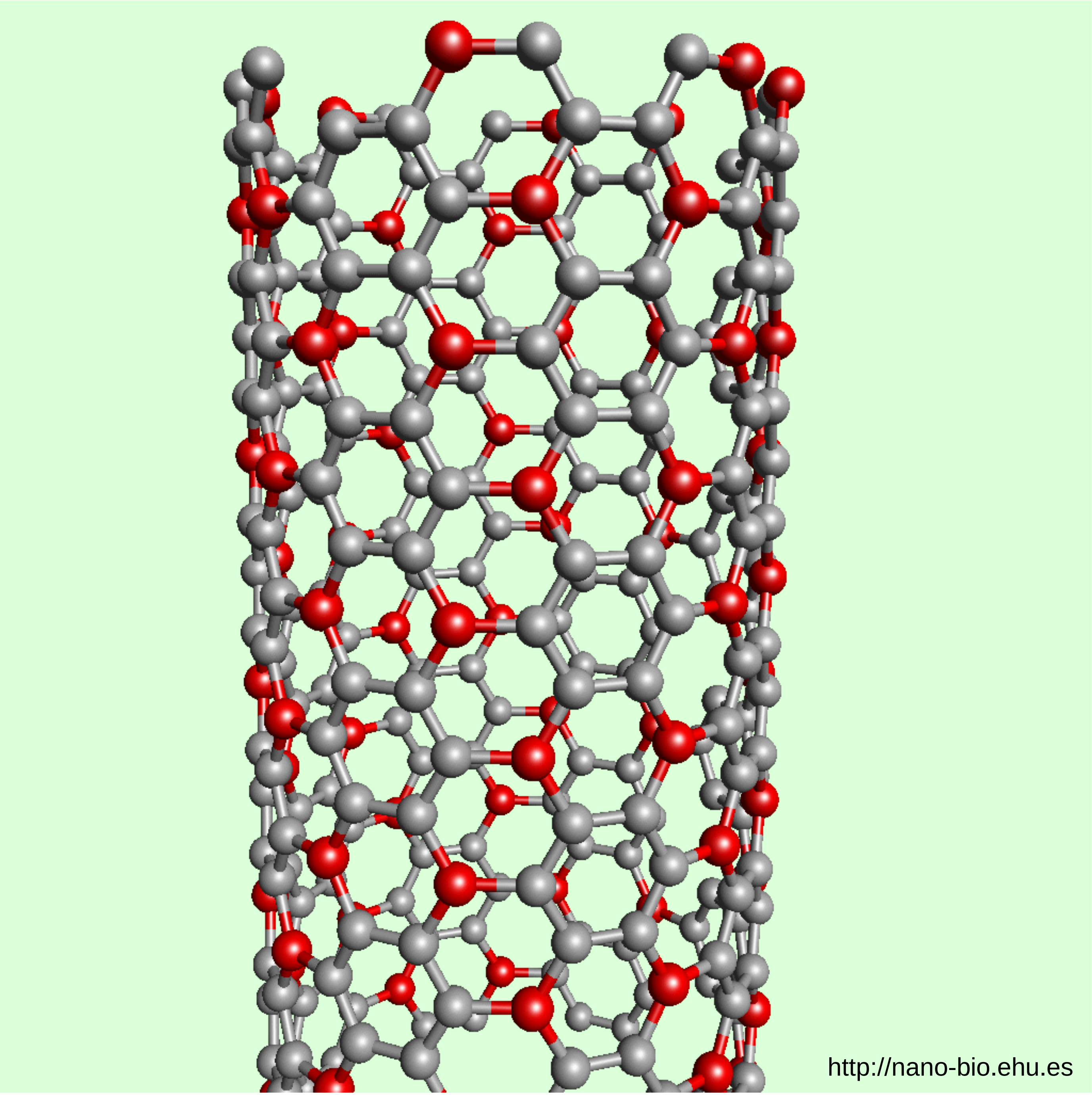
Cross-section, four-wall BNNT?



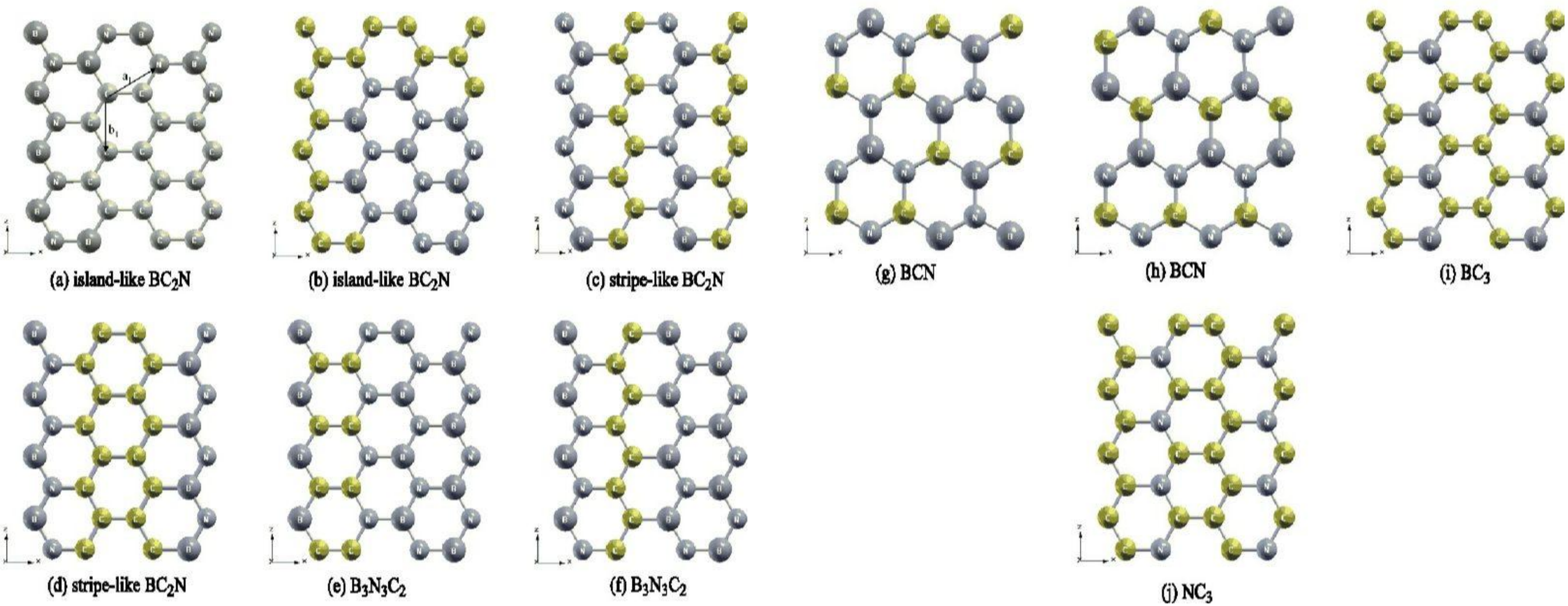
HRTEM images of multiwalled BN NTs found in the specimens synthesized using Ag_2O (a) and MoO_3 (b) promoters. Definite but different stacking order is apparent in marked areas in (a) and (b) as highlighted in the insets. Hexagonal type stacking in (a) and rhombohedral-type stacking in (b) are confirmed by corresponding computer simulated HRTEM images (right-hand side images) for BN NTs having the axes parallel to the [1010] orientation (zigzag tubes).

Source: 'Insights into the structure of BN nanotubes. 'Applied Physics Letters, 2000 Golberg et al.

Example of BC_3 Nanotube

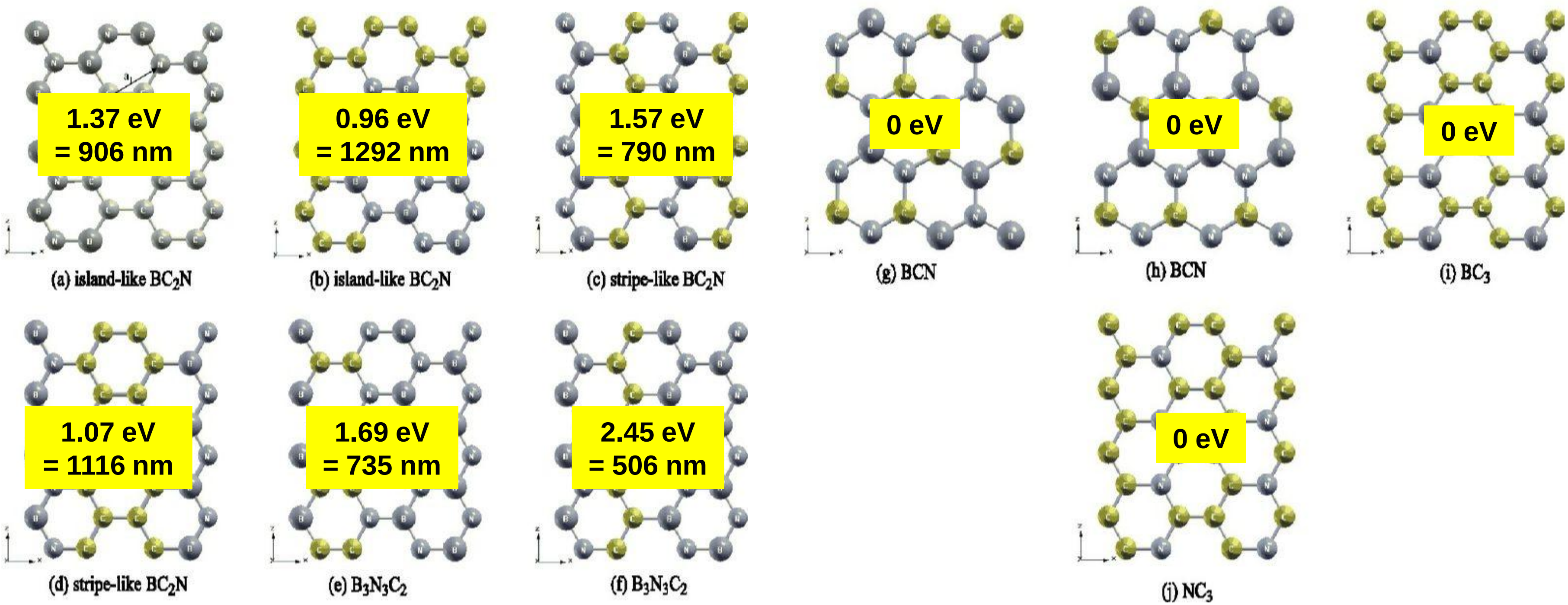


Possible Combinations of $B_xC_yN_z$



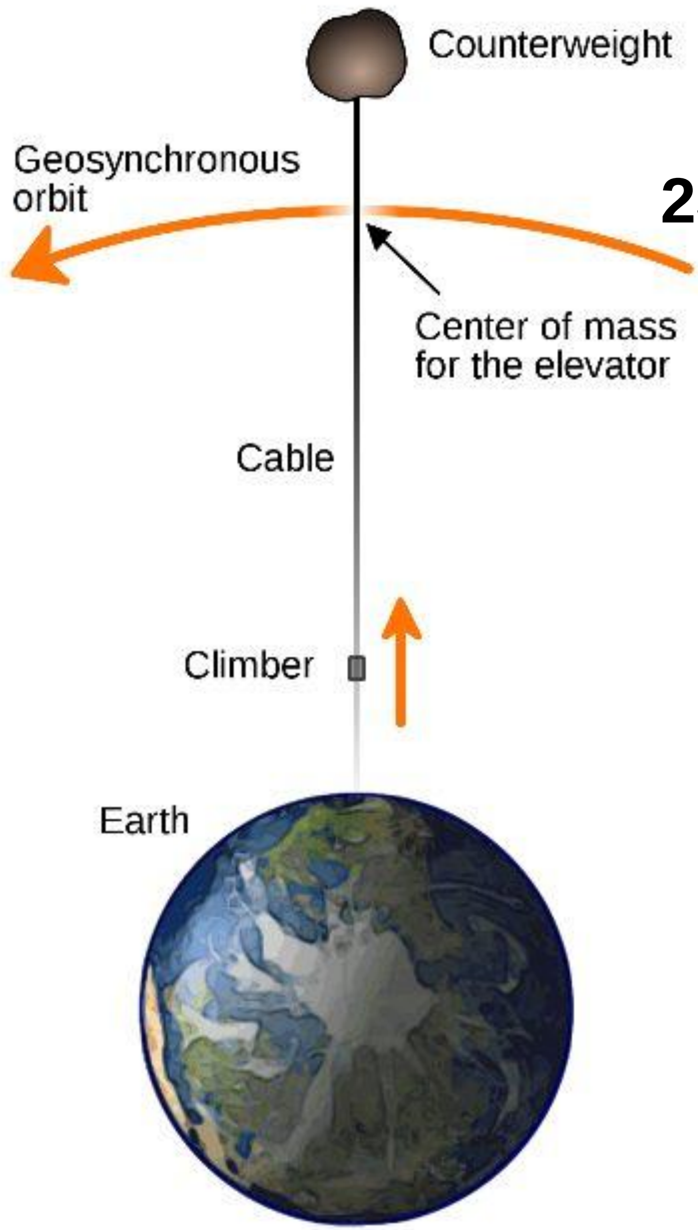
S. Azevedo and R. de Paiva 2006 Europhys. Lett. 75 126

Possible Combinations of $B_xC_yN_z$



calculated band gaps

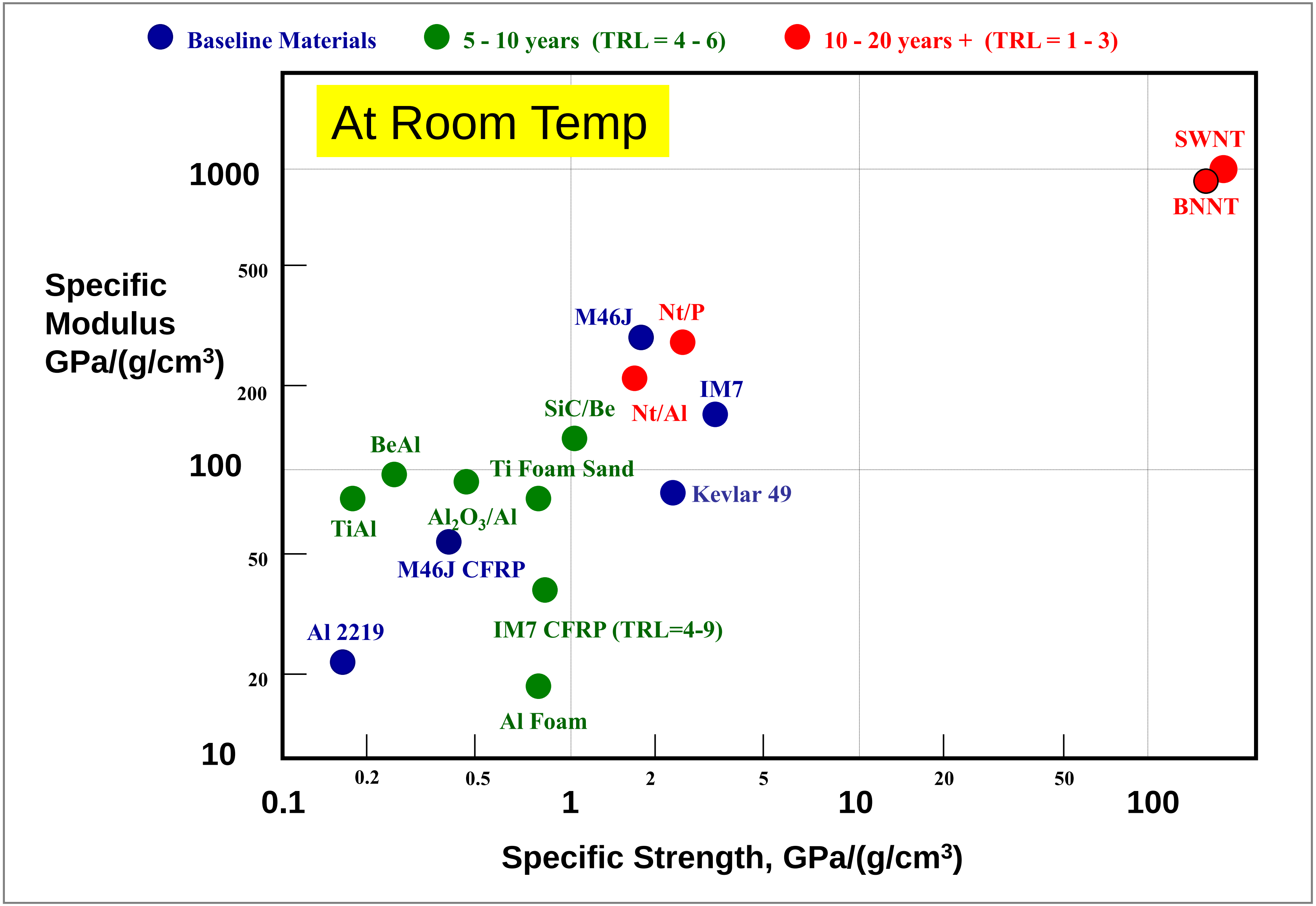
S. Azevedo and R. de Paiva 2006 Europhys. Lett. 75 126



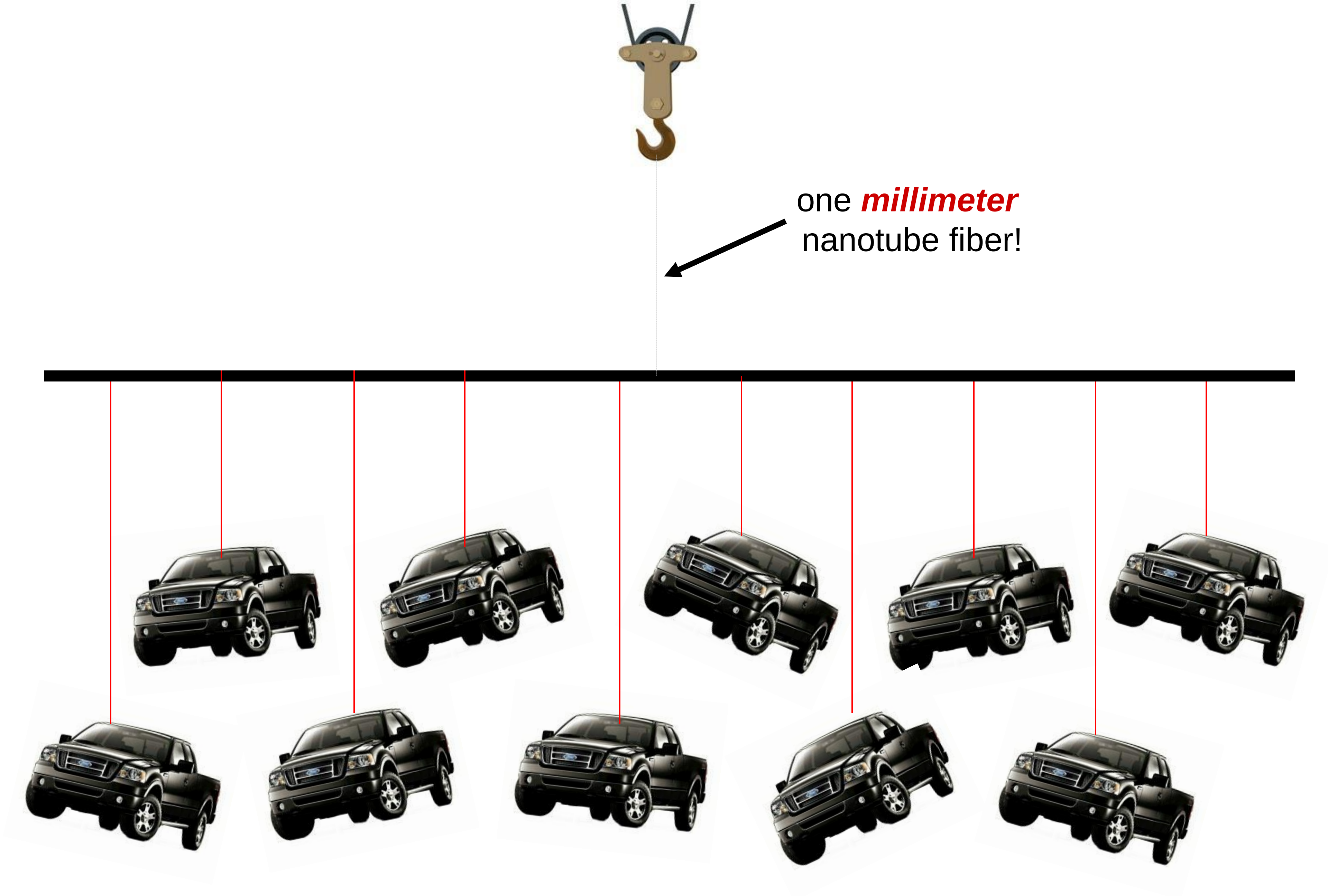
23,200 miles

Image: http://commons.wikimedia.org

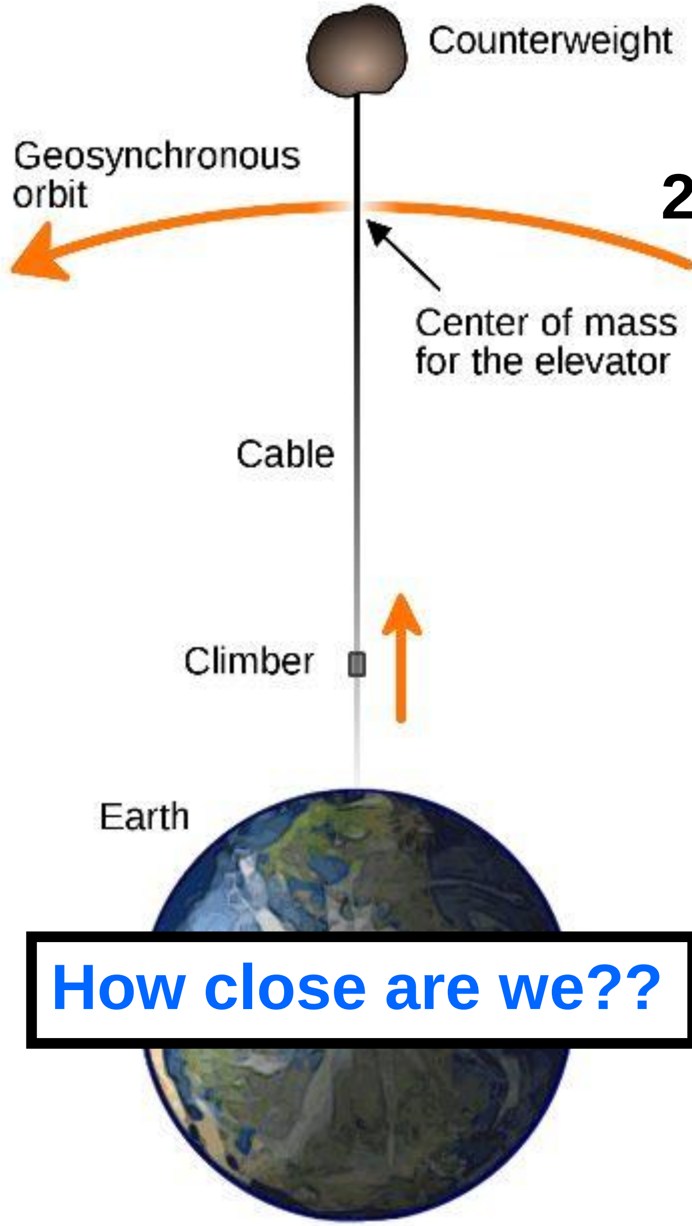
Properties of Materials for Vehicle Structure



Based on: Charlie E. Harris, M. J. Shuart, H. Gray, NASA/TM-2002-211664



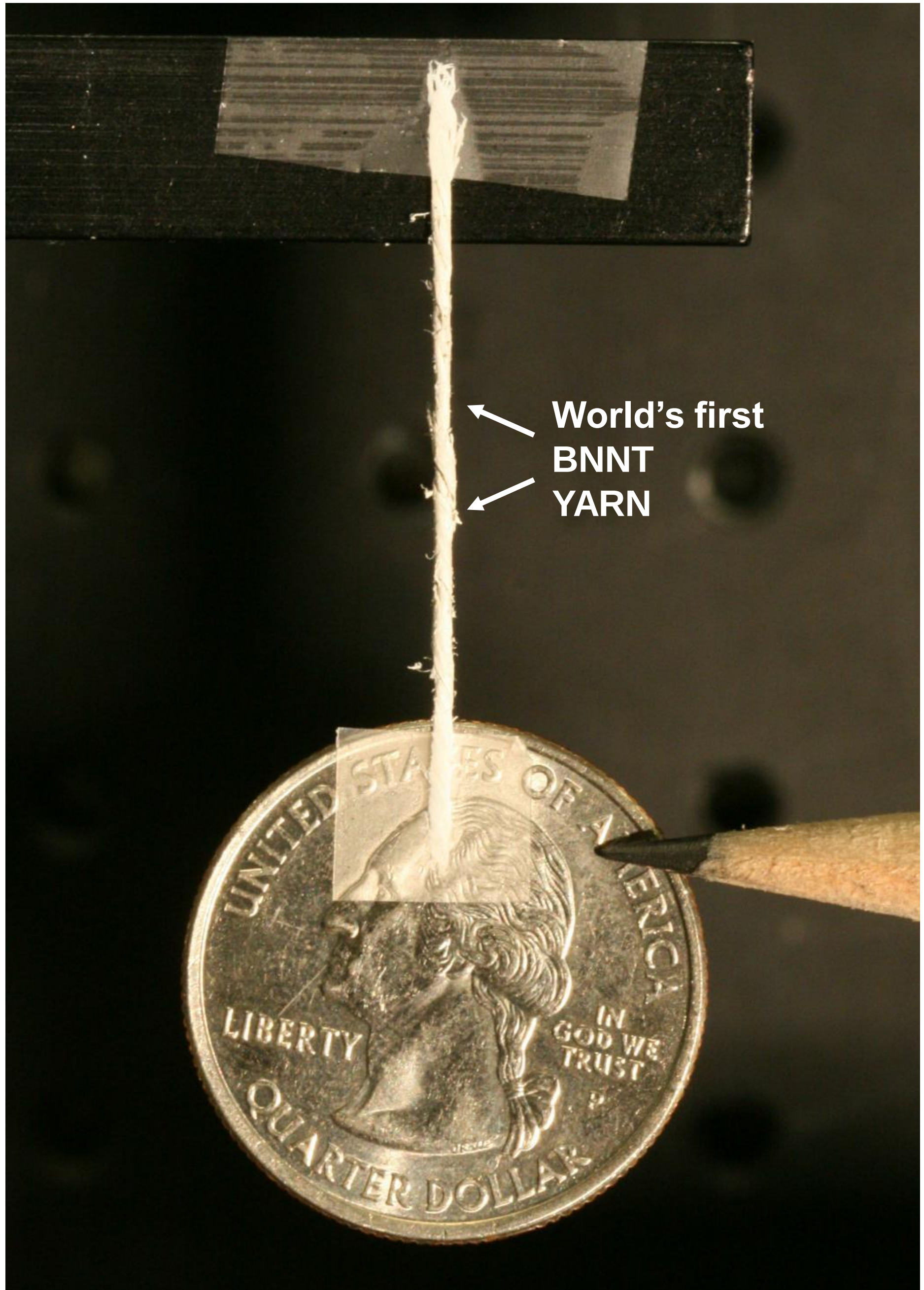
images: www.vectorstock.com http://www.wallpaper.net.au



23,200 miles

How close are we??

Image: http://commons.wikimedia.org



(From: M. W. Smith et al, Nanotechnology, 20, 505604 (2009))

Russian…

Создана первая нить из нитрид-борных нанотрубок

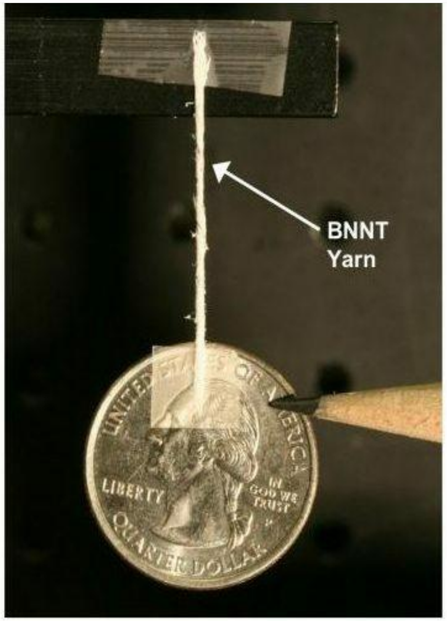
8 декабря 2009, 10:23

При помощи лазеров исследователи создали первую макроскопическую нить из волокон нитрида бора, что открывает путь к целому ряду приложений – от противорадиационных щитов для космических кораблей до защитного облачения для тела. Техника синтеза высококачественных нитрид-борных нанотрубок (boron-nitride nanotube, BNNT) разработана в Исследовательском центре NASA в Лэнгли (NASA's Langley Research Center) и других лабораториях. Эти нанотрубки обладают микроскопическим диаметром, значительной длиной и структурно содержат несколько стенок. Нитрид бора не экзотический материал – он встречается в косметических средствах и пудре.

По словам учёного из Лэнгли Майка Смита (Mike Smith), до сих пор никому не удавалось изготовить достаточно длинные и при этом прочные нанотрубки, передает 3DNews. Техника синтеза, названная PVC (pressurized vapor/condenser – испарение и конденсация под давлением), стала возможной благодаря лазеру на свободных электронах и затем была усовершенствована для использования с коммерческими лазерами, применяемыми в сварке. Она состоит в следующем. Лазерный луч направляется в мишень, расположенную в закрытой камере, заполненной азотом. Мишень испаряется, формируя облако бора. Конденсация охлаждает испарения, вызывая формирование жидких капель бора, которые объединяются с азотом в BNNT. Получившиеся нанотрубки достаточно длинные, чтобы сплести из подобной хлопку массы макроскопическую нить миллиметровой толщины и длиной в сантиметры. Длина же самих нанотрубок – около миллиметра.

Фотоновости

Еще фотоновостей!



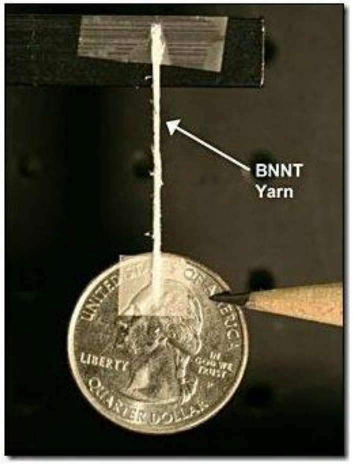
"Они большие и мягкие, как текстиль, - утверждает Кевин Джордан (Kevin Jordan) из Национального комплекса работы с ускорителем Томаса Джефферсона (Thomas Jefferson National Accelerator Facility). – Это означает, что возможно использовать коммерческий производственный процесс и распространённые техники для изготовления из трубок защиты для тела, солнечных ячеек и других устройств". TEM (Transmission electron microscope – просвечивающий электронный микроскоп) показывает, что толщина нанотрубок составляет несколько микрон. Особенность BNNT – это тенденция к "оборачиванию" их в несколько стенок. Следующим шагом исследователей будет тестирование свойств BNNT с целью определения наиболее подходящих областей применения нового материала. В теории, говорит Джордан, они найдут нишу и в энергетике, и в медицине, и в аэрокосмической

http://itnews.com.ua

…Korean…

레이저로 나노튜브 실을 짜다.

레이저를 이용하여 질화붕소 섬유로부터 실용적인 최초의 거시적 실이 만들어짐으로써, 태양전지에서부터 더 강력한 방탄복에 이르기까지 다양한 분야에 응용할 수 있게 되었다.



질화붕소 나노튜브로 짠 실이 25센트 경화를 매달고 있다.

나사 랭글리연구센터(NASA's Langley Research Center), 토마스 제퍼슨 국립가속기시설(Thomas Jefferson National Accelerator Facility) 및 국립항공우주연구소(National Institute of Aerospace)의 연구진이 결정성이 크고 직경이 작은 고품질 질화붕소 나노튜브(BNNTs)를 합성하는 기술을 개발했다.

또한 이 나노튜브들은 구조적으로 몇 개의 벽을 갖고 있으며 매우 길다. 질화붕소는 어릿광대의 분장과 안분에 쓰이는 흰색 물질이다. "다른 연구소에서 만든 나노튜브들은 매우 우수하지만 짧고, 그렇지 않으면 길지만 너무 지저분하다. 우리는 아주 길면서도 매우 우수한 나노튜브를 제작하는 기술을 개발했다."라고 랭글리연구소 과학자인 마이크 스미스(Mike Smith)는 말했다.

다음 과제는 이 새로운 질화붕소 나노튜브의 특성을 시험하여 이 신물질의 가장 좋은 용도를 찾는 일이라고 연구진은 말한다. 이들은 또한 생산공정을 개선하고 확장하려고 한다. **"이론적으로 이러한 나노튜브들은 에너지, 의료 및 항공우주 분야에 응용될 수 있다."**라고 조던은 말했다. "이들 중 어떤 나노튜브들은 더 이상 가망이 없어지고 있고, 어떤 것들은 연구할 가치가 생기고 있지만, 물질을 손에 넣기까지는 알 수 없을 것이다."라고 스미스는 말했다. 이번 연구는 저널 'Nanotechnology' 12월 16일호에 출판될 예정이며, 또한 미국재료학회의 2009년도 가을 학술회의에 제출되었다.

…German…

MATERIALIEN

GARN AUS NANORÖHRCHEN

KONTEXT: Nanoröhrchen gelten seit Jahren als Grundstoff für extrem stabile Seile. Bislang ließen sich die mikroskopisch kleinen Röhrchen aber noch nicht fest genug verbinden. Nun gelang US-Wissenschaftlern erstmals die Synthese langer Bornitrid-Fasern, die sich zu einem stabilen Garn verspinnen ließen.

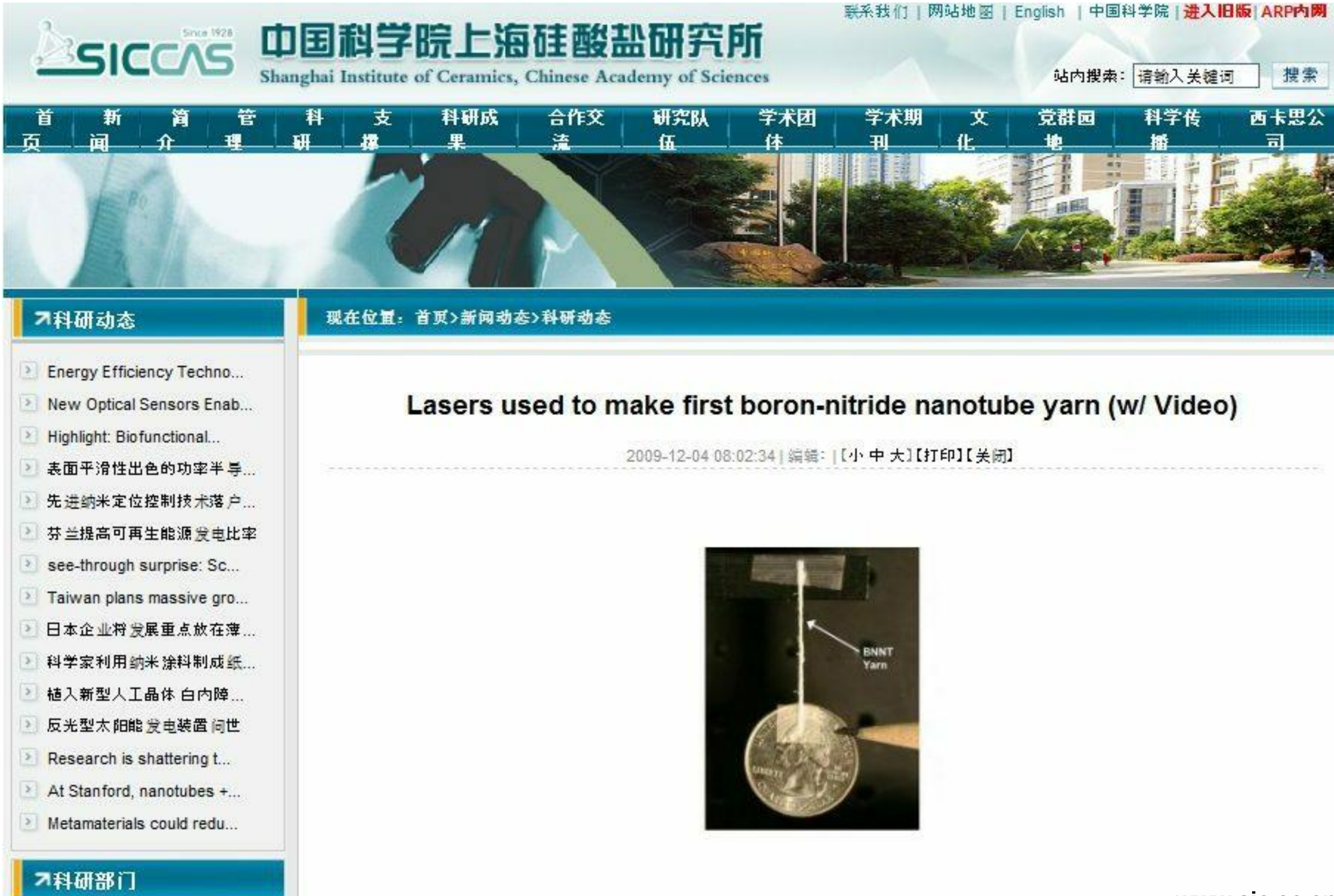
METHODE: Die Gruppe um Mike Smith vom Langley Research Center der Nasa in Hampton verdampfte in einer mit Stickstoff gefüllten Druckkammer Bor mit einem Laser. An einem gekühlten Metalldraht bildeten sich daraufhin bis zu einen Millimeter lange, mehrwandige Nanoröhrchen mit Durchmessern von wenigen Mikrometern. Diese lagerten sich selbstständig zu Fasern von zehn Zentimetern Länge mit etwa einem Millimeter Durchmesser zusammen.

RELEVANZ: Das Verfahren liefert Nanoröhrchen, die etwa 100-mal länger sind als bisher. Die Fasern lassen sich zu einem weißen, baumwollartigen Garn verspinnen. Doch da Bor relativ teuer ist, bleiben Fasern aus günstigem Kohlenstoff weiterhin eine der wichtigsten Herausforderungen an die Materialforscher.

■ Quelle: „Very long single- and few-walled boron nitride nanotubes via the pressurized vapor/condenser method", Michael W. Smith, Joycelyn S. Harrison, et al.; Nanotechnology, Vol. 20, S. 505604

Technology Review, Feb 2010

…and Chinese.



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Science NOW UP TO THE MINUTE NEWS FROM SCIENCE

Better Nanotubes May Be on the Way

by Karen Fox on December 10, 2009 12:00 AM | Permanent Link | 0 Comments

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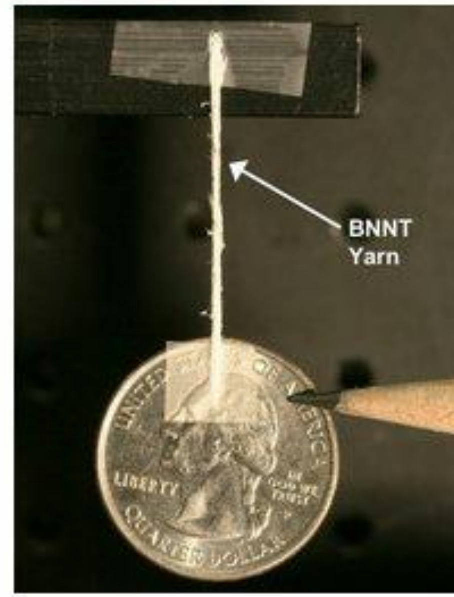
In the world of nanotechnology, few things get as much billing as nanotubes. Experts say that these cylinders composed of one-molecule-thin sheets could someday be used in everything from superstrong jet engines to cancer cures. Now researchers think they've found a way to make large amounts of an elusive type of nanotube that could provide even more impressive applications.

Researchers have long been able to make nanotubes out of carbon, but they have struggled to craft them from boron nitride. The two have about the same strength, but boron nitride nanotubes (BNNTs) can survive temperatures that are twice as high as those carbon nanotubes can survive--800°C and higher. Scientists have only been able to create high-quality tubes a micron long; larger versions have been riddled with defects in the crystalline structure.

Now in a paper published 16 December in *Nanotechnology*, a team of materials scientists describe the first creation of high-quality, uniformly crystalline BNNTs in large quantities: Each piece of fiber is long enough that it can be spun into user-friendly yarn. To do this, the researchers aimed a laser at a cake of boron inside a chamber filled

ENLARGE IMAGE



Small wonder. The first macroscopic, commercially usable BNNTs, spun into a 3-centimeter-long, 1-milimeter-diameter piece of yarn.

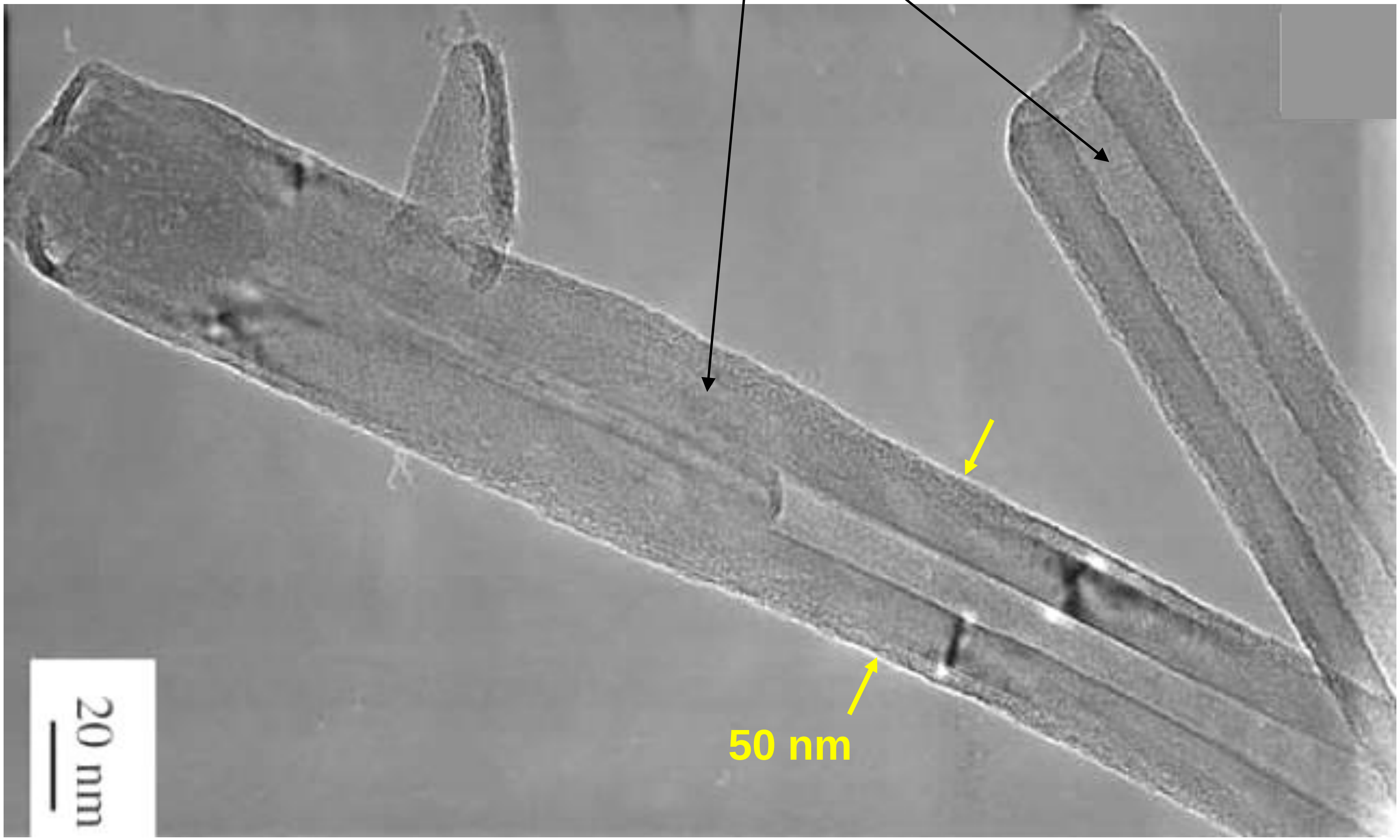
Credit: Michael Smith

http://sciencenow.sceincemag.org

Two reasons for interest:

1. Crystallinity + aspect ratio = ‘quality’

Japanese NIMS, B_2O_2/NH_3 CVD-Grown BNNTs



C. Zhi, Y. Bando, C. Tan, D. Golberg,
Solid State Commun. 135, 67-70 (2005).

BNNT, new method (same scale)

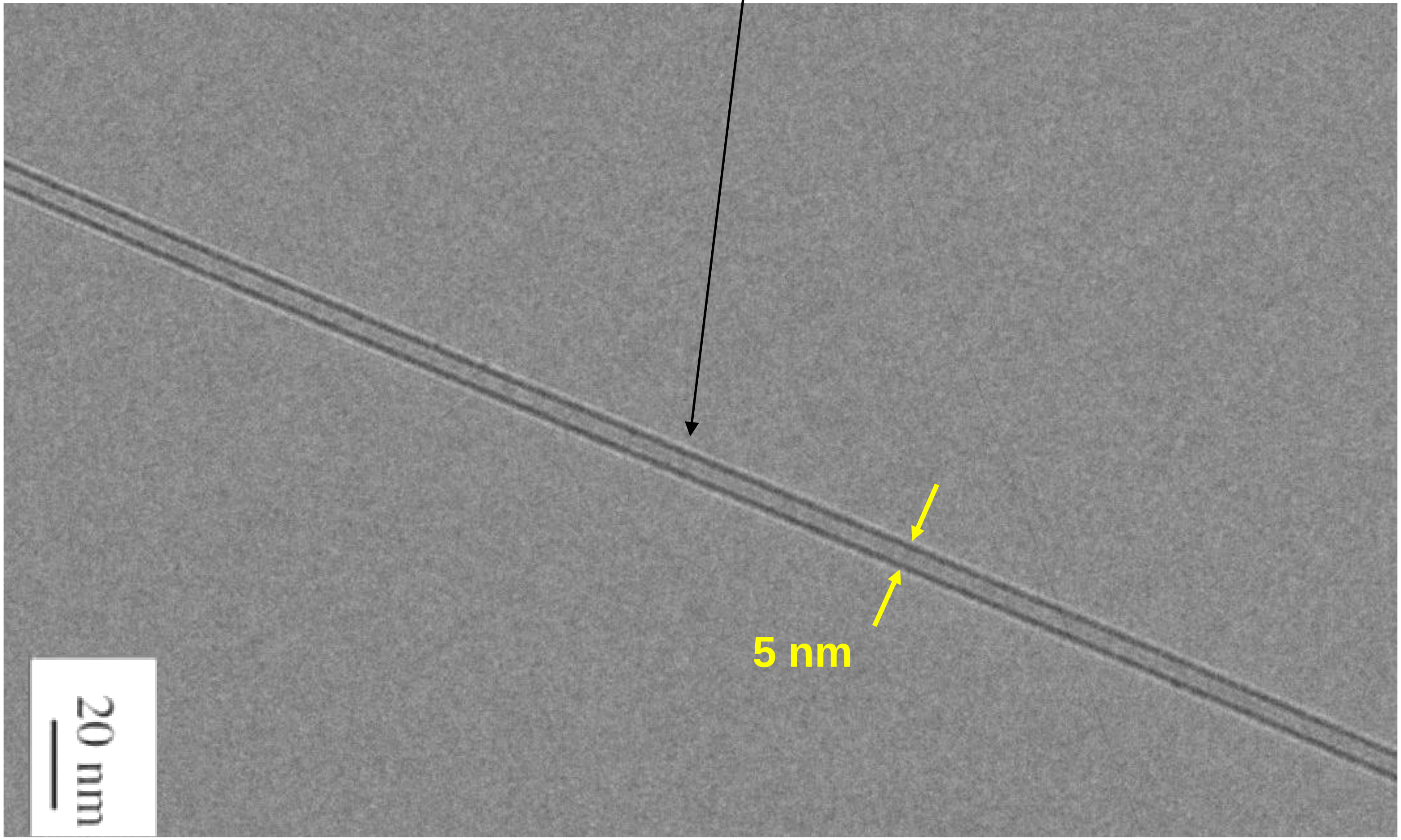


Image: Wei Cao, ODU/ARC

BNNT, new method (same scale)

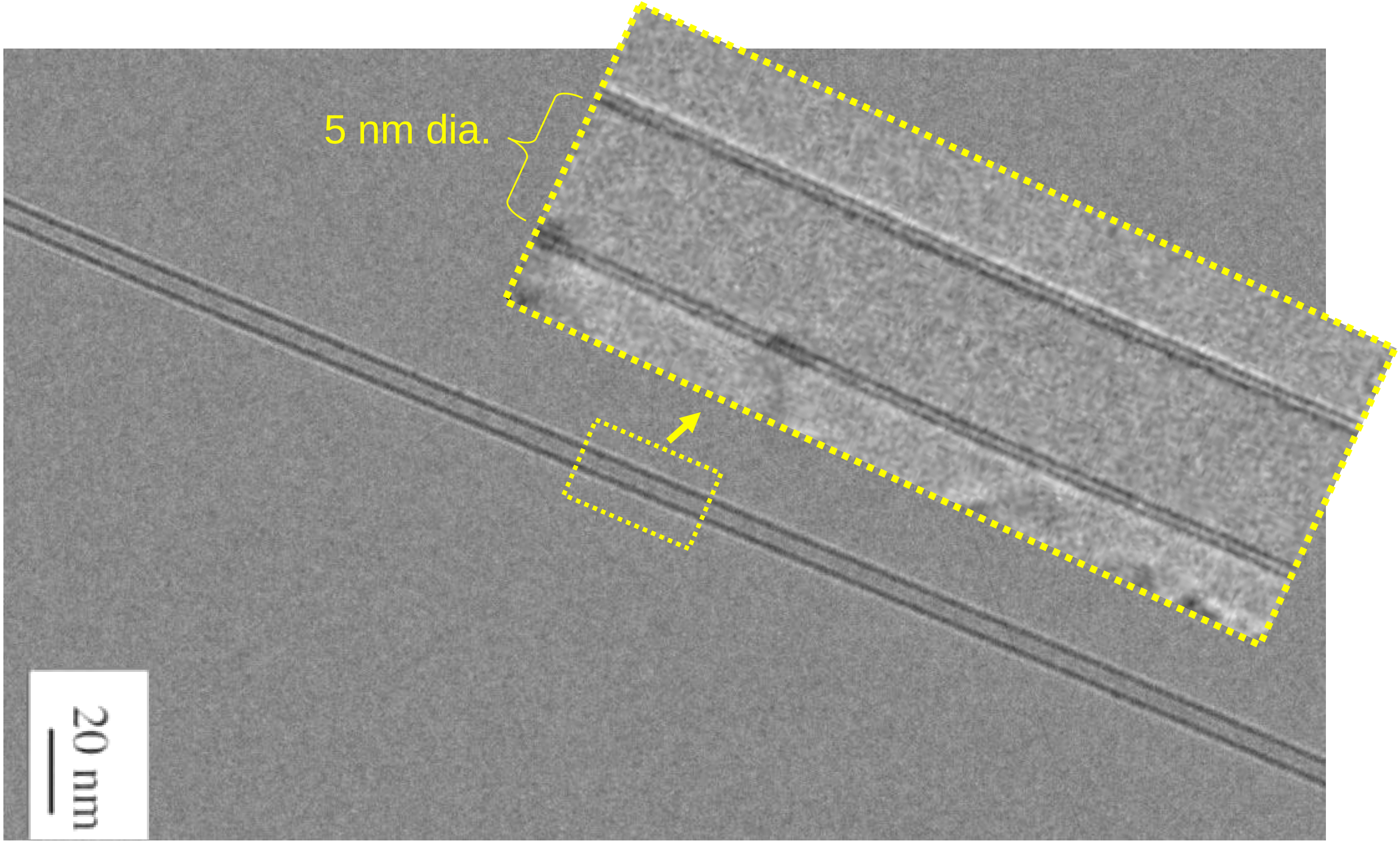
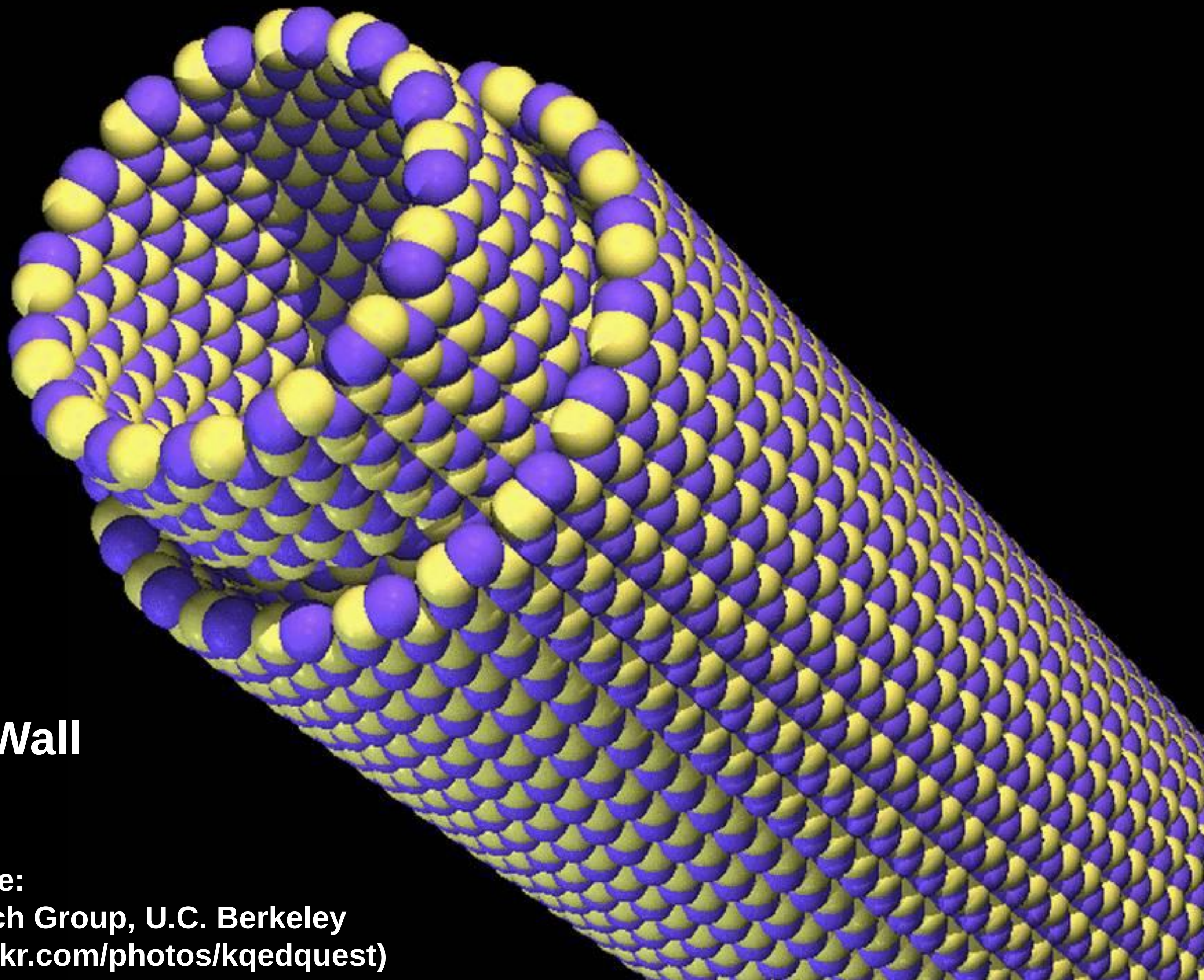
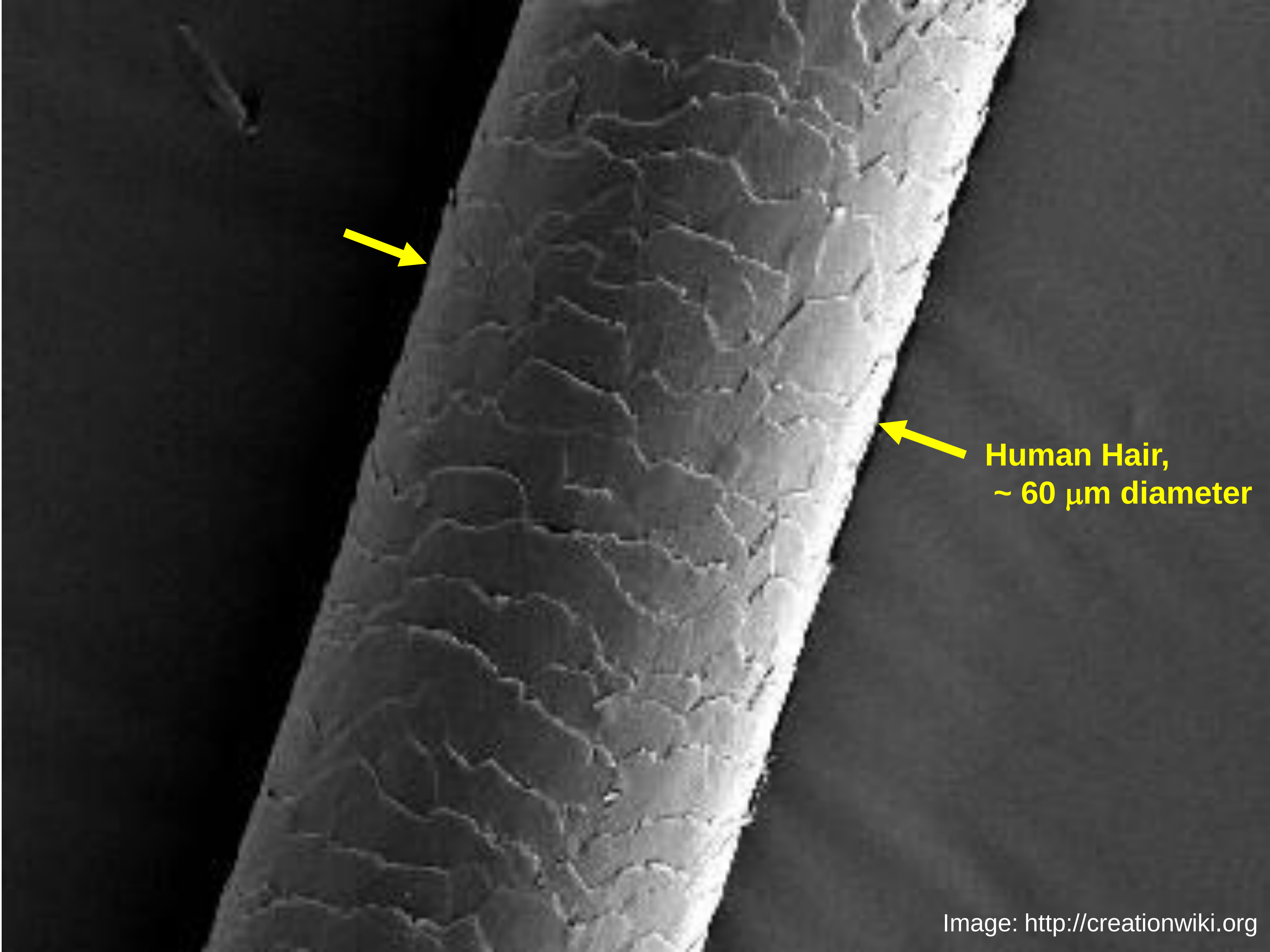


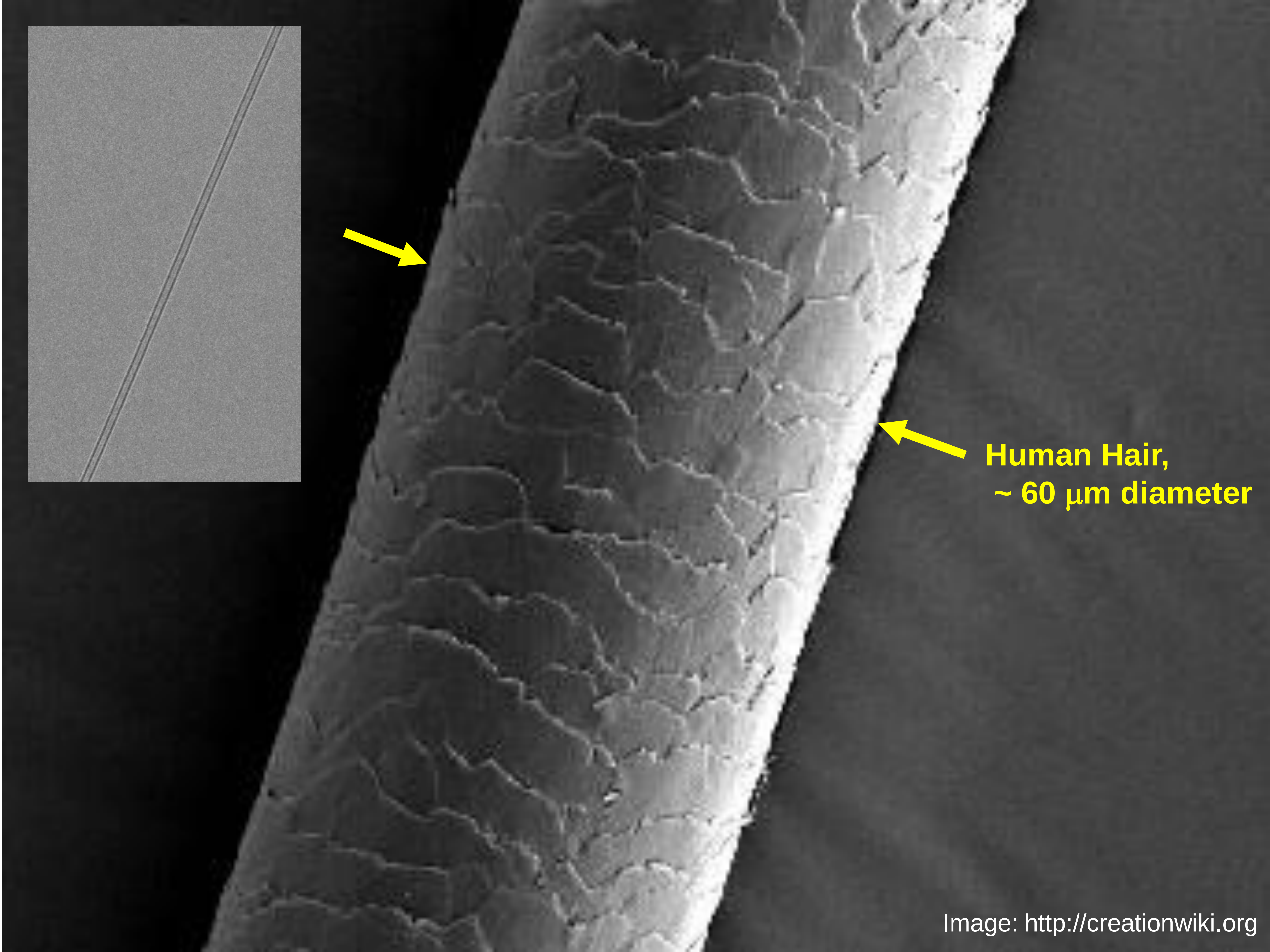
Image: Wei Cao, ODU/ARC

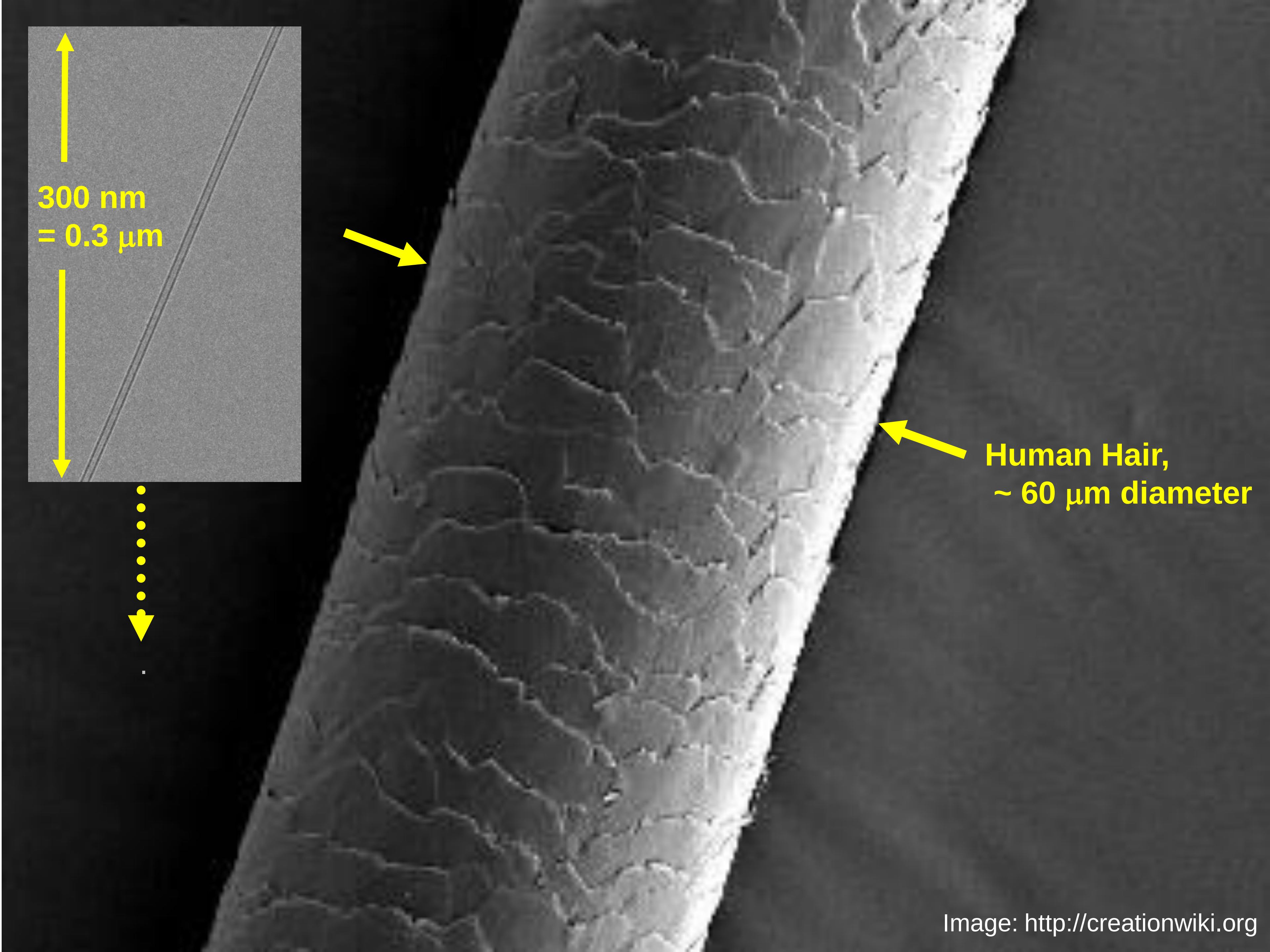


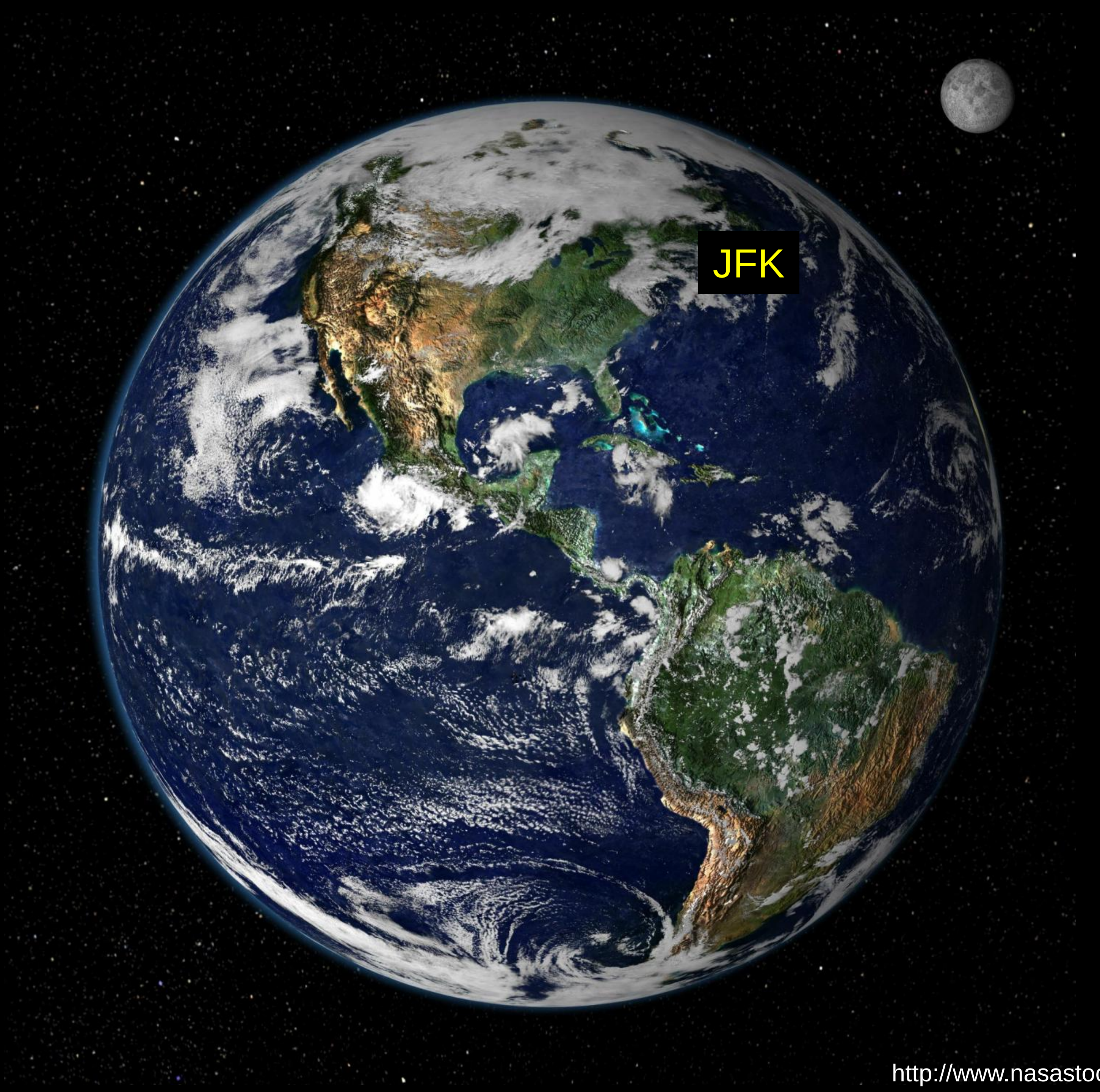
Double-Wall BNNT

Image Source:
Zettl Research Group, U.C. Berkeley
(via www.flickr.com/photos/kqedquest)

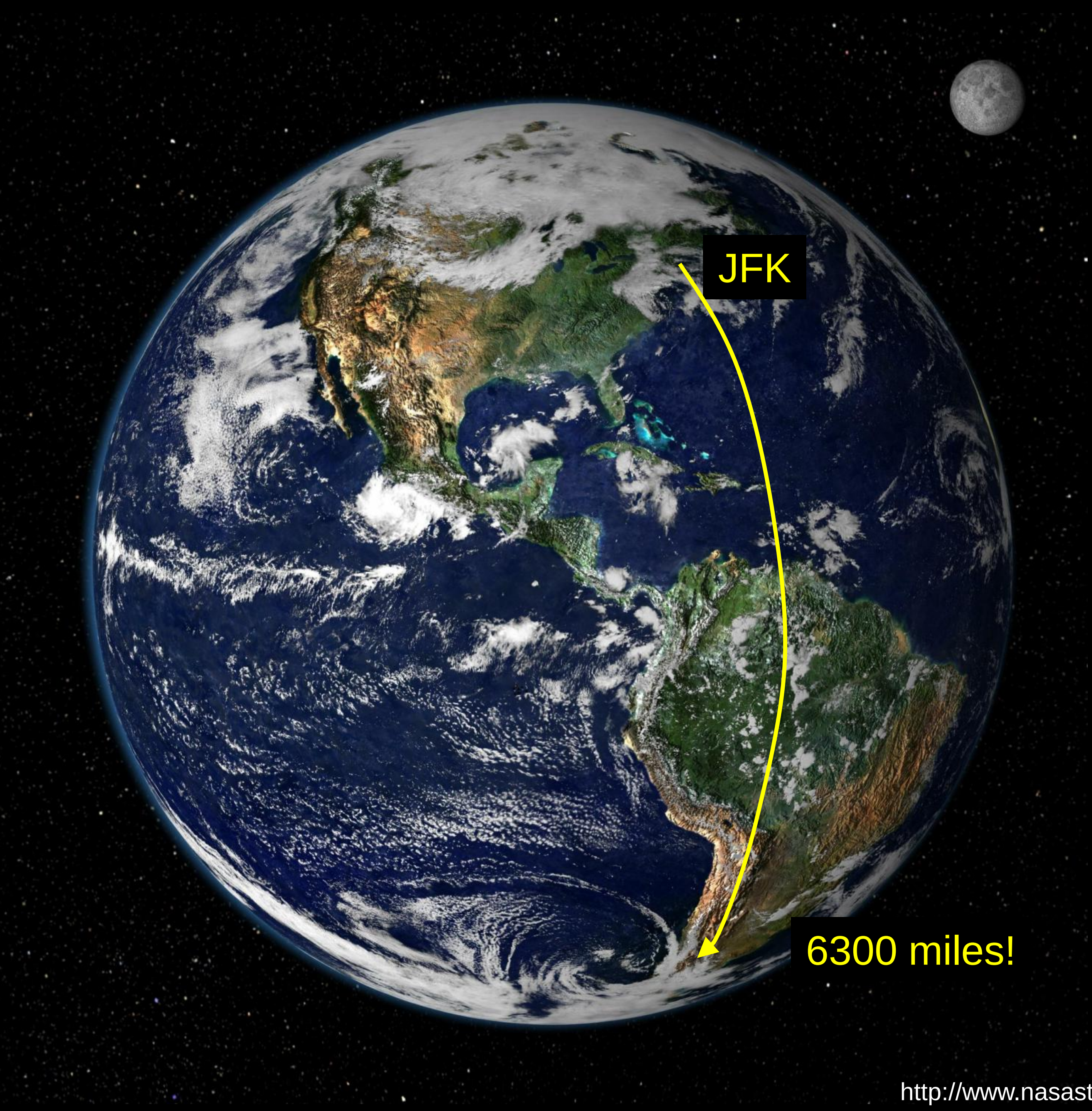

Human Hair,
~ 60 μm diameter
Image: http://creationwiki.org


Human Hair,
~ 60 μm diameter
Image: http://creationwiki.org

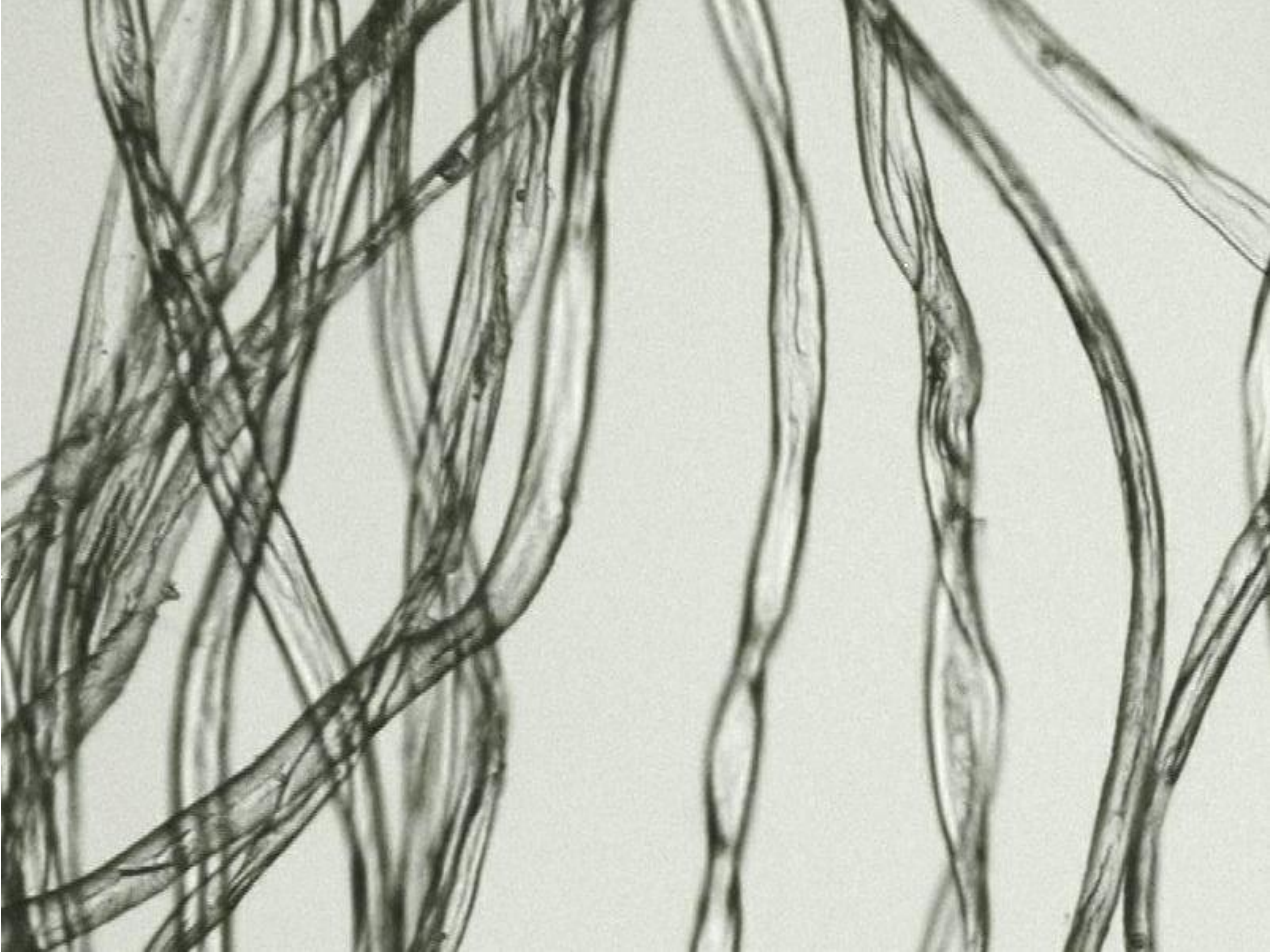

300 nm
= 0.3 µm
Human Hair,
~ 60 µm diameter
Image: http://creationwiki.org

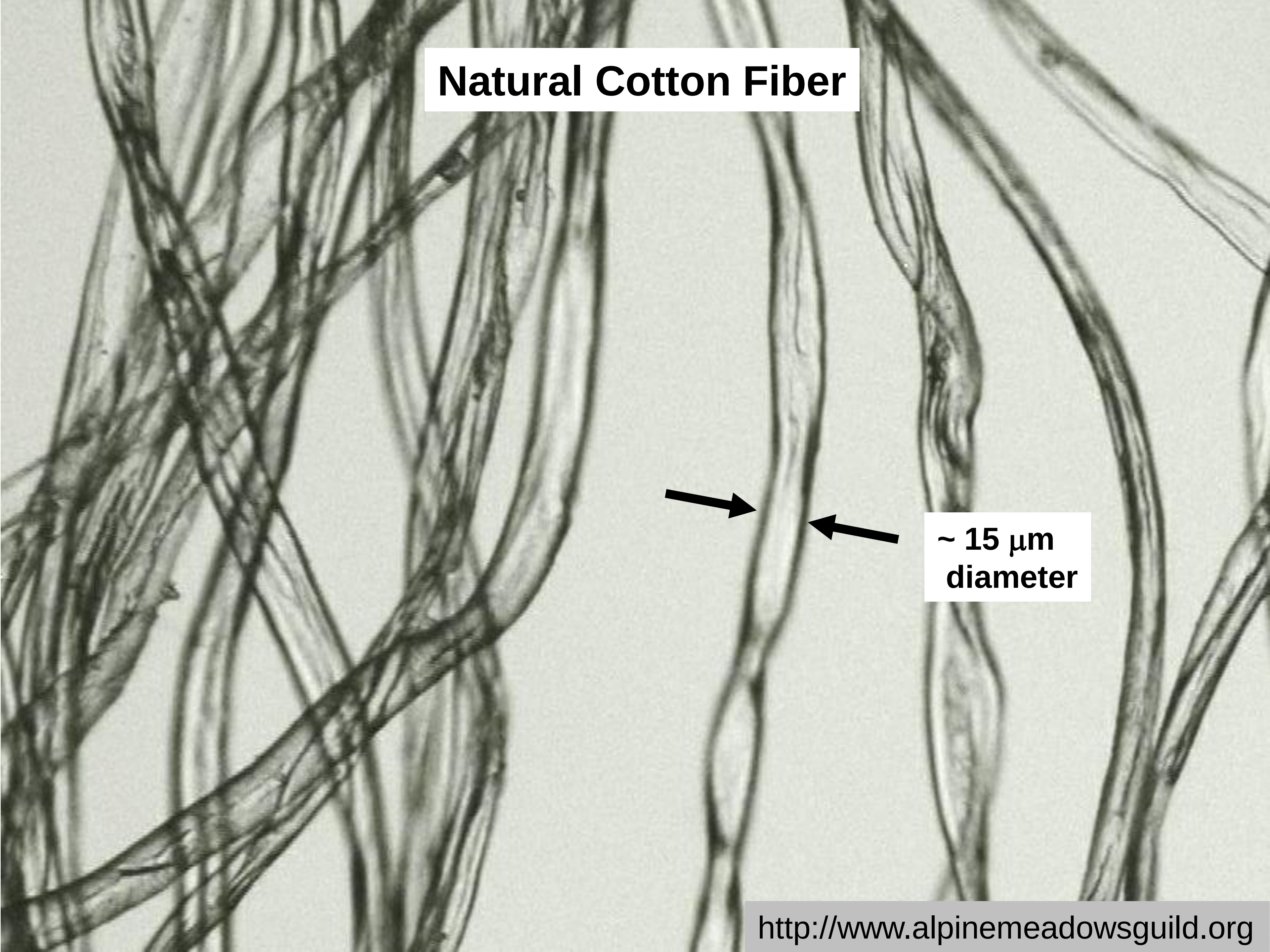


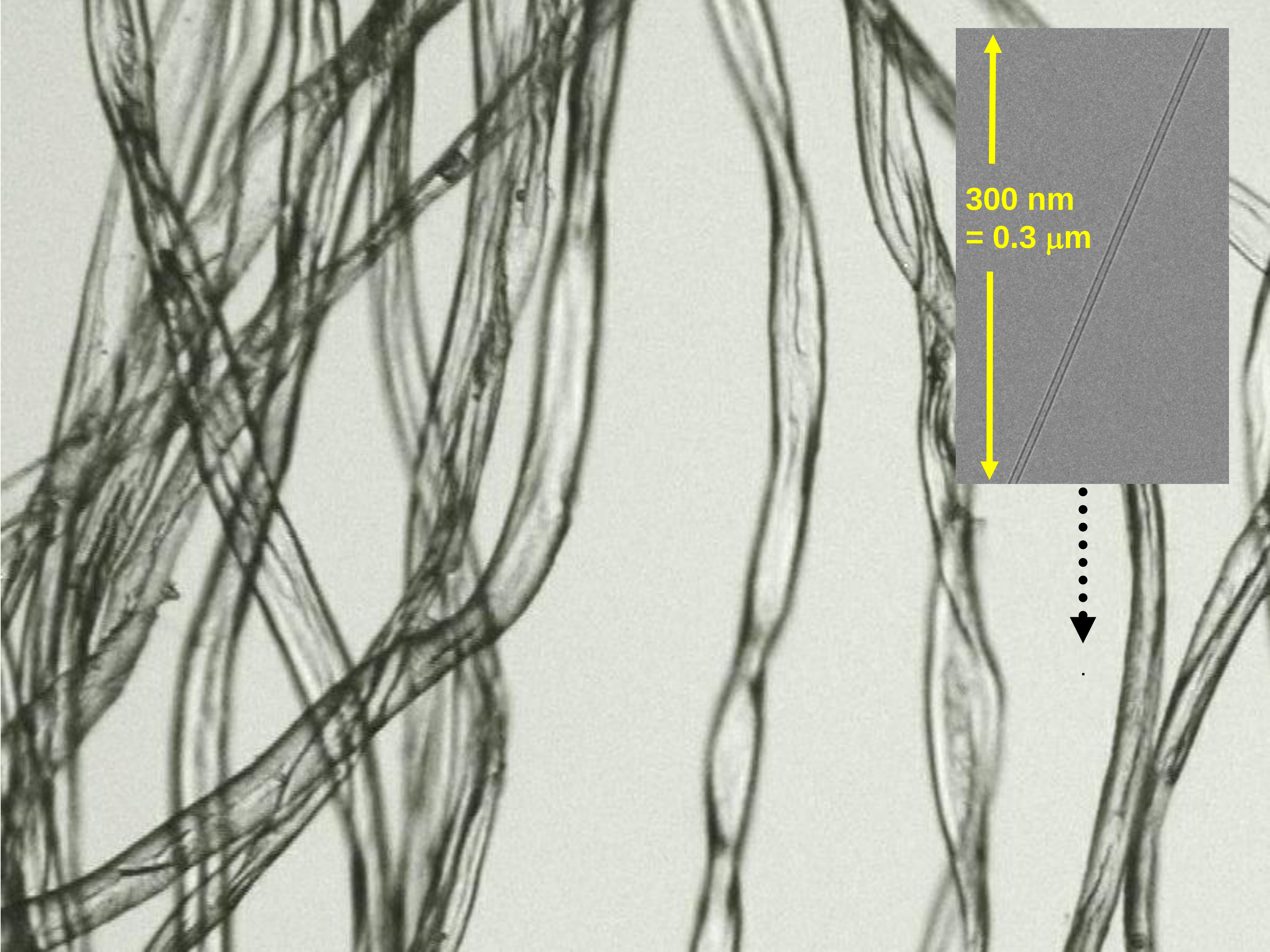
http://www.nasastockphotos.com



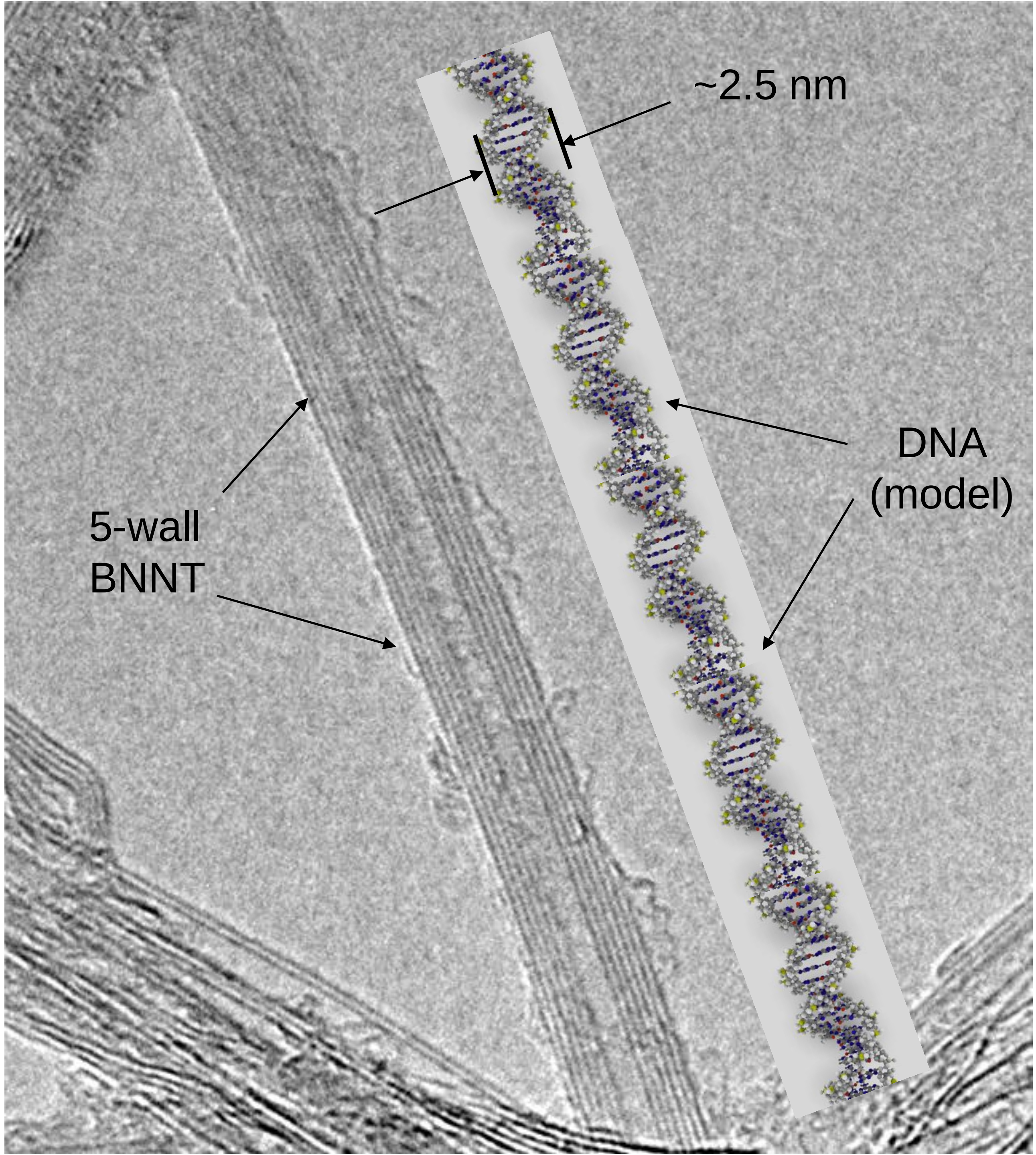
http://www.nasastockphotos.com



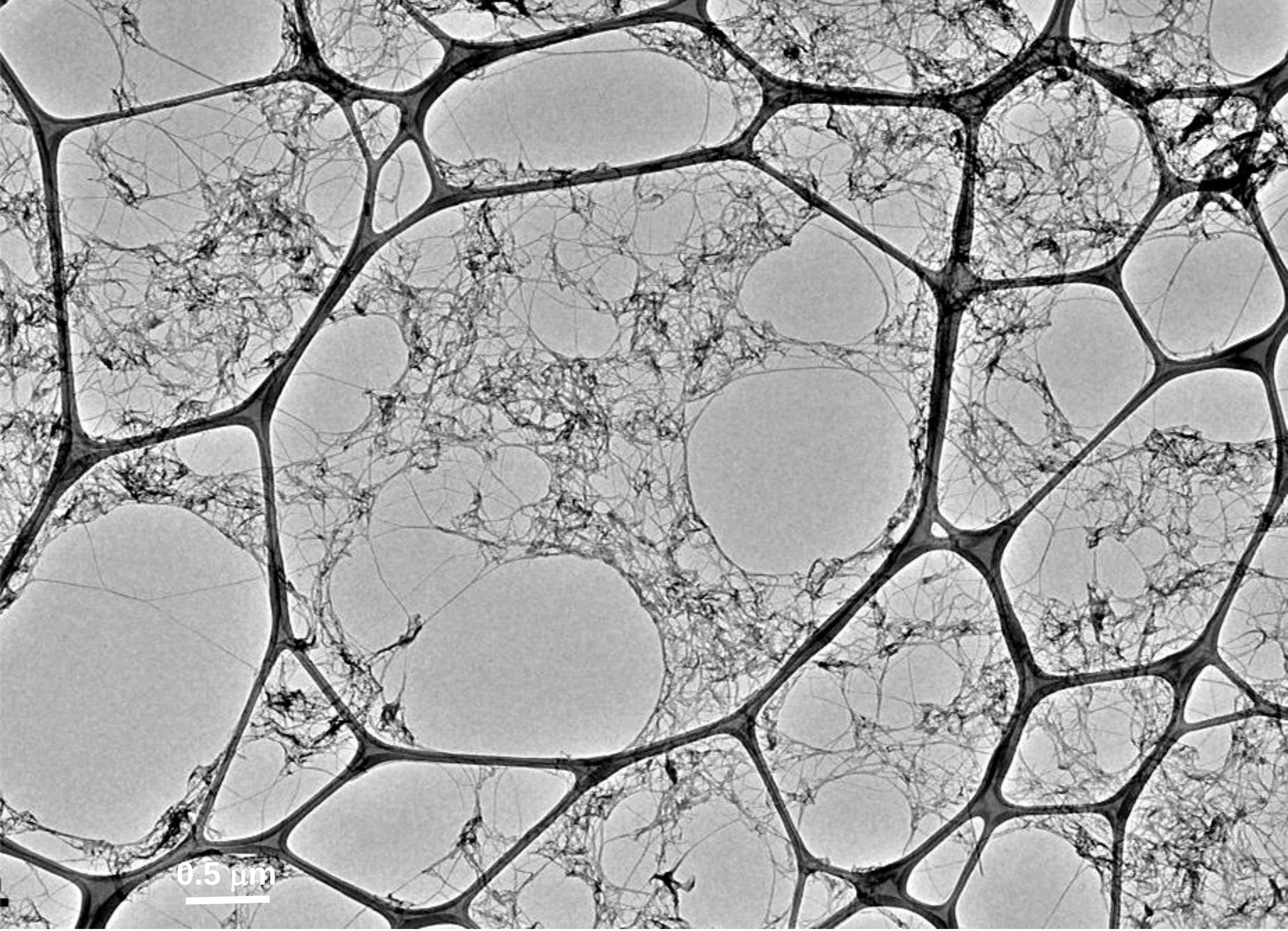

Natural Cotton Fiber
~ 15 μm
diameter
http://www.alpinemeadowsguild.org


300 nm
= 0.3 μm

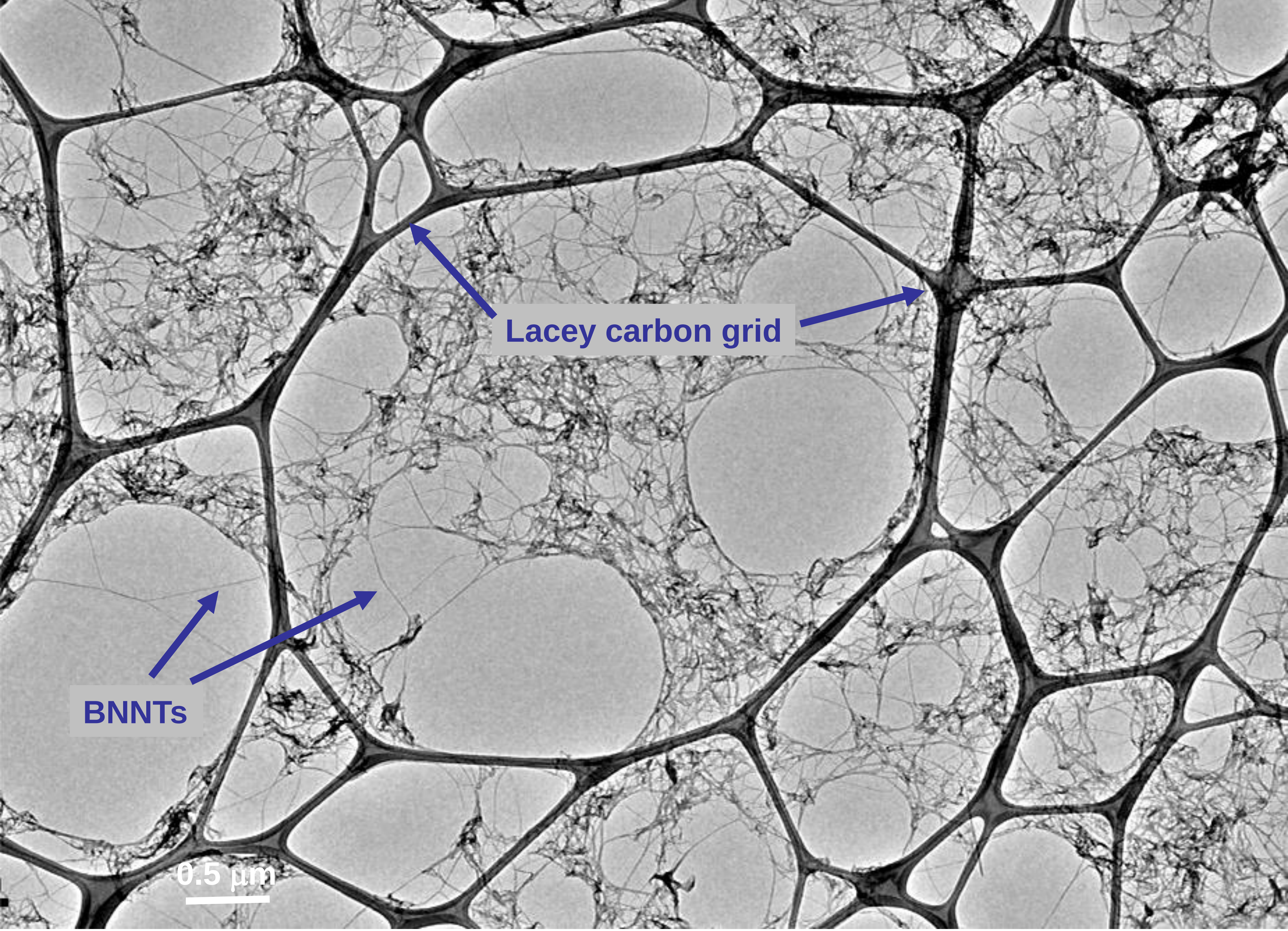
Scale Comparison: BNNT and DNA



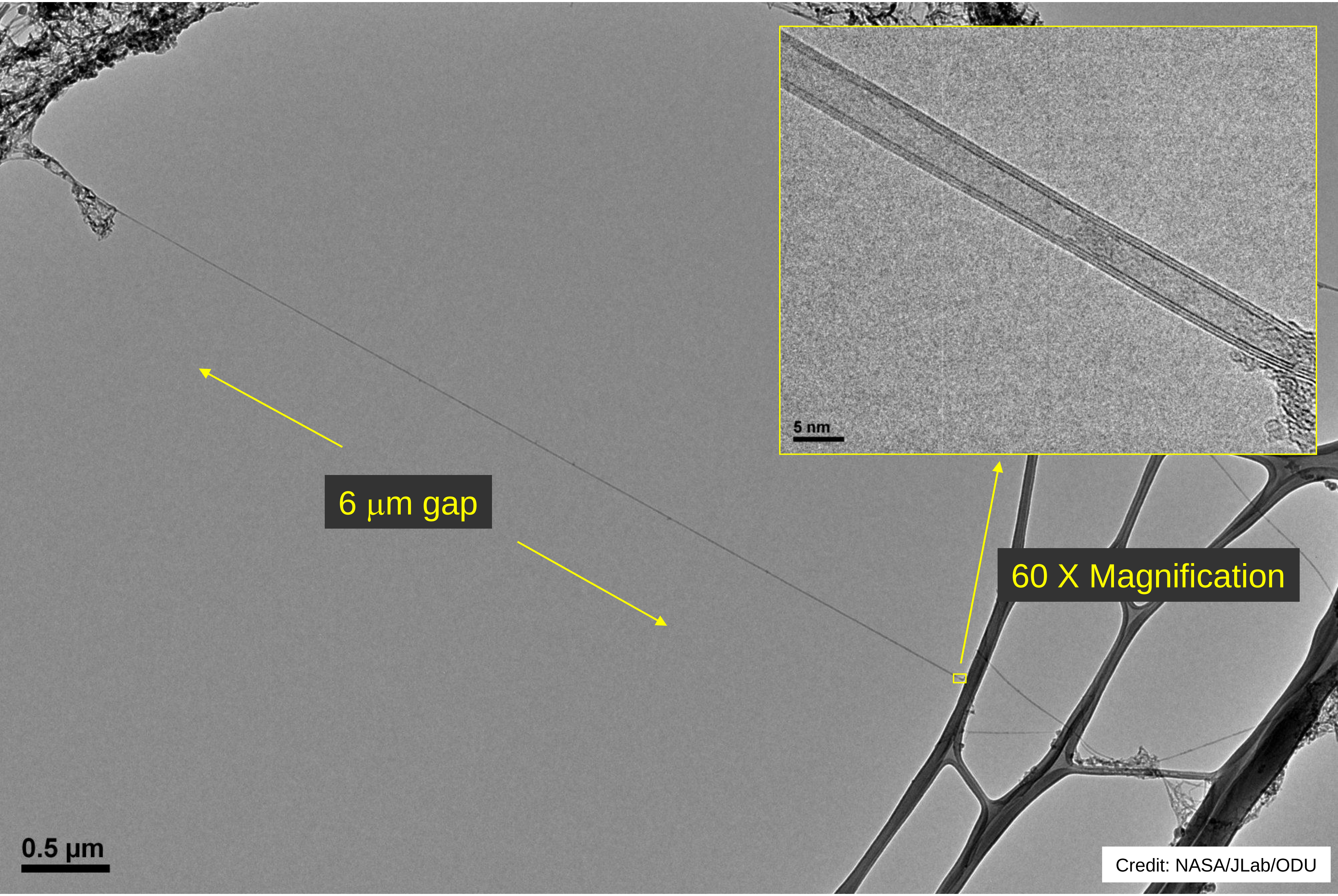
DNA model:
flickr.com/photos/ynse/542370154/



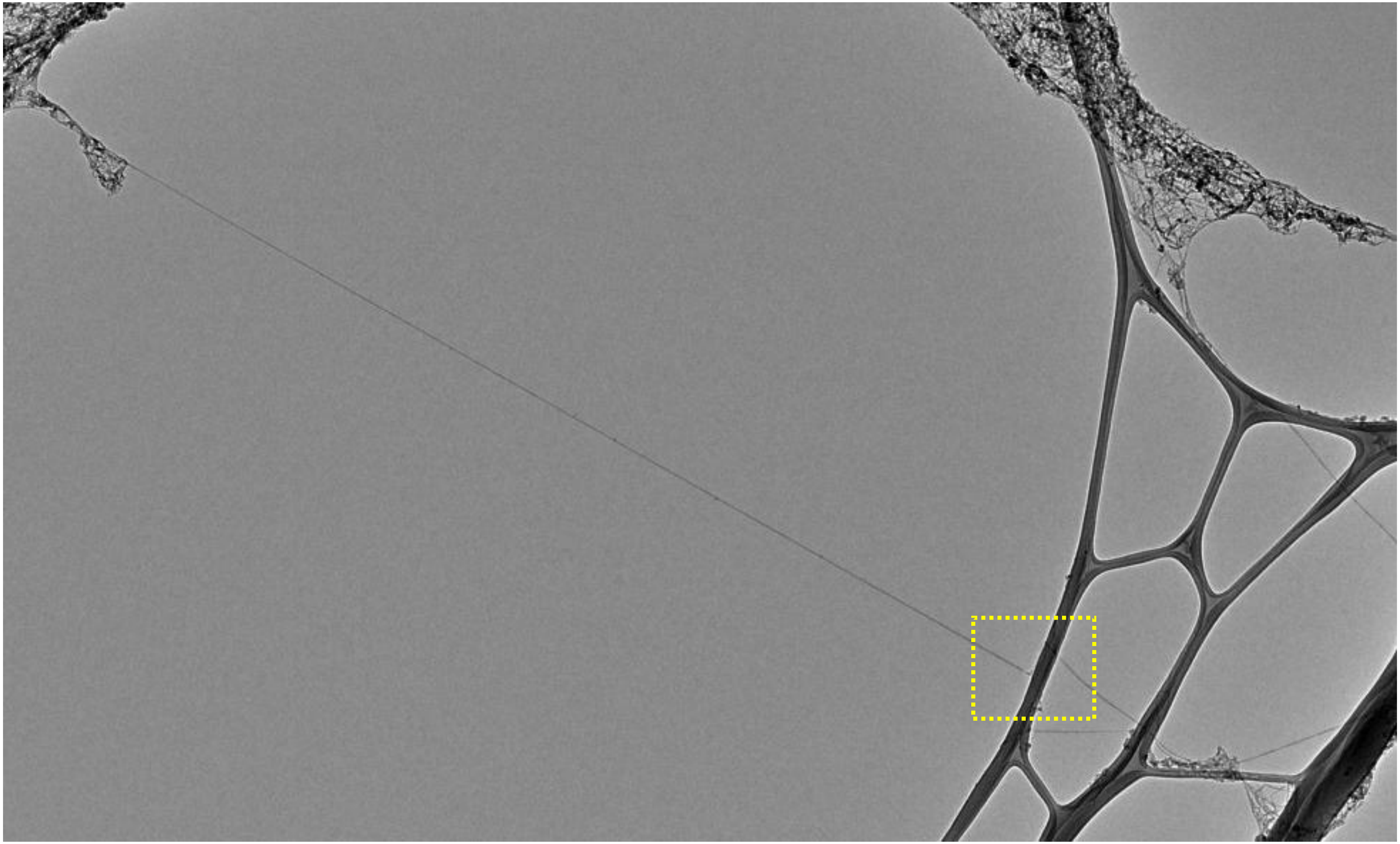
TEM image: Dr Wei Cao, ODU/ARC

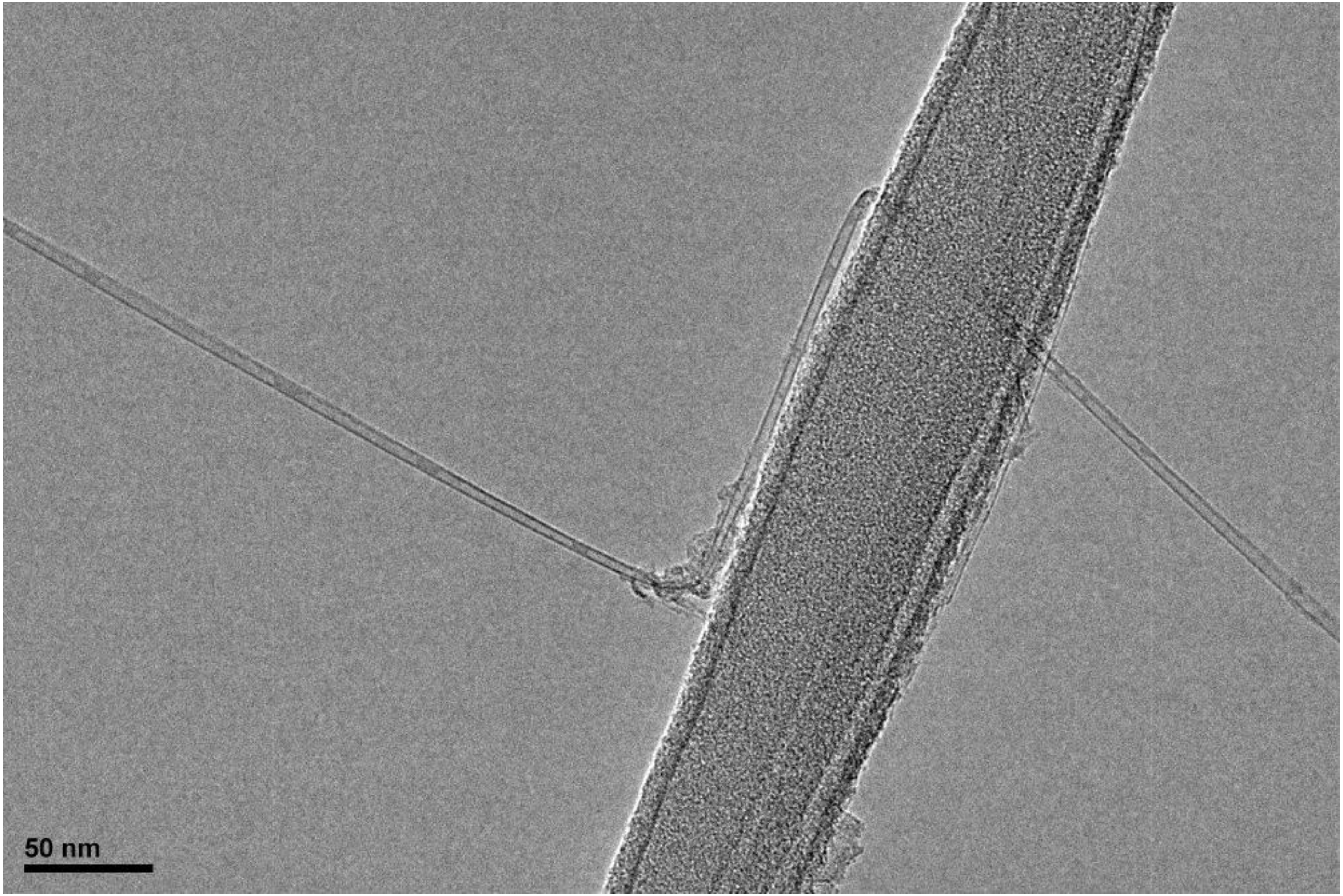


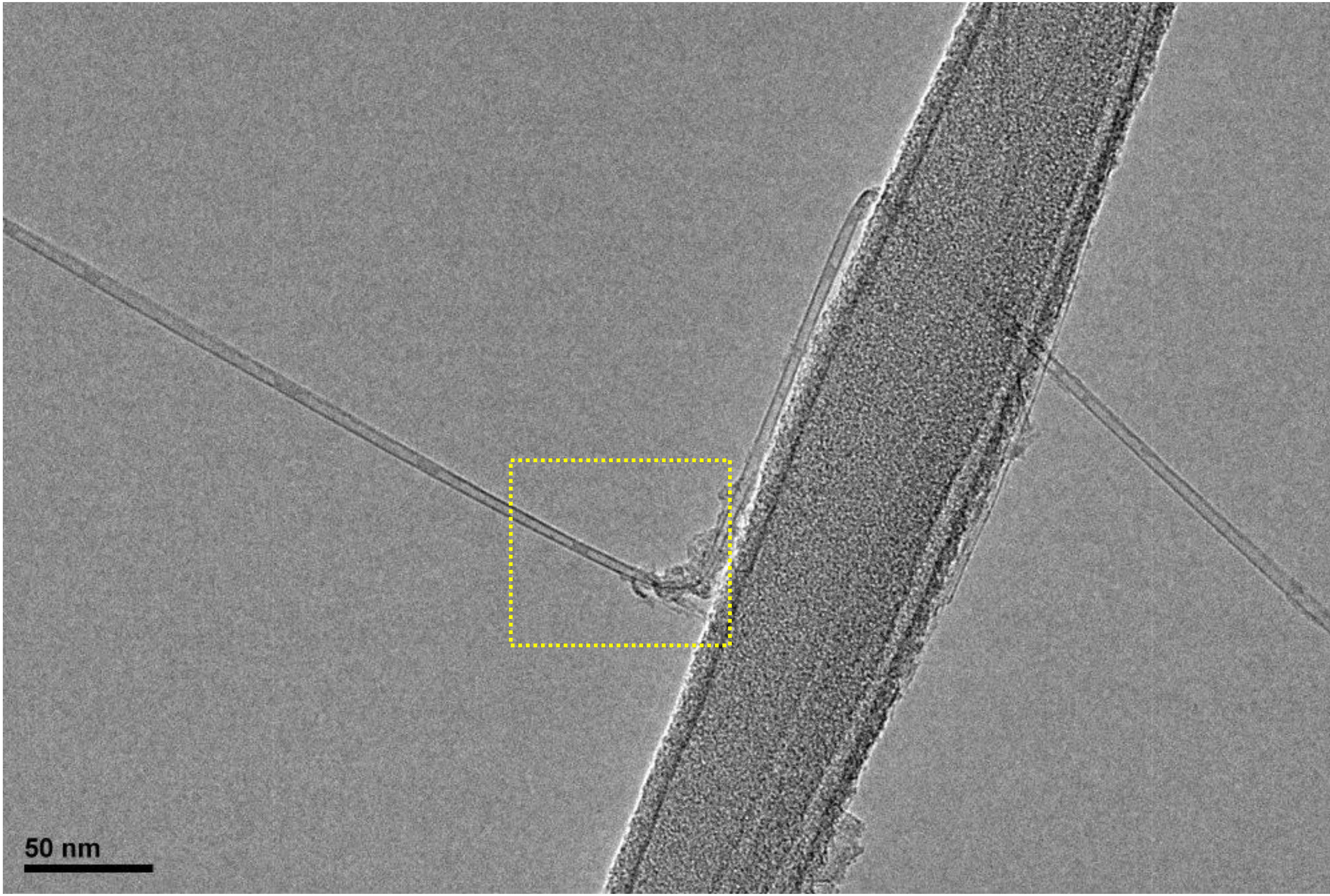
TEM image: Dr Wei Cao, ODU/ARC

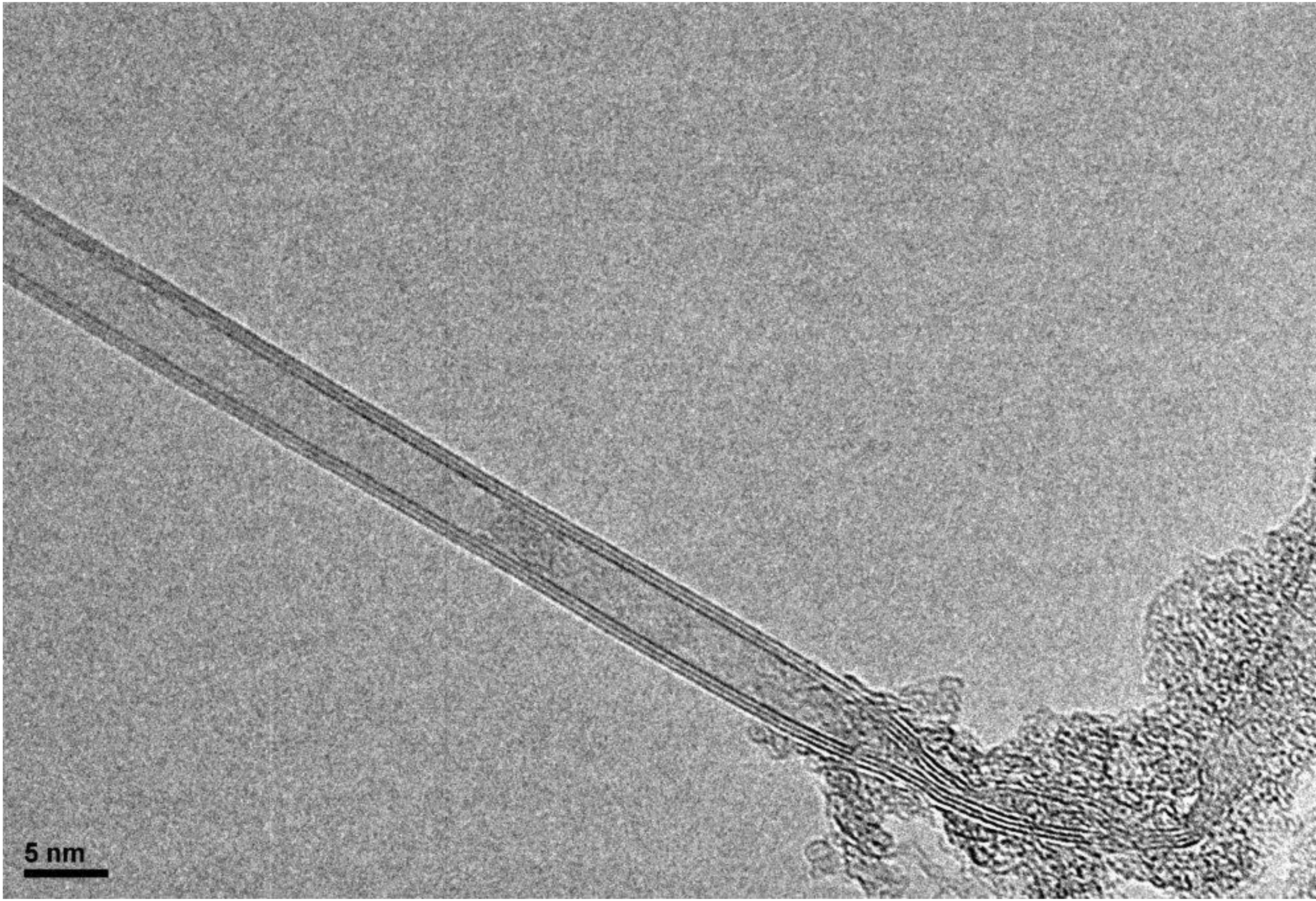


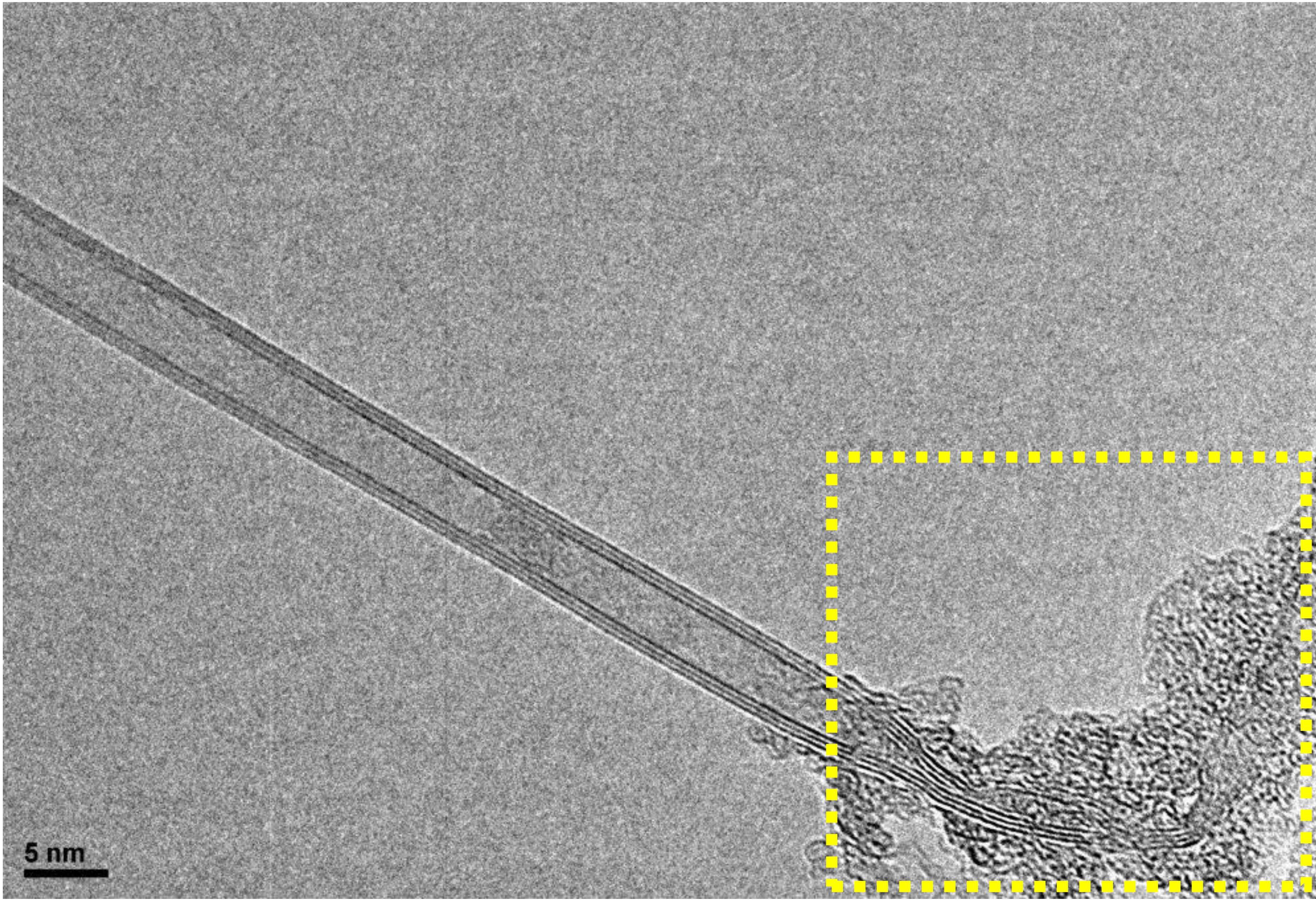
Isolated, highly crystalline, 10 μm x 4 nm, 3-wall BNNT, strung across air gap (aspect ratio > 2500).




50 nm


50 nm


5 nm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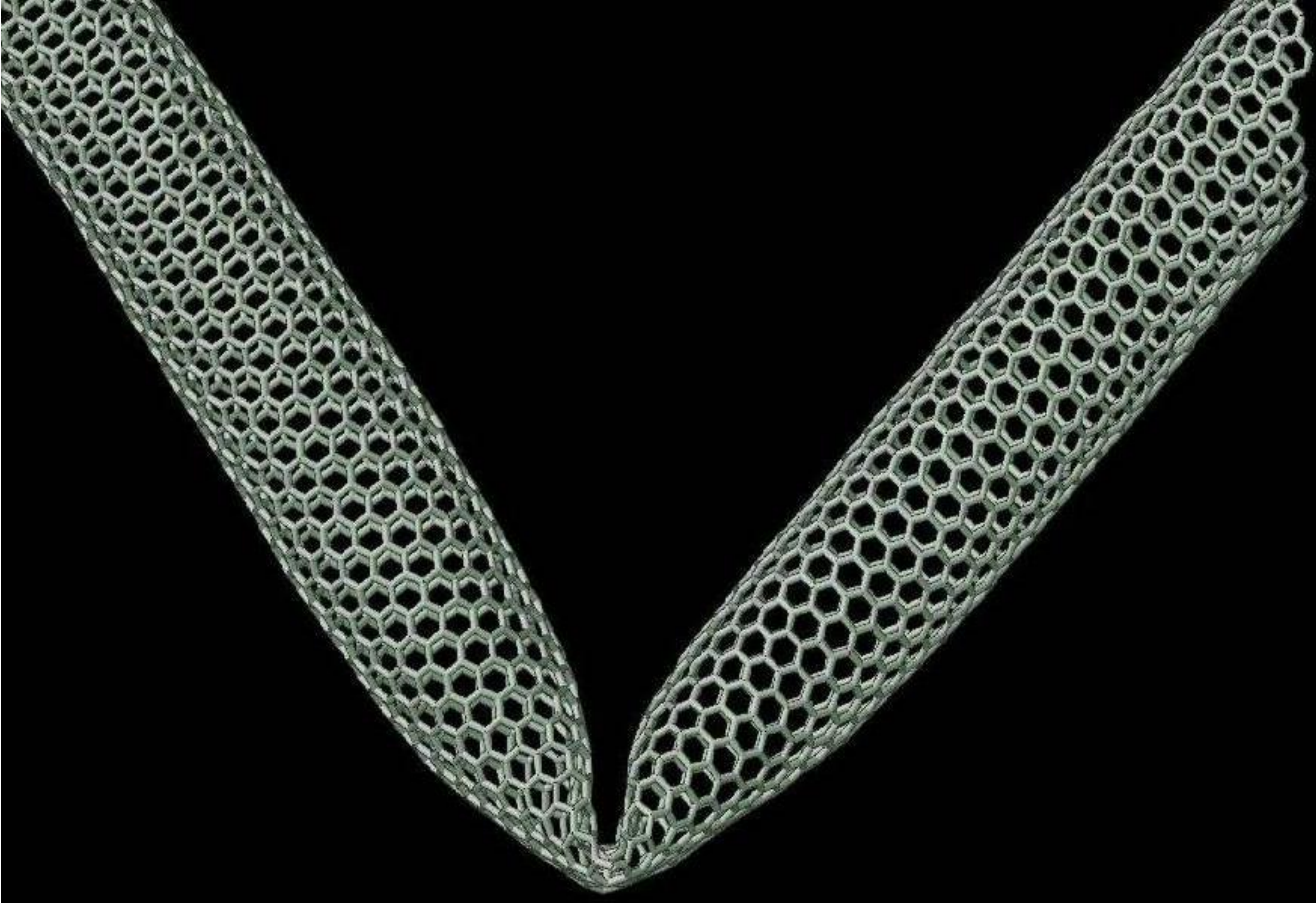
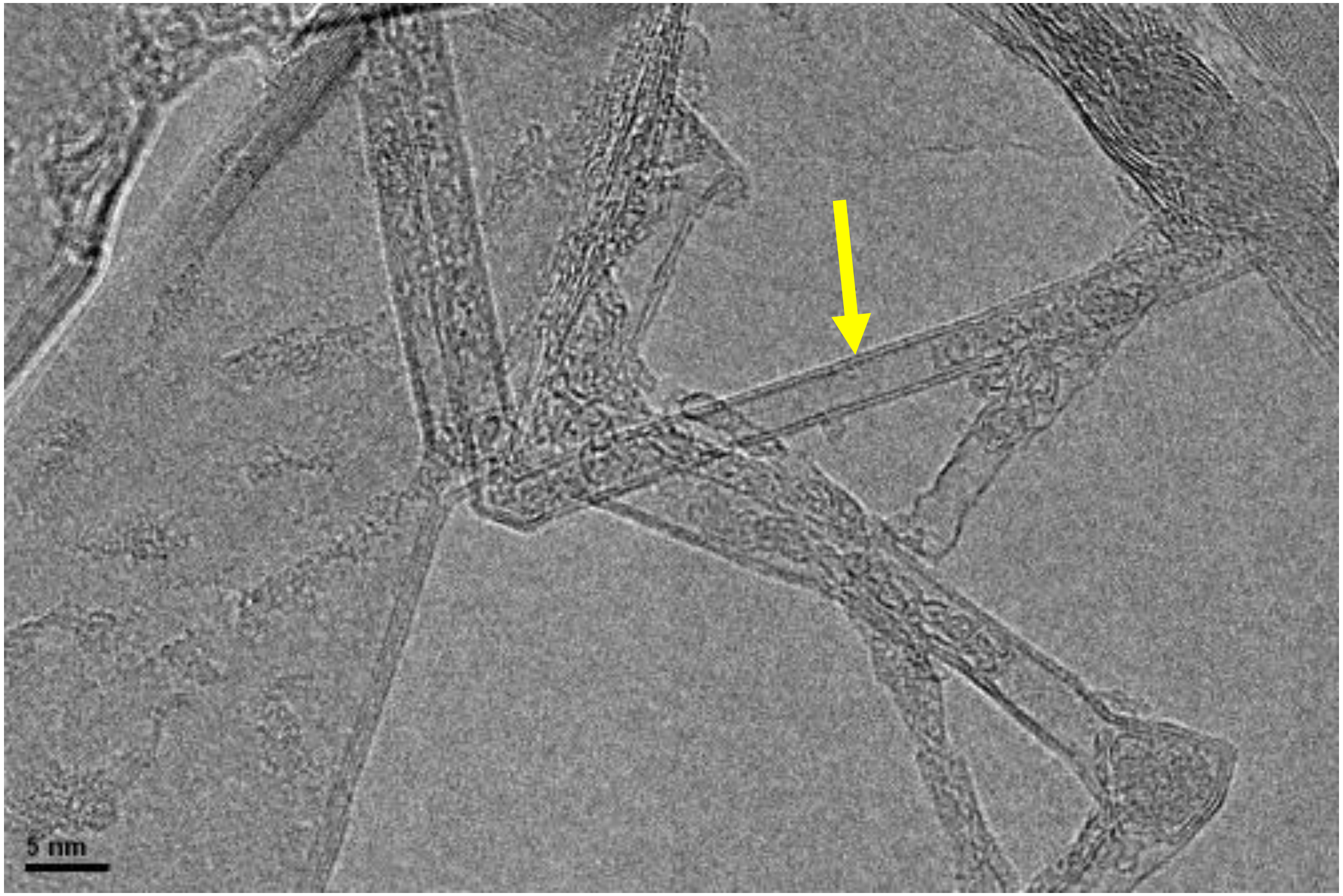
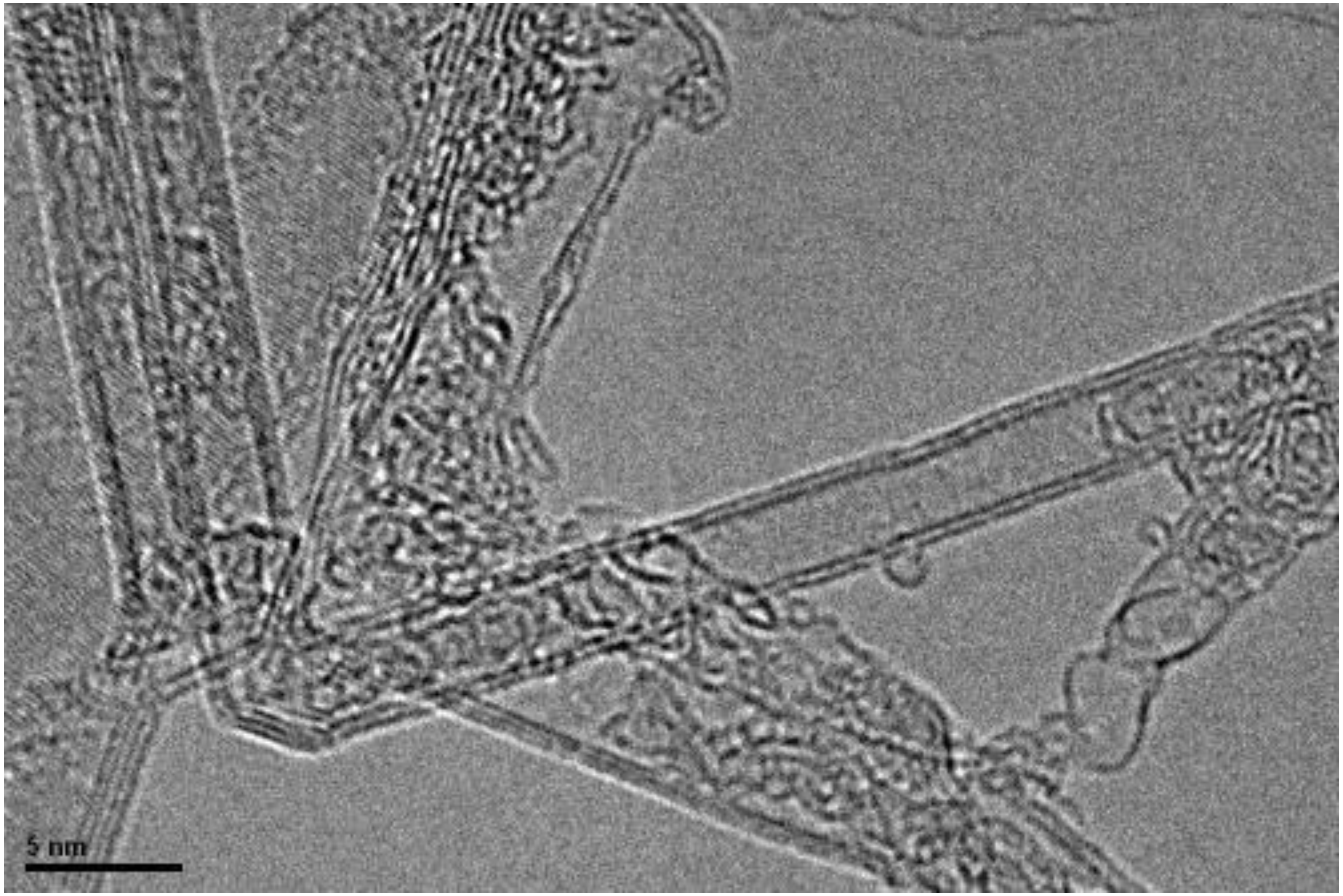


http://mt.seas.upenn.edu

E-beam modification

BNNT modification under 200 keV electron beam

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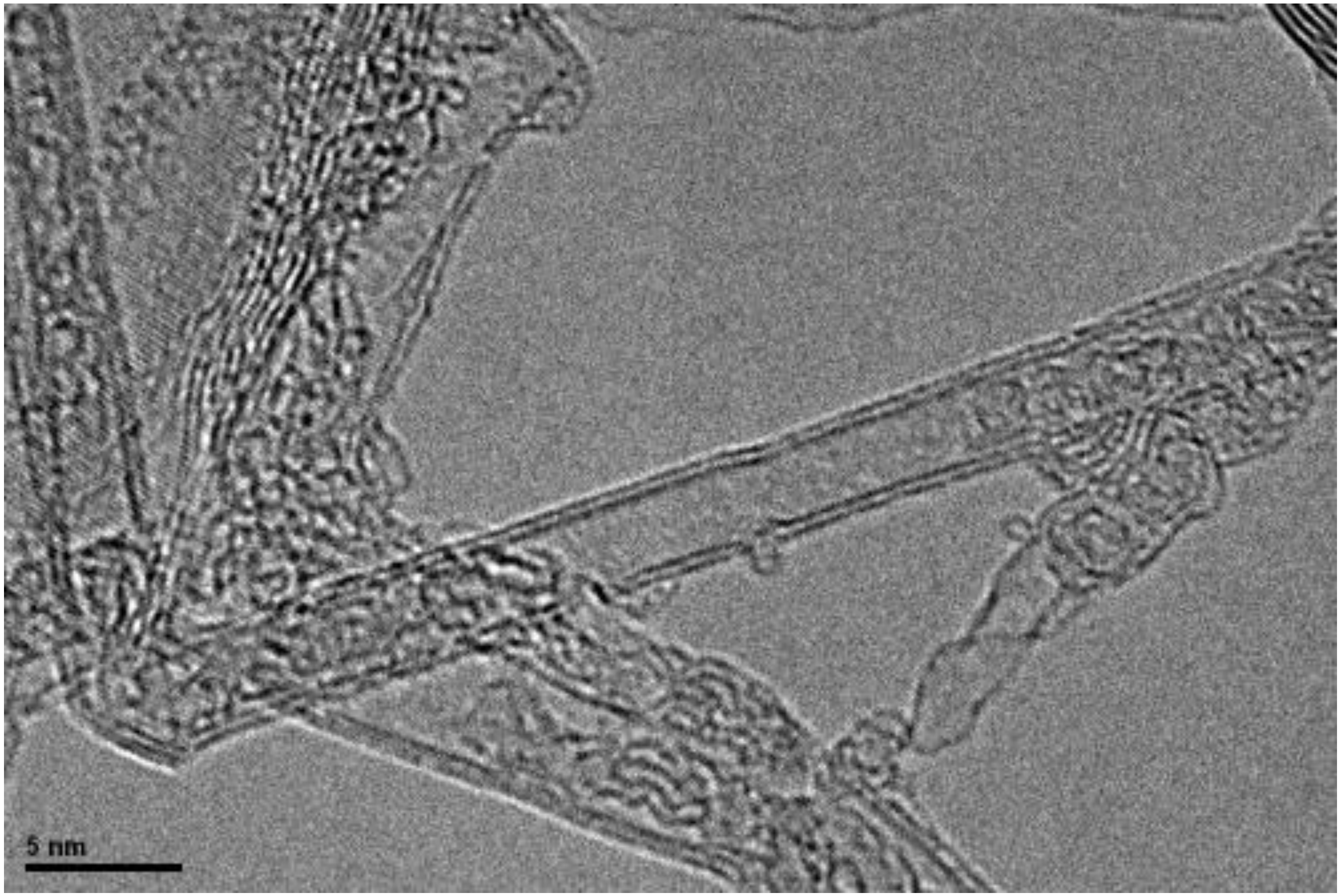
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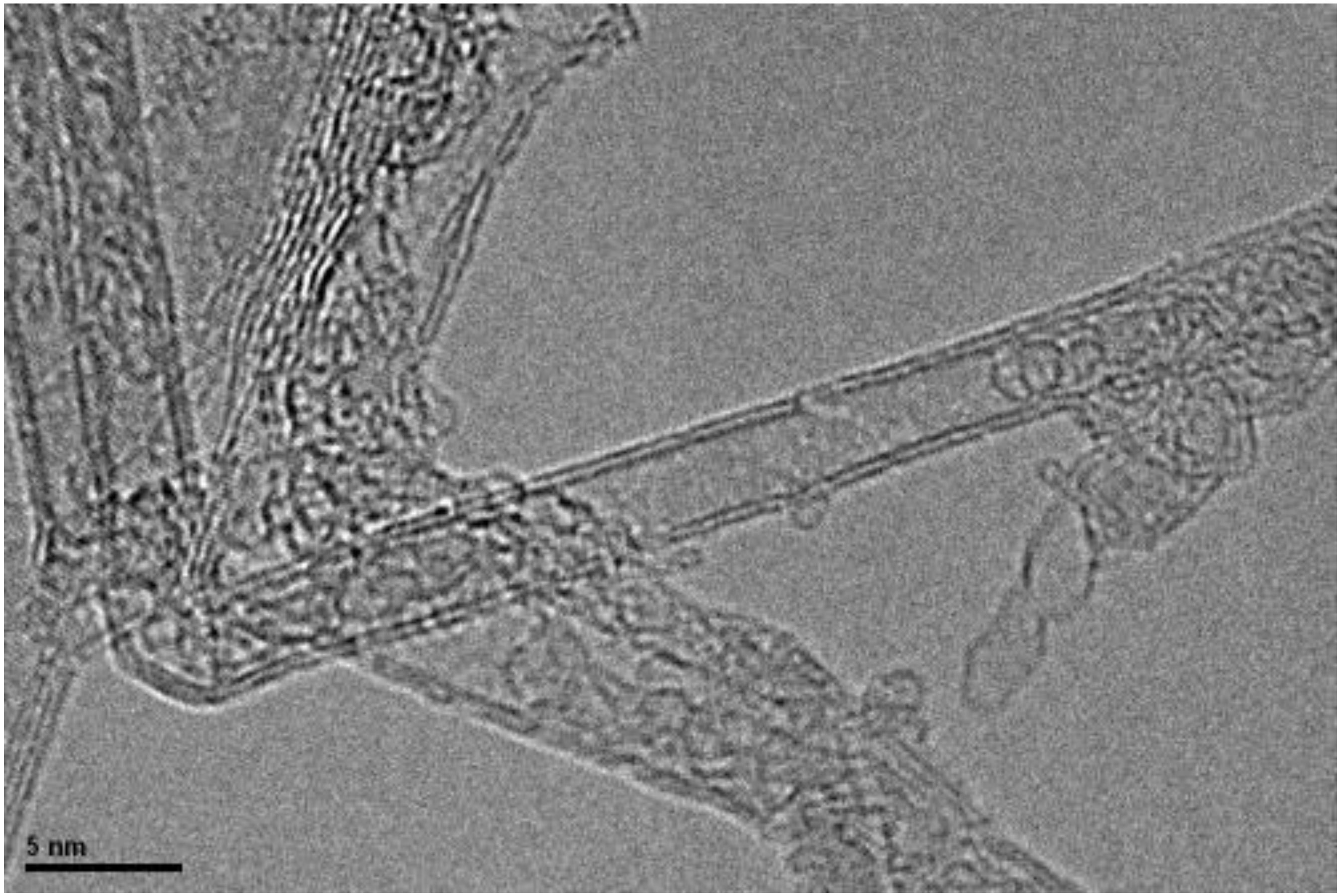
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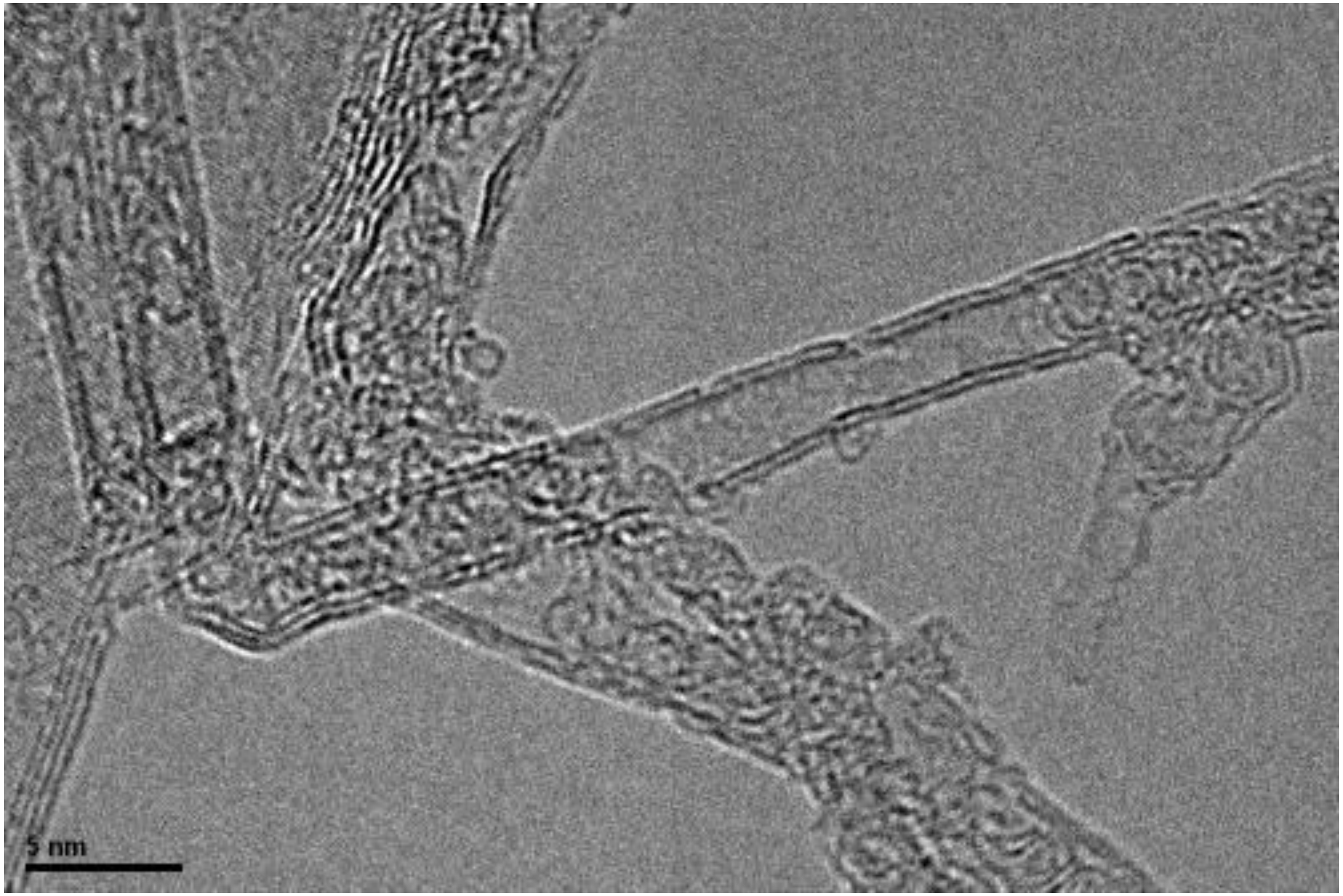
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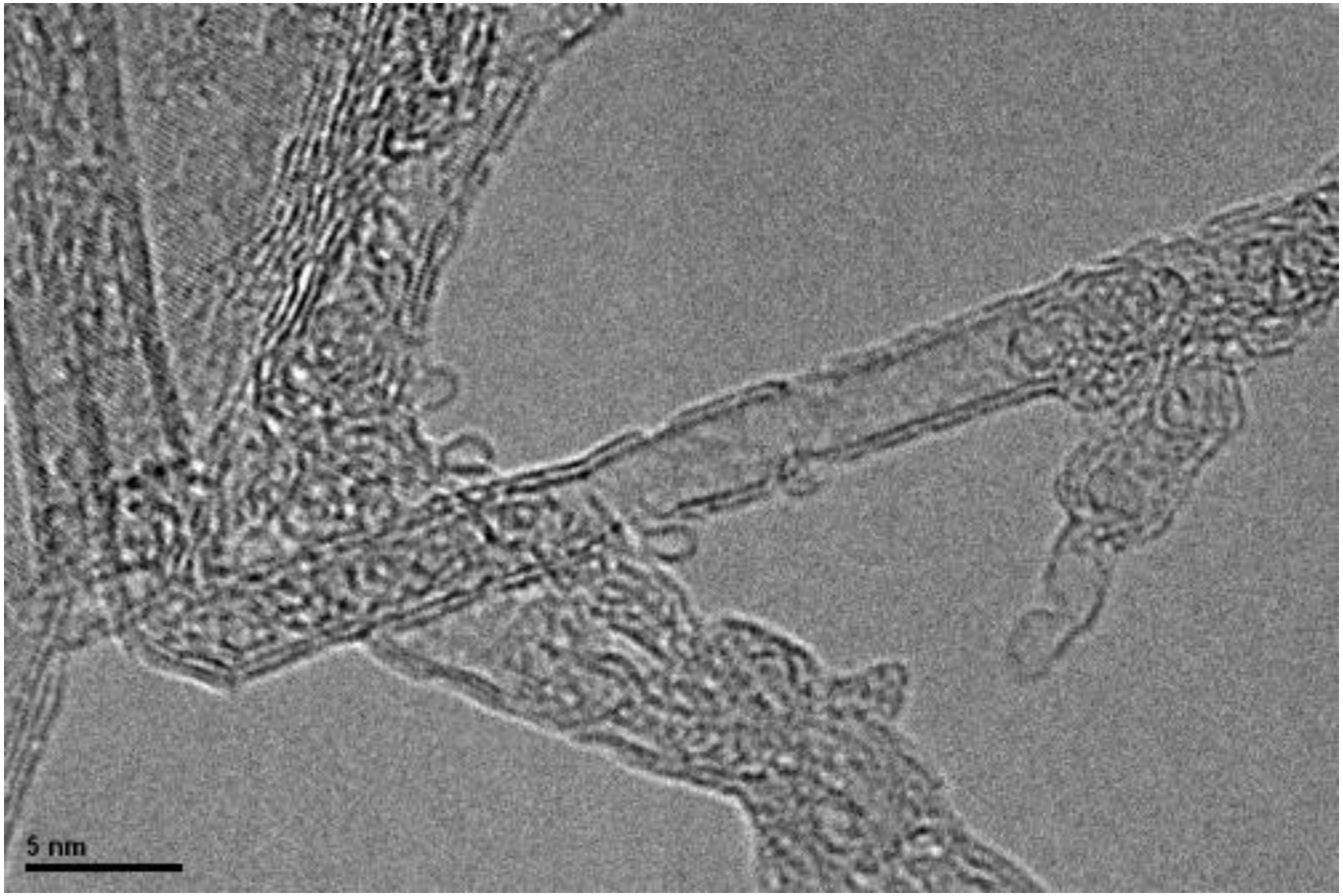
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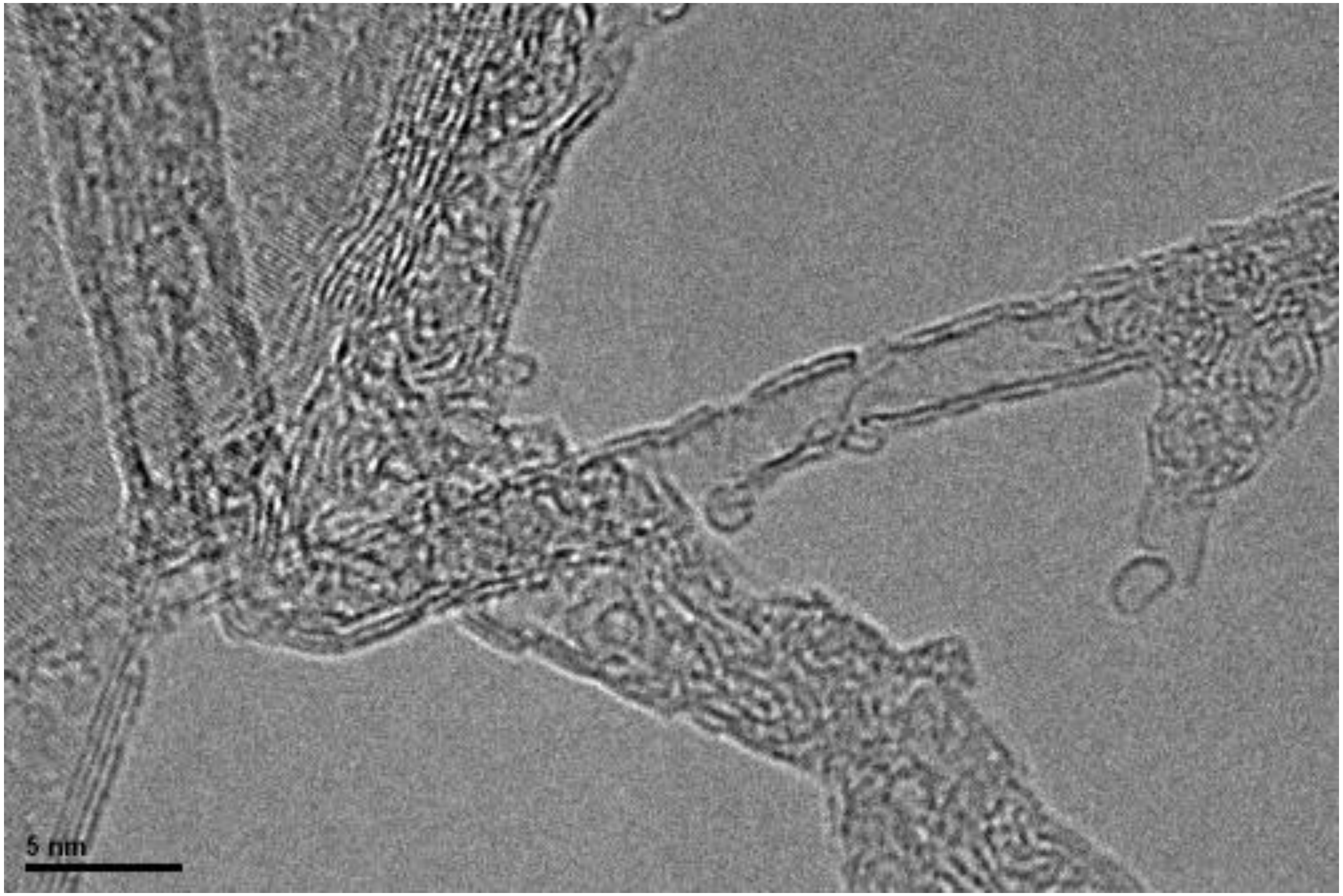
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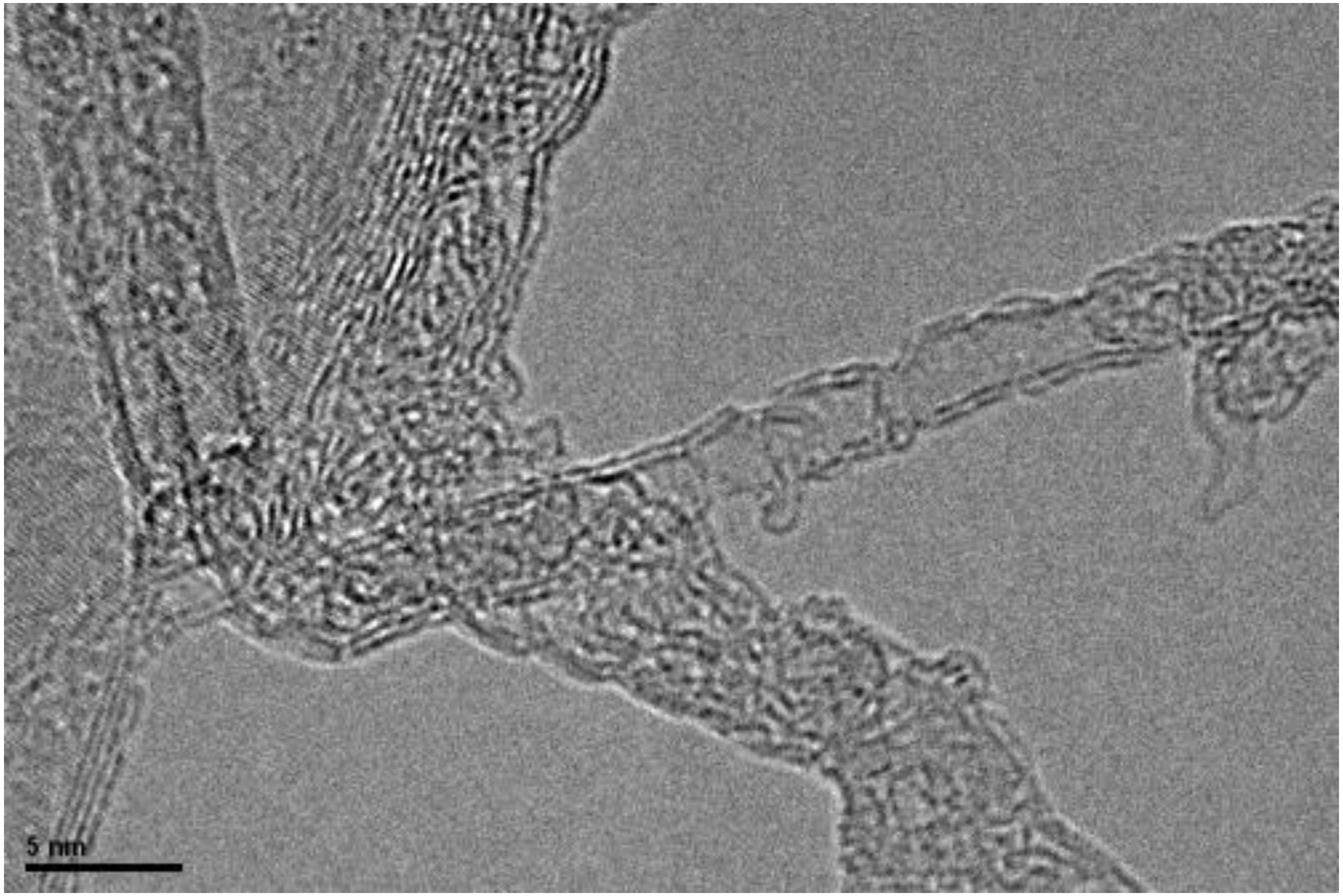
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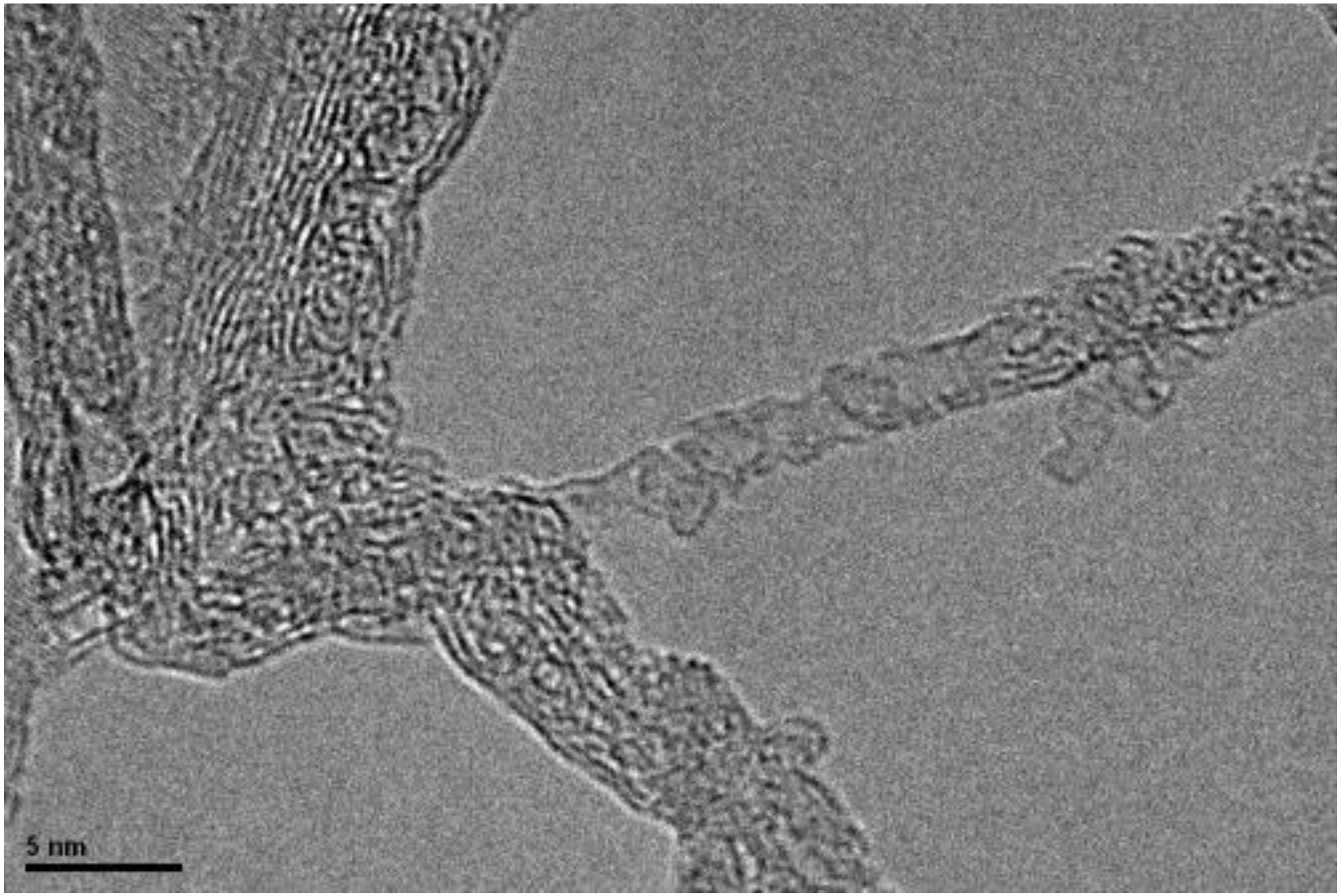
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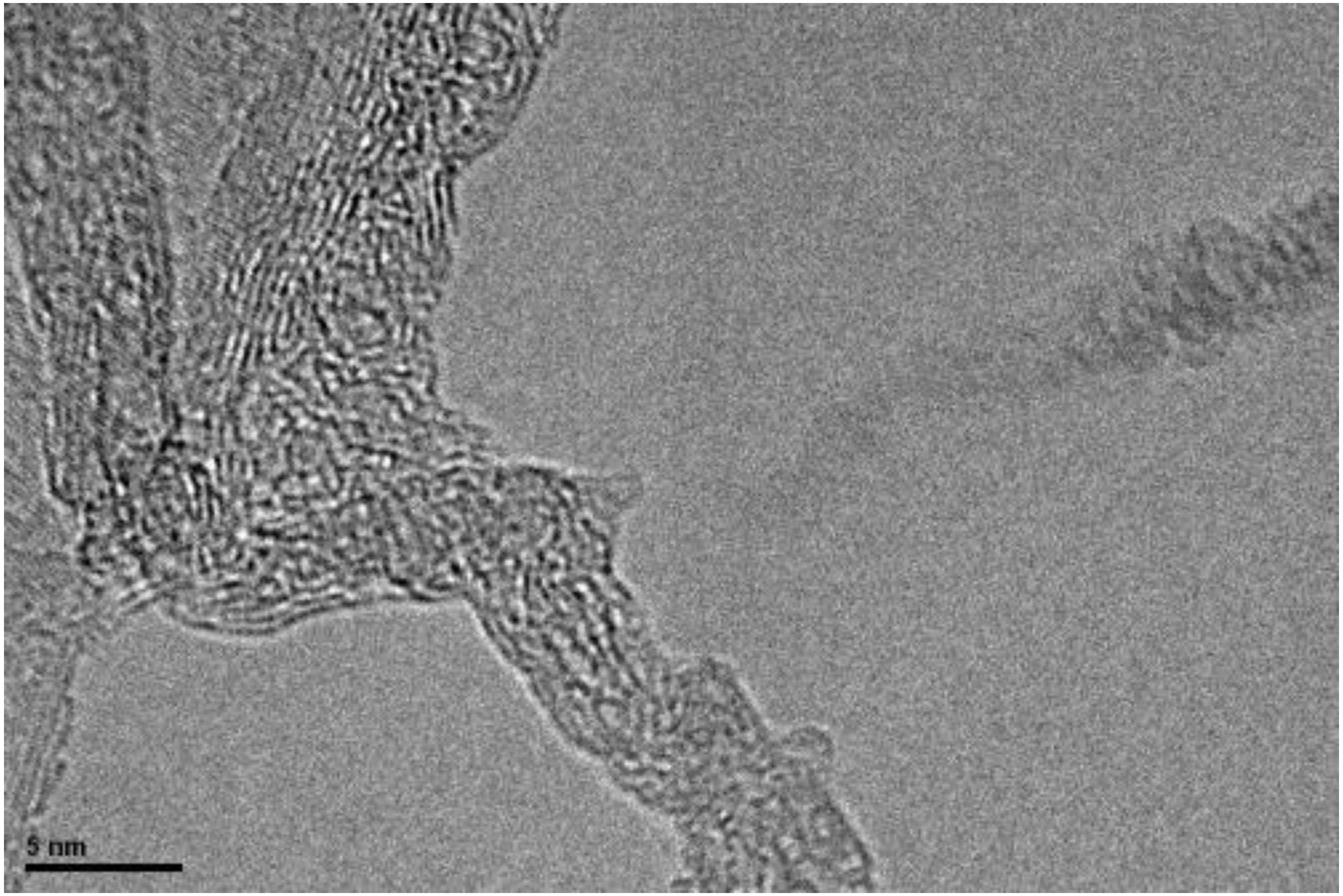
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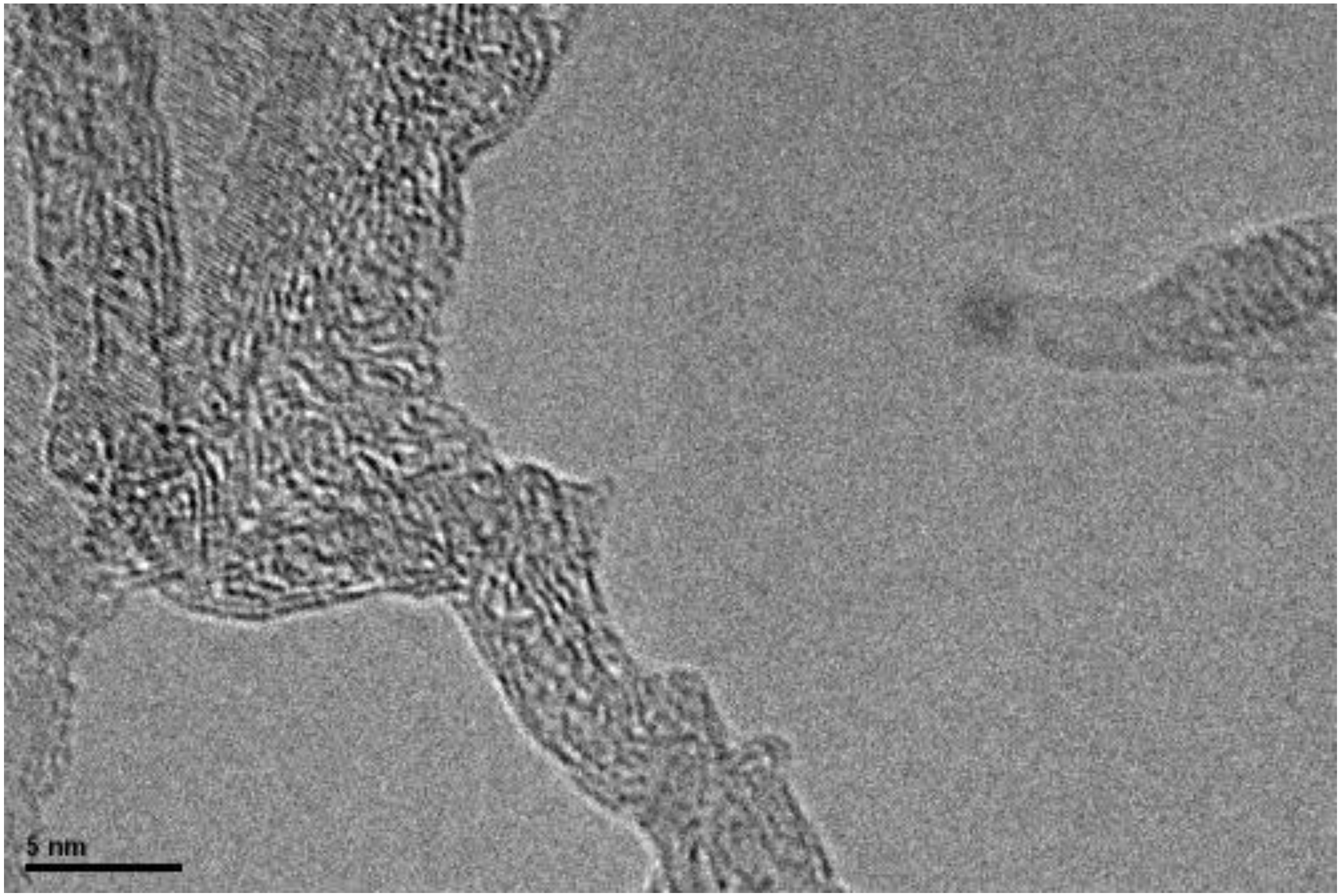
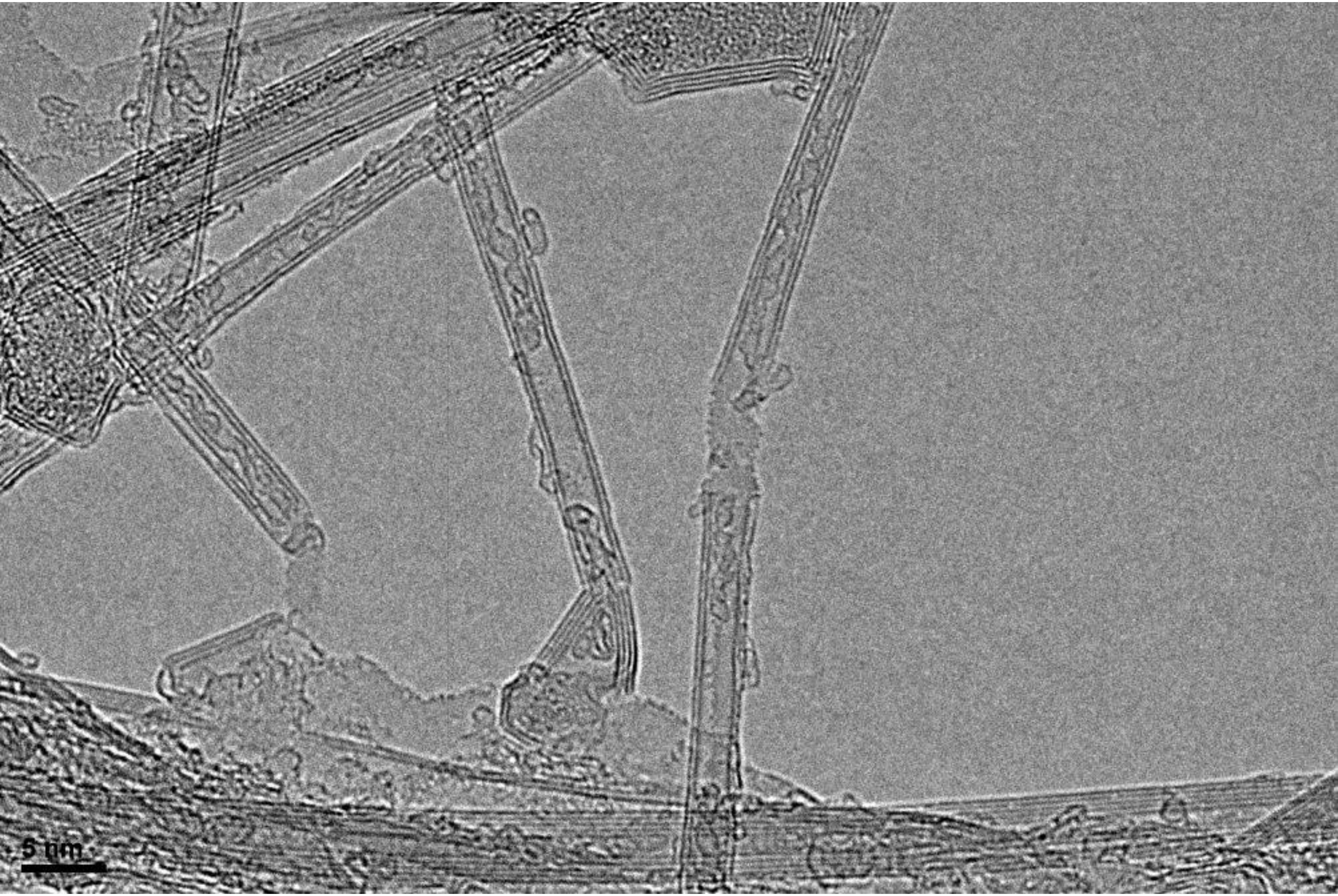
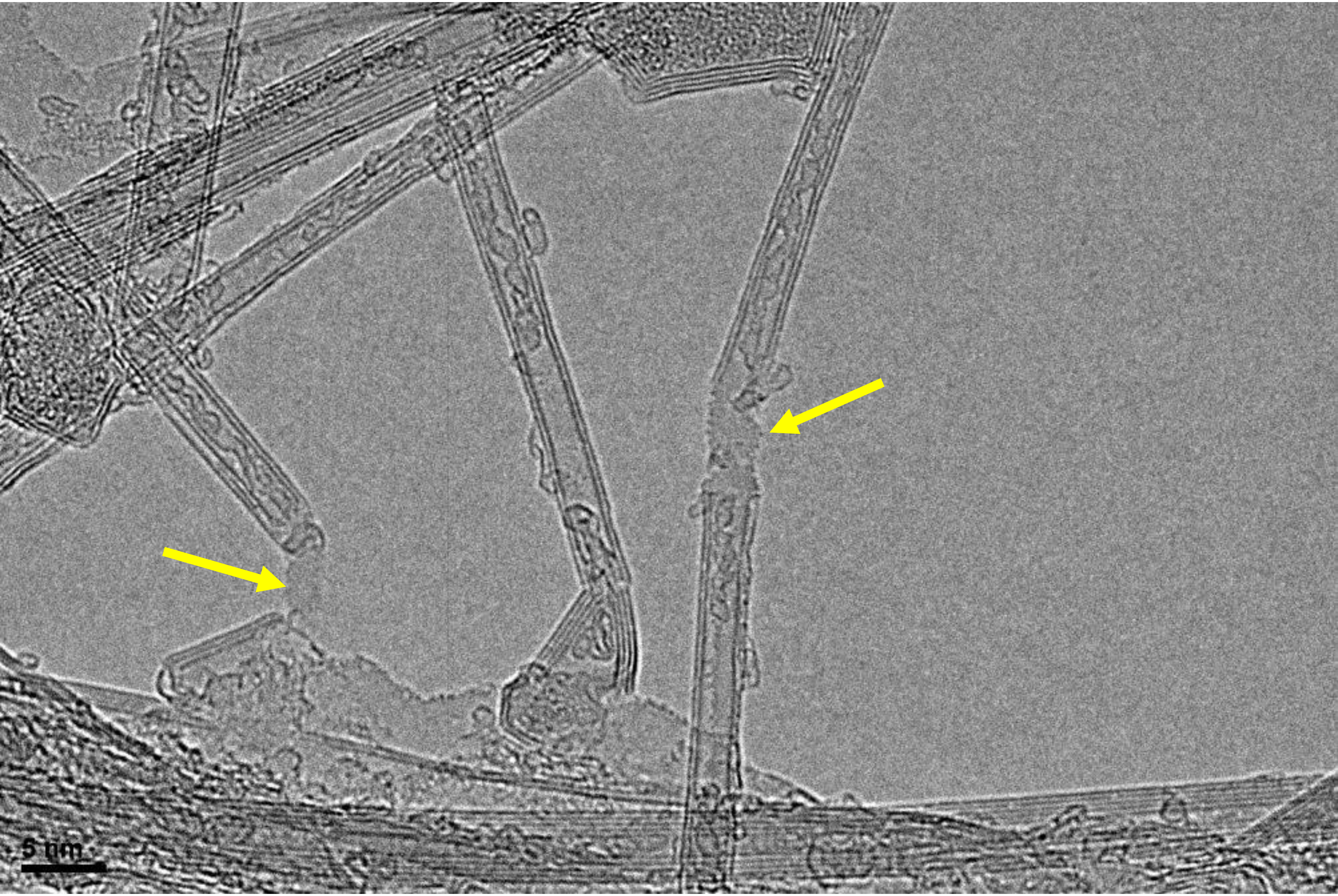

5 nm

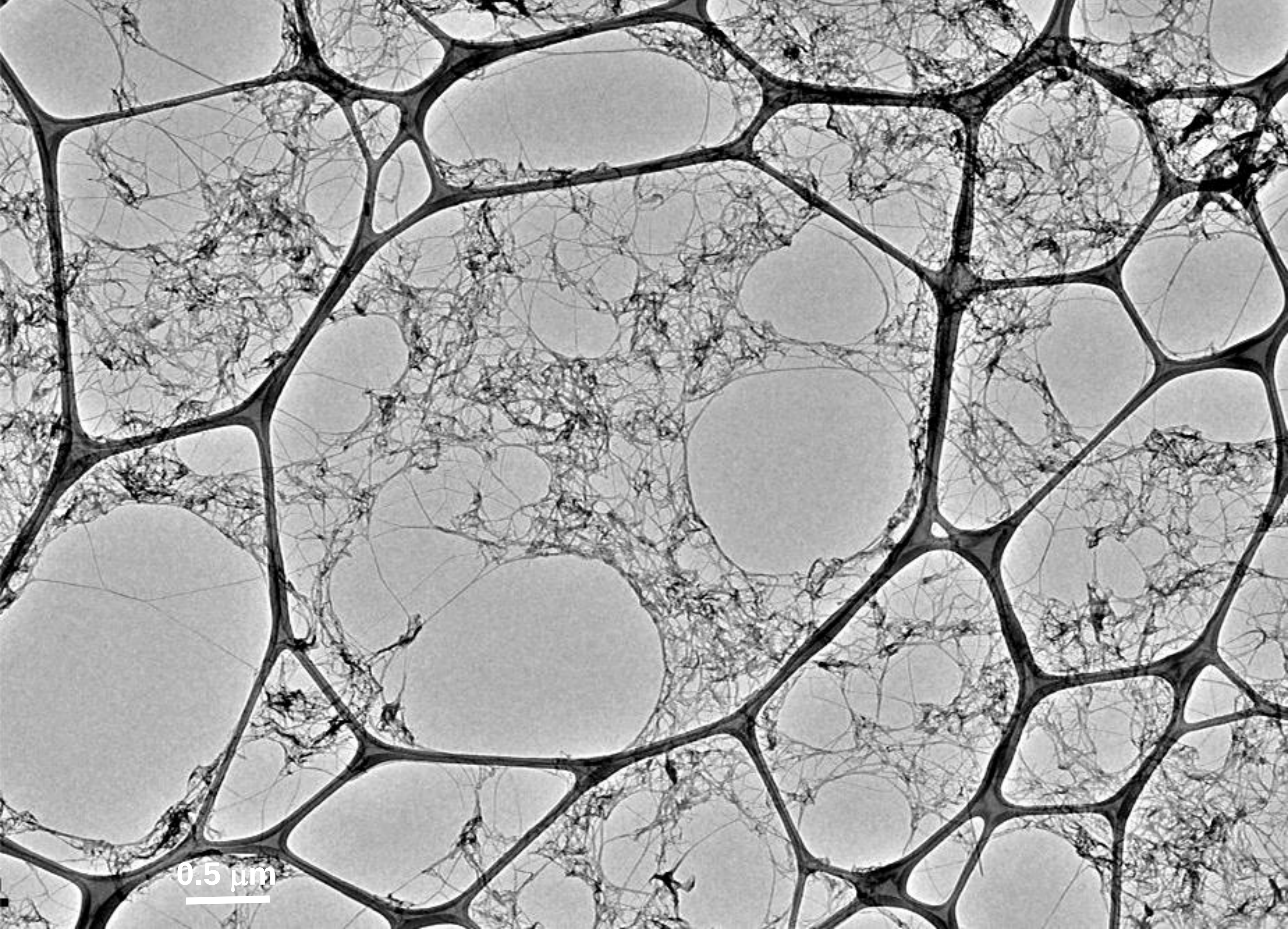
BN Nanoribbons (white graphene)



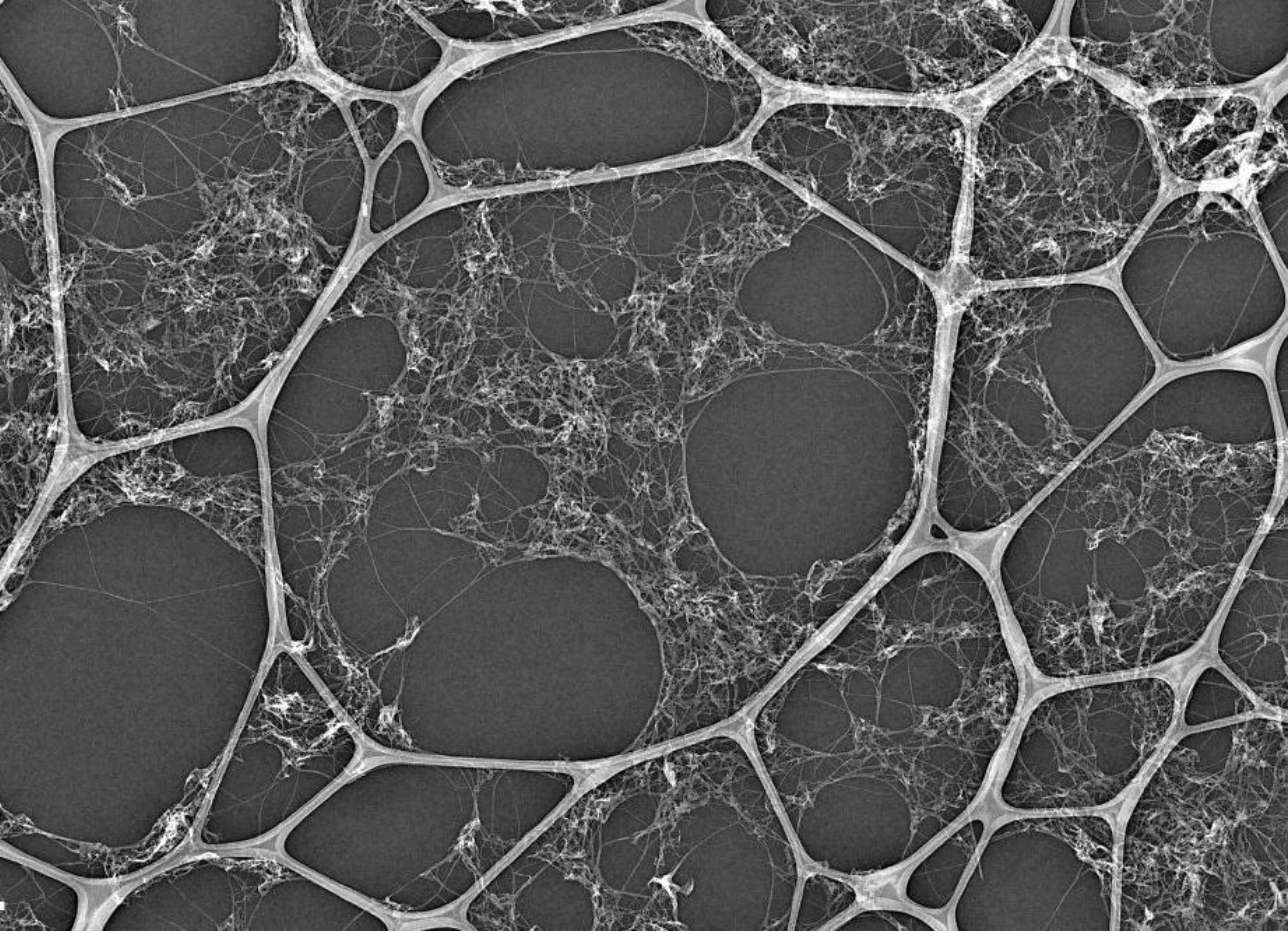
BN Nanoribbons (white graphene)



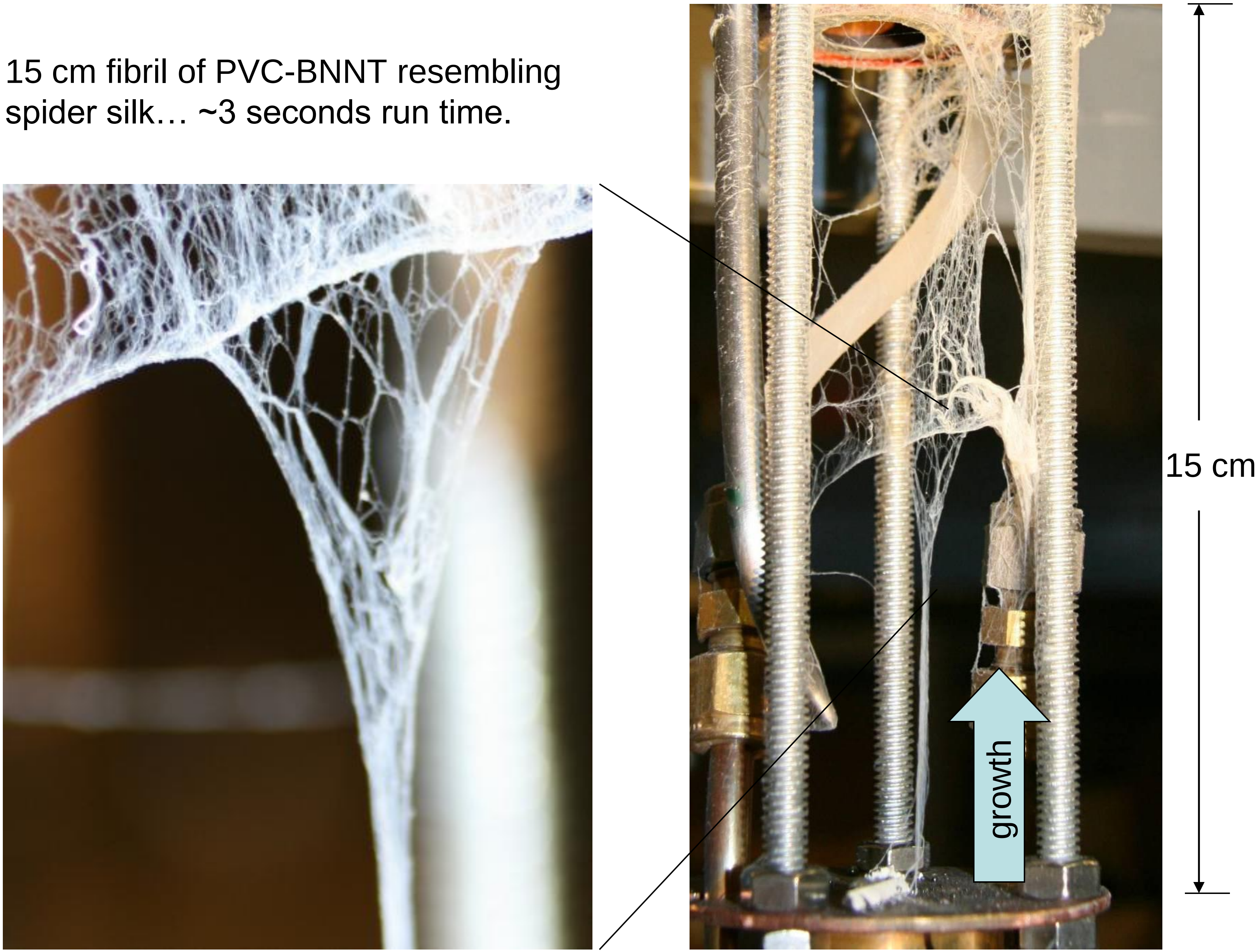
Fractal?



TEM image: Dr Wei Cao, ODU/ARC



15 cm fibril of PVC-BNNT resembling spider silk… ~3 seconds run time.

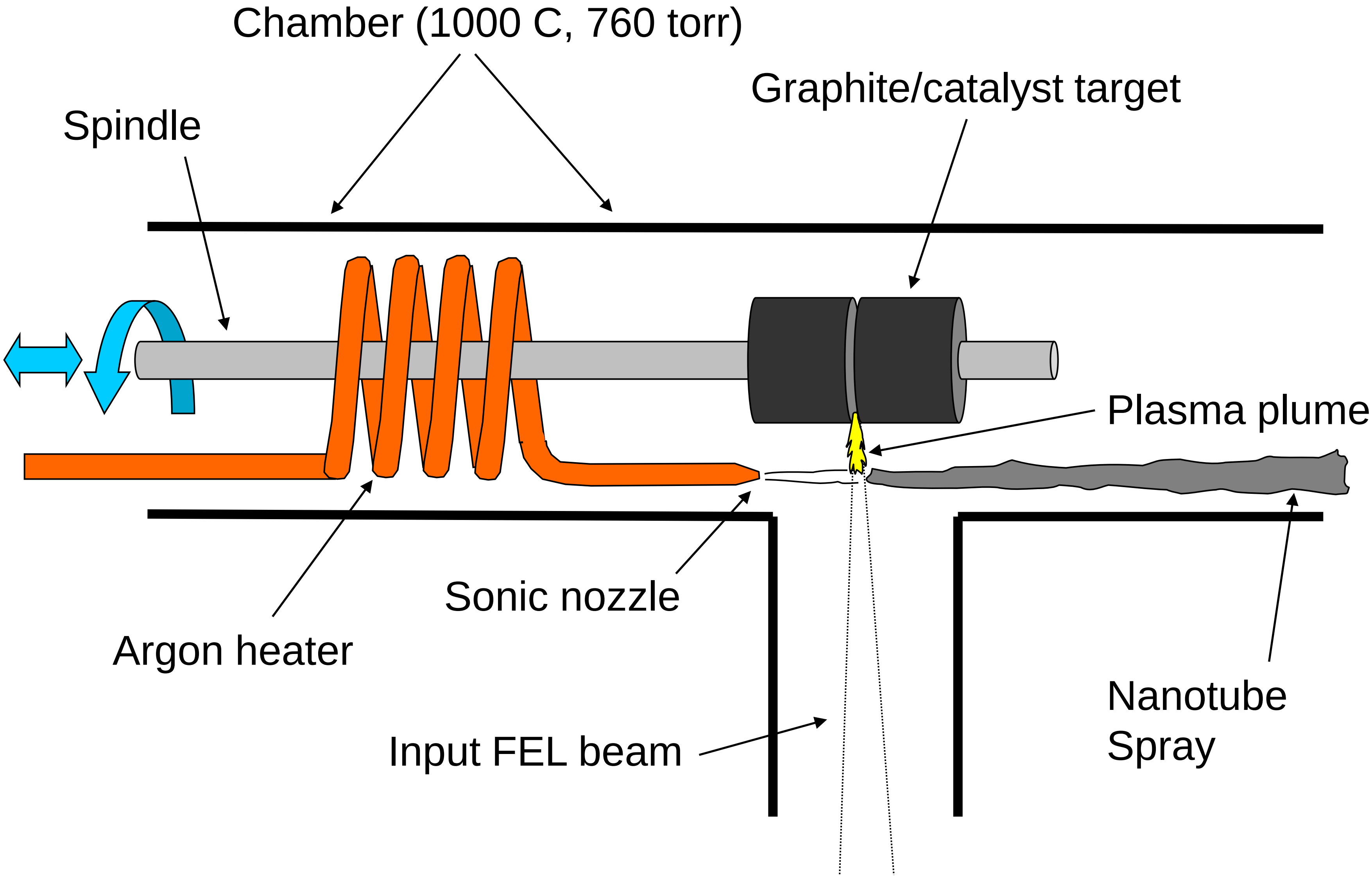


Two reasons for interest:

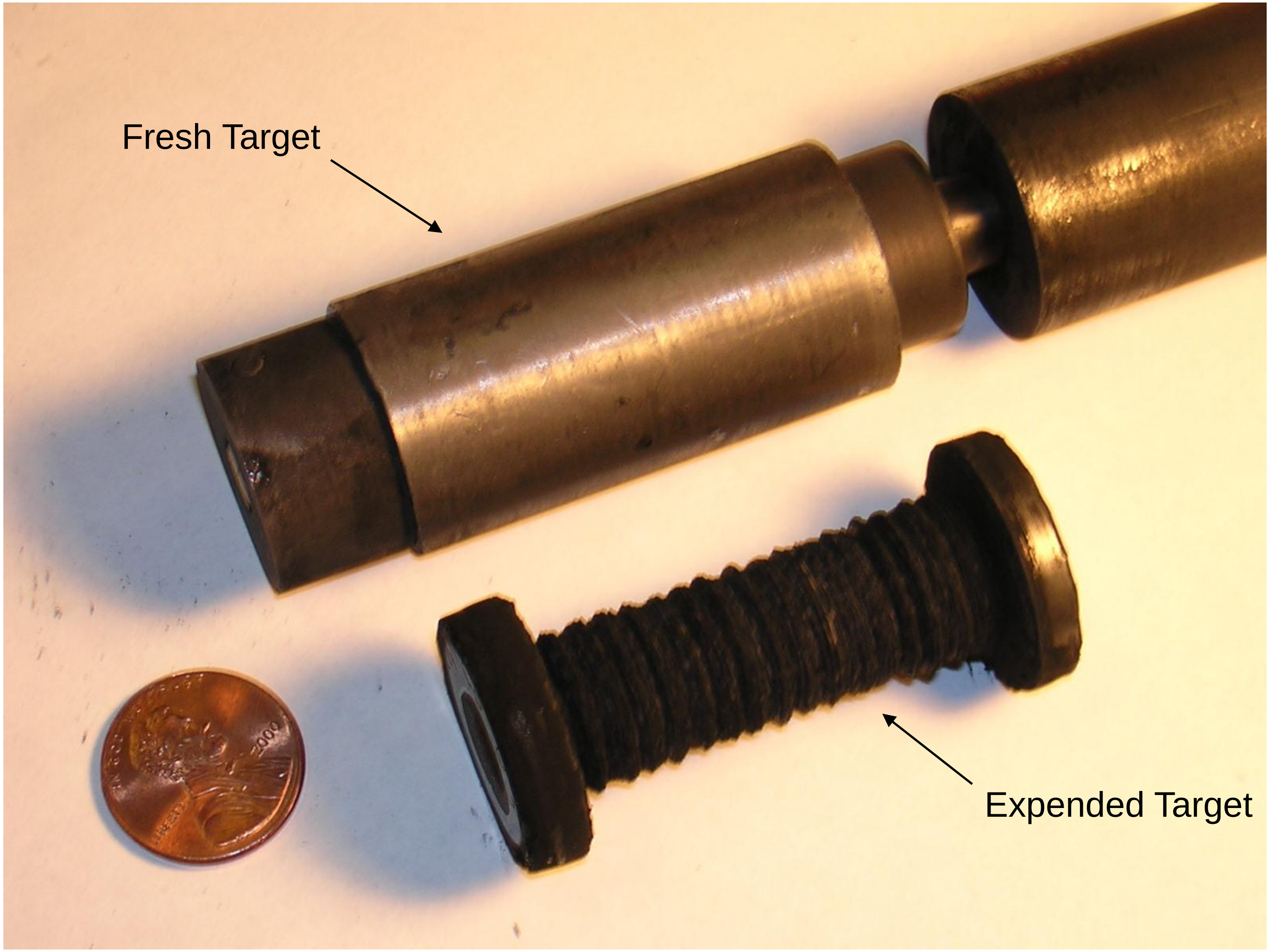
1. Crystallinity + aspect ratio = quality
2. Self assembly. Our BNNTS can vigorously self-assemble.

A movie on self assembly,
but first a bit of history…

Schematic of First Carbon Nanotube Side-Pumped Synthesis Chamber

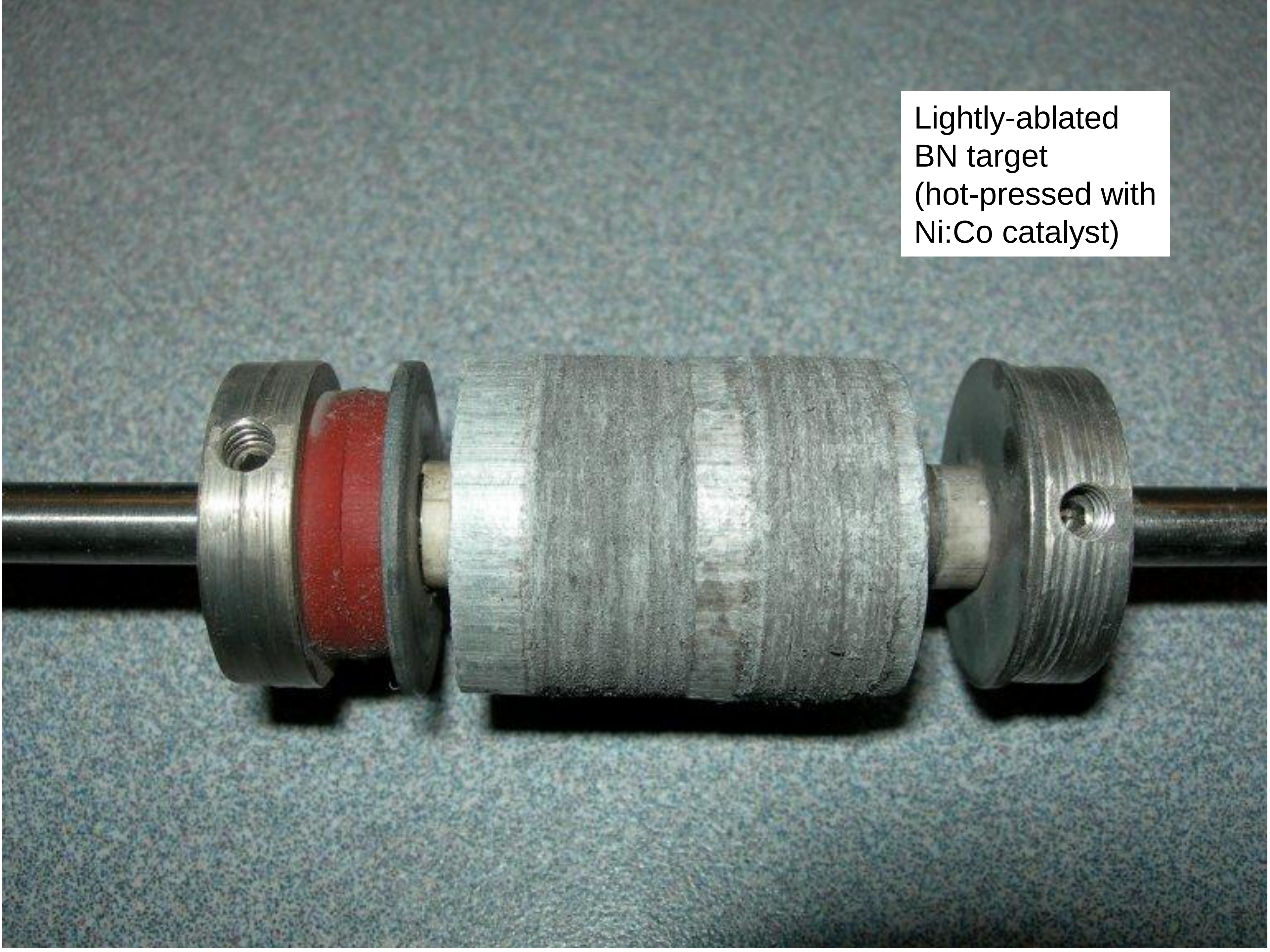


4/05/06, Carbon Nanotube Targets, 75 Minutes Elapsed Time

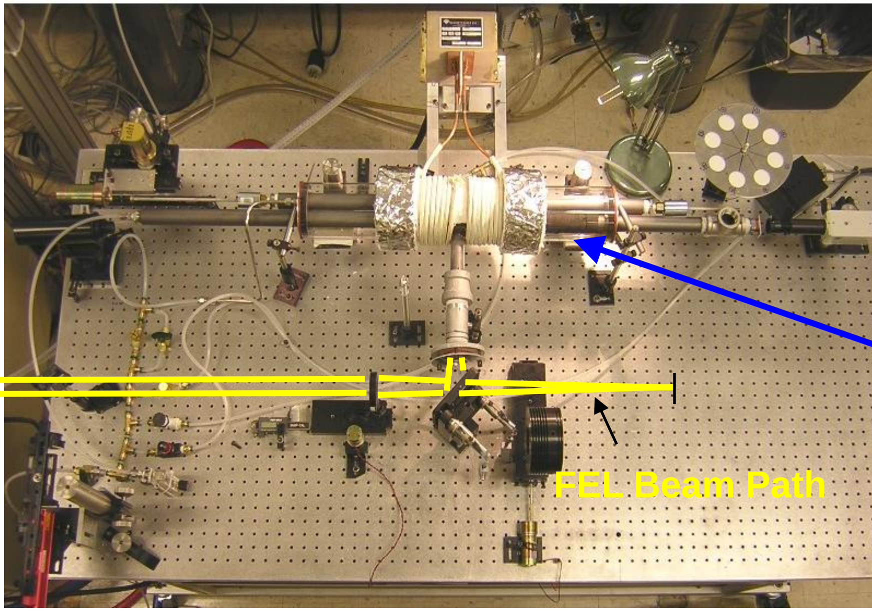


4/05/06, 7.5 grams Raw Material Collected
1.25 Hour Exposure


Hot-pressed
BN Target

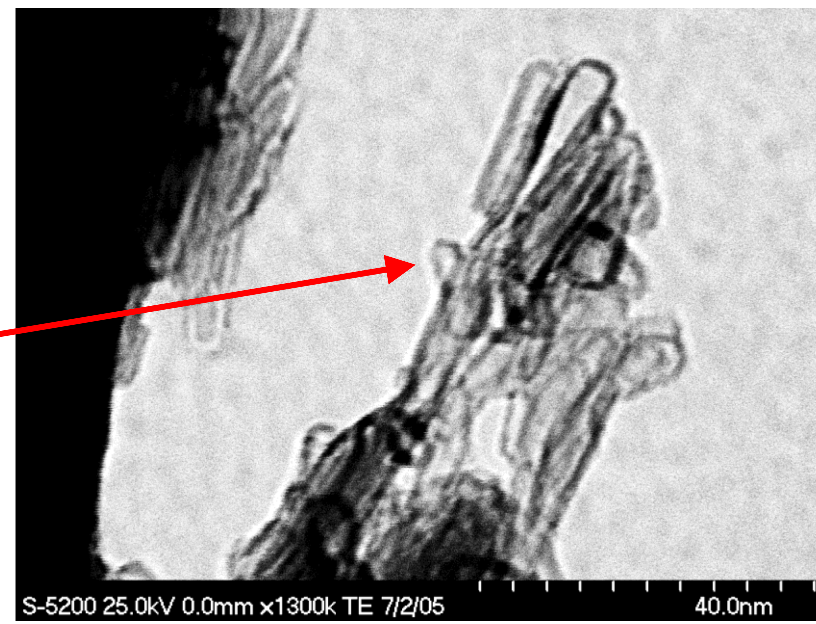

Lightly-ablated
BN target
(hot-pressed with
Ni:Co catalyst)

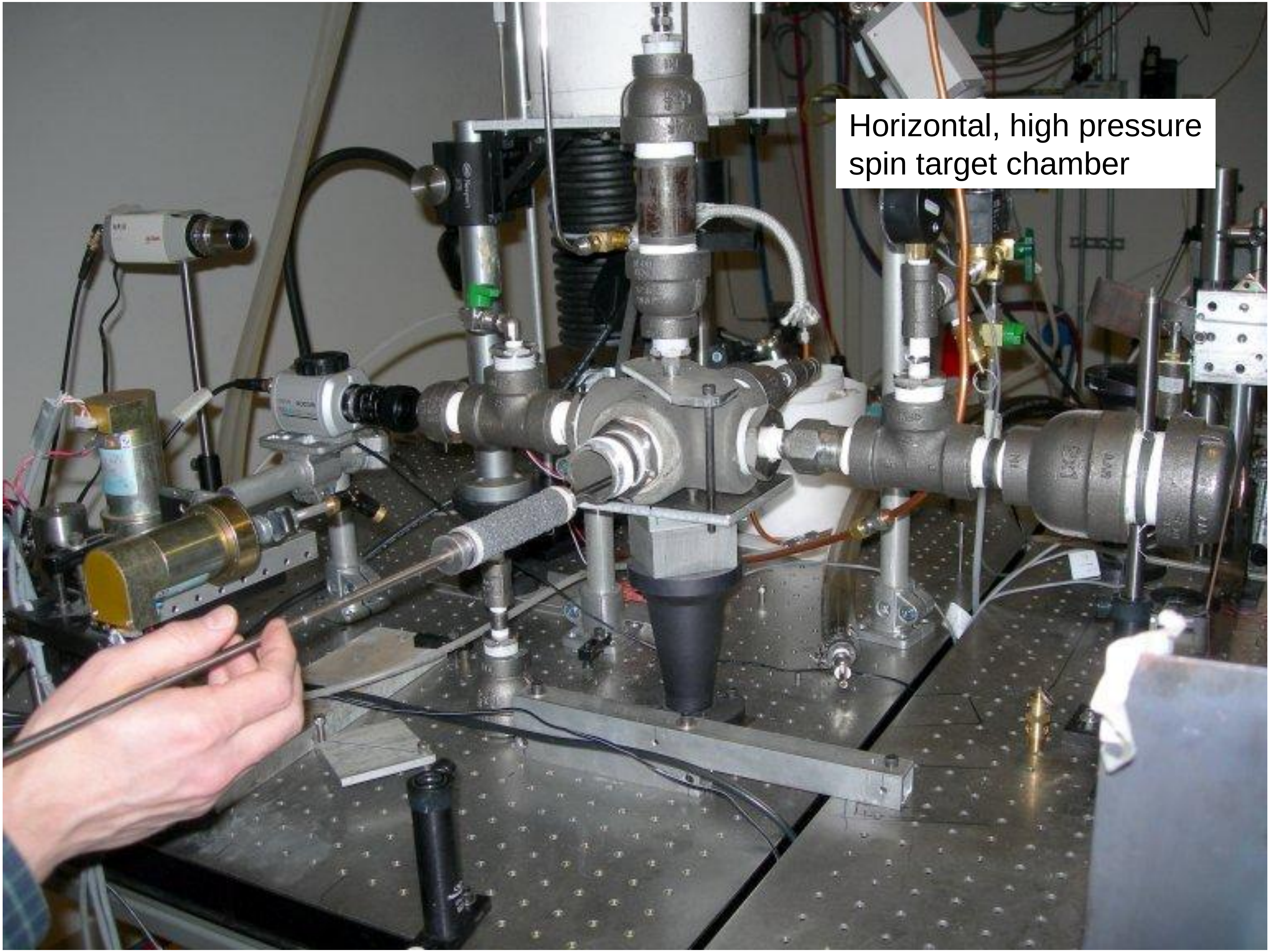
Use CNT Synthesis Rig for BNNT's?

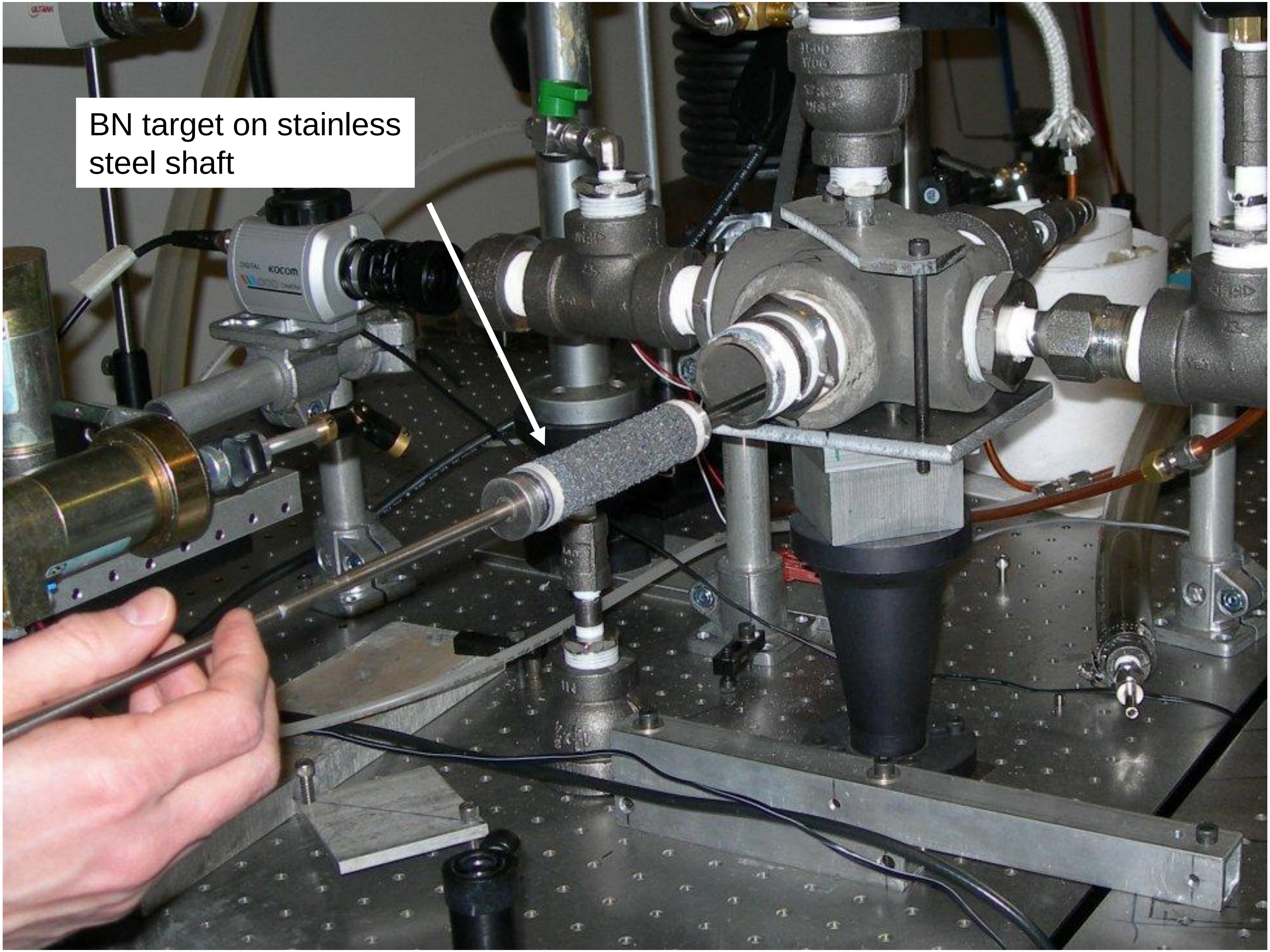


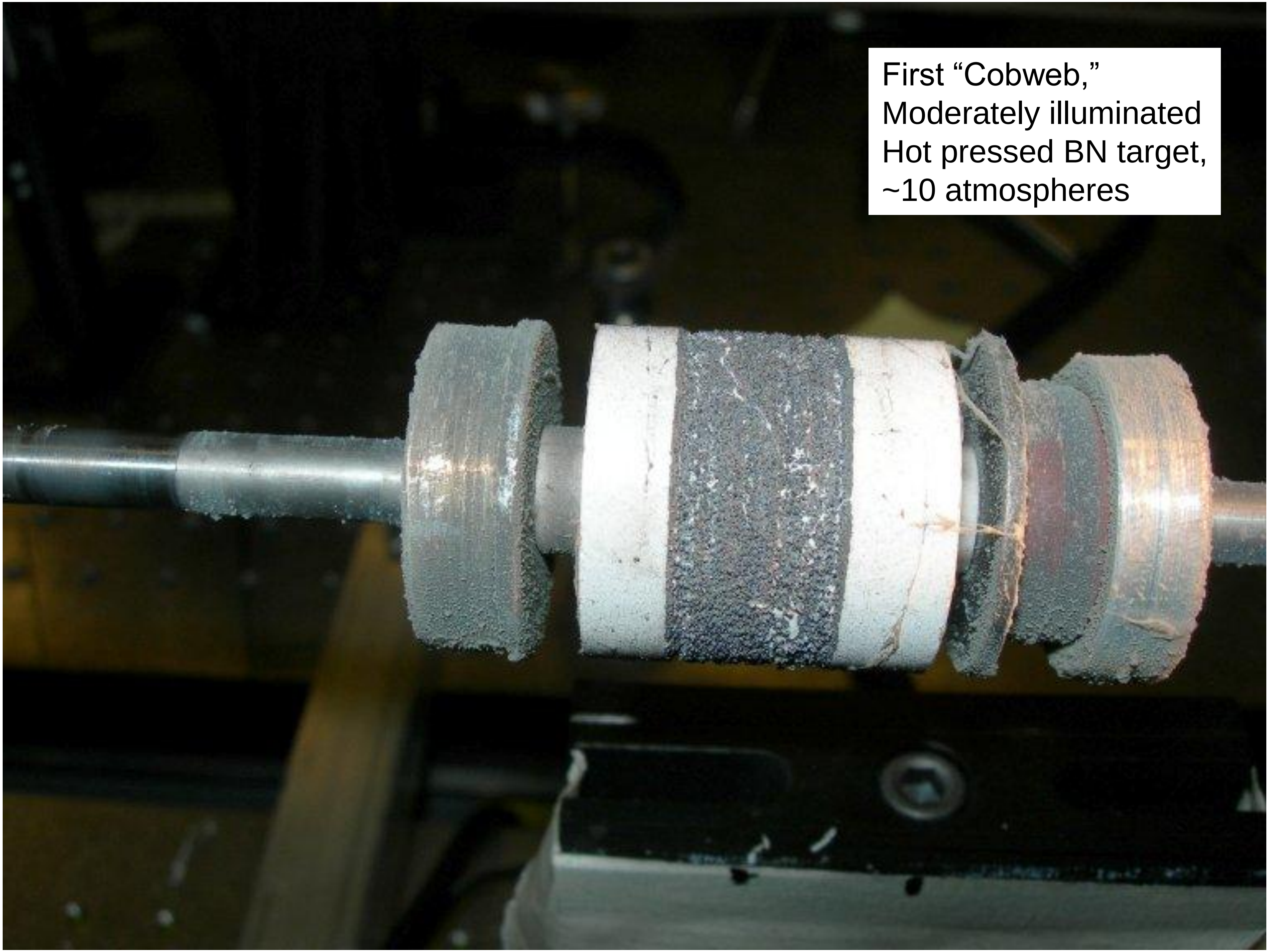
Laser ablation chamber normally used for Carbon Nanotubes

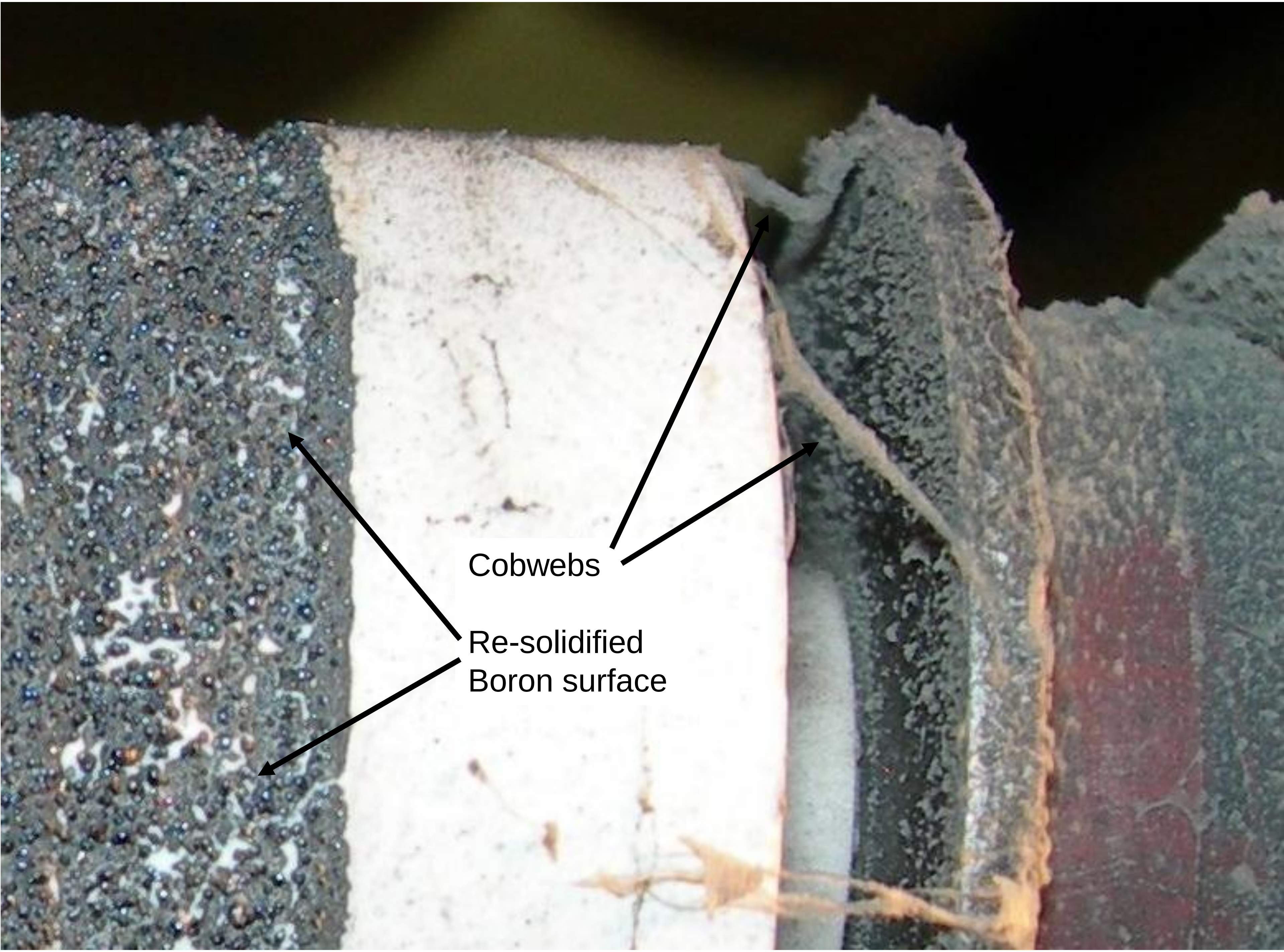
HRSEM image of BN material made by FEL

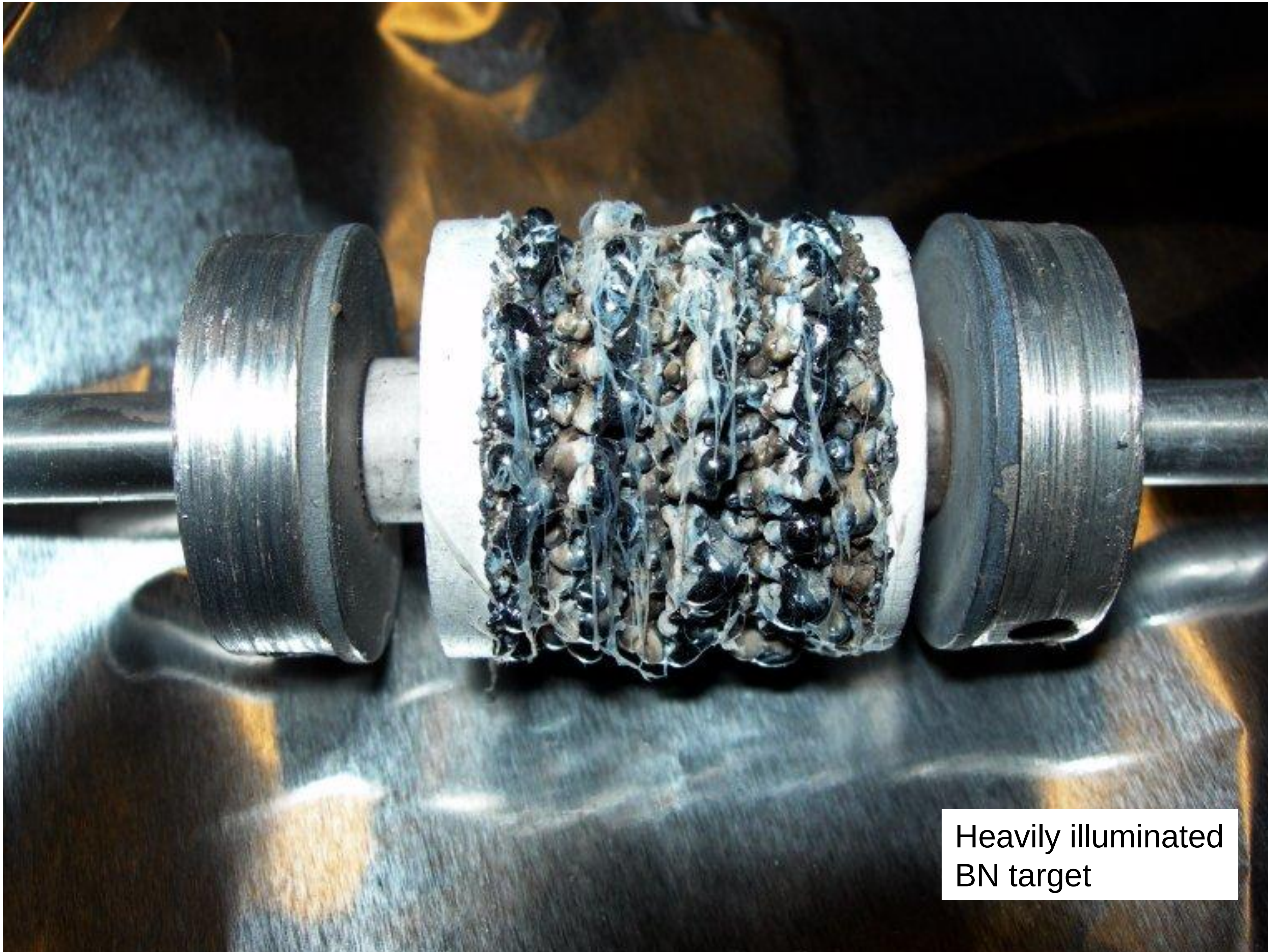



Horizontal, high pressure
spin target chamber

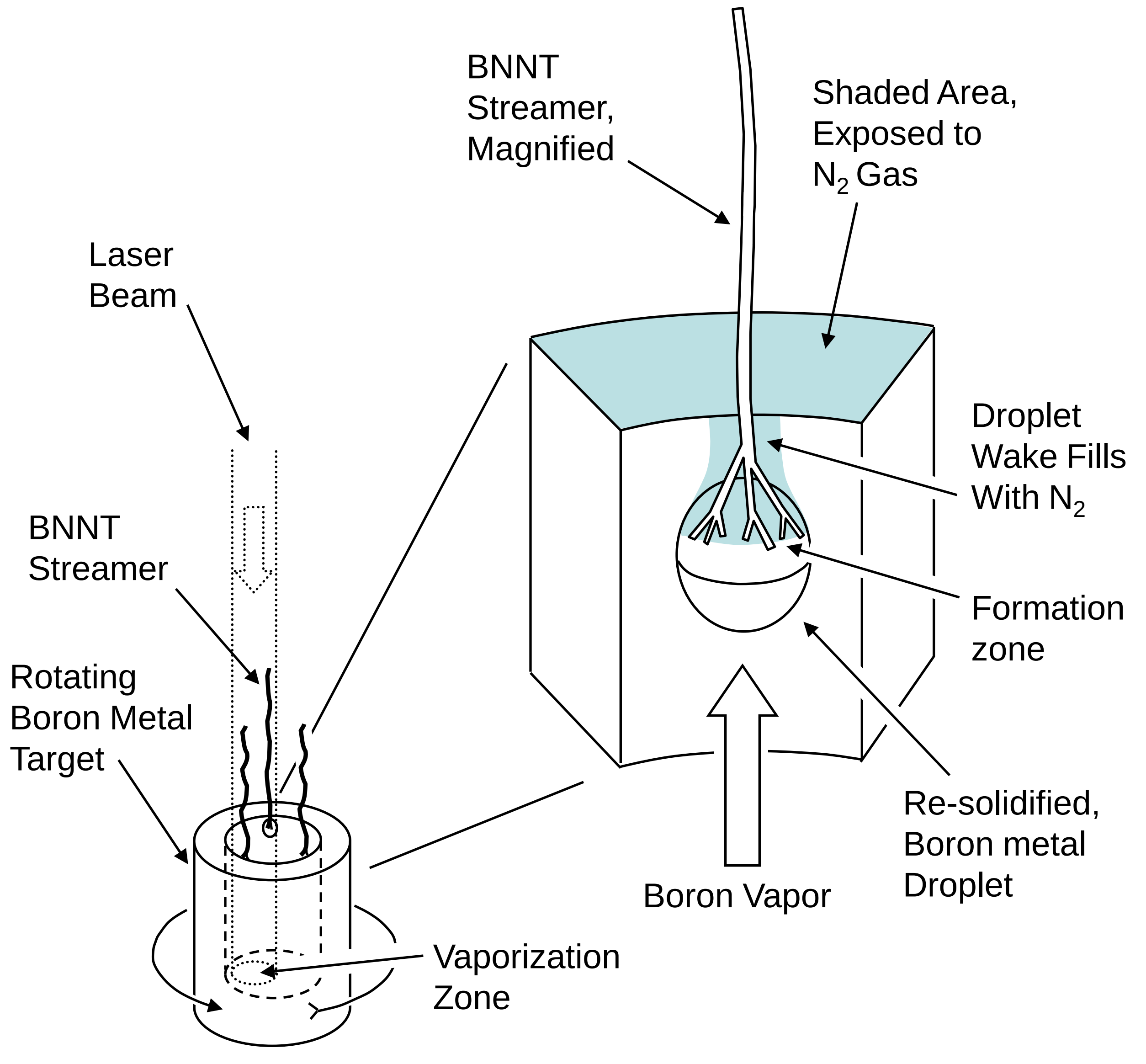

BN target on stainless
steel shaft


First "Cobweb,"
Moderately illuminated
Hot pressed BN target,
~10 atmospheres

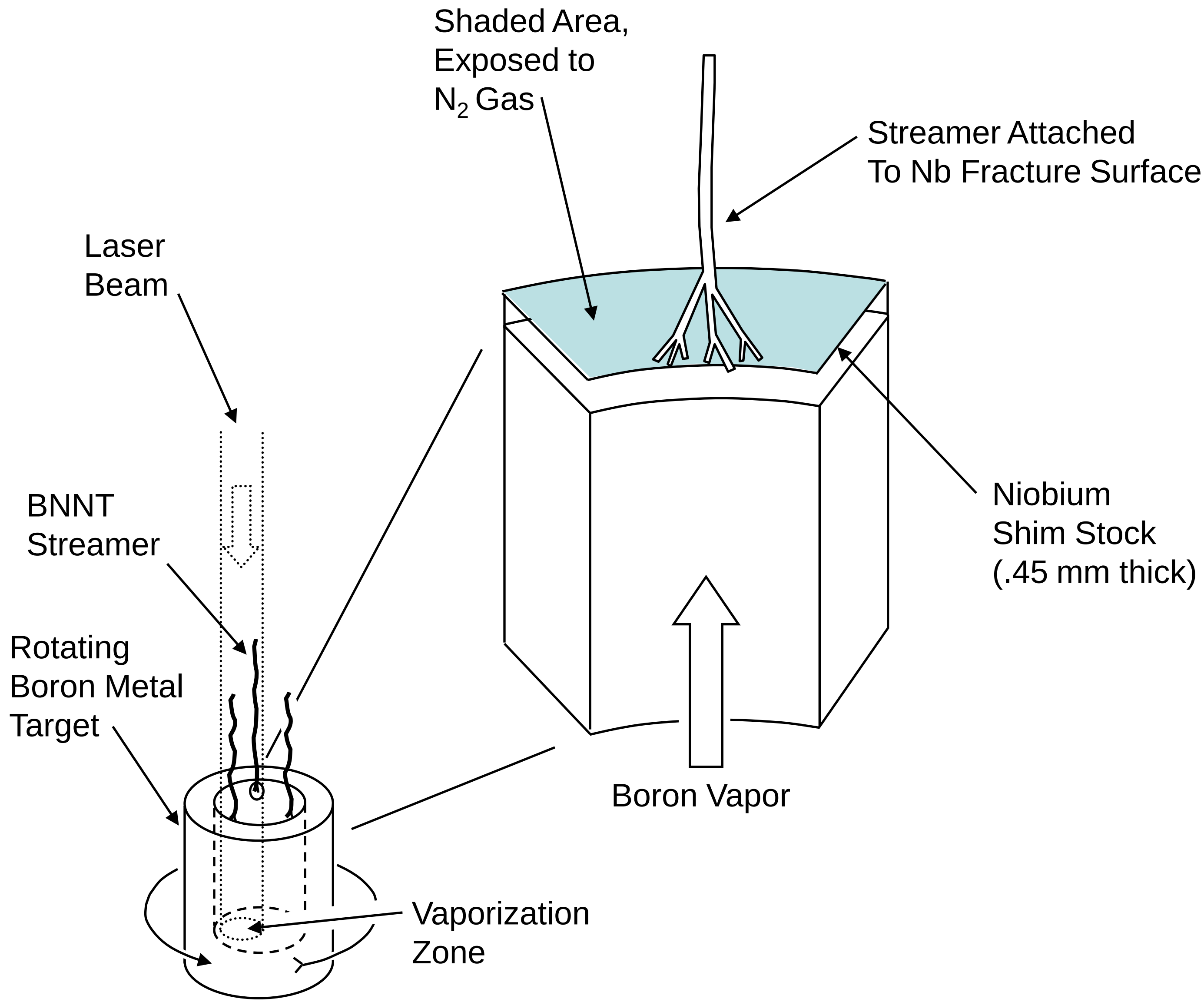

Cobwebs
Re-solidified
Boron surface


Heavily illuminated
BN target

Heavily illuminated
BN target



BNNT
Streamer,
Magnified
Shaded Area,
Exposed to
N_2 Gas
Laser
Beam
Droplet
Wake Fills
With N_2
BNNT
Streamer
Formation
zone
Rotating
Boron Metal
Target
Re-solidified,
Boron metal
Droplet
Boron Vapor
Vaporization
Zone

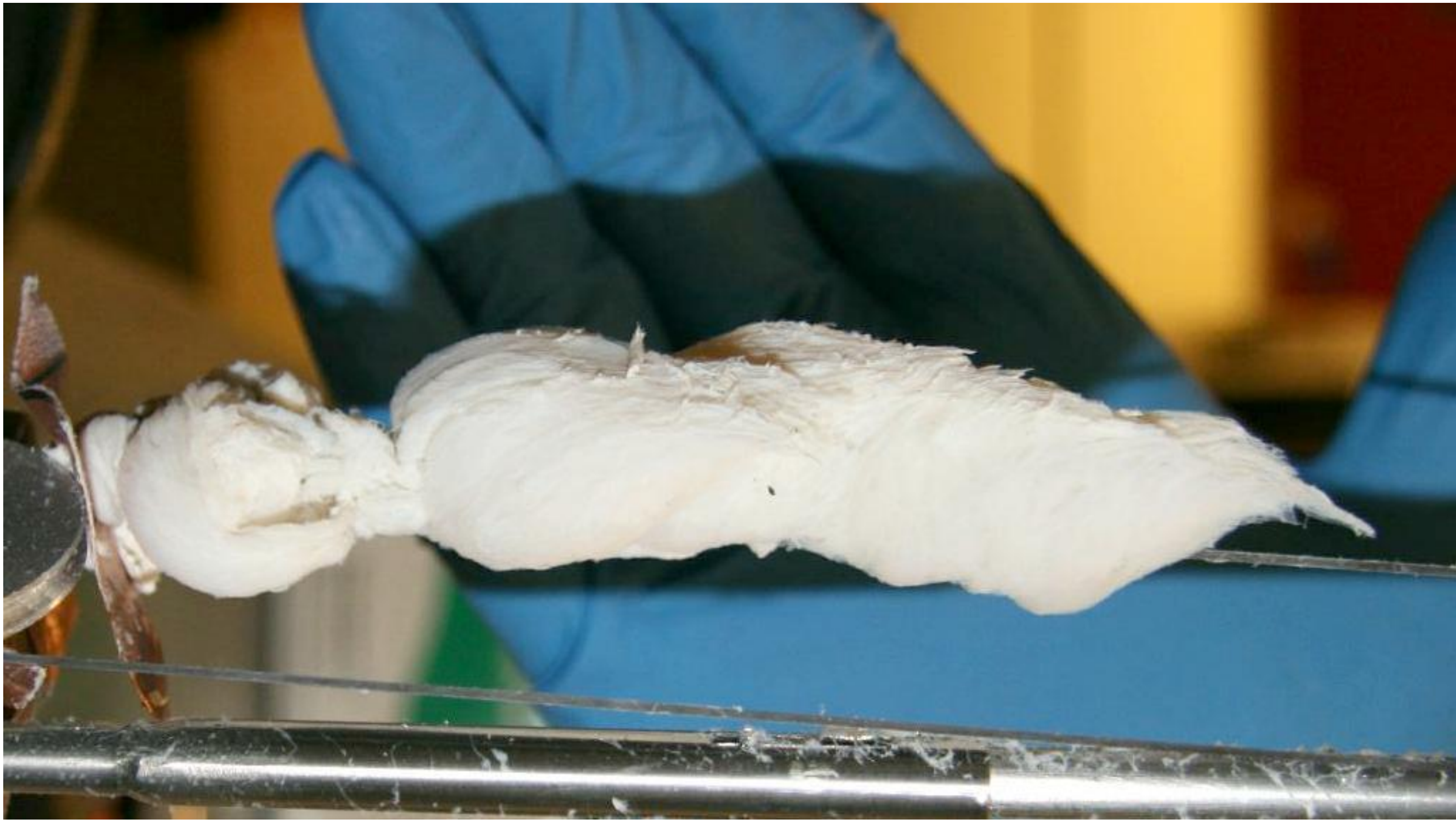

Shaded Area,
Exposed to
N_2 Gas
Streamer Attached
To Nb Fracture Surface
Laser
Beam
BNNT
Streamer
Rotating
Boron Metal
Target
Niobium
Shim Stock
(.45 mm thick)
Boron Vapor
Vaporization
Zone

5 kW CO_2 Industrial
Cutting/welding laser

5 kW CO_2 Industrial cutting/welding laser controls: 5 minute warm up, 1000's hours duty time.

Growth Movie

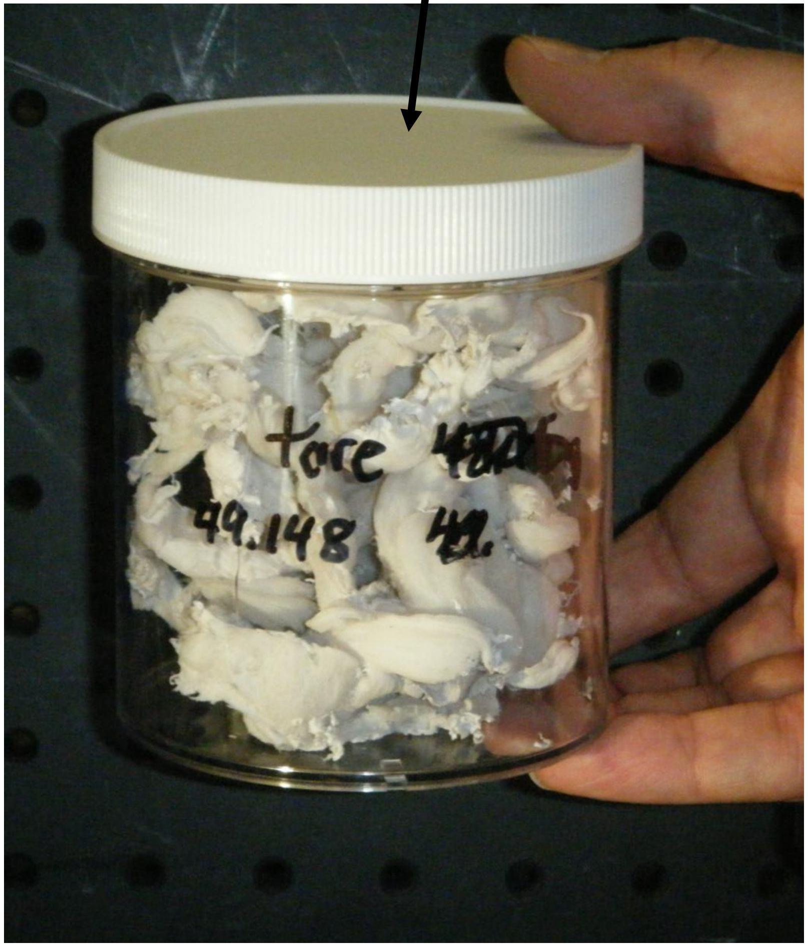
Cotton-like PVC-BNNT mass (~ 30 minutes run time)



(From: M. W. Smith et al, Nanotechnology, 20, 505604 (2009))

Comparison: Equal Mass of PVC BNNT to NIMS CVD BNNT

200 mg BNNT
NASA/JLab PVC method



200 mg BNNT
Japanese NIMS
B_2O_2/NH_3 CVD

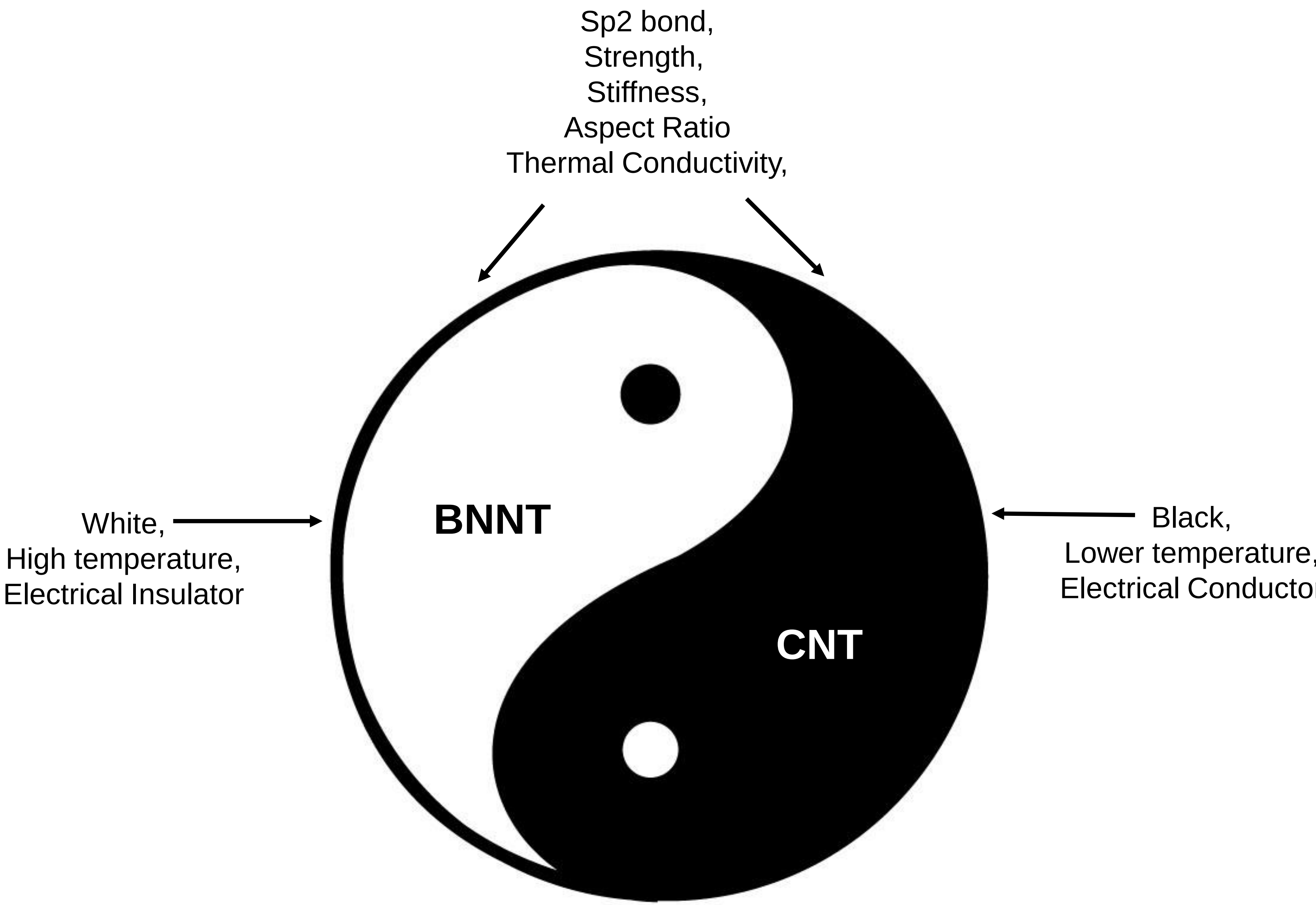
C. Zhi, Y. Bando, C. Tan, D. Golberg,
Solid State Commun. 135, 67-70 (2005).

Jars are shown to scale

As-grown PVC-BNNT is a very low density, high surface area material.
One pound (.45 kg) would occupy about 30 cubic feet…

NASA Applications

The Yin-Yang of Nanotubes



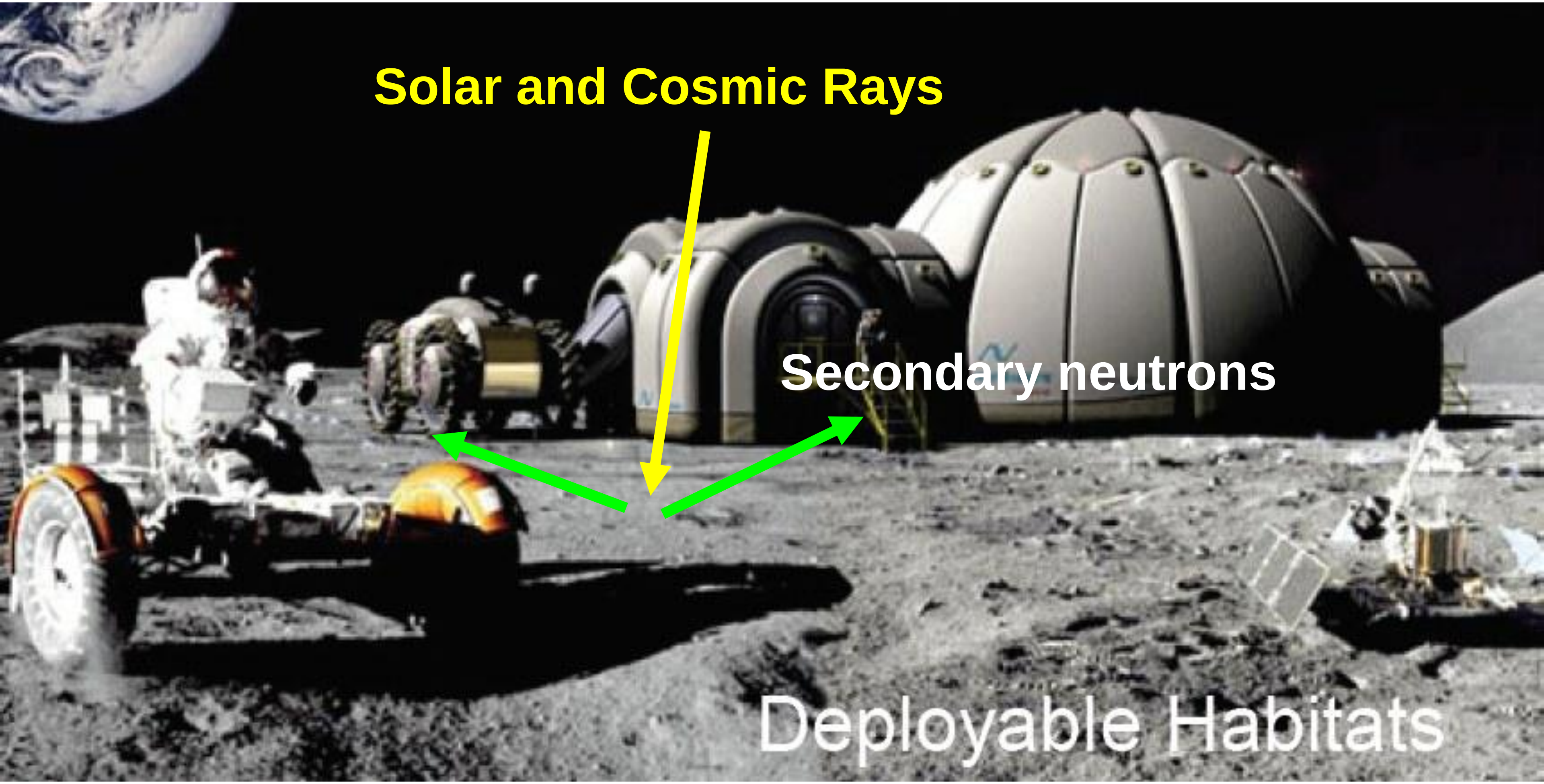
Comparison of Material Properties, CNT v BNNT

	Carbon nanotubes	**Boron nitride nanotubes**
Electrical properties	Metallic or semiconducting	Always semiconducting (about 5.5 eV band gap)
Mechanical properties (Young’s modulus)	1.33 TPa	1.18 TPa
Thermal conductivity	60 – 40,000 W/mK	~ 3000 W/mK (Cu = 400 W/mK)
Thermal oxidation resistance	Stable up to 300–400˚C in air	Stable up to 800˚C in air
Neutron scattering cross-section	C = 0.0035	B = 767 (B^{10} ~ 3800) N = 1.9 Excellent radiation shielding
Polarity	Covalent bond (No dipole)	Permanent dipole **Piezoelectric** (0.25–0.4 C/m^2)
Surface morphology	Smooth	Corrugated
Color	Black	Gray
Coefficient_of Thermal Expansion	-1×10^{-6}	-1×10^{-6}

Image: nasa

Image: nasa

Image: nasa


Solar and Cosmic Rays
Secondary neutrons
Deployable Habitats

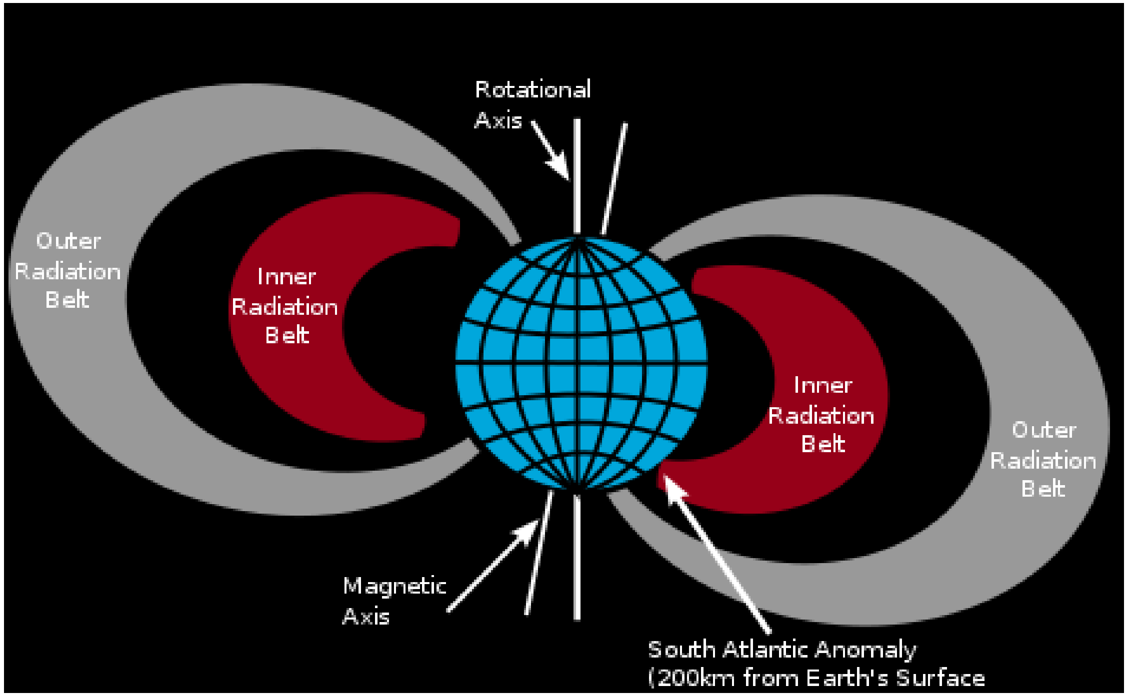
http://www.freedesktopwallpapers4u.com

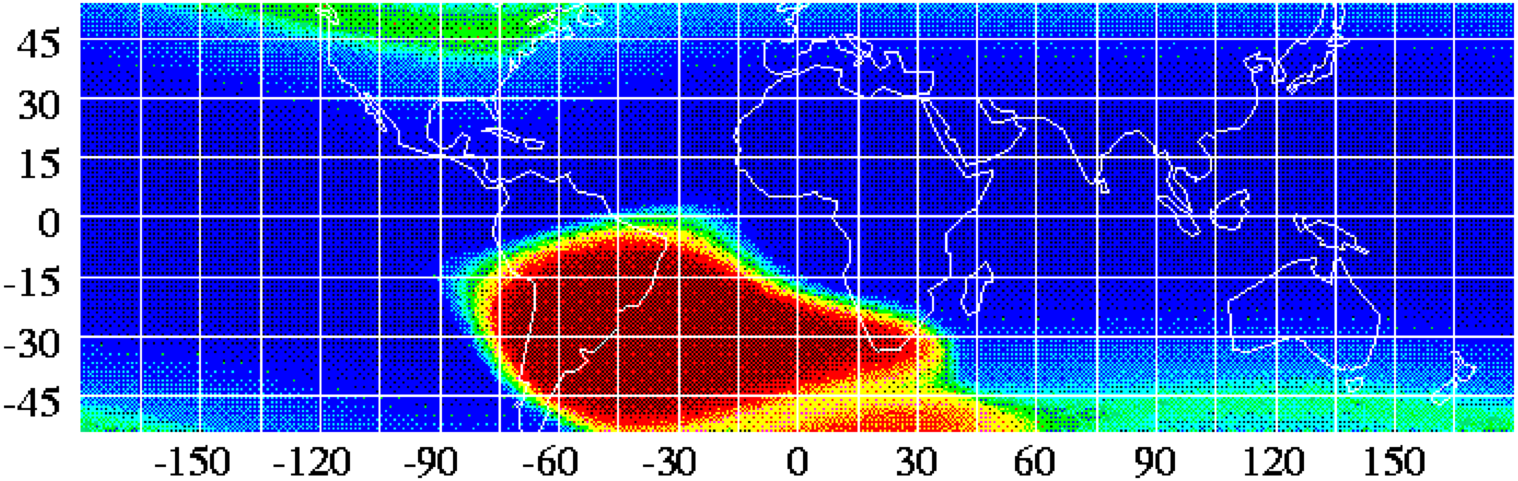
…aircrew are subjected to atmospheric secondary radiation produced by cosmic rays and solar particle events.
European Union legislation requires the control of aircrew exposure*…

*** Radiation Effects on Spacecraft & Aircraft (2001)**
Clive Dyer, *Space Department, QinetiQ, Cody Technology Park, Farnborough, Hampshire GU14 0LX, UK*

http://www.freedesktopwallpapers4u.com

South Atlantic Anomaly





http://en.wikipedia.org

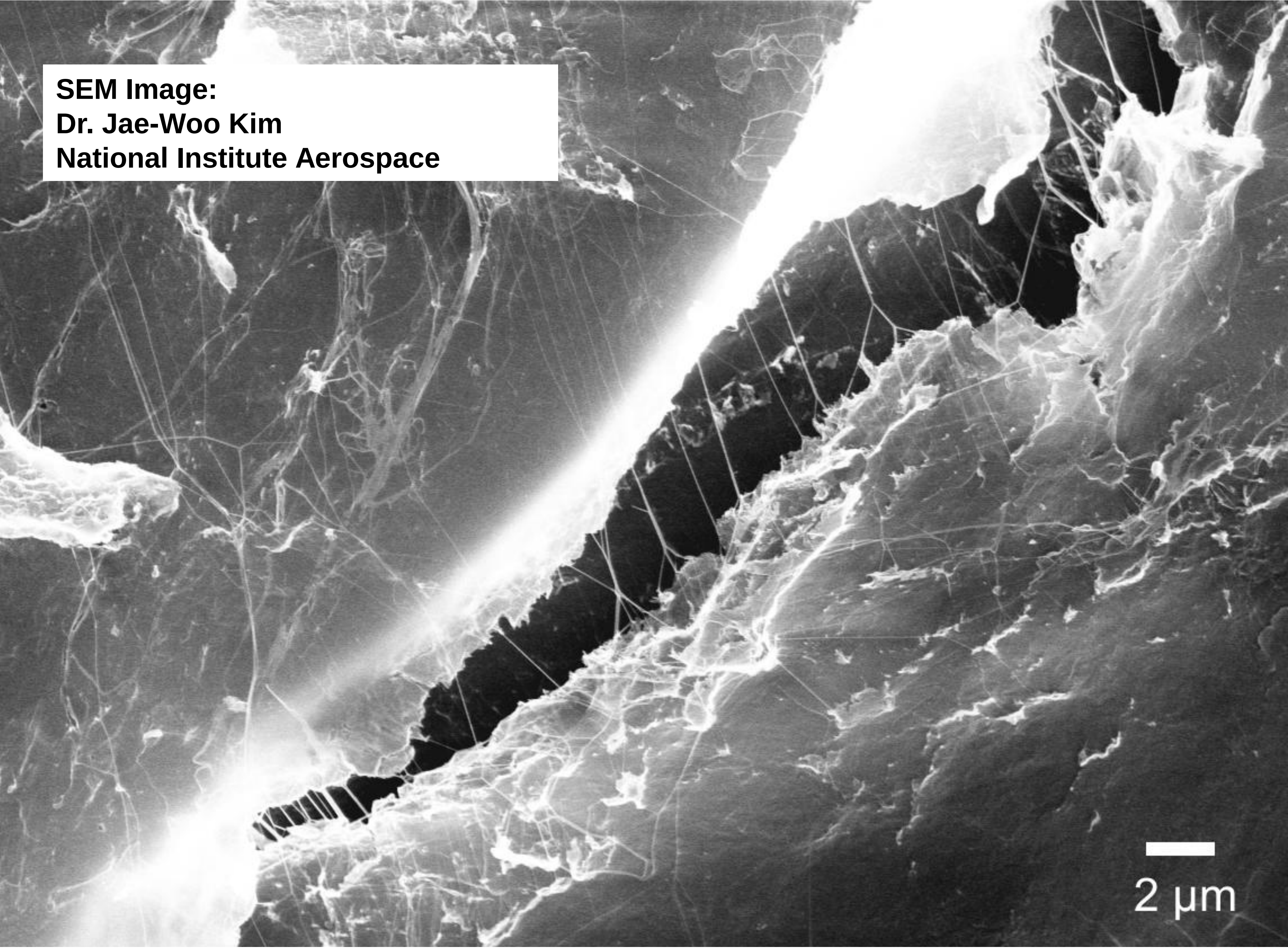
Radiation threatens avionics as chip geometries shrink, Jan 2004 *Military & Aerospace Electronics*

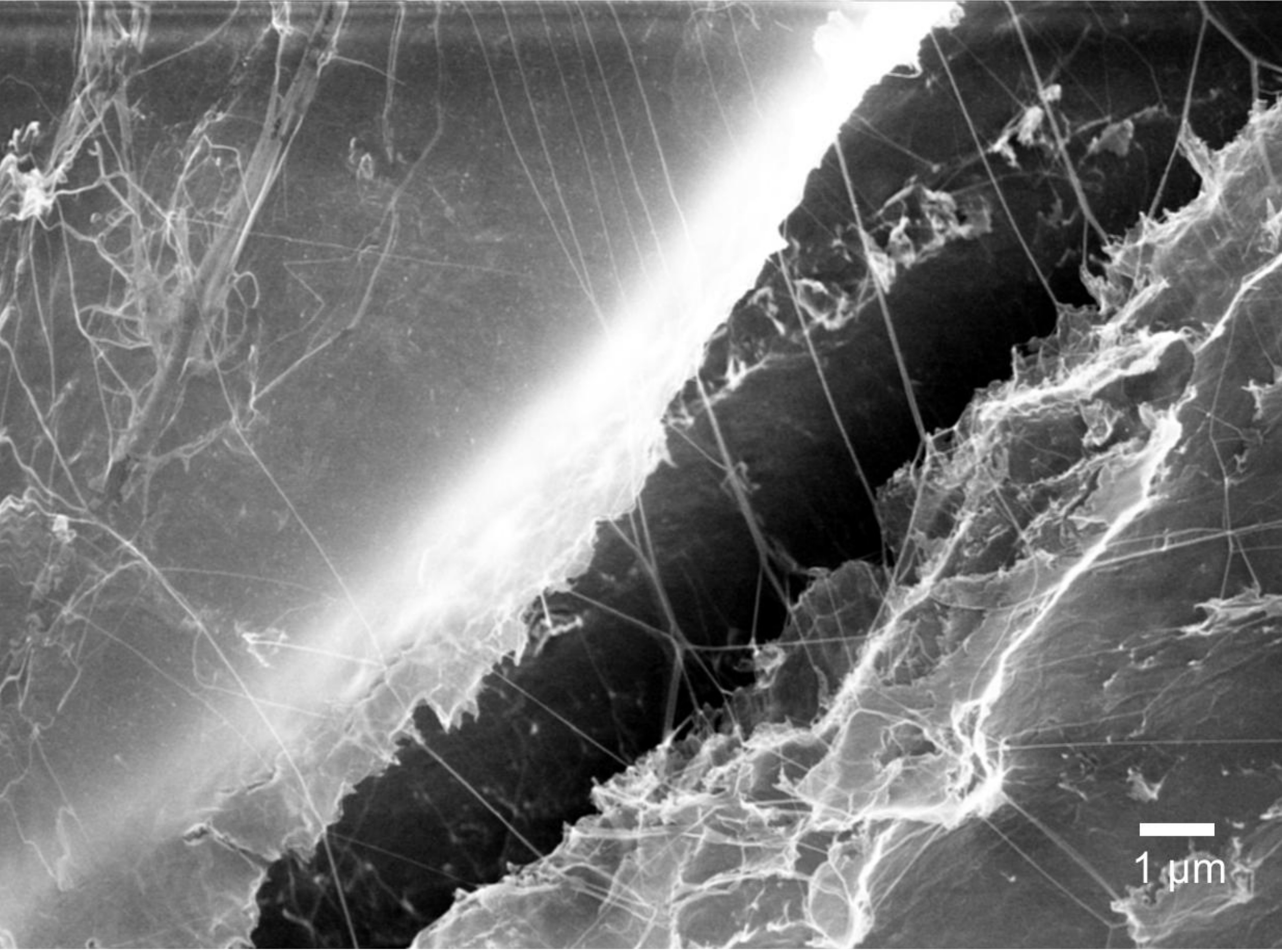
“Yet this trend has a fatal flaw. Electronic components become vulnerable to neutron radiation as they use ever-smaller feature sizes and lower supply voltages, says John Fink, staff engineer at Honeywell Commercial Avionics Products in Minneapolis”

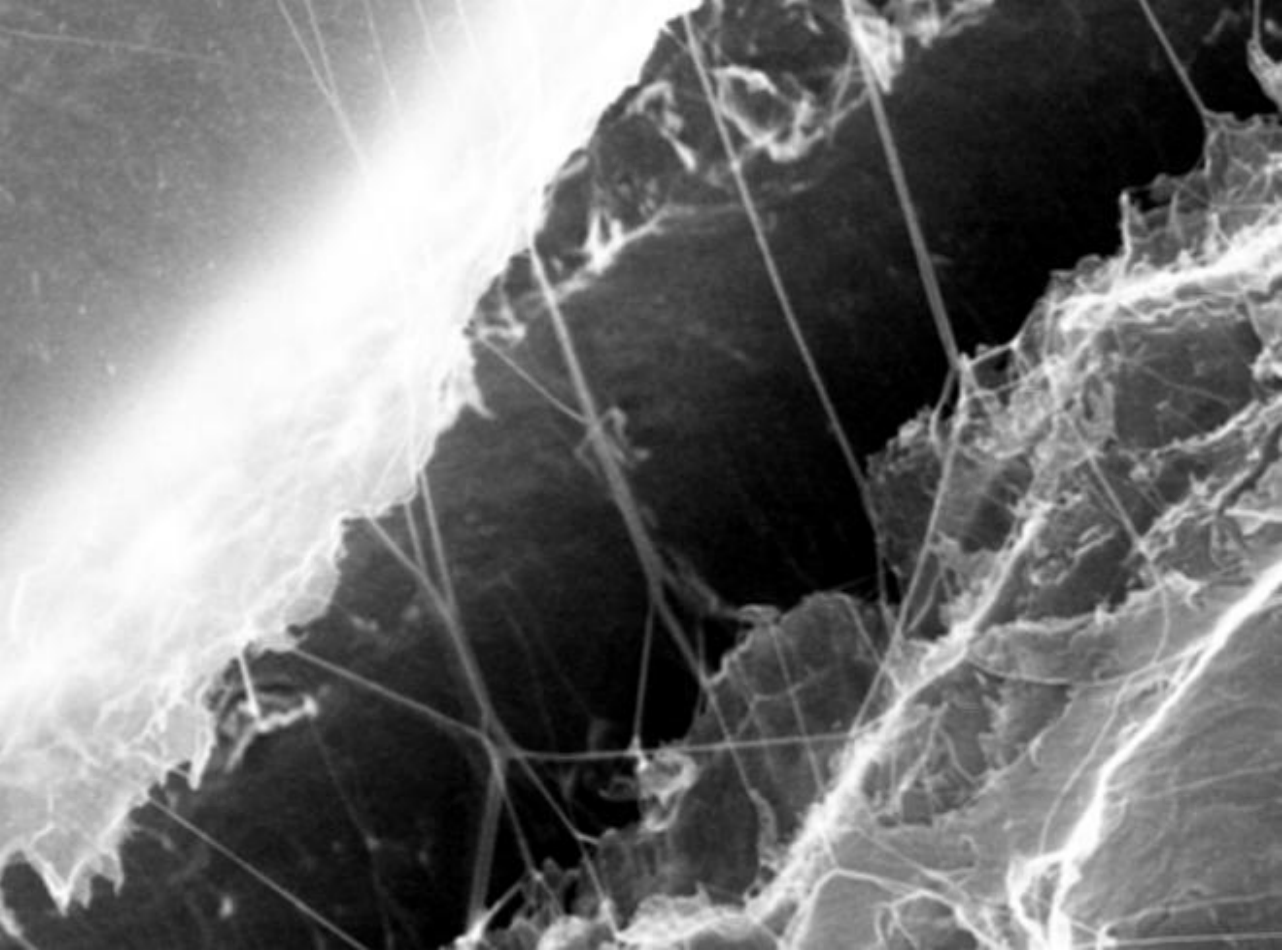
NASA has reported that modern laptops have crashed when the space shuttle flights passed though the anomaly. *

* http://www.nasa.gov/mission_pages/shuttle/flyout/flyfeature_shuttlecomputers.html

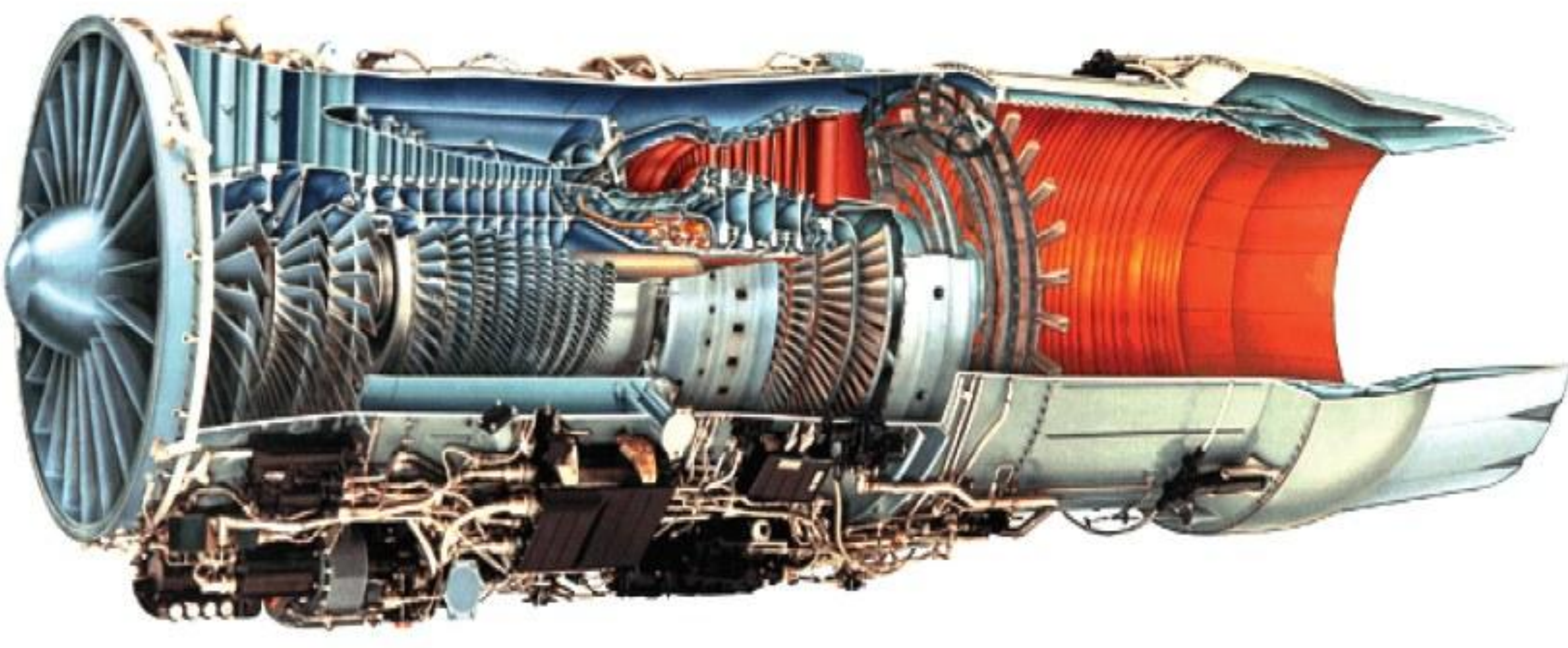
Polymer Composites


SEM Image:
Dr. Jae-Woo Kim
National Institute Aerospace
2 μm


1 µm



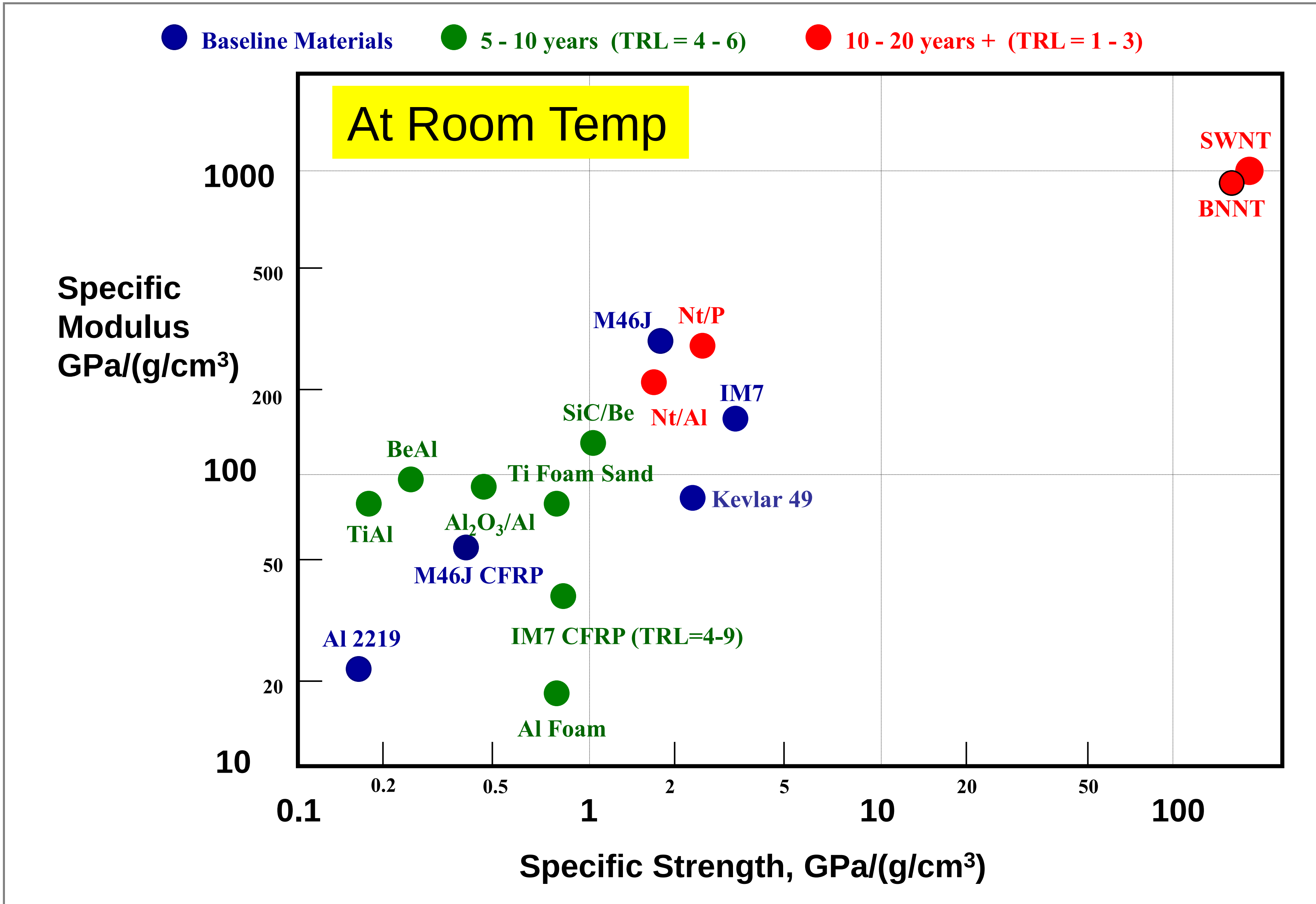
Ceramic Composites



Turbo-machinery flow-path

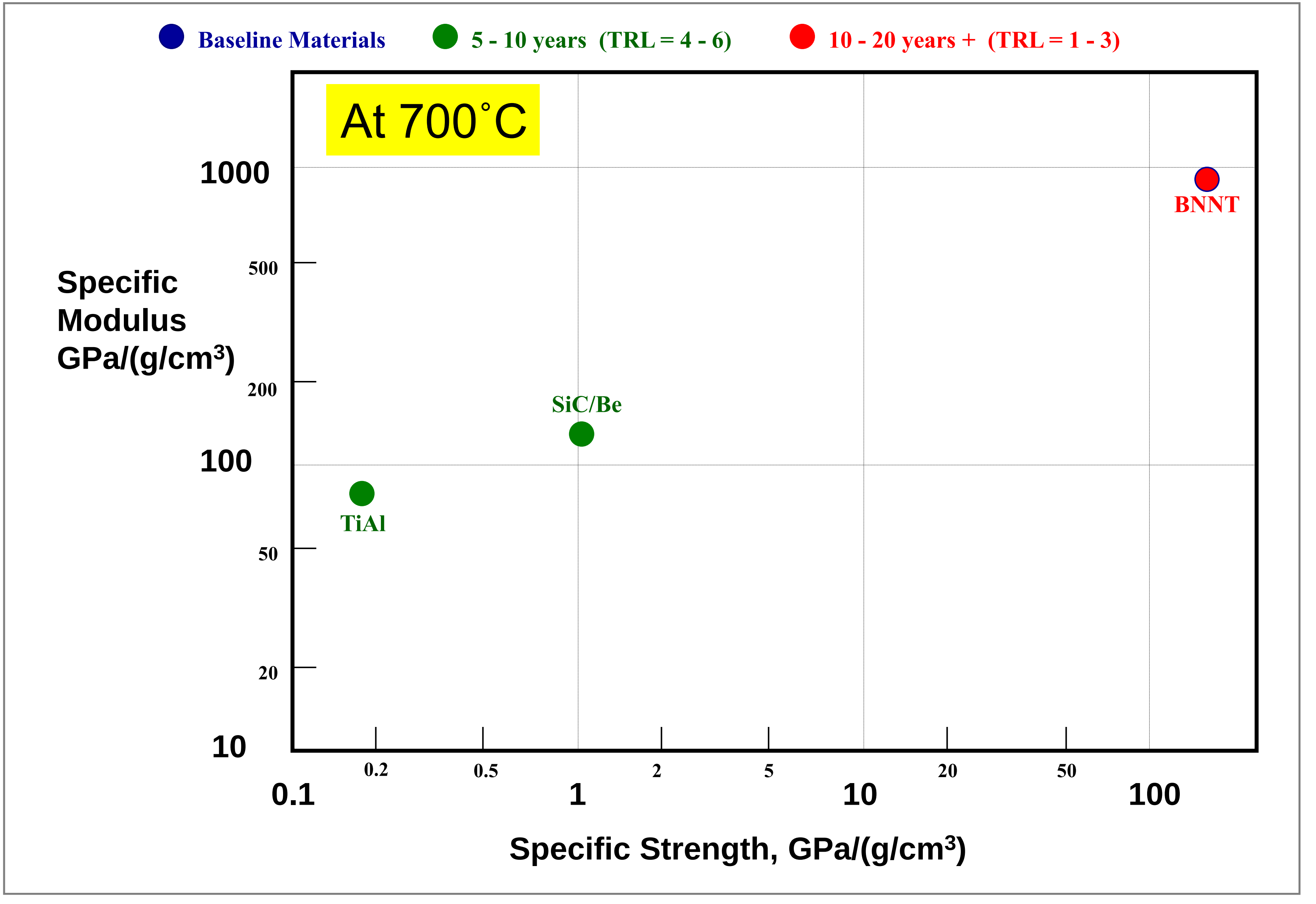
Image: nasa

Properties of Materials for Vehicle Structure

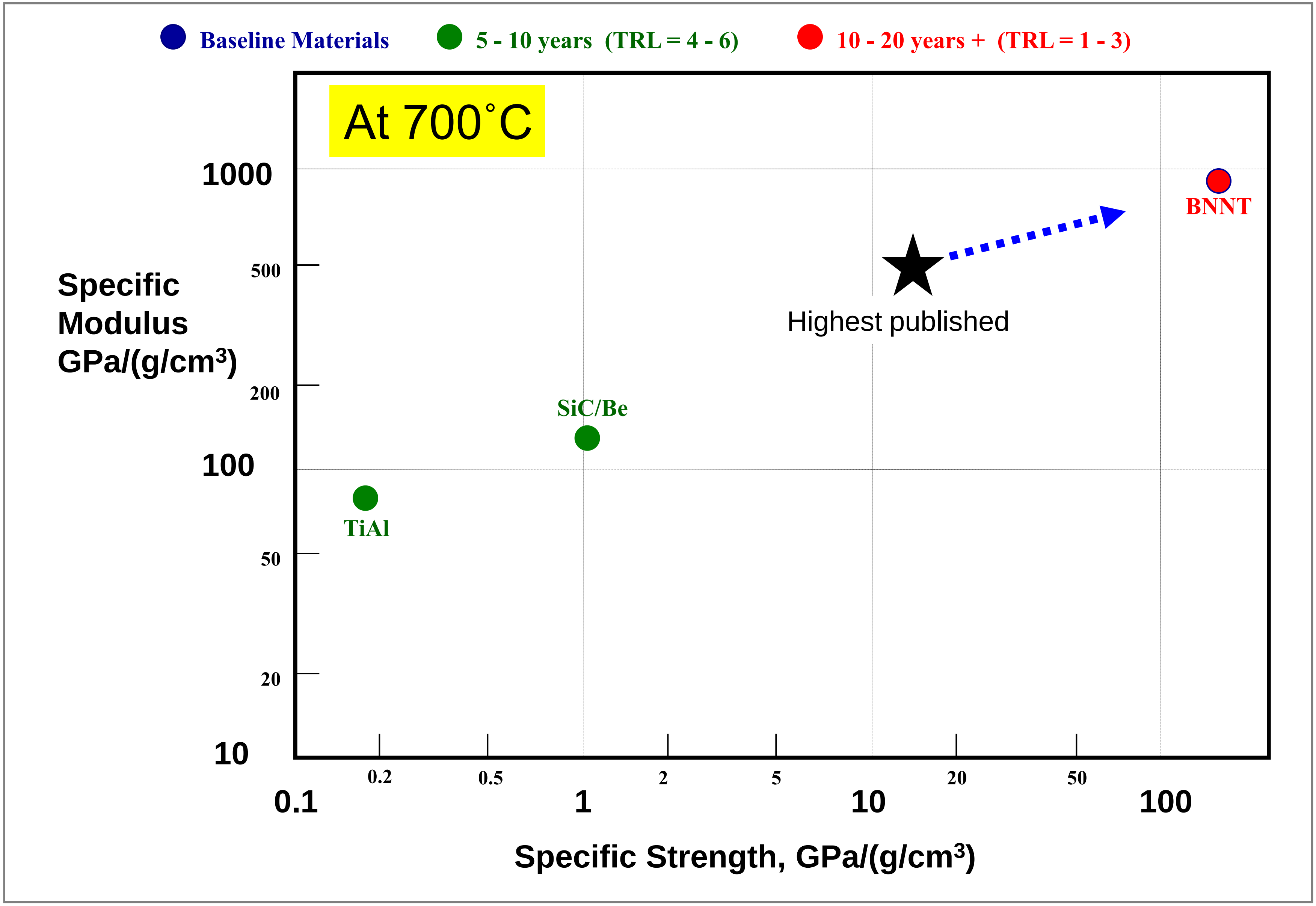


Based on: Charlie E. Harris, M. J. Shuart, H. Gray, NASA/TM-2002-211664

Properties of Materials for Vehicle Structure



Properties of Materials for Vehicle Structure



★ Wei, et al., Tensile Tests on Individual Multi-Wall Boron Nitride Nanotubes, ***Advanced Materials***, V 22, 43, p 4895, 2010

Image: http://www.laserdesign.com

…formula one racing brakes (carbon/carbon) don't wear out, they fail by oxidation!

Image: http://www.gtplanet.net/forum

Other Applications

Solar Power: BNNTs and Organic Photovoltaics

Image: http://www.thegreenergrass.org

Spray-On Solar Cells Come One Step Closer to Reality

by Sarah Parsons, 04/02/10

Ever think about how amazing it would be if tech as complex as solar cells could be simply sprayed onto a surface? A group of researchers found that a common organic semiconductor may make that situation a reality. Scientists from the **National Institute of Standards and Technology (NIST)** recently determined that poly(3-hexylthiopene), or P3HT, may be a useful material for creating **spray-on transistors.** Once the tech is optimized, we could see electronics like solar cells and displays that can be sprayed onto a surface just like paint.

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100 m
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Report a problem

TECHNOLOGY UPDATE

Feb 26, 2008

Nanocomposite protects organic solar cells

Coating organic photovoltaics (OPVs) with a boron-nitride nanotube loaded polymer can significantly improve device lifetime, according to research published in *Nanotechnology*. Scientists at Wake Forest University (WFU), US, and the Indian Institute of Technology have shown that a nanotube concentration of 1.5% offers good thermal protection with excellent transparency in the visible region.

Encapsulated device

OPVs offer an affordable route to harnessing the sun's energy. Polymer-based photovoltaics are typically less efficient than silicon photovoltaics, but the material is more versatile and can be applied to flexible substrates. Device degradation remains an issue for OPVs as oxidation, exposure to moisture and photochemical reactions can greatly reduce the working life of the unit.

"The ultraviolet part of the spectrum can be devastating to polymer device performance," David Carroll, director of WFU's Center for Nanotechnology and Molecular Materials, told *nanotechweb.org*. "However, by removing it through scattering and absorption, devices live longer."

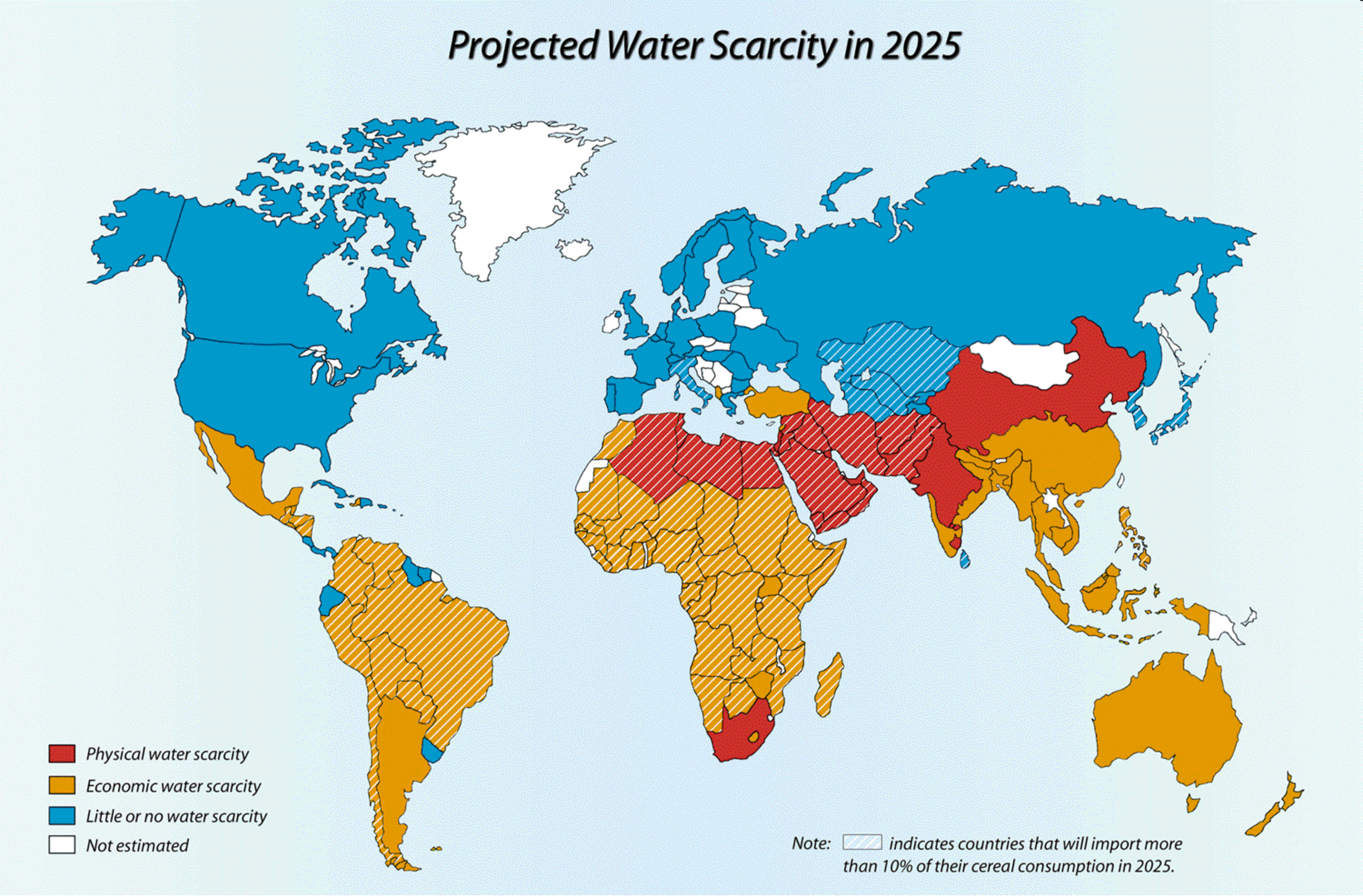
OPV testing

Boron-nitride materials are well matched to ultraviolet frequencies and act as a scattering centre for the incoming radiation. As Carroll explains, particle shape plays a key role in the process. "The high aspect ratio of the nanotubes provides increased oscillator strength, which allows better antenna behaviour," he said. "It means that this method of removing ultraviolet radiation is more effective than simply having the boron-nitride in the form of a thin film."

Source:
http://nanotechweb.org
supported by
AFOSR grant No. FA9550-04-1-0161

Desalination with BNNTs

Image: http://www.greenpacks.org



http://www.irri.org

Salt Rejection and Water Transport Through Boron Nitride Nanotubes

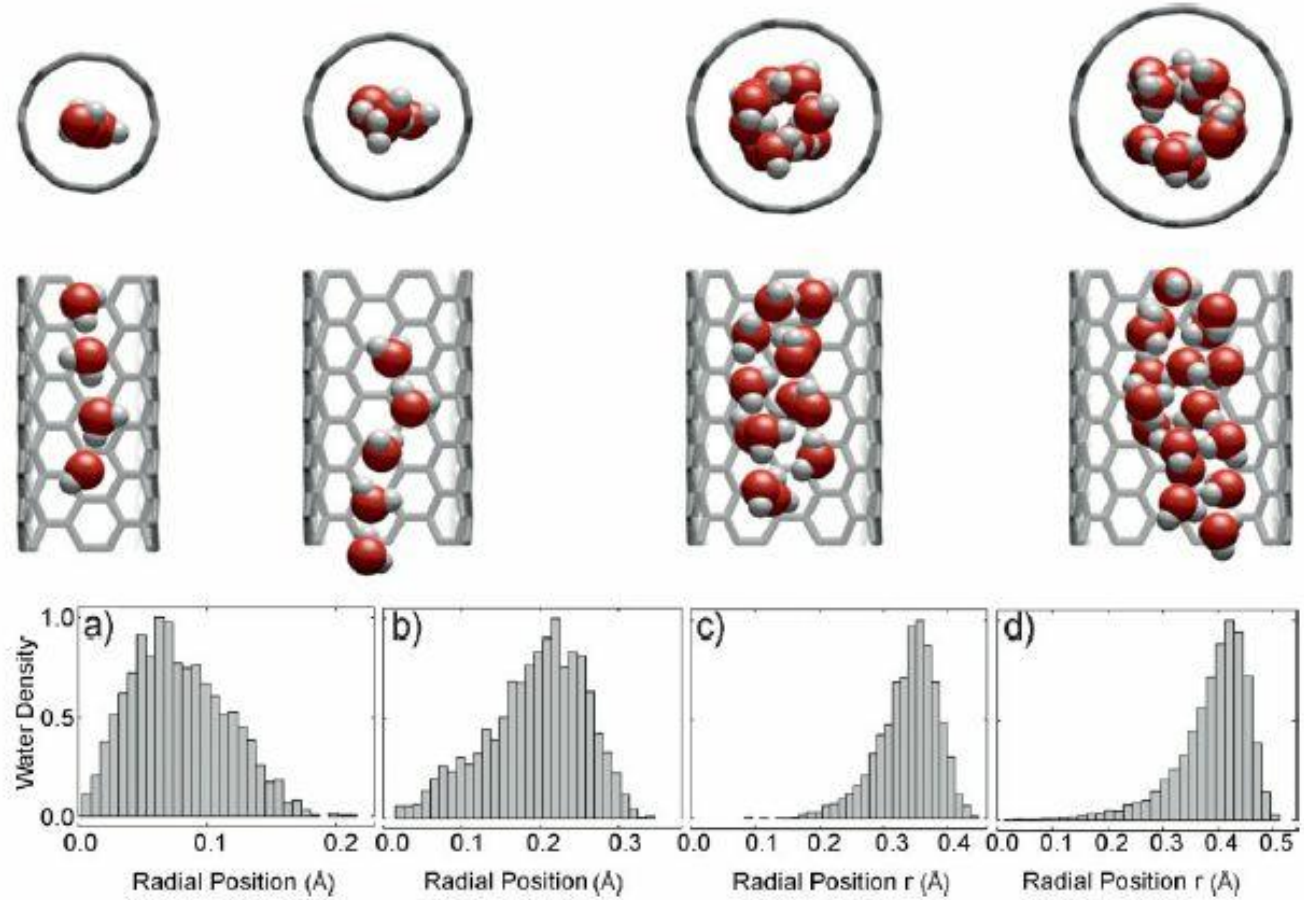


Figure 2. Water molecules inside boron nitride nanotubes. Bottom: The radial water density distribution of water molecules, where the *x*-axis represents the radial position from the center of the nanotube. Top: The average position of water from MD simulations for a) (5, 5), b) (6, 6), c) (7, 7), and d) (8, 8) tubes.

Source: Salt Rejection and Water Transport Through Boron Nitride Nanotubes, Tamsyn A. Hilder, Daniel Gordon, and Shin-Ho Chung, "Small," 2009, 5, No. 19, 2183–2190

Boron-nitride nanotubes speed desalination, says Australian research

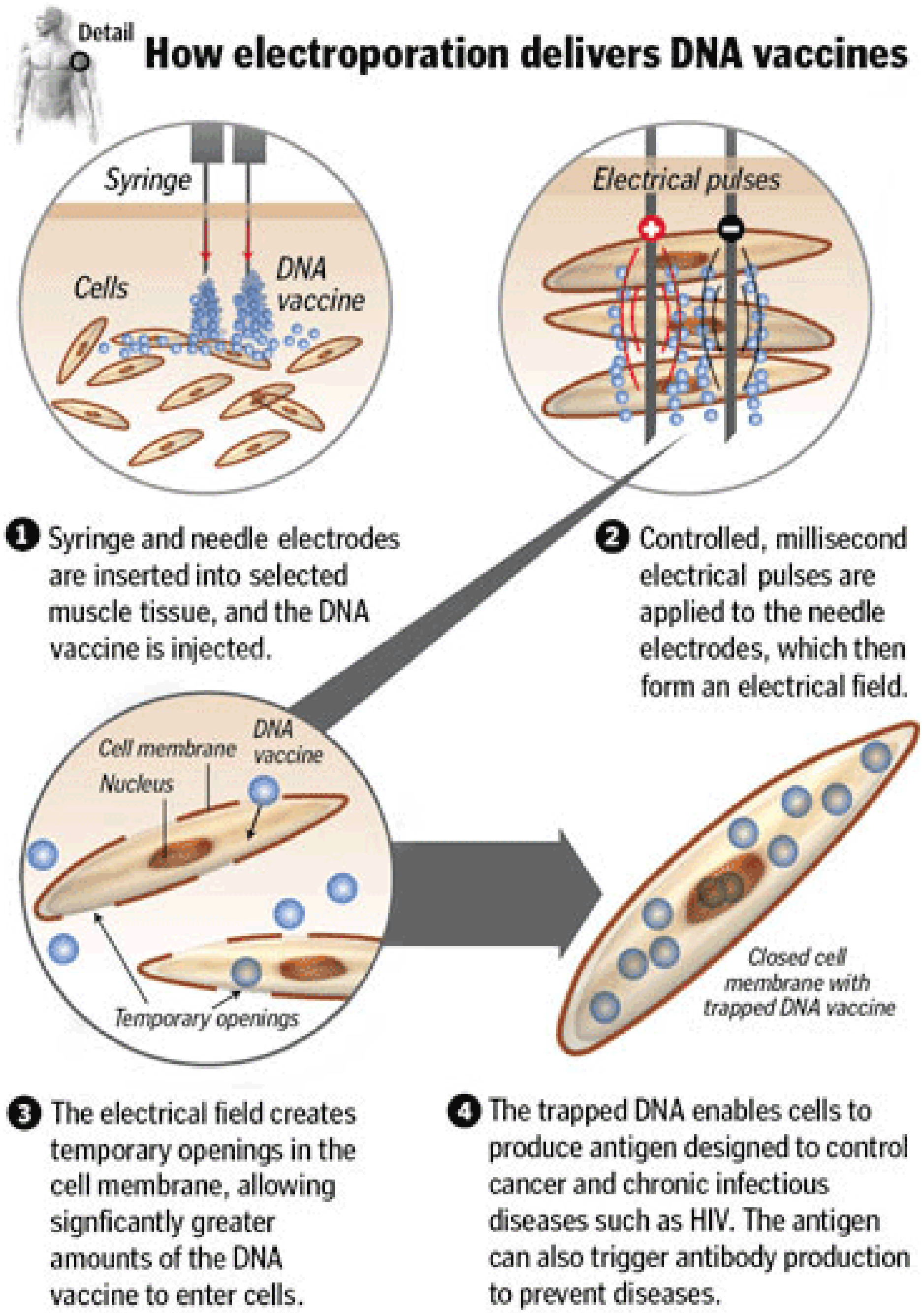
Researchers from The Australian National University (ANU) claim to have discovered a way to speed the desalination of seawater by up to five times using nanotubes made from boron and nitrogen atoms.

In a paper published in the journal *Small*, researchers Dr Tamsyn Hilder, Dr Dan Gordon and group leader Professor Shin-Ho Chung from the Computational Biophysics Group at the Research School of Biology at ANU say that boron-nitride nanotubes have shown superior water flow properties compared with carbon nanotubes, and are thus expected to provide a more efficient water purification device.

"Using boron nitride nanotubes, and the same operating pressure as current desalination methods, we can achieve 100% salt rejection for concentrations twice that of seawater with water flowing four times faster, which means a much faster and more efficient desalination process," says Dr Hilder.

Hilder, Gordon and Chung use computational tools to simulate the water and salt moving through the nanotube. They found that the boron nitride nanotubes not only eliminate salt but also allow water to flow through extraordinarily fast, comparable to biological water channels naturally found in the body.

Cancer Therapy No. 1: EP (Electroporation aka Electropermeabilization)



Source:

http://fredcobio.wordpress.com/2008/03/
Inovio Biomedical Corp. of San Diego, CA

IOP Publishing NANOTECHNOLOGY
Nanotechnology **20** (2009) 075104 (5pp) doi:10.1088/0957-4484/20/7/075104

Enhanced low voltage cell electropermeabilization by boron nitride nanotubes

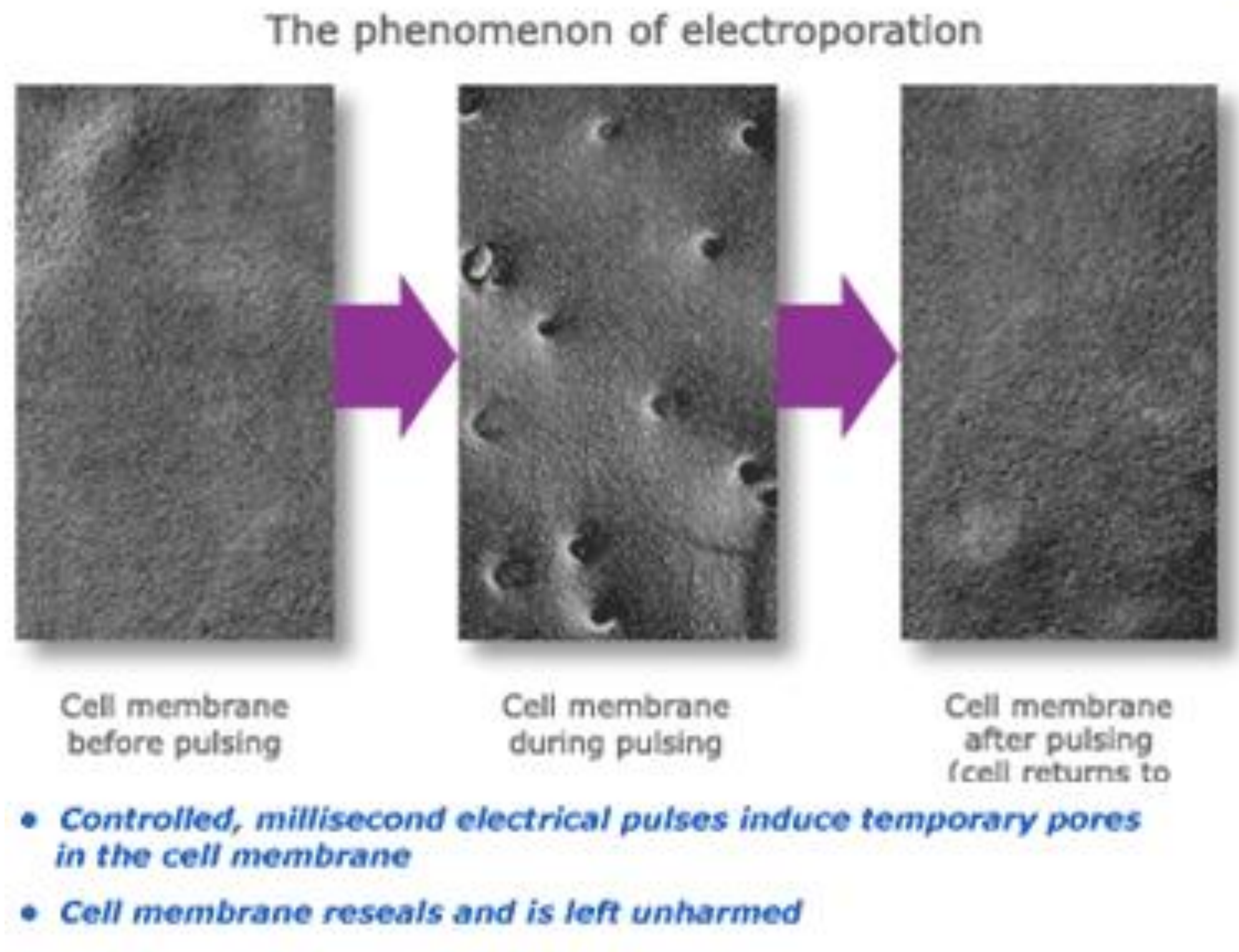
V Raffa, G Ciofani and A Cuschieri

Scuola Superiore Sant'Anna, Piazza Martiri della Libertà 33, 56127 Pisa, Italy

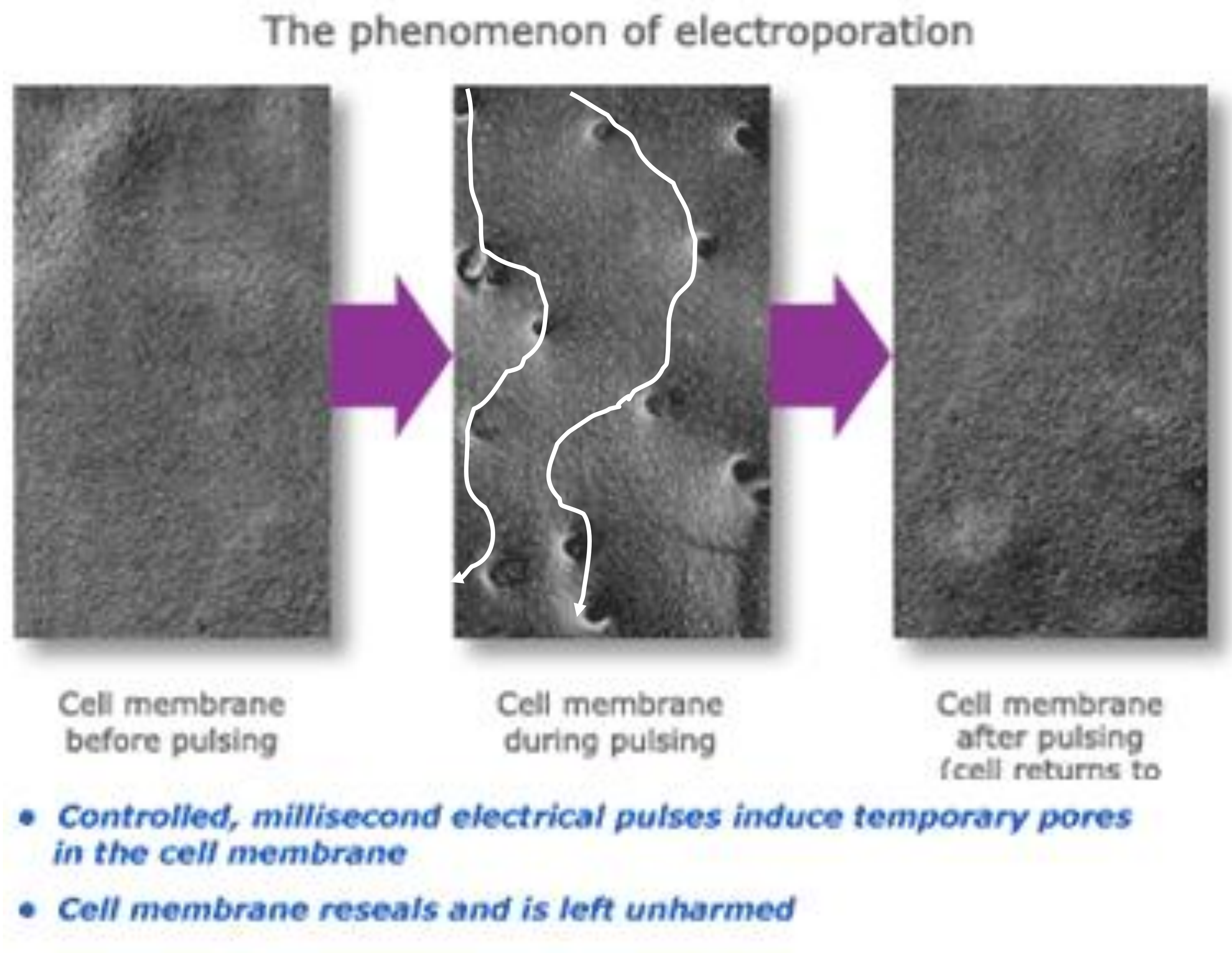
E-mail: s.raffa@crim.sssup.it

Received 23 September 2008, in final form 10 December 2008
Published 23 January 2009
Online at stacks.iop.org/Nano/20/075104

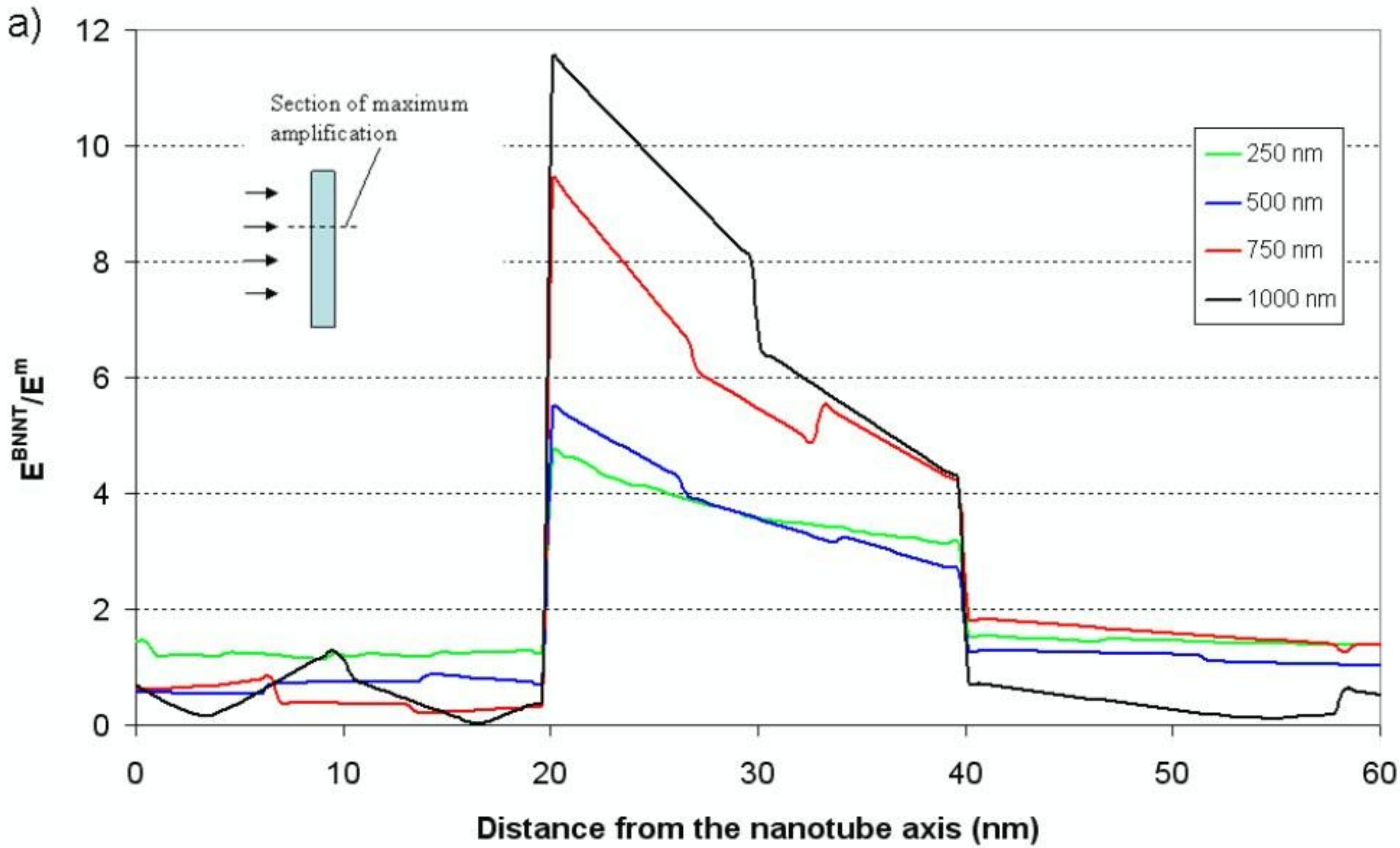
Abstract
Boron nitride nanotubes (BNNTs) are a structural analogue of carbon nanotubes (CNTs), with alternating B and N atoms which entirely substitute for C atoms in a graphitic-like sheet with almost no change in atomic spacing. BNNTs have generated considerable interest within the scientific community by virtue of their unique properties. Very recently, biomedical applications of BNNTs have also been proposed. In the present *in vitro* study, we demonstrate that BNNTs can be used as nanotools to enable cell electropermeabilization with very low electric fields (40–60 V cm^{-1}). An explanation of this behaviour based on the dielectric response of BNNTs to static electric fields is proposed.



Source: http://fredcobio.wordpress.com/2008/03/
Inovio Biomedical Corp. of San Diego, CA

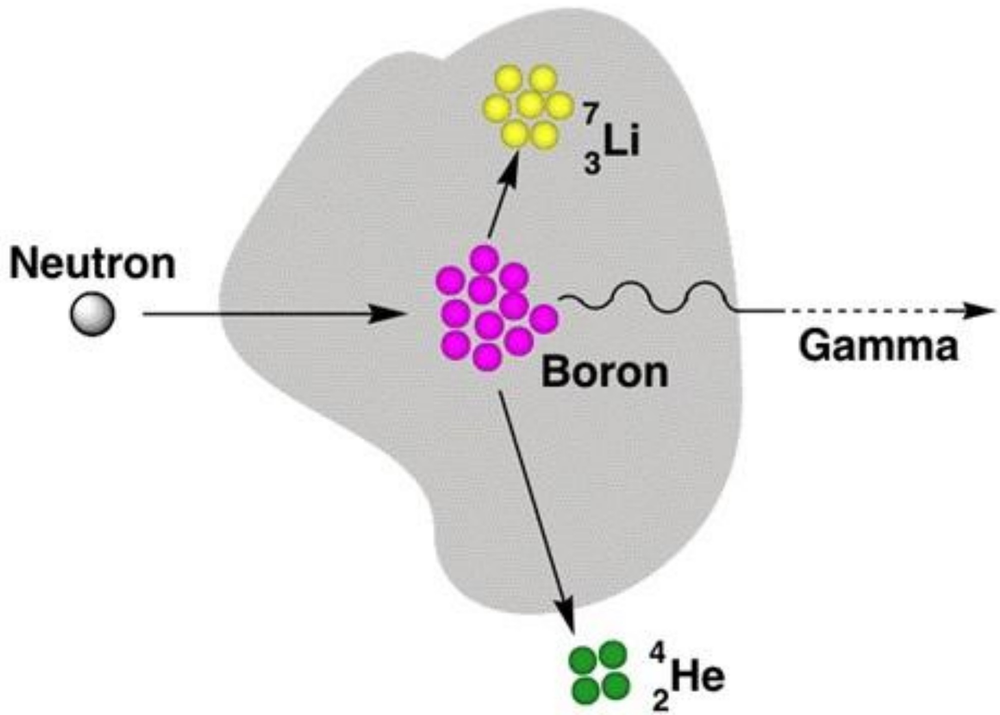


Source: http://fredcobio.wordpress.com/2008/03/
Inovio Biomedical Corp. of San Diego, CA

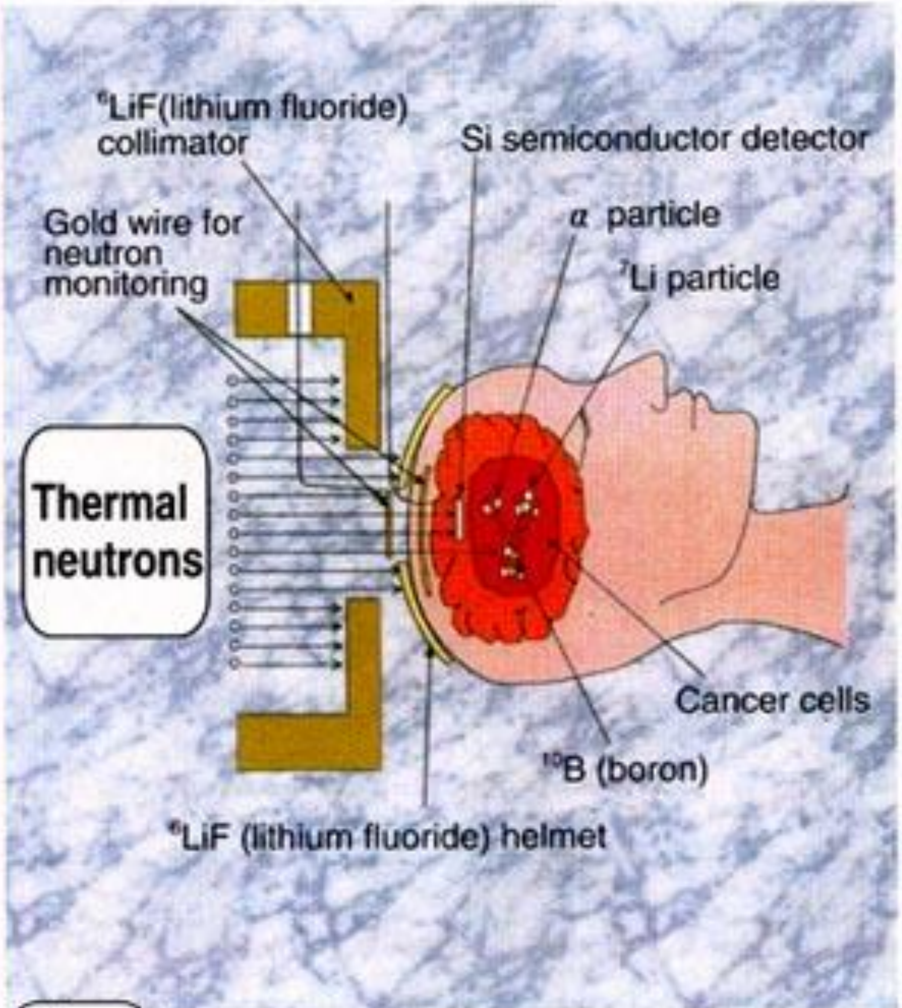


Source: Nanotechnology 20 (2009) 075104 (5pp) Enhanced low voltage cell electropermeabilization by boron nitride nanotubes
V Raffa, G Ciofani and A Cuschieri

Cancer Therapy No. 2: BNCT
(Boron Neutron Capture Therapy)


Neutron
7
3
Li
Boron
Gamma
4
2
He

Principle of Boron Neutron Capture Therapy (BNCT)



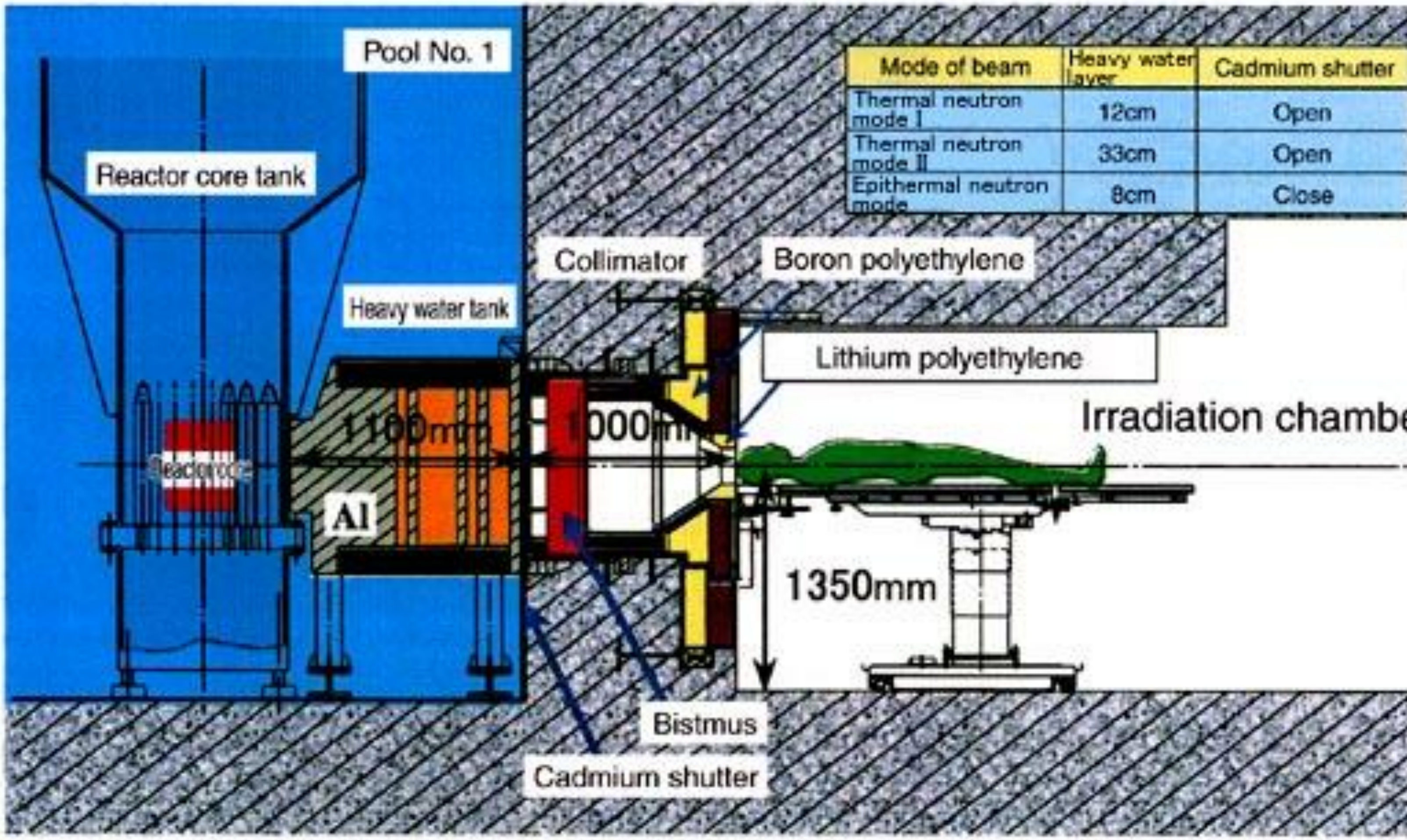
In boron neutron capture therapy (BNCT), boron compound is injected into a patient's body in advance. Owing to the blood-brain barrier function, boron compounds do not enter healthy brain cells easily but readily find their way into malignant tumor cells. Neutrons are irradiated on the affected part of the brain, enabling selective destruction of the tumor cells containing boron by the alpha and lithium particles generated from the $^{10}B(n, \alpha)\,^{7}Li$ reaction.

Fig.1

Source: Japan Atomic Energy Agency

Neutron Beam Facility

Neutron beam irradiation mode can be changed according to remedy conditions



Mode of beam	Heavy water layer	Cadmium shutter
Thermal neutron mode I	12cm	Open
Thermal neutron mode II	33cm	Open
Epithermal neutron mode	8cm	Close

Fig.3

Source: Japan Atomic Energy Agency

Nanoscale Res Lett (2009) 4:113–121
DOI 10.1007/s11671-008-9210-9

NANO EXPRESS

Folate Functionalized Boron Nitride Nanotubes and their Selective Uptake by Glioblastoma Multiforme Cells: Implications for their Use as Boron Carriers in Clinical Boron Neutron Capture Therapy

Gianni Ciofani · Vittoria Raffa · Arianna Menciassi · Alfred Cuschieri

Received: 17 October 2008 / Accepted: 11 November 2008 / Published online: 25 November 2008

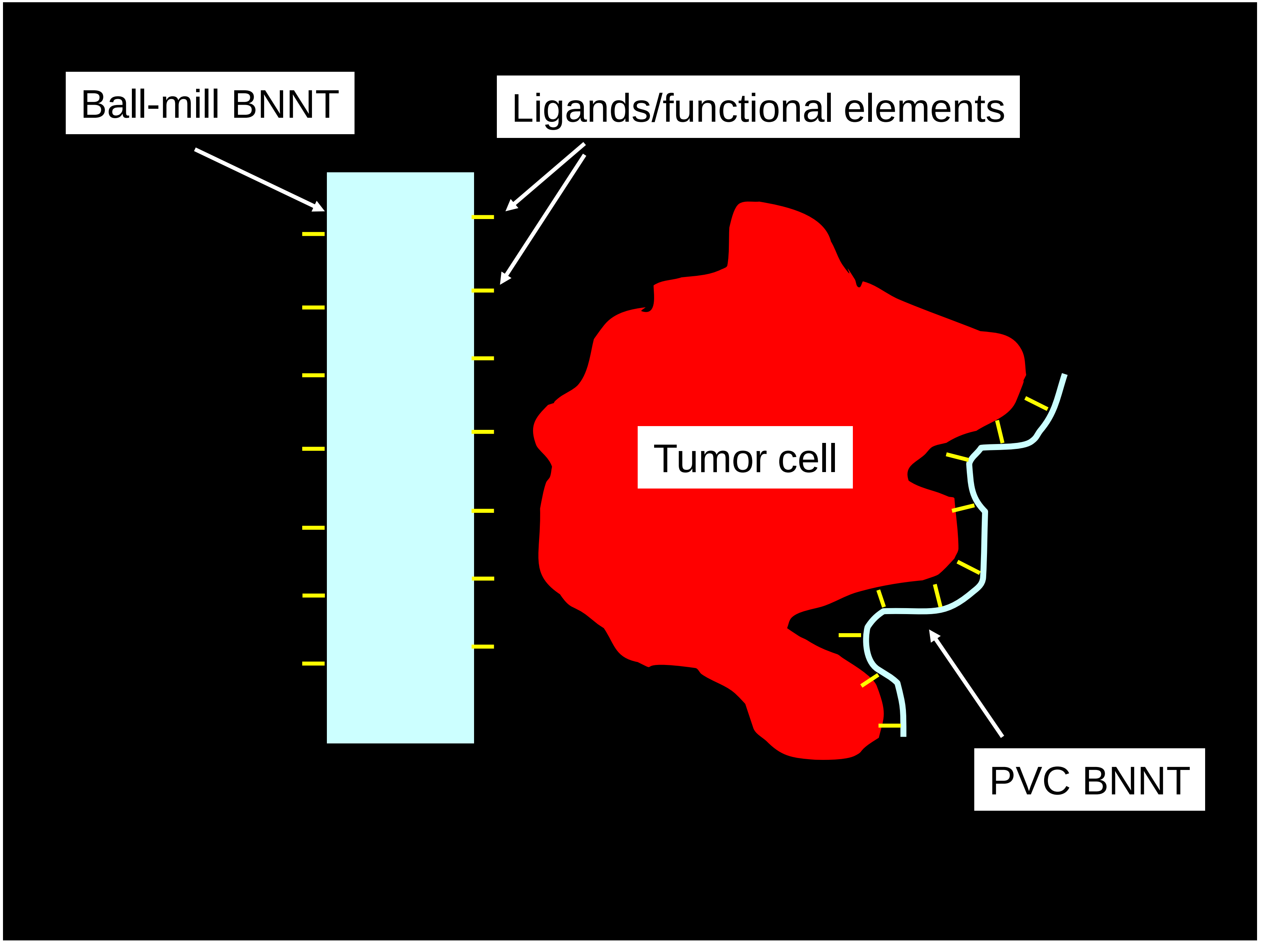
Abstract Boron neutron capture therapy (BNCT) is increasingly being used in the treatment of several aggressive cancers, including cerebral glioblastoma multiforme. The main requirement for this therapy is selective targeting of tumor cells by sufficient quantities of ^{10}B atoms required for their capture/irradiation with low-energy thermal neutrons. The low content of boron targeting species in glioblastoma multiforme accounts for the difficulty in selective targeting of this very malignant cerebral tumor by this radiation modality. In the present

Keywords Boron nitride nanotubes · Folate · Glioblastoma multiforme · Boron neutron capture therapy

Introduction

High-grade glioblastoma multiforme is uniformly fatal and largely unresponsive to all available treatments. Patients with these tumors usually survive for <1 year from the time of first diagnosis. Conventional surgical excision, generally limited to the main tumor mass, does not remove

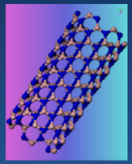
BNNT morphology affects cellular uptake



The Complete History of BNNTs (including the future)

1995

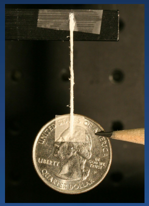
‘Science’ Paper



Proof of Concept UC Berkeley

2009

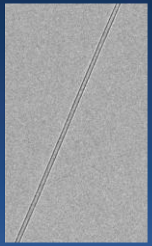
‘Science’ Blurb



High Aspect Ratio, High Crystallinity (VA group)

2010

Electronics, Physics, Photonics, Sensors



Isolated, Individual BNNTs (VA Group)

?

Wet Chemistry Research, Ductile Ceramics

High Mass Synthesis (10^2-10^6 x) (?)

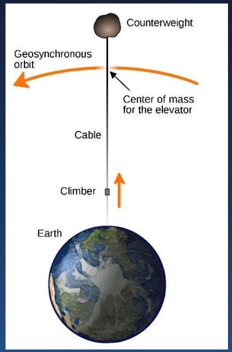
?

Piezo Devices, Polymer Composites, Radiation Materials, Desalination, Drugs and Medical Applications

Separation And Purification (?)

?

Spun Structures, Space Elevators



Continuous Draw of Fibers (?)

Grand Challenges (time)

image: moonrise from the ISS, http://spaceflight.nasa.gov

Helical microtubules of graphitic carbon

Sumio Iijima

NEC Corporation, Fundamental Research Laboratories, 34 Miyukigaoka, Tsukuba, Ibaraki 305, Japan

THE synthesis of molecular carbon structures in the form of C_{60} and other fullerenes[1] has stimulated intense interest in the structures accessible to graphitic carbon sheets. Here I report the preparation of a new type of finite carbon structure consisting of needle-like tubes. Produced using an arc-discharge evaporation method similar to that used for fullerene synthesis, the needles grow at the negative end of the electrode used for the arc discharge. Electron microscopy reveals that each needle comprises coaxial tubes of graphitic sheets, ranging in number from 2 up to about 50. On each tube the carbon-atom hexagons are arranged in a helical fashion about the needle axis. The helical pitch varies from needle to needle and from tube to tube within a single needle. It appears that this helical structure may aid the growth process. The formation of these needles, ranging from a few to a few tens of nanometres in diameter, suggests that engineering of carbon structures should be possible on scales considerably greater than those relevant to the fullerenes.

Solids of elemental carbon in the sp^2 bonding state can form a variety of graphitic structures. Graphite filaments can be

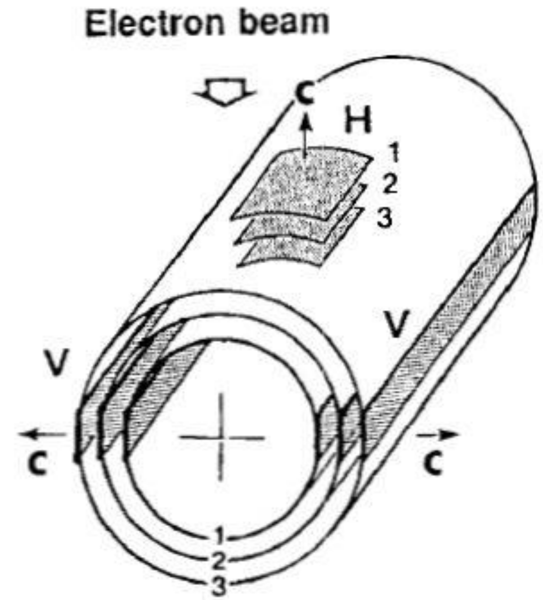


FIG. 2 Clinographic view of a possible structural model for a graphitic tubule. Each cylinder represents a coaxial closed layer of carbon hexagons. The meaning of the labels V and H is explained in the text.

graphite filaments[5]. The apparatus is very similar to that used for mass production of C_{60} (ref. 9). The needles seem to grow plentifully on only certain regions of the electrode. The electrode on which carbon was deposited also contained polyhedral particles with spherical shell structures, which were 5–20 nm in

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Helical microtubules of graphitic carbon

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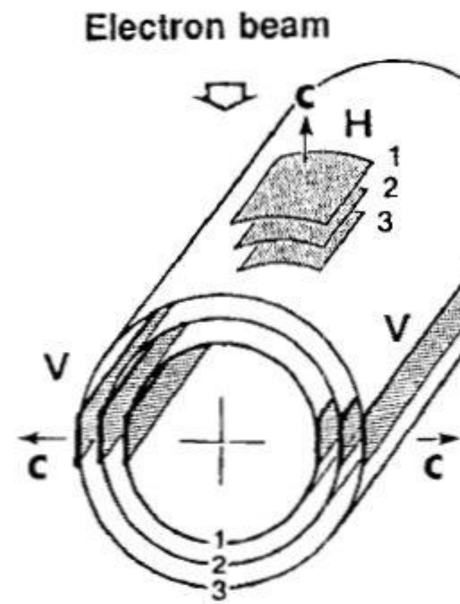

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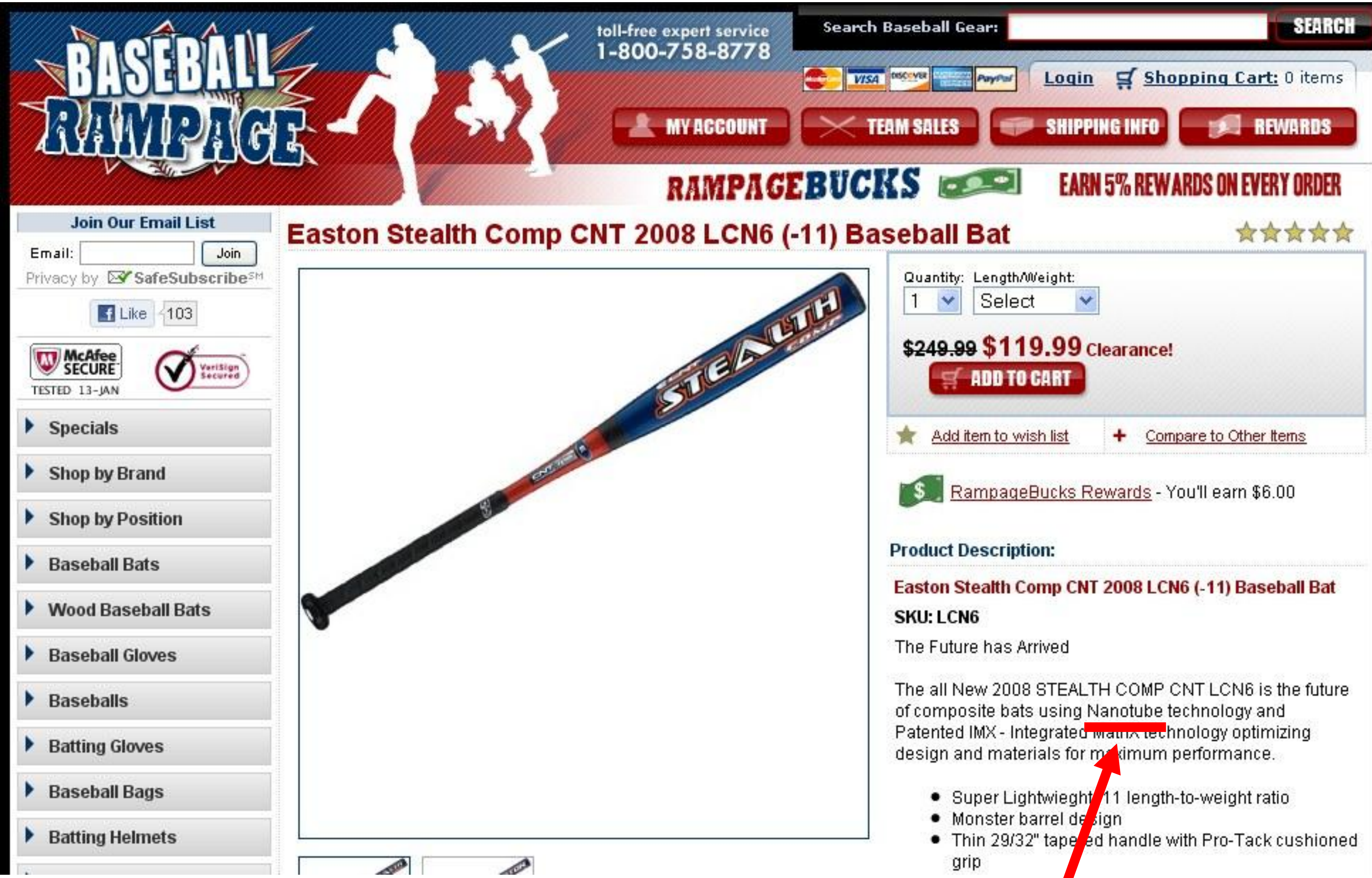

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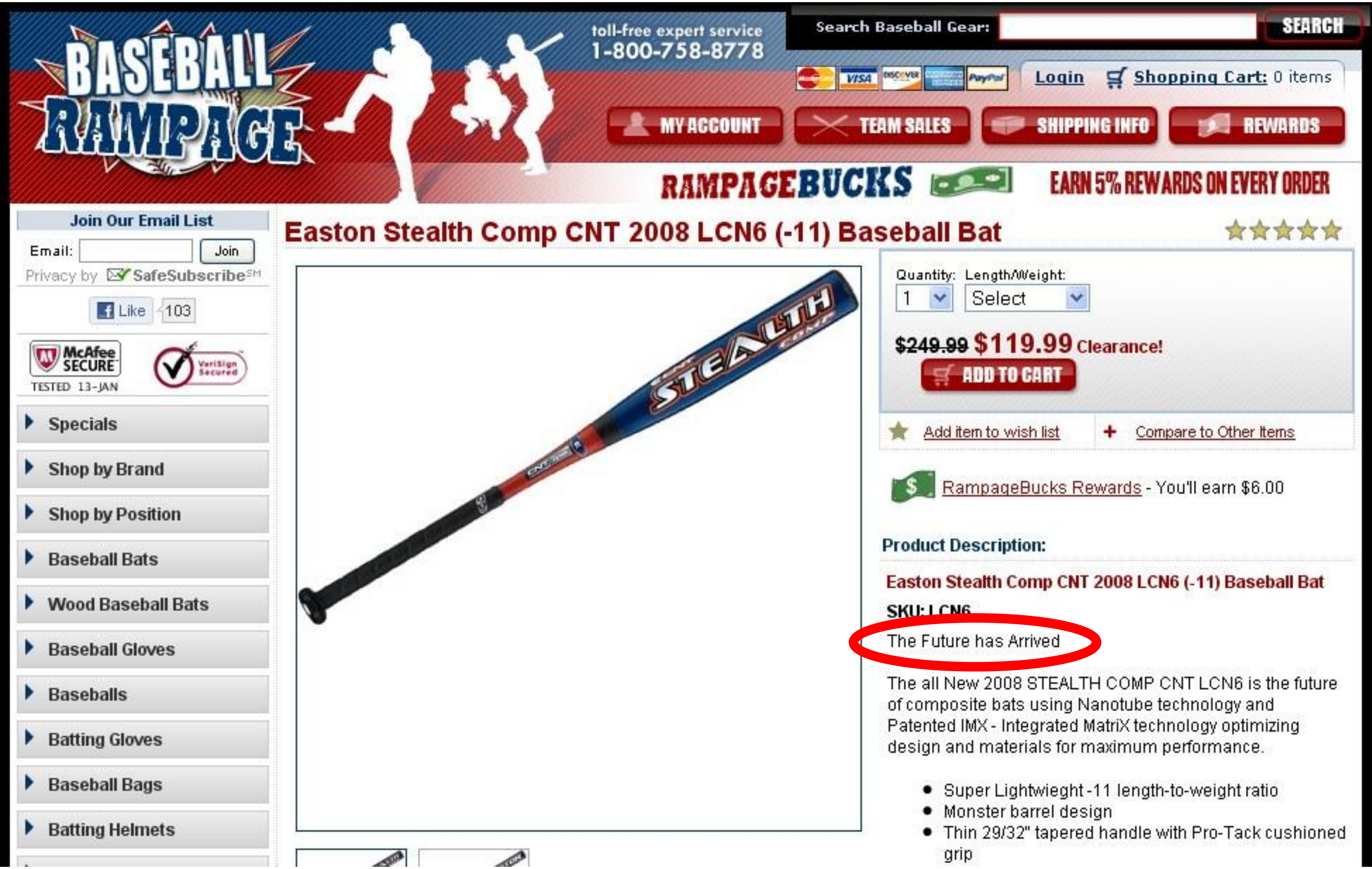
Monster barrel design
Thin 29/32" tapered handle with Pro-Tack cushioned grip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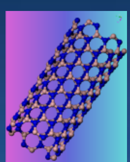
The Complete History of BNNTs (including the future)

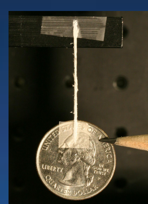
‘Science’ Paper



1995

Proof of Concept UC Berkeley

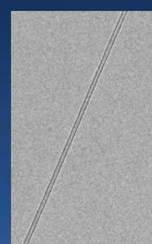
‘Science’ Blurb



2009

High Aspect Ratio, High Crystallinity (VA group)

Electronics, Physics, Photonics, Sensors



2010

Isolated, Individual BNNTs (VA Group)

Wet Chemistry Research, Ductile Ceramics

?

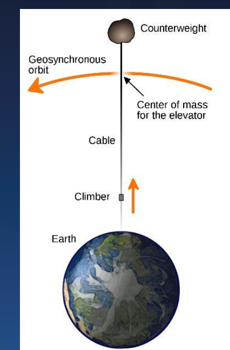
High Mass Synthesis (10^2-10^6 x) (?)

Piezo Devices, Polymer Composites, Radiation Materials, Desalination, Drugs and Medical Applications

?

Separation And Purification (?)

Spun Structures, Space Elevators



?

Continuous Draw of Fibers (?)

Grand Challenges (time)

image: moonrise from the ISS, http://spaceflight.nasa.gov

Image: science.discovery.com

"…(the nanotube is) the strongest fiber that you can make out of anything, ***ever***."

~ (the late) Prof. Richard Smalley
Nobel Prize, Chemistry, 1996

image: moonrise from the ISS, http://spaceflight.nasa.gov

…incentives for energy efficiency and clean energy are the right thing to do for our future because the nation that leads the clean energy economy will be the nation that leads the global economy. And America must be that nation.

President Barack Obama
(State of the Union Address, Jan. 26, 2011)

image: moonrise from the ISS, http://spaceflight.nasa.gov

…jars reminder.