Applications of Nanotechnology to Materials

Seventh Science Conclave

IIIT Allahabad

December 2014

What caused the world emphasis on nanotechnology?

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Nanotechnology is much older than nanoscience.

Lycurgus Cup

4th Century Roman Cup

Persian Khanjar

Precipitation Hardening

Metal alloys can be strengthened by precipitating out nanoparticles of a minor component of the alloy. These stop cracks thereby strengthening the metal.

First used ~1900 in aluminum

Theory published in 1919

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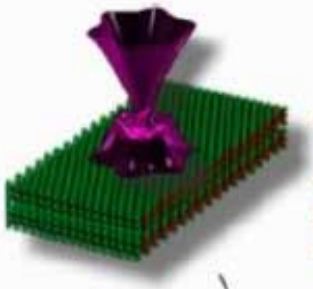
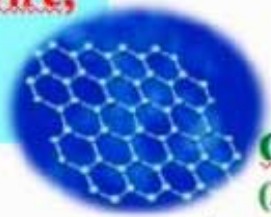
But we have been unwittingly using nanotechnology for about 2 millenia and carbon nanotechnology for about 500 years.

"Star Materials"

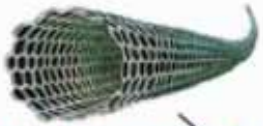
quantum dot, C60, CNT, nanowire, metamaterial, graphene, topological insulator, …



Topological insulator
Kane, PRL 95, 146802 (2005)
Zhang, Science 314,1757 (2006)
Moore, PRB 75, 121306 (2007)



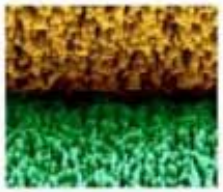
Graphene, 2004
(Manchester Univ.)
A. Geim, Science, 306, 666 (2004)



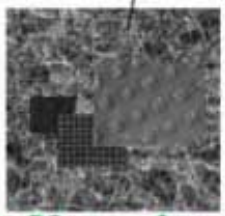
Carbon nanotube, 1991 (NEC)
S. Iijima, Nature, 354, 56 (1991)

Fullerene, 1985 (Rice Univ.)
Kroto, Nature, 318, 162 (1985)

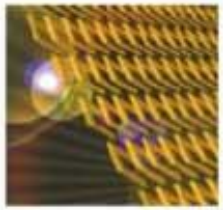
1980 1985 1990 1995 2000 2005 2010



ZnO nanowire, 2001
Z. L. Wang, Science 291, 1947 (2001)



Si & Ge Nanowires,
C.M. Lieber, Science 279, 208 (1998)



Metamaterial, 2000
(UCSD, USA)
D. R. Smith, PRL, 84, 418495 (2000)

Quantum dot, 1981
(Vavilov State Opt. Ins.)
A. Ekimov, JETP Lett., 34, 345 (1981)

What gave the push to “nano”?

Besides Drexler’s book, which did not draw much attention.

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Tools (science depends on technology)

New: proximate probes (STM, AFM, other)

Improved: Electron Microscopy

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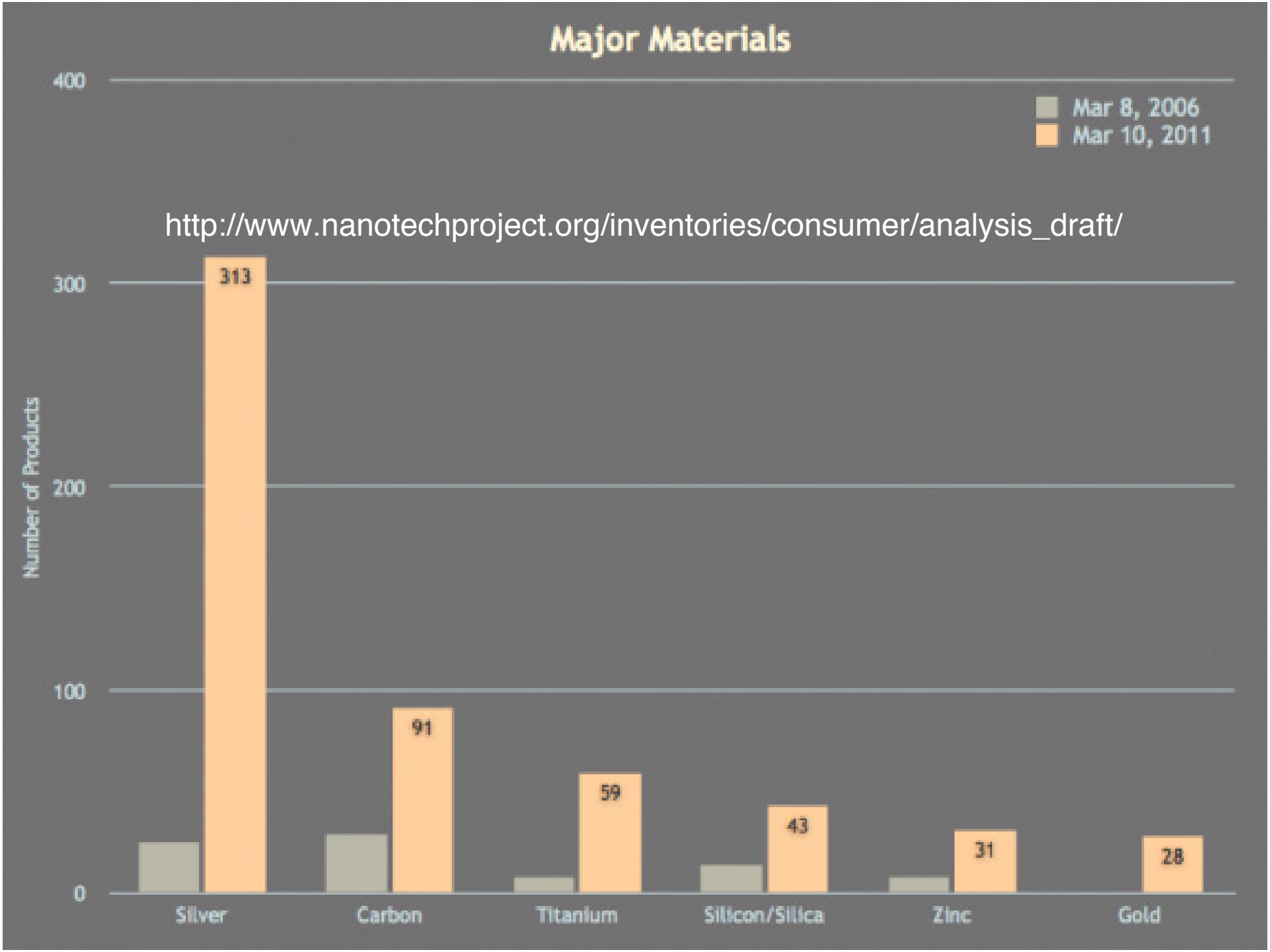
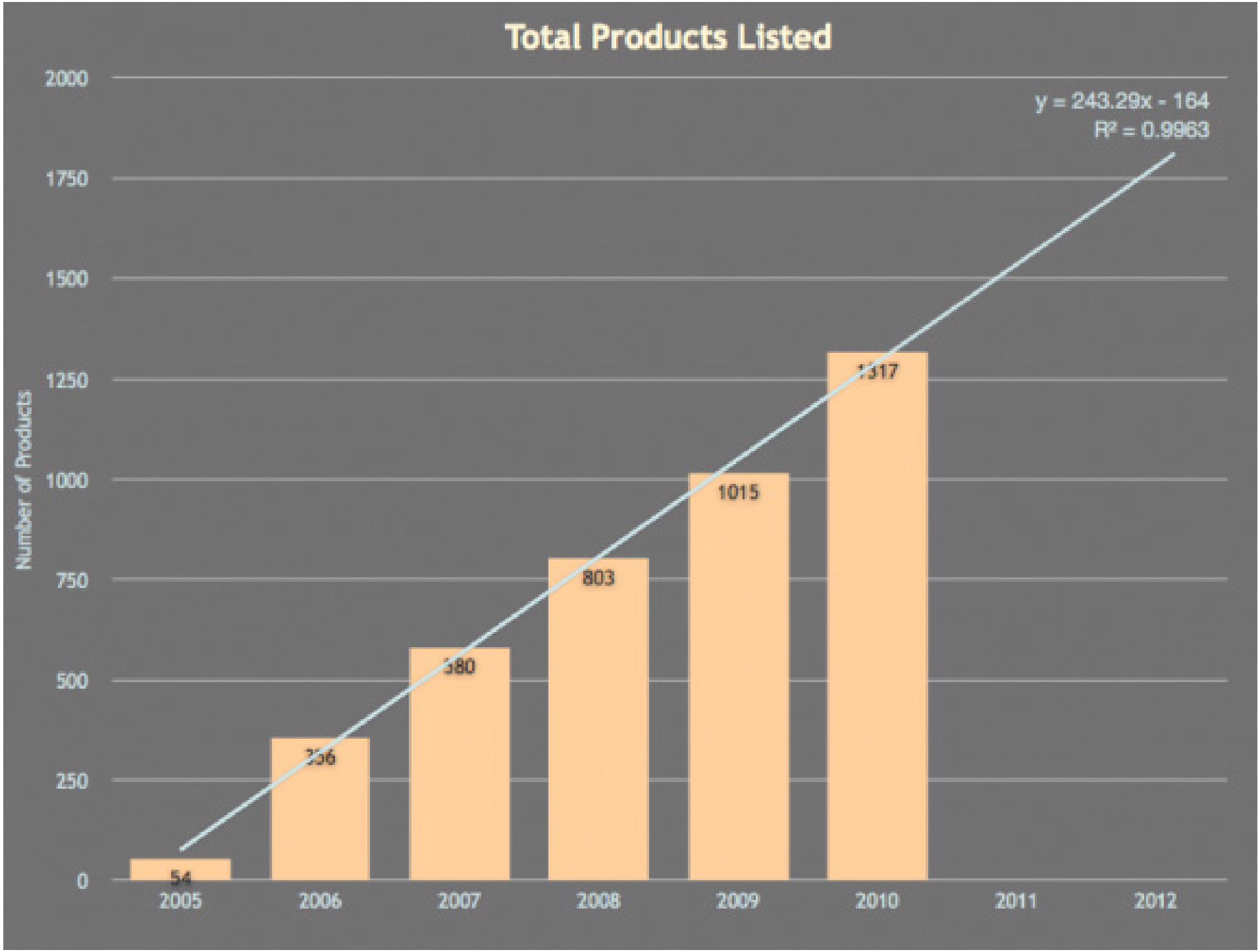
Rick Smalley

He believed now that one could examine nanostructures, it would be possible to create them with atomic precision.

National Nanotechnology Program
White House – November 2003


Major Materials
Mar 8, 2006
Mar 10, 2011
http://www.nanotechproject.org/inventories/consumer/analysis_draft/
Number of Products
400
300
200
100
0
313
91
59
43
31
28
Silver
Carbon
Titanium
Silicon/Silica
Zinc
Gold


Total Products Listed
y = 243.29x - 164
R² = 0.9963
Number of Products
2000
1750
1500
1250
1000
750
500
250
0
54
803
1015
2005
2006
2007
2008
2009
2010
2011
2012

Nature nanotech inspires development of waterproof and stainproof fabrics

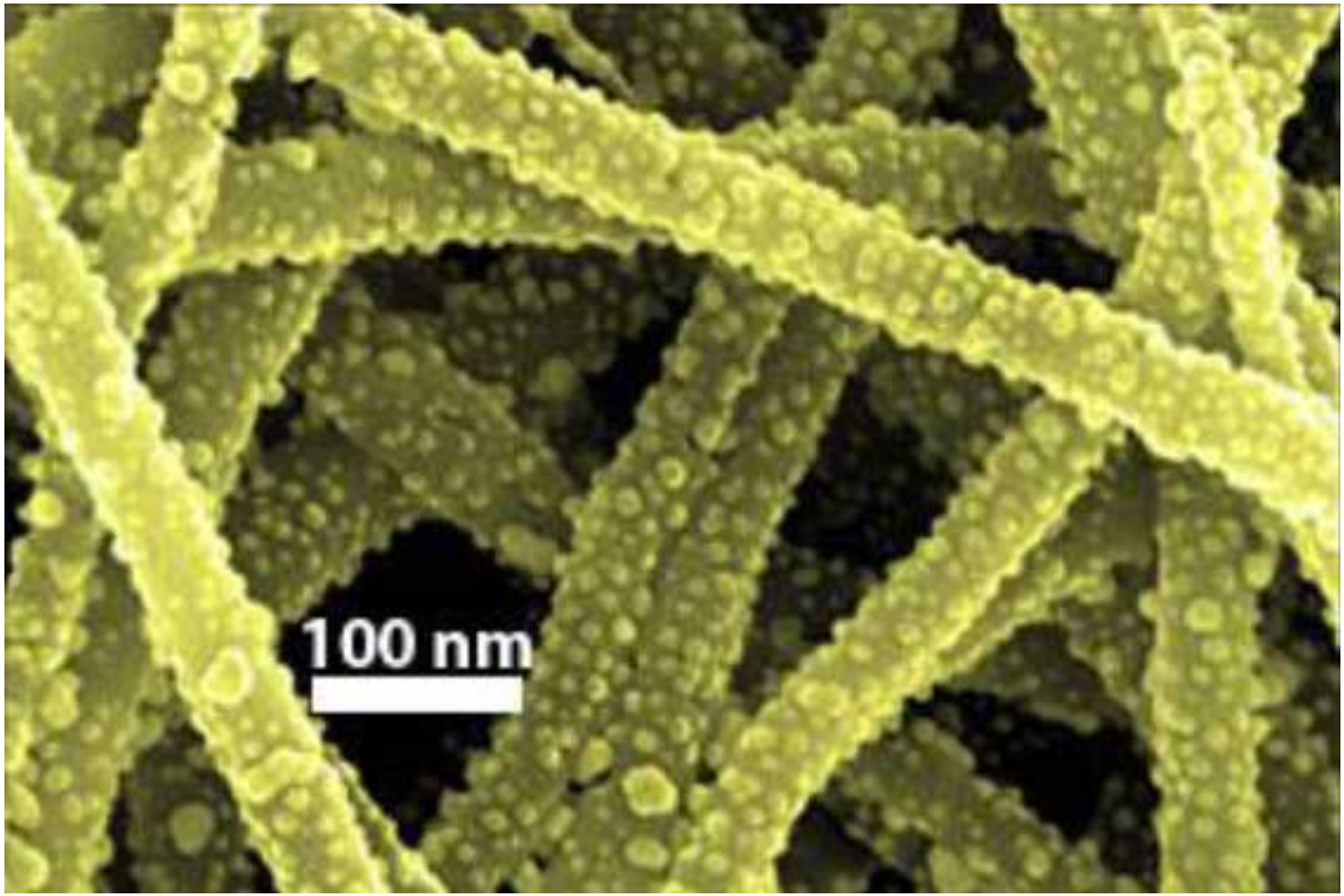
NanoTex

Water strider

Brooks Bros. stain resistant ties

Nano-Tex Treated

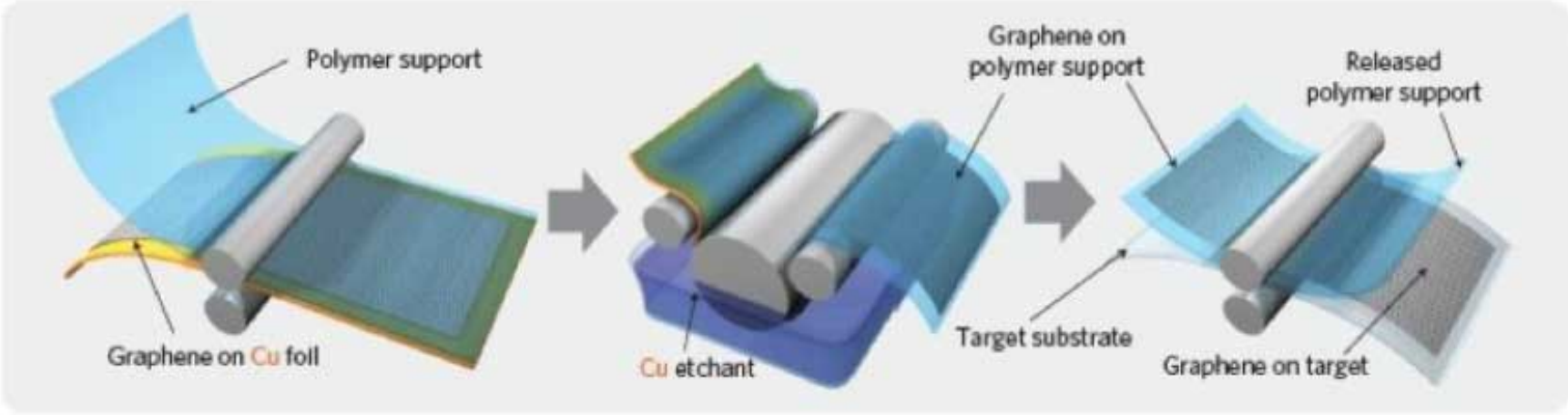
TiO_2 fiber cotton treatment

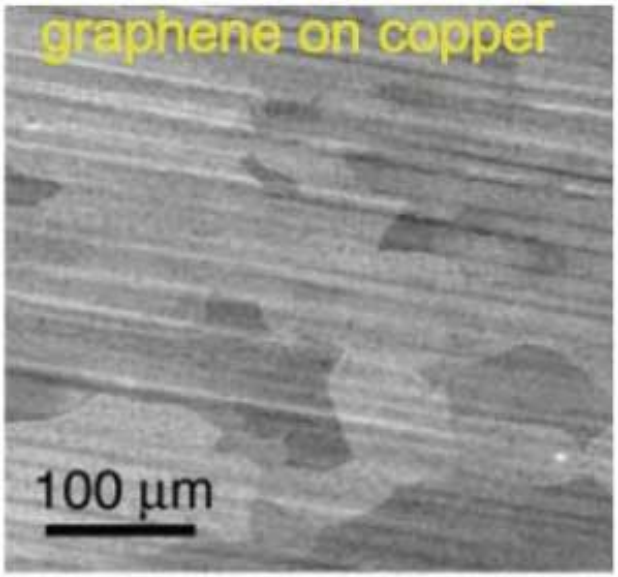


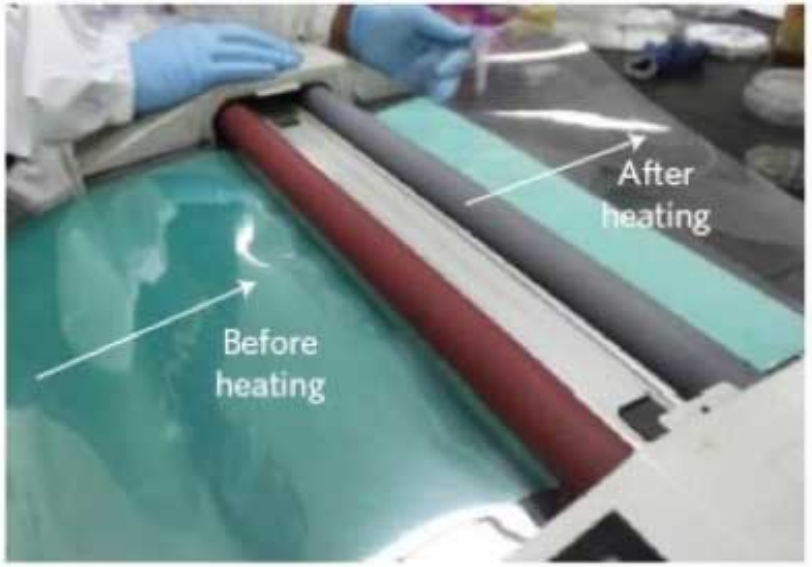
TiO_2 web decorated with TiO_2 nanoparticles used for treating cotton to produce photoactive

Konarka flexible portable panel

Manufacture of graphene on polymer







Bae et al, Nature Nanotechnology **5**, 574 (2010)

Filtering Membranes- Example NanoCeram

2 nm aluminum oxide fibres possess unusually strong bio-adhesive properties

Removing >99.9999% at 0.2 microns

Removing >99.997% at 0.02 microns (Virus level)

Lowest Pressure Drop - Comparable to a 2-3 μ/micron filter

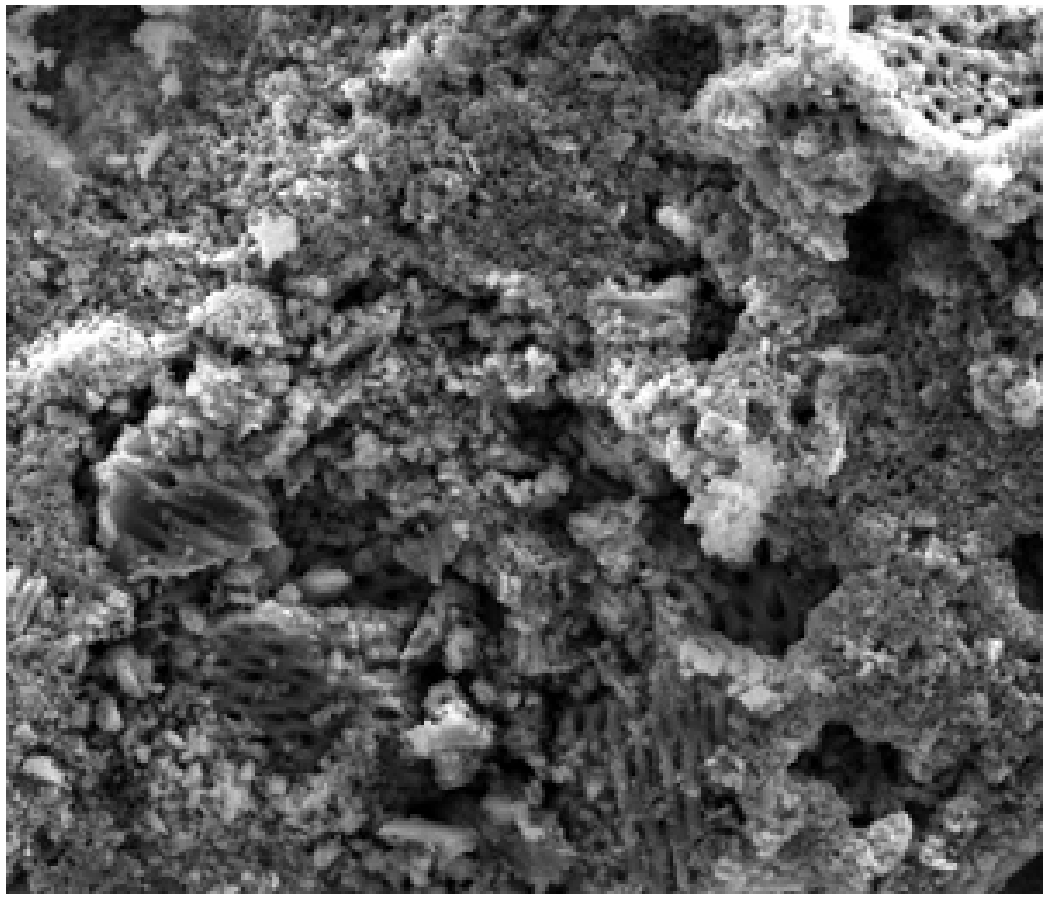
Wide pH Ranges - Effective from pH 4 to pH 9

High Dirt Retention - Up to 25 times greater dirt holding capacity

Heavy Metal Removal - Copper, Iron, Lead, Tin

NanoCeram® was developed to recycle drinking water on spacecraft and was shown to remove >99.9999% of viruses

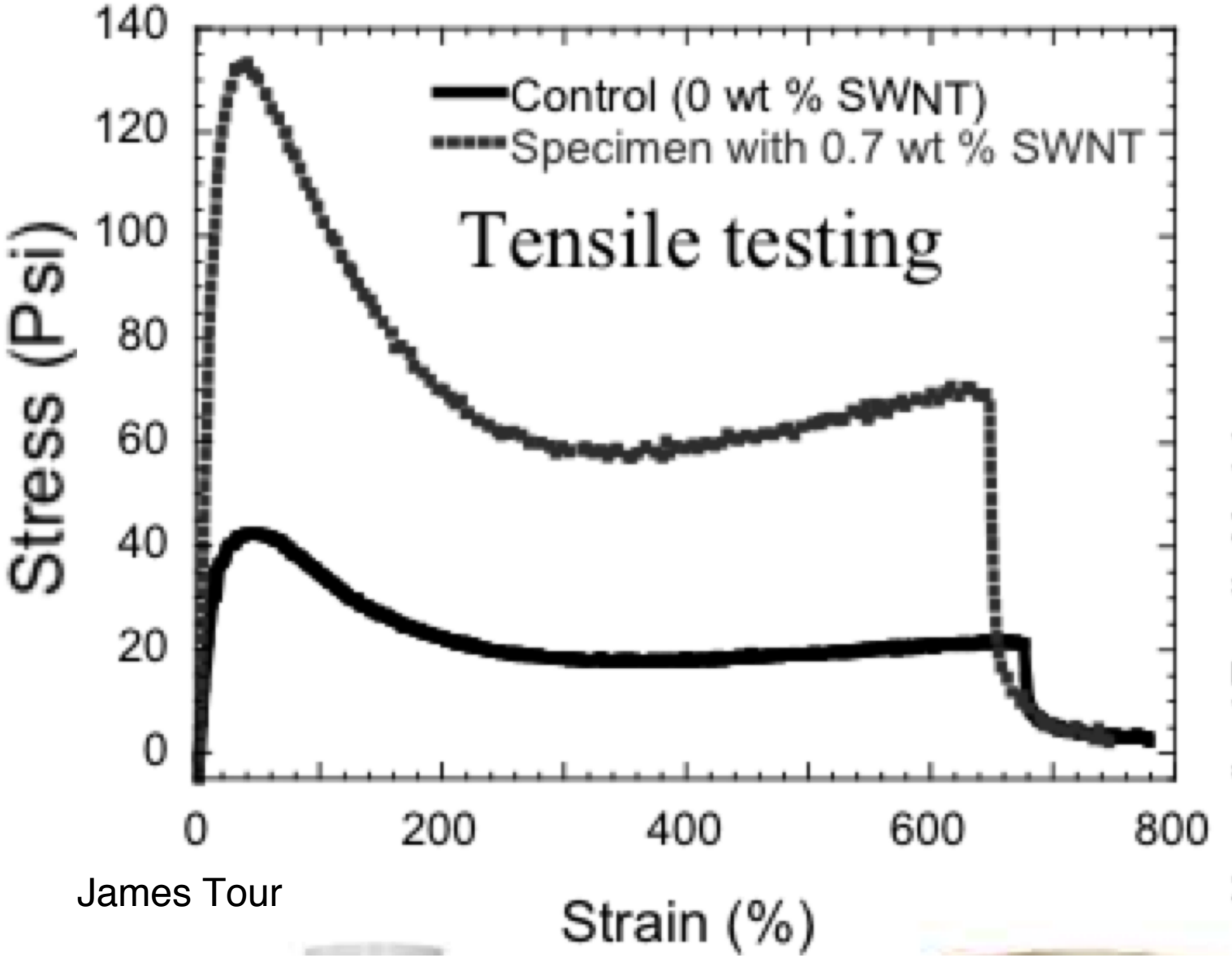
Nanoporous Si powder Li ion anodes



3 times the capacity of graphite electrodes and > 500 cycles without degradation of the electrode structure

Madhuri Thakur et al, Nature Scientific Reports November 2012

Elastomer reinforced with carbon nanotubes



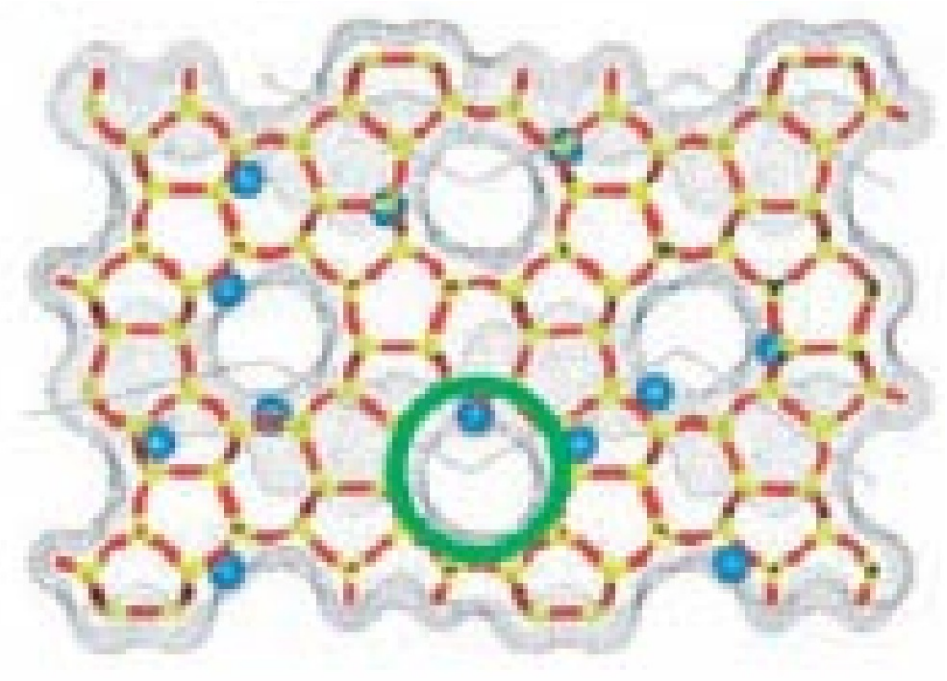
James Tour

Elastomer used in oil field o-rings

Annular blow out preventers

Operating conditions:
20,000 psi 90 inch o-rings

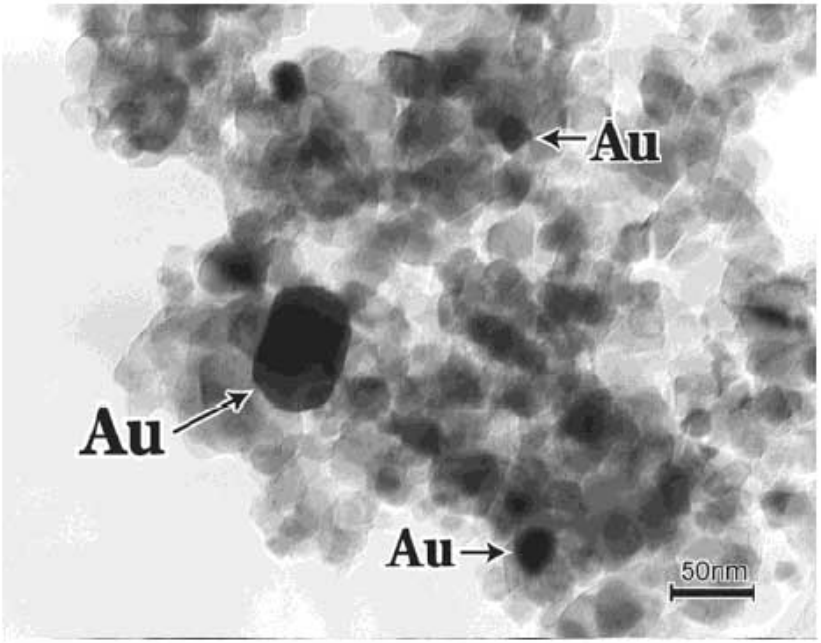
Nanostructured catalysts

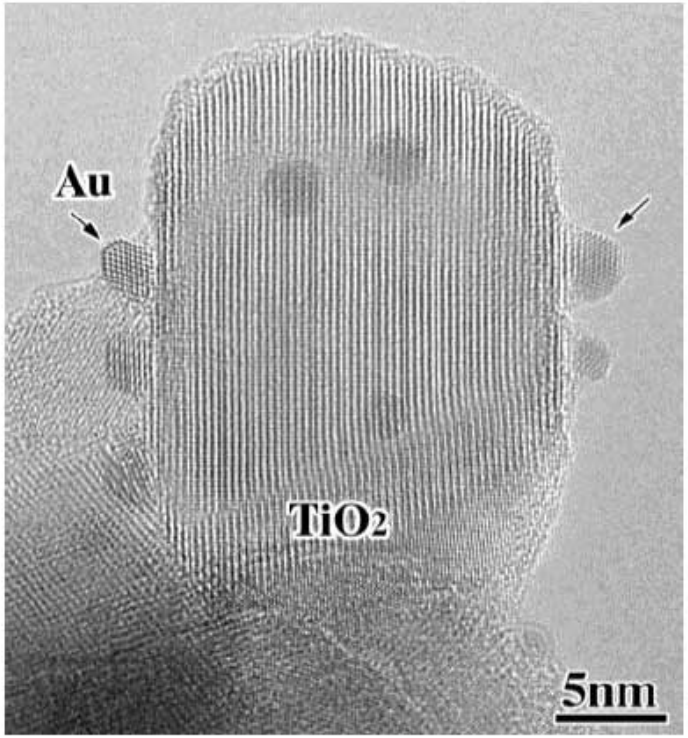


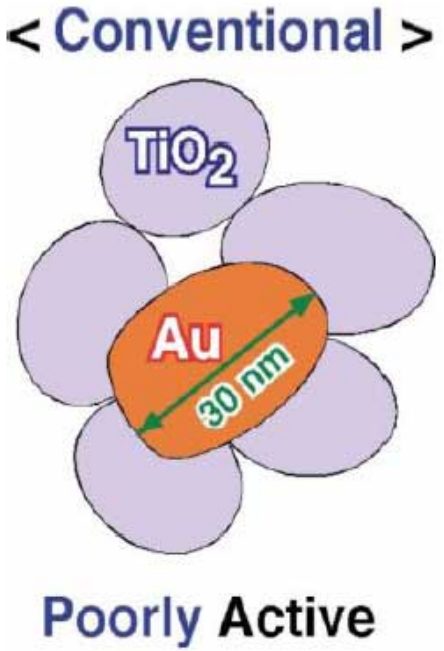
Metal impregnated zeolite

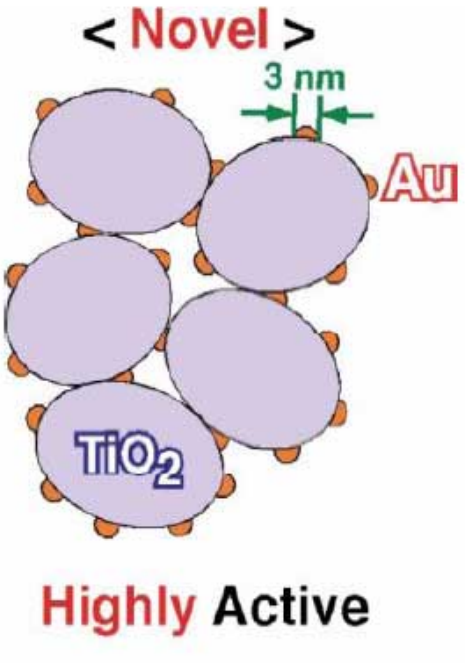
Gold Catalysts

M. Haruta









Top-down fabrication of nanostructures

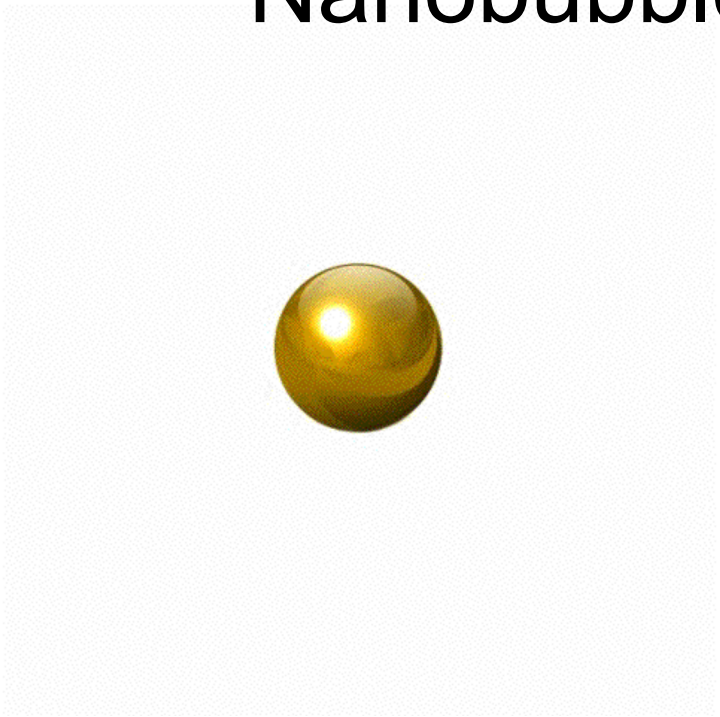
Comparison of Process Roadmaps (for Volume Production)

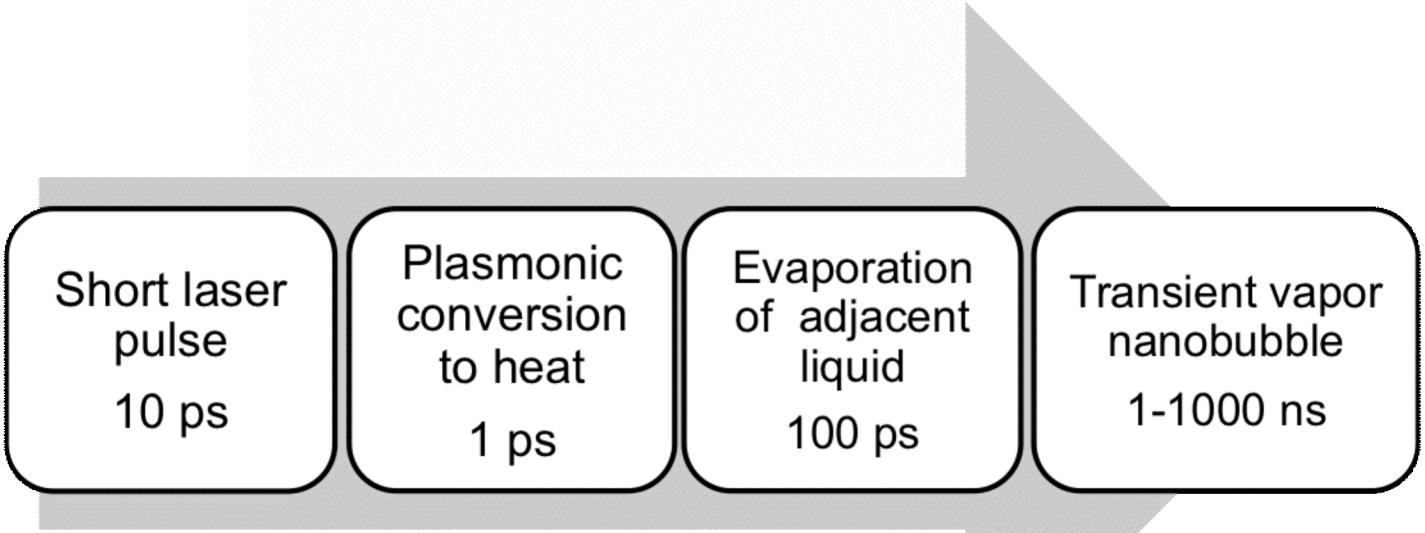
	2011	2012	2013	2014	2015	2016
Intel	22nm tri-gate transistor			14nm	10nm	
GlobalFoundries		28nm		20nm	14nm finFET, 20nm BEOL	10nm 14nm BEOL
Samsung		28nm		20nm	14nm finFET, 20nm BEOL	10nm
TSMC	28nm		20nm	16nm finFET, 20nm BEOL		10nm
UMC		28nm		14nm finFET, 20nm BEOL		10nm

Source: Companies, conference reports, IC Insights

http://www.icinsights.com/news/

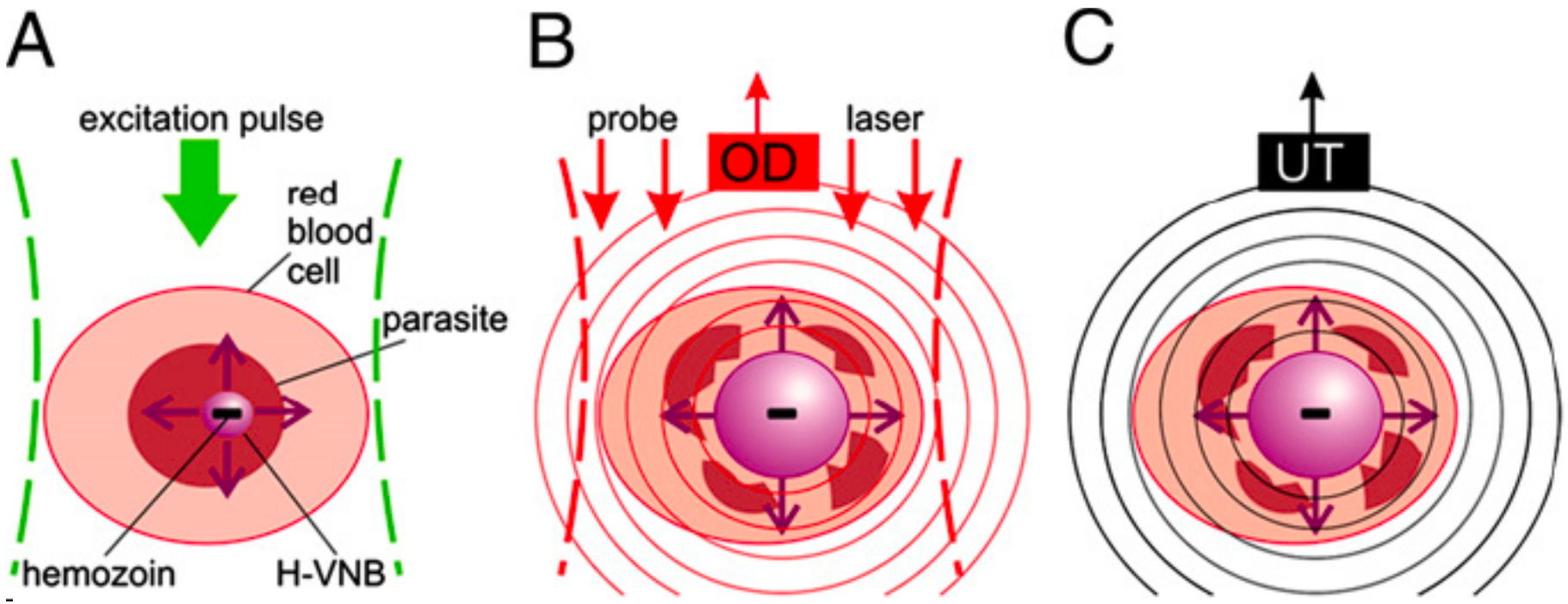
Laser pulse + gold = Plasmonic Nanobubble





On-demand non-stationary transient event, not a particle

Non-invasive rapid malaria diagnosis



E. Y. Lukianova-Hleb,….,Dmitri Lapotka, Proceedings of the National Academy of Sciences, **111** 900-905 (2014)