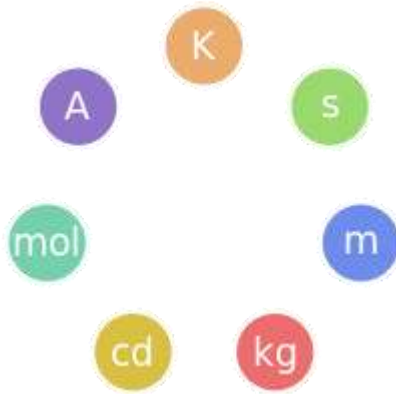


SI Units and Prefixes

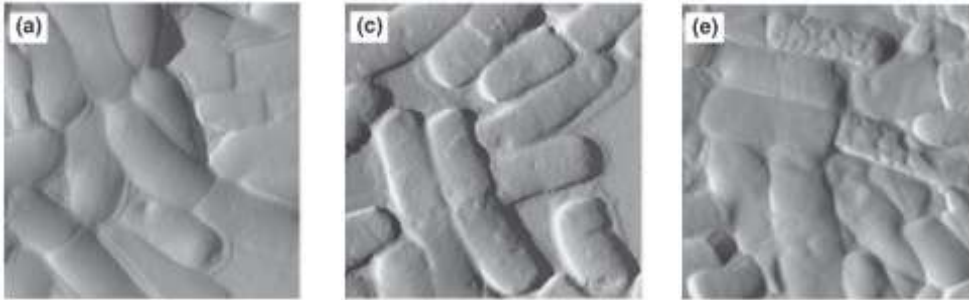


Symbol	Name	Quantity
A	ampere	electric current
K	kelvin	temperature
s	second	time
m	metre	length
kg	kilogram	mass
cd	candela	luminous intensity
mol	mole	amount of substance

Metric prefixes in everyday use			
Text	Symbol	Factor	Power
yotta	Y	1000000000000000000000000	10^{24}
zetta	Z	100000000000000000000000	10^{21}
exa	E	10000000000000000000000	10^{18}
peta	P	1000000000000000000000	10^{15}
tera	T	100000000000000000000	10^{12}
giga	G	1000000000	10^9
mega	M	1000000	10^6
kilo	k	1000	10^3
hecto	h	100	10^2
deca	da	10	10^1
(none)	(none)	1	10^0
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	μ	0.000001	10^{-6}
nano	n	0.000000001	10^{-9}
pico	p	0.000000000001	10^{-12}
femto	f	0.000000000000001	10^{-15}
atto	a	0.000000000000000001	10^{-18}
zepto	z	0.00000000000000000001	10^{-21}
yocto	y	0.0000000000000000000001	10^{-24}

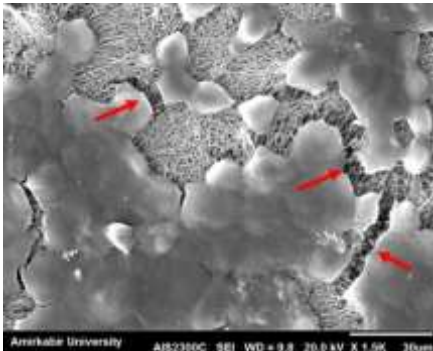
Drying Artifacts

Lactobacillus bacteria:



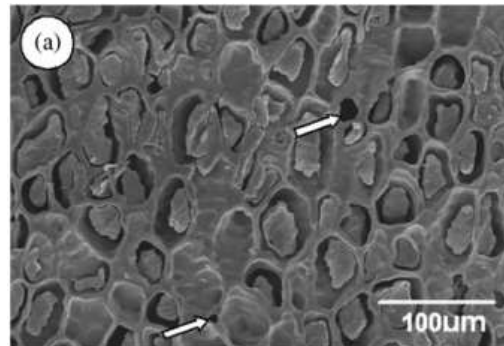
Santivarangkna *et al.* Journal of Applied Microbiology **102** (2007)

Smooth muscle cells on scaffold:



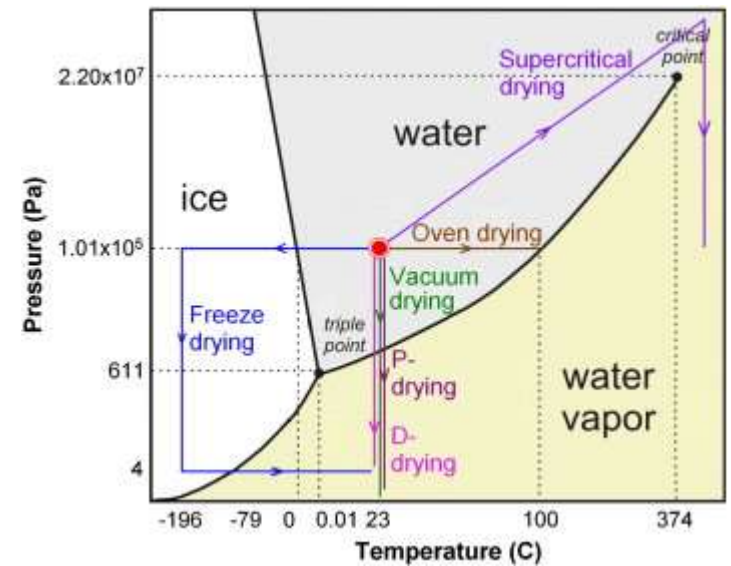
Mojtaba Zarei, Tehran University of Medical Sciences

Coffee seeds :



Borém *et al.* Biosystems Engineering **99** (2008)

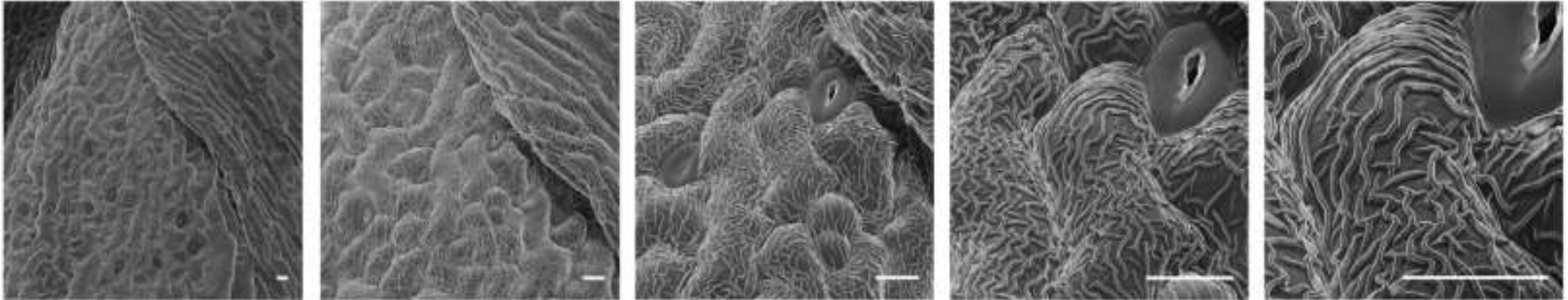
Freeze vs. critical point drying:



<http://freedryinc.com>

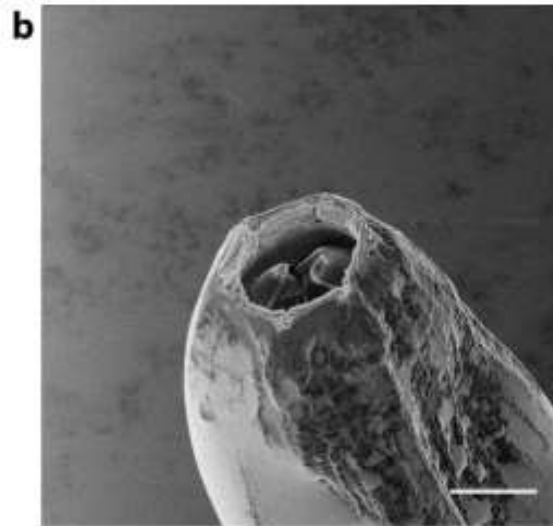
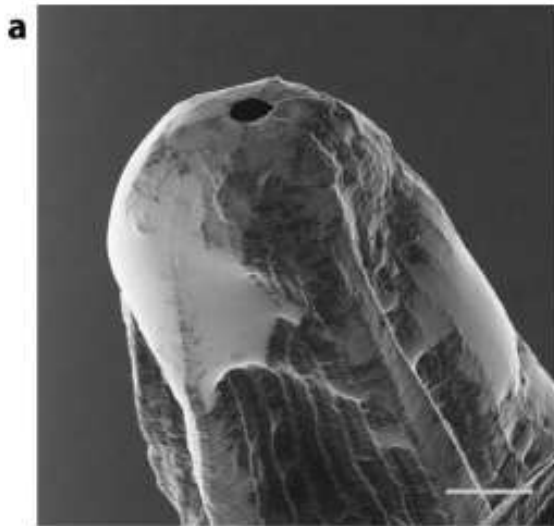
SEM and HIM

Arabidopsis thaliana plant cells:

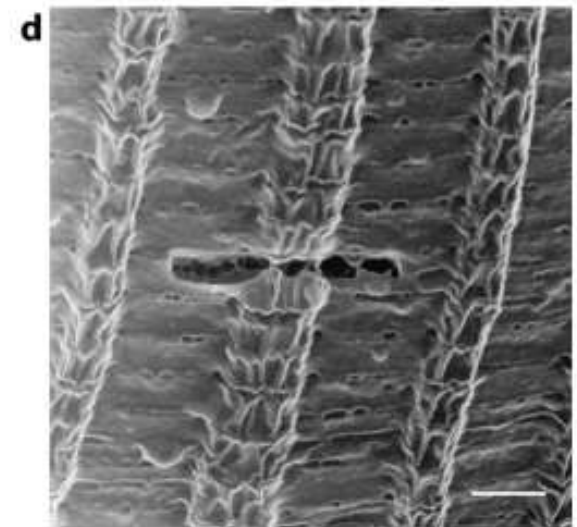


Scale bar 10 μ m

“Neon milling” pf *Pristionchus pacificus* roundworm

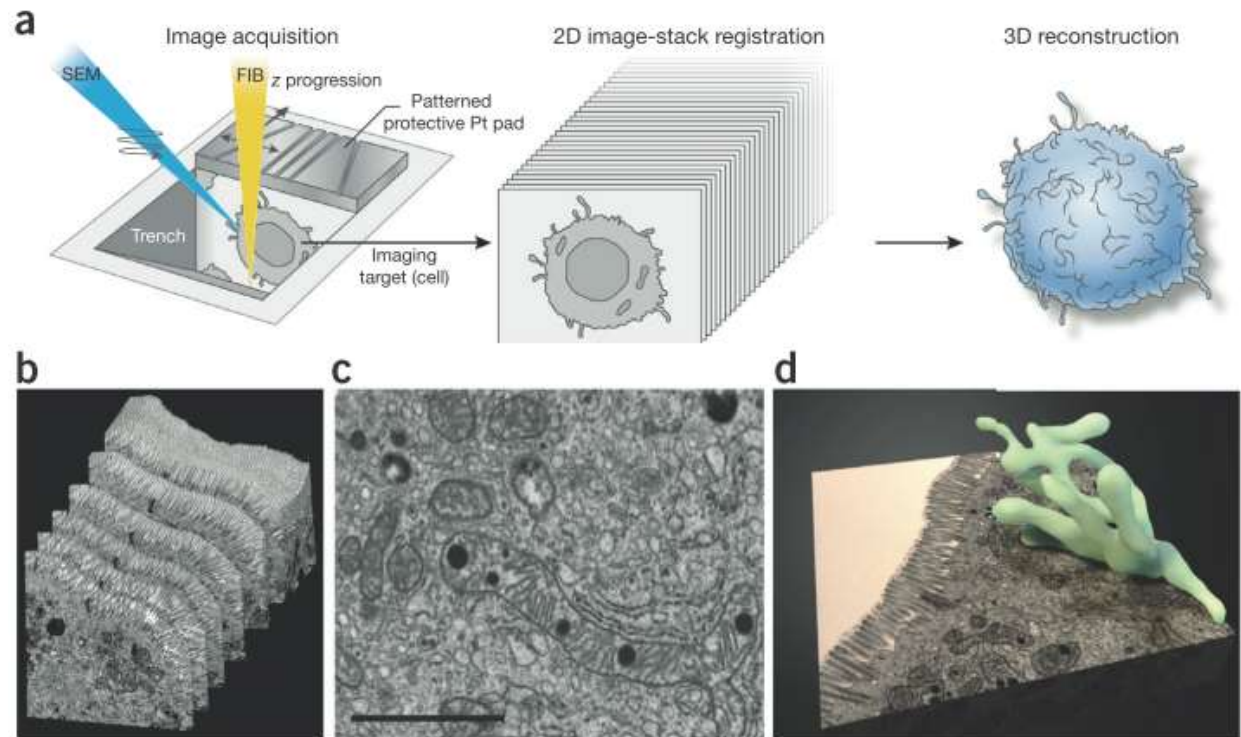


Scale bar 5 μ m

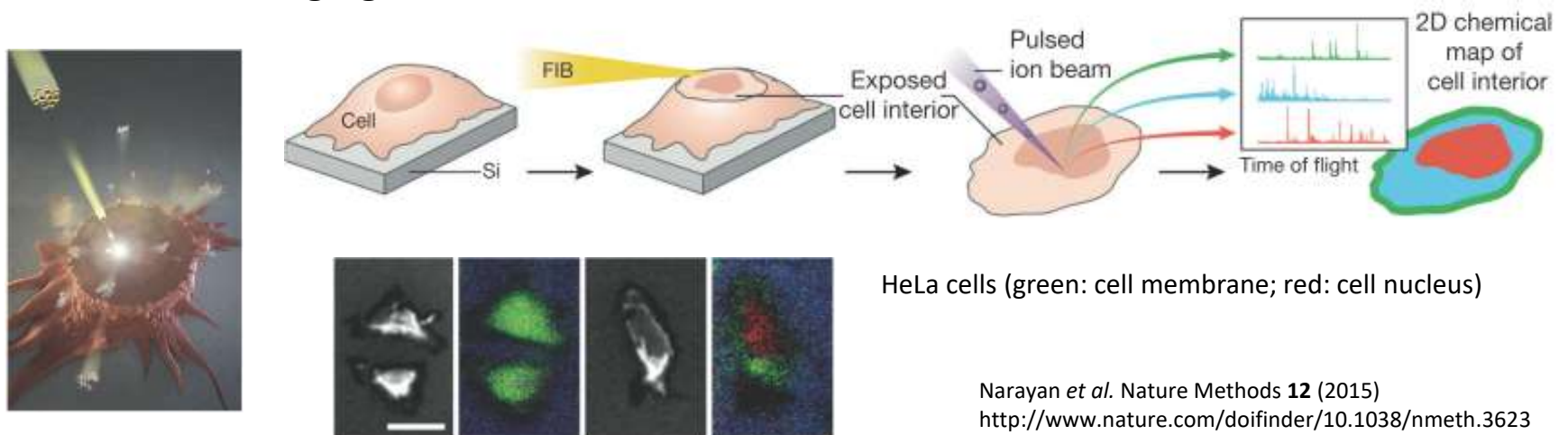


Scale bar 1 μ m

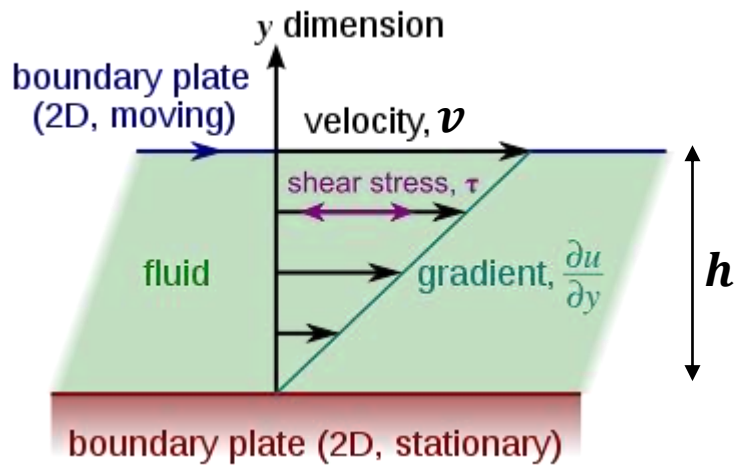
Focused Ion Beam (FIB)



FIB chemical imaging



Viscosity



$$\tau = \frac{F}{A} = \eta \frac{\partial u}{\partial y} = \eta \frac{v}{h}$$

Typical η values of liquids

water $10^{-3} \text{ Pa}\cdot\text{s} = 1 \text{ mPa}\cdot\text{s}$

blood 3 – 4 mPa·s

gases (air) $10^{-5} \text{ Pa}\cdot\text{s} = 10 \text{ }\mu\text{Pa}\cdot\text{s}$

honey 10 Pa·s

ketchup 100 Pa·s

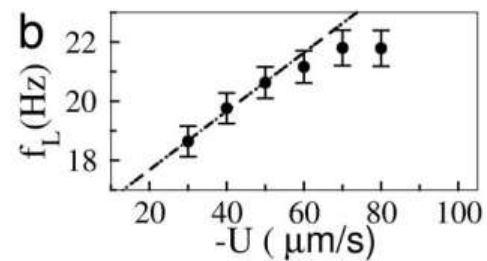
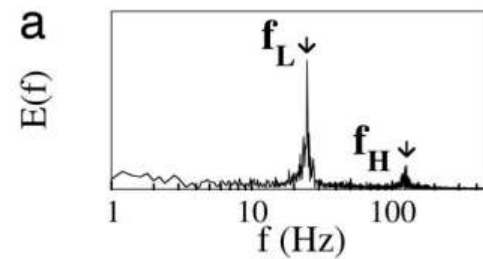
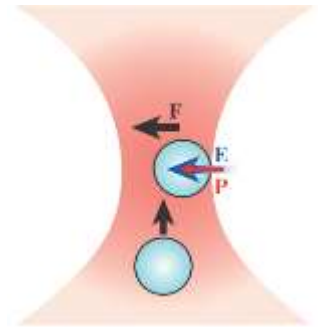
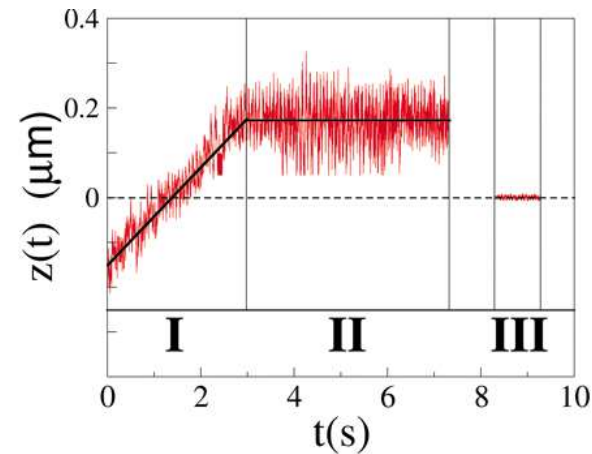
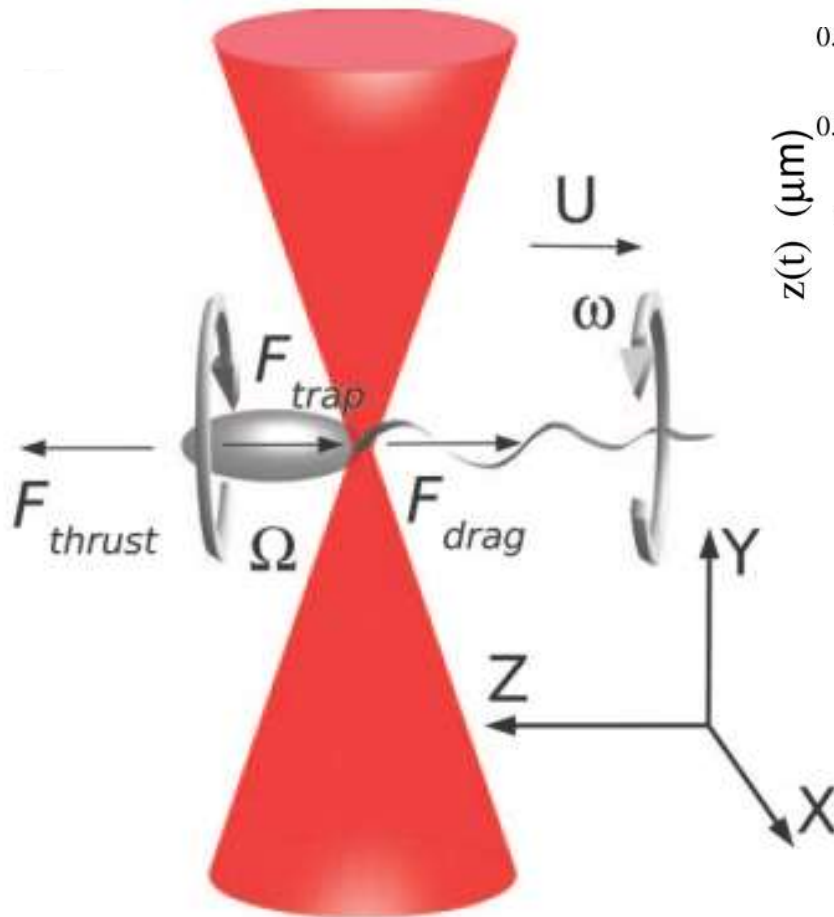
pitch $10^8 \text{ Pa}\cdot\text{s}$

Pitch Drop Experiment @ U Queensland:



~100 month between drops
<http://smp.uq.edu.au/content/pitch-drop-experiment>

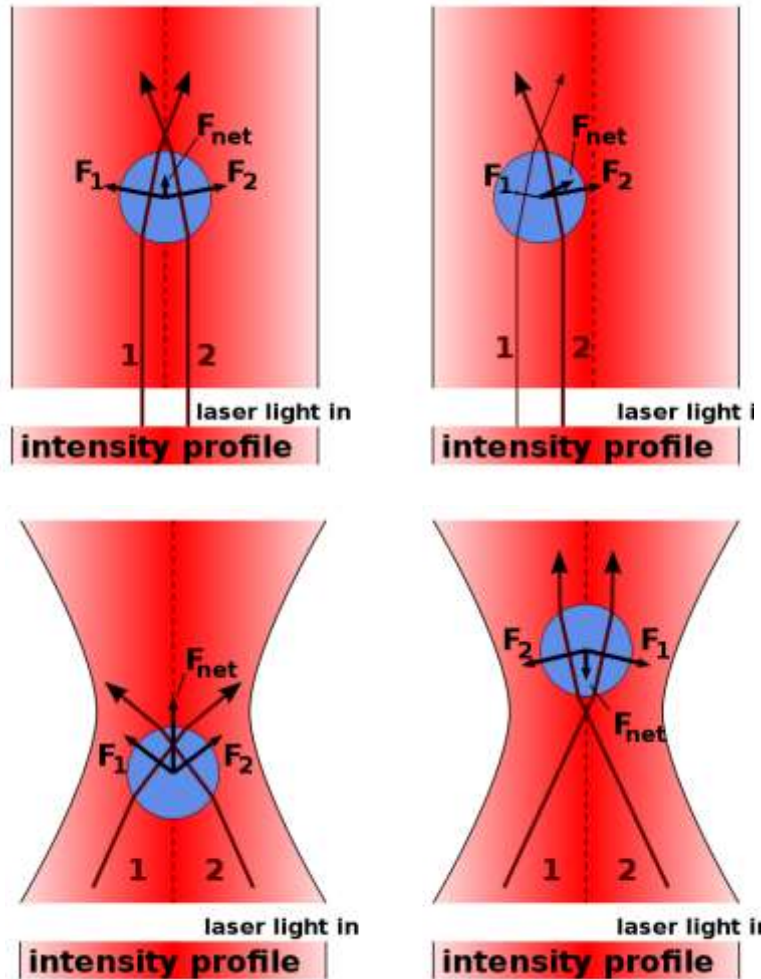
Thrust of a Swimming Bacterium



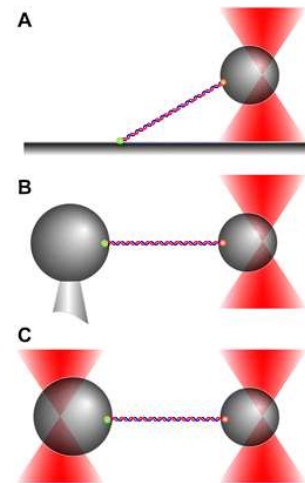
Chattopadhyay *et al.* PNAS 103 (2006)

Optical Tweezers

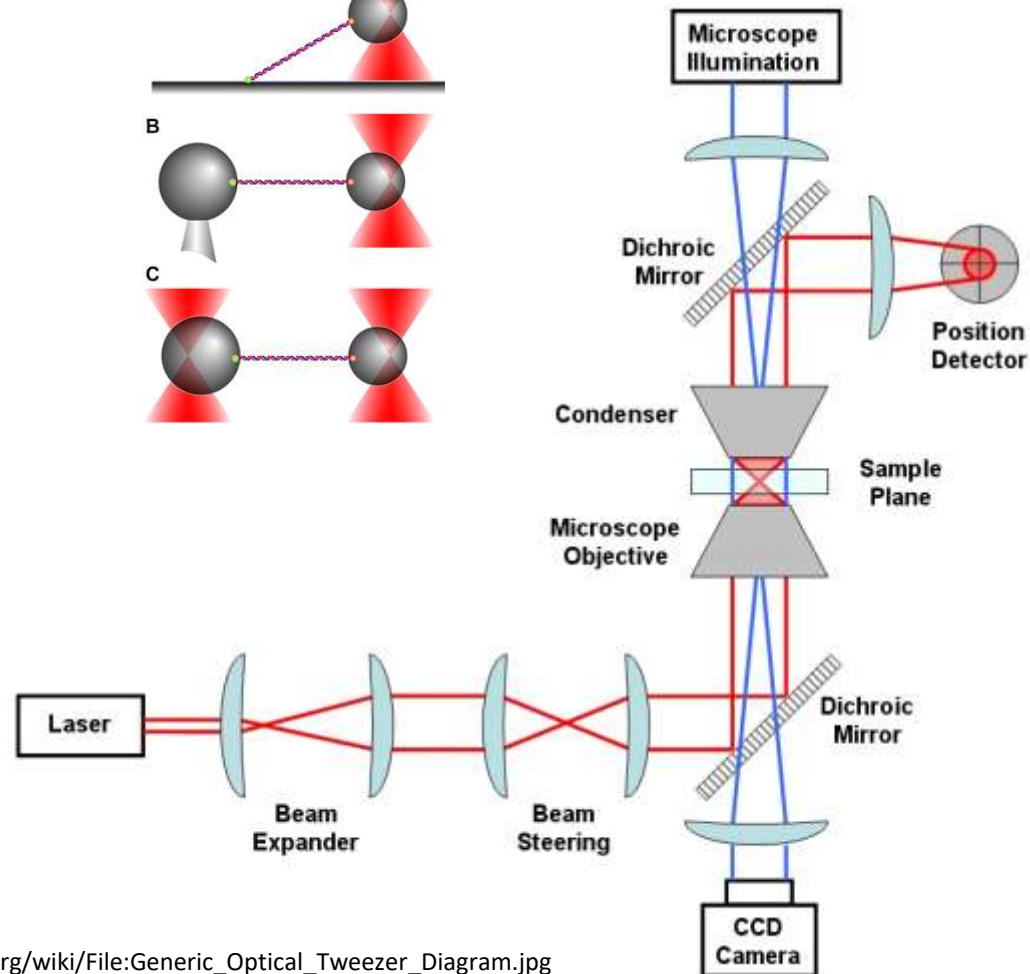
Physical principle



Trap geometries

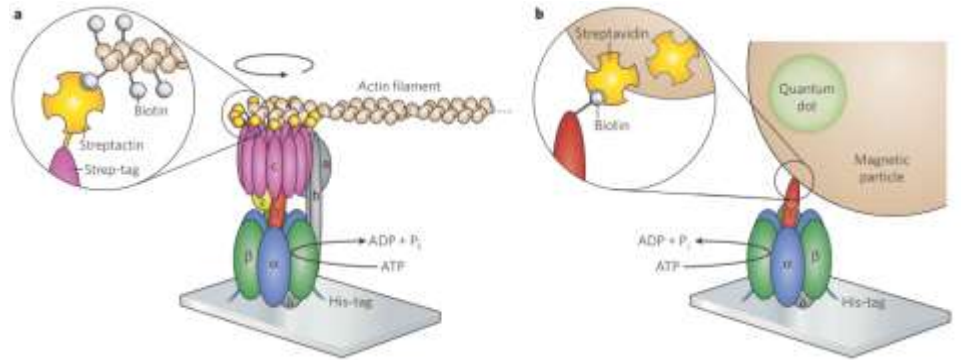
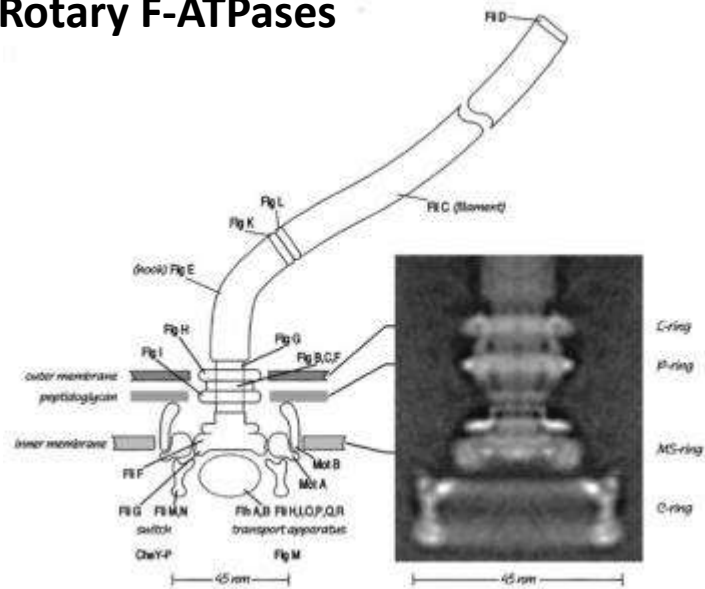


Experimental setup



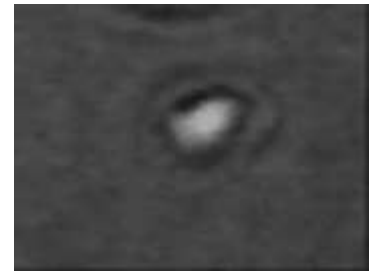
Thrust of a Swimming Bacterium

Rotary F-ATPases

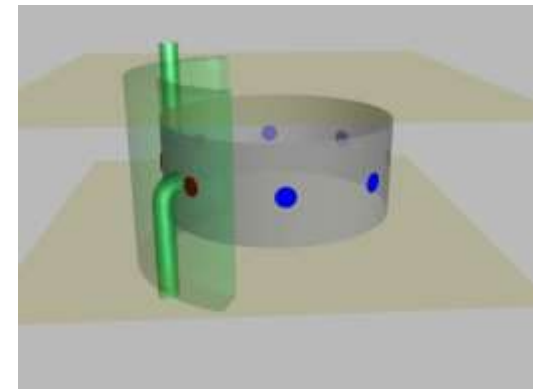
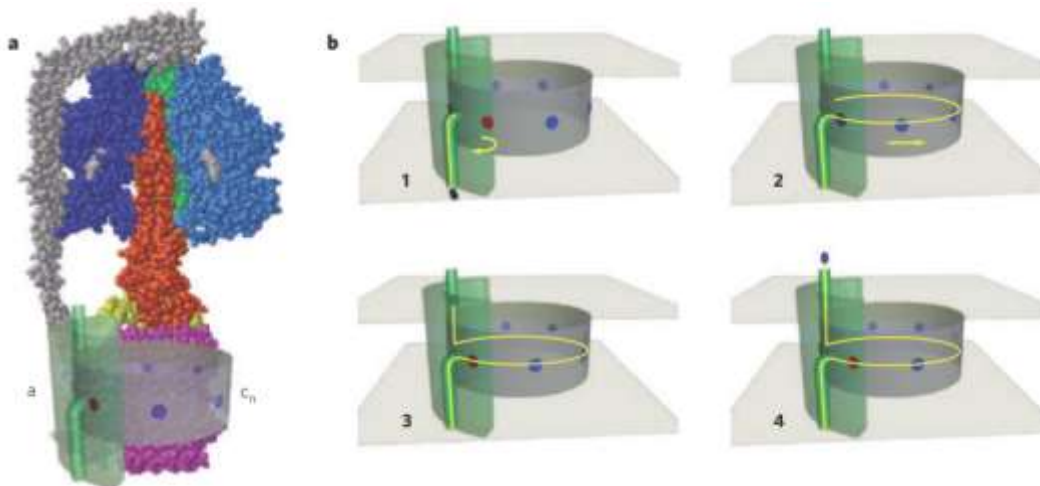


N.C. Darnton, Amherst College. <https://www.amherst.edu>

F₀F₁-ATPase

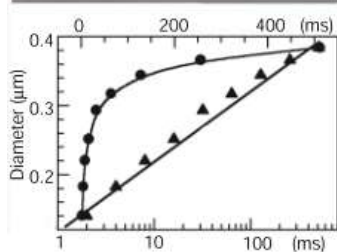
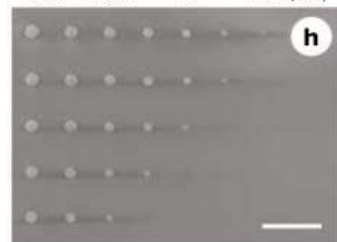
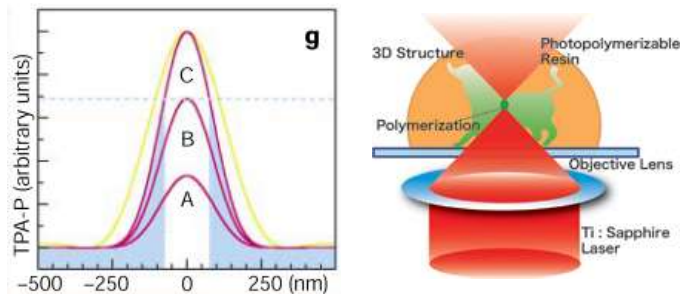


<http://www.youtube.com/watch?v=oFgMTdVRI6I>



Junge *et al.* Nature 459 (2009)

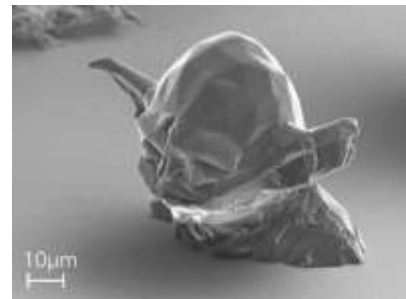
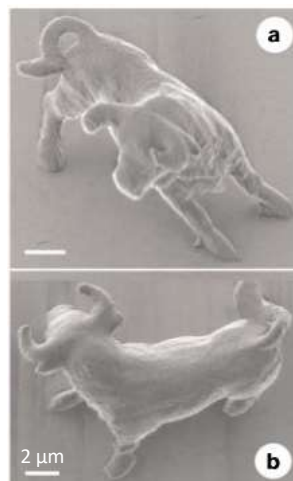
Fabrication of Micromachines by Two-Photon-Absorption-Polymerization



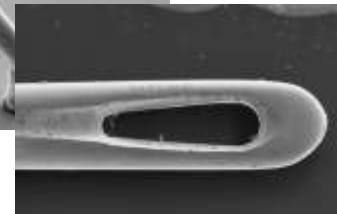
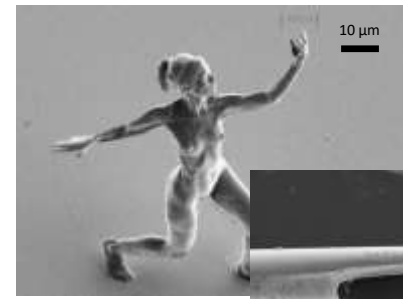
Kawata *et al.* Nature 412 (2001)

DOI: 10.1038/35089130

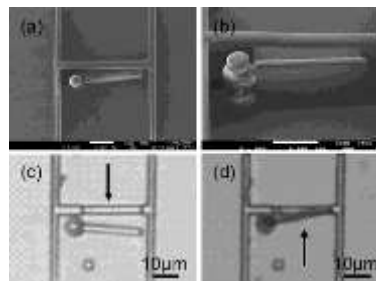
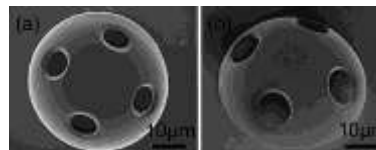
http://lasie.ap.eng.osaka-u.ac.jp/res_2pfab.html



<https://www.isc.fraunhofer.de>



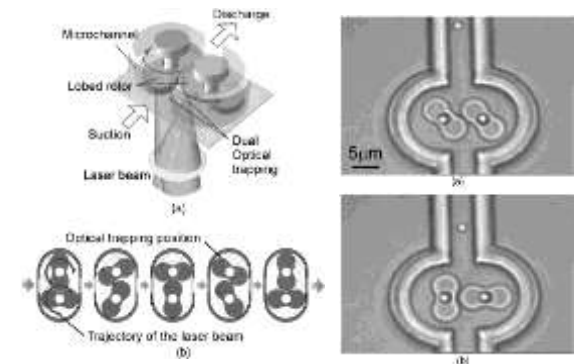
Nanoshells and Valves



Wu *et al.* Lab Chip 9 (2009)

DOI: 10.1039/B902159K

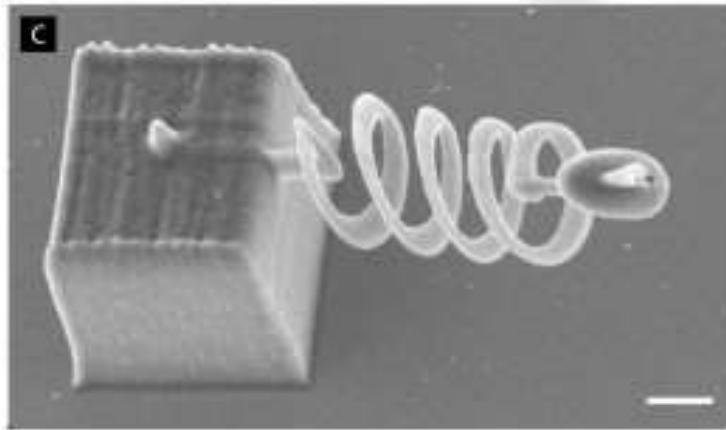
Optically-Driven Nanopump



Maruo & Inoue Appl. Phys. Lett. 89 (2006)

DOI: 10.1063/1.2358820

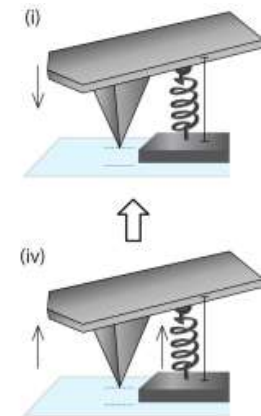
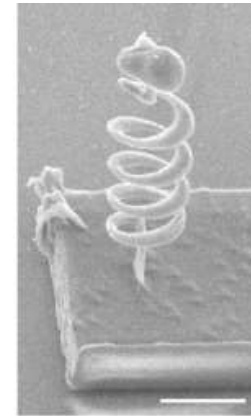
Fabrication of Micromachines by Two-Photon-Absorption-Polymerization



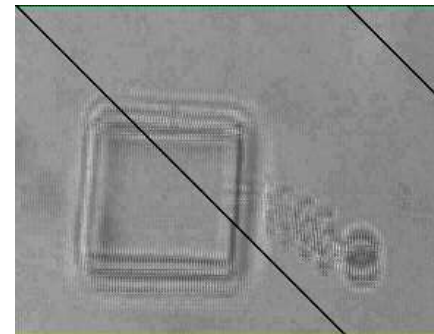
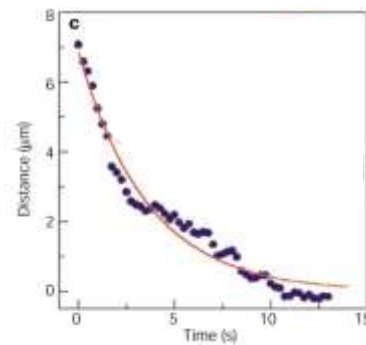
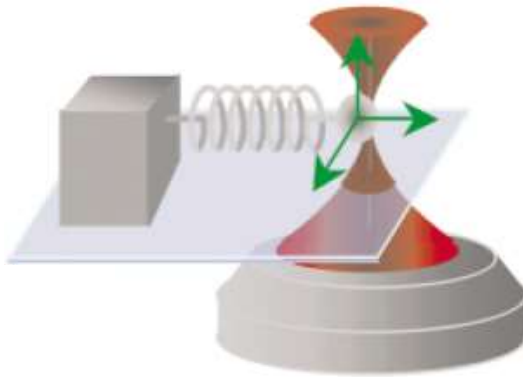
Kawata *et al.* Nature **412** (2001)
DOI: 10.1038/35089130



<https://www.schulminator.com>

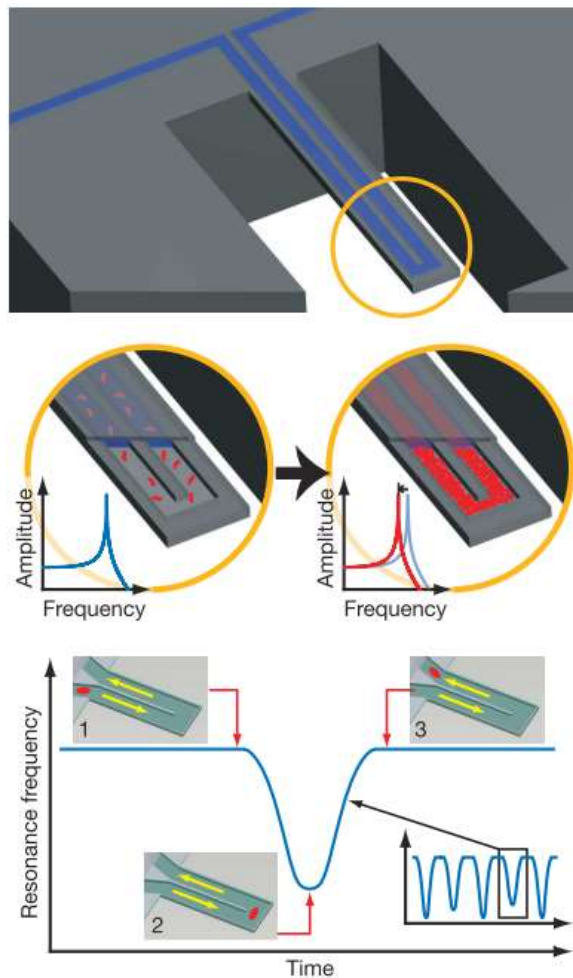


Ushiba *et al.* Sci. Rep. **5**:17152 (2015)
DOI: 10.1038/srep17152

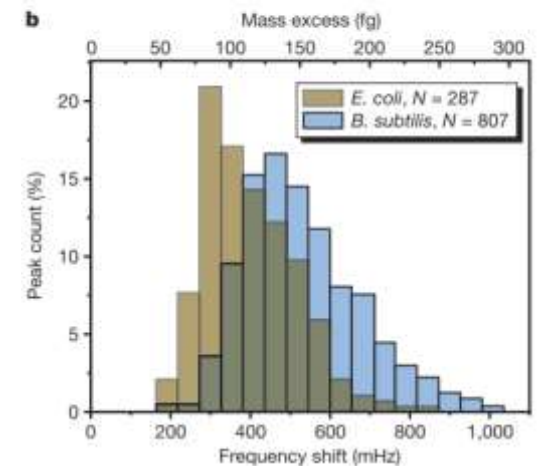
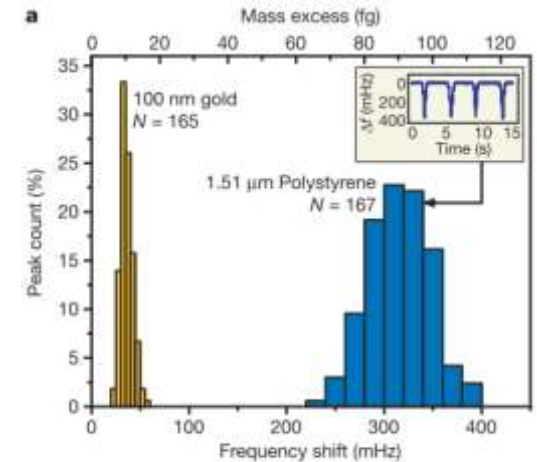
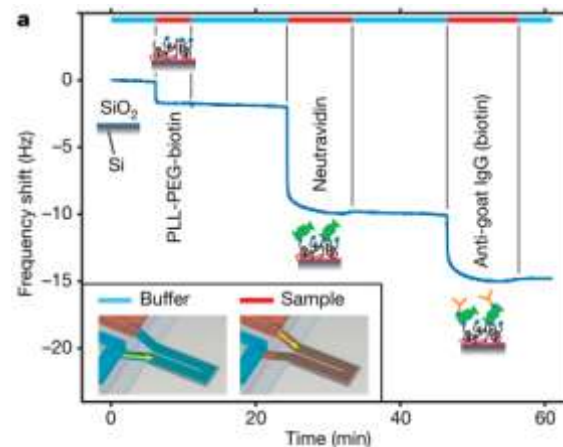
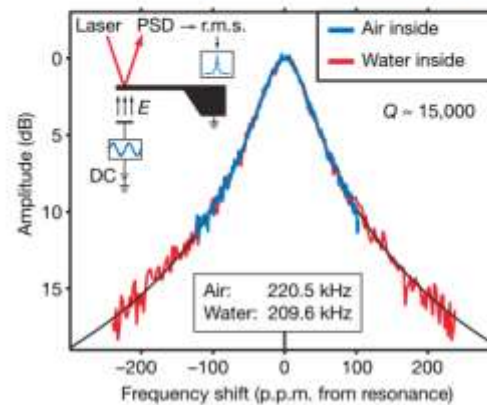
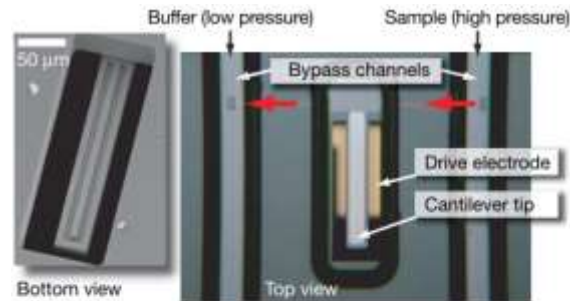


Ushiba *et al.* Sci. Rep. **5**:17152 (2015)
DOI: 10.1038/srep17152

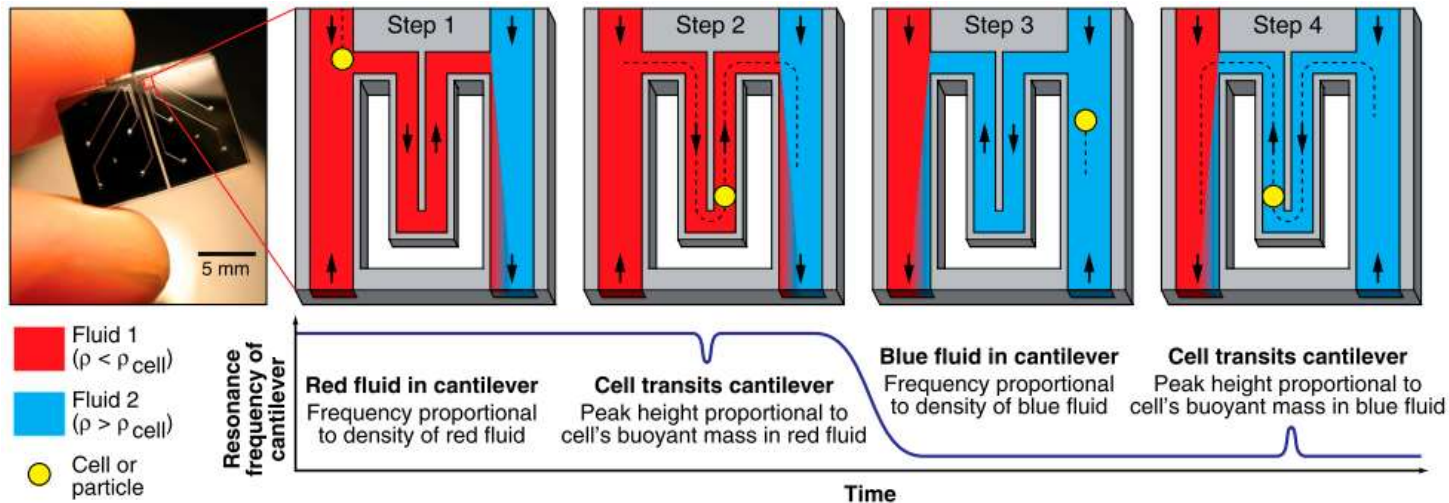
Weighting using Nanomechanical Resonators



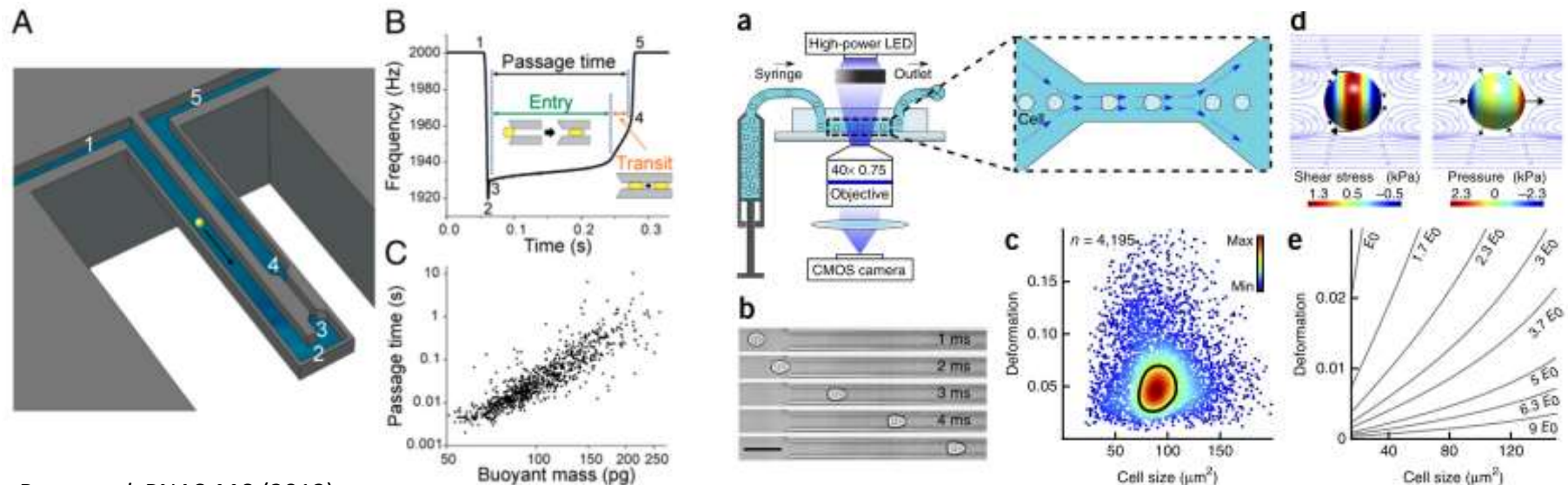
Burg *et al.* Nature 446 (2007)



Nanomechanical Resonators & Real-Time Deformability Cytometry



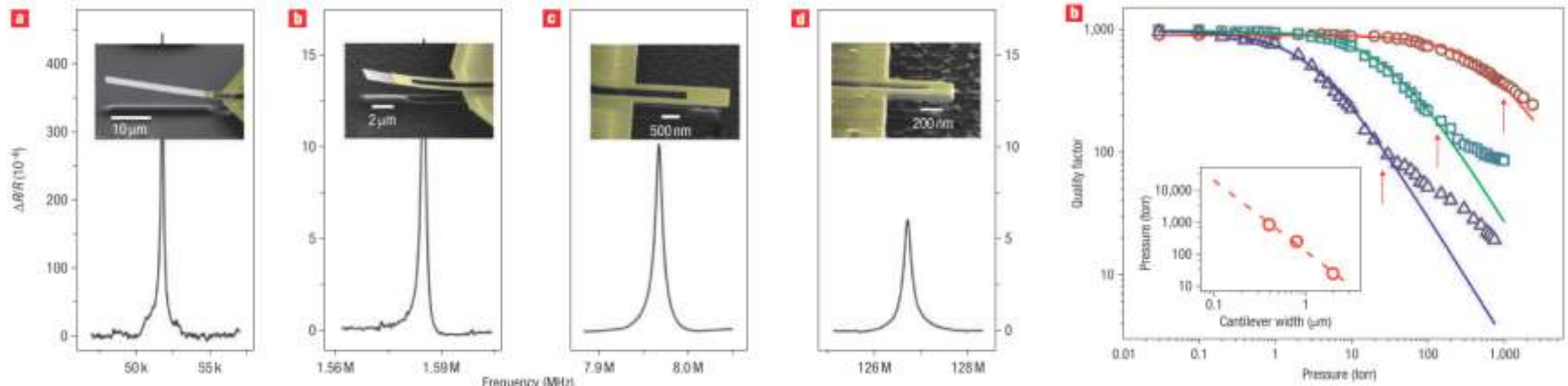
Grover *et al.* PNAS **108** (2011)



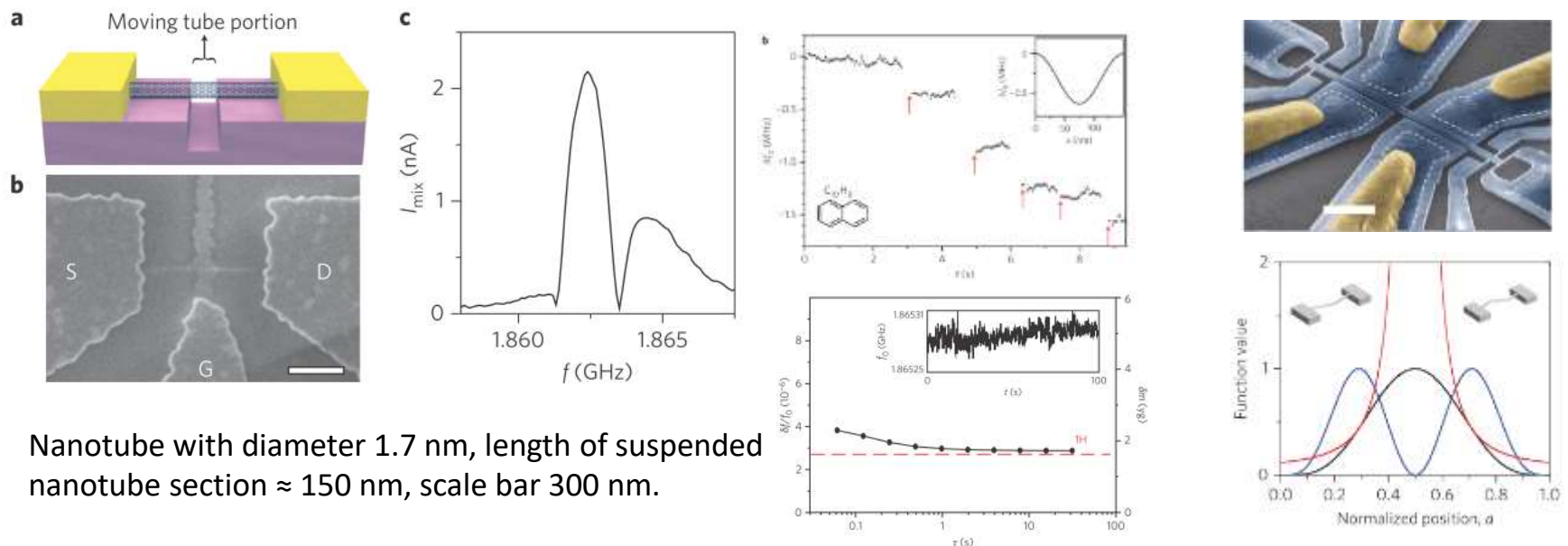
Byun *et al.* PNAS **110** (2013)

Otto *et al.* Nat. Meth. **12** (2015)

Weighting using Nanomechanical Resonators



Li *et al.* Nat. Nanotechnol. **2** (2007)



Nanotube with diameter 1.7 nm, length of suspended nanotube section $\approx$ 150 nm, scale bar 300 nm.

Chaste *et al.* Nat. Nanotechnol. **7** (2012)

Hanay *et al.* Nat. Nanotechnol. **7** (2012)

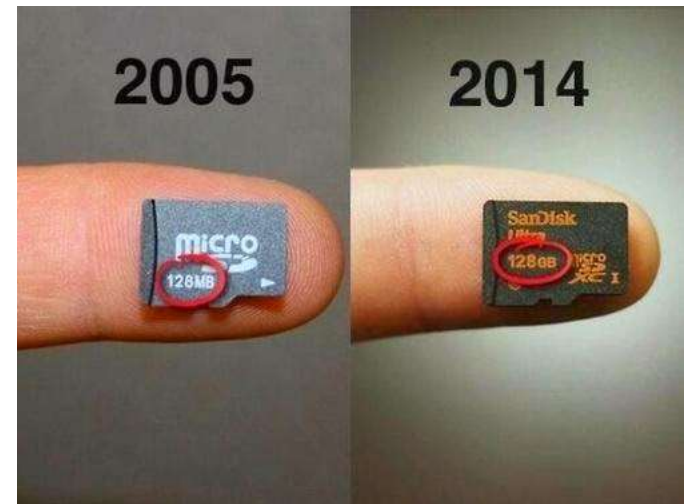
Scaling effects in electronics



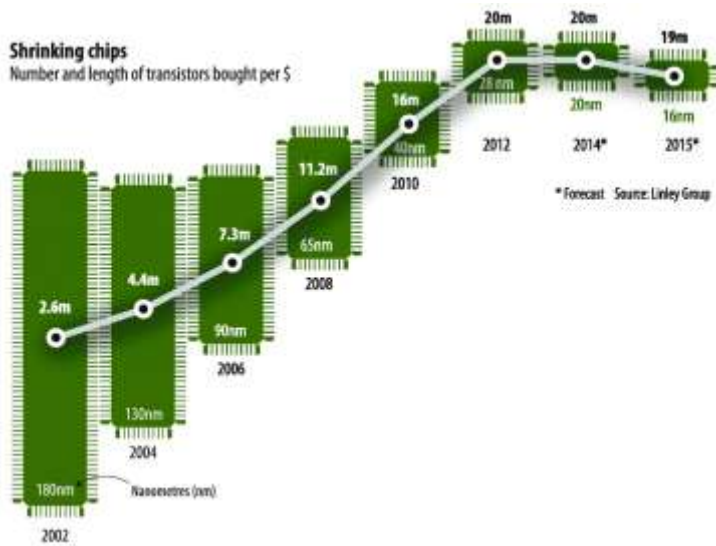
<http://www.123rf.com>



<http://wonderfulengineering.com>



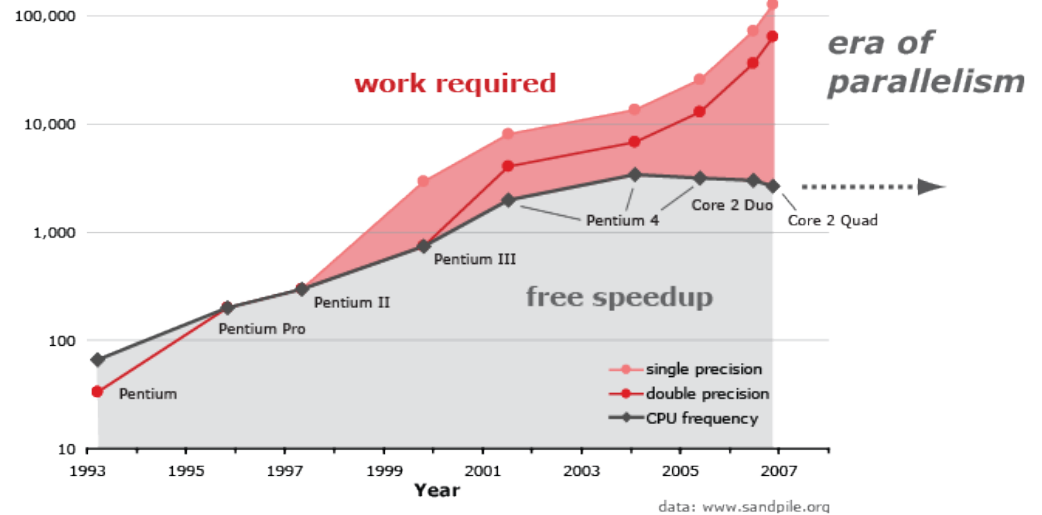
D. Brin. <https://plus.google.com>



<http://cdn.static-economist.com>

Evolution of Intel Platforms

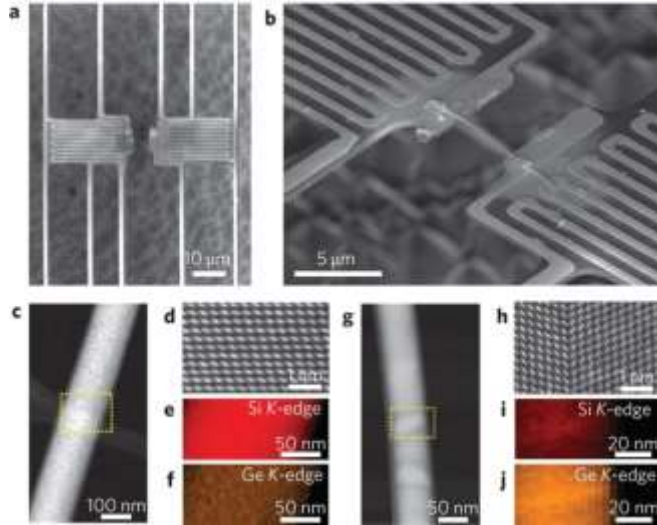
Floating point peak performance [Mflop/s]
CPU frequency [MHz]



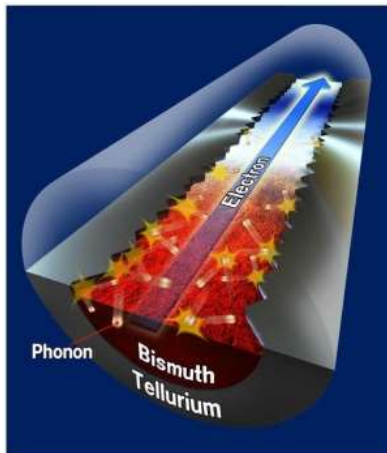
<http://www.spiral.net/problem.html>

Micro- and Nanoelectronics

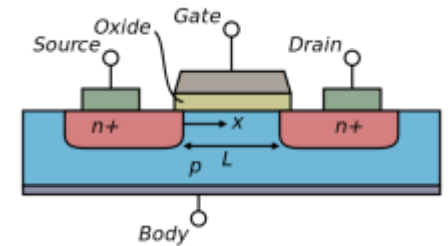
Thermal conduction in SiGe nanowire



Hsiao *et al.* Nature Nanotechnology **8** (2013)



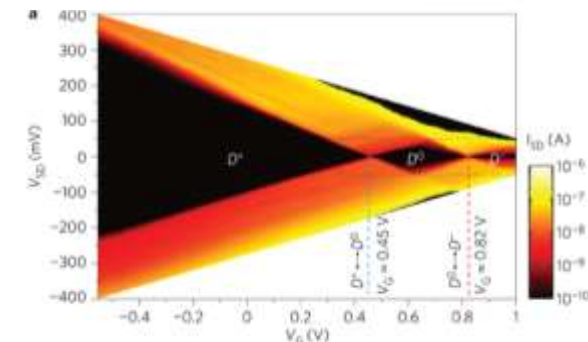
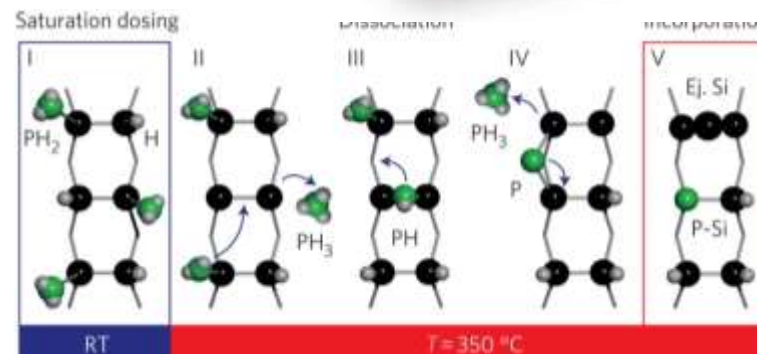
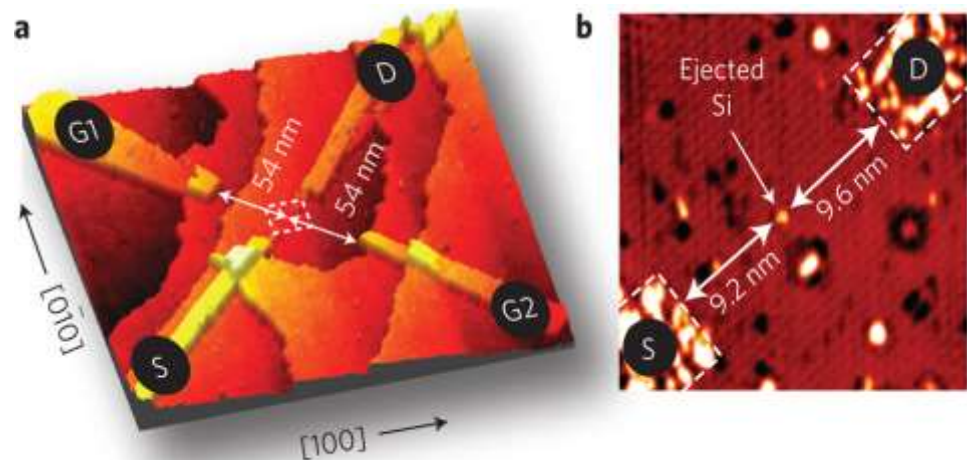
"Thermoelectrics: Roughing it"
NPG Asia Mater 2011



https://en.wikipedia.org/wiki/Field-effect_transistor

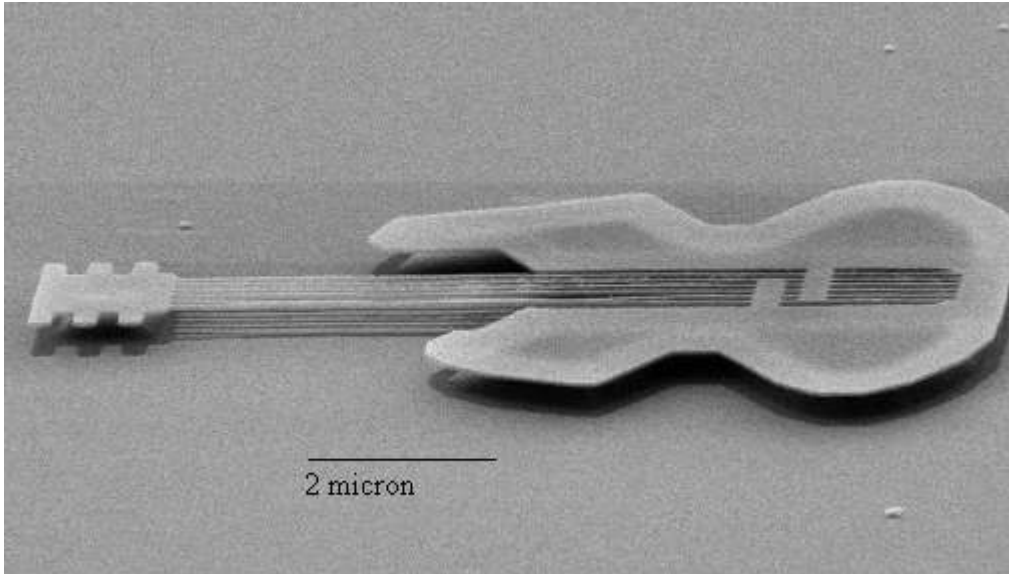
Single-atom transistor

STM of Si surface with source, drain, and gates



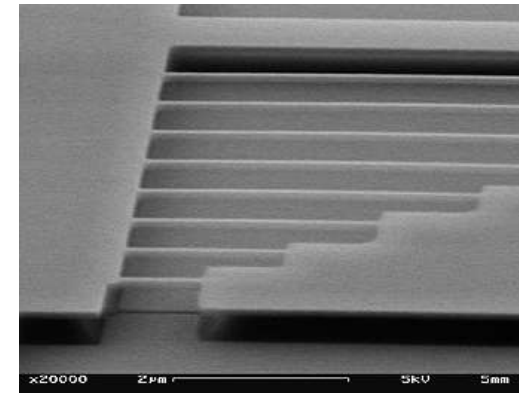
Fuechsle *et al.* Nature Nanotechnology **7** (2012)

Worlds smallest guitar



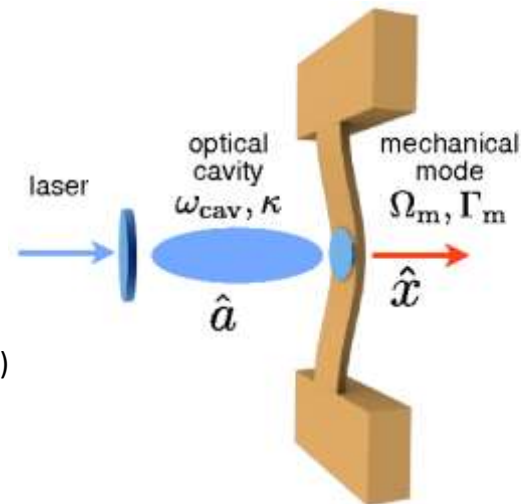
D. Carr and H. Craighead, Cornell University. <http://www.news.cornell.edu>

Nano-harp

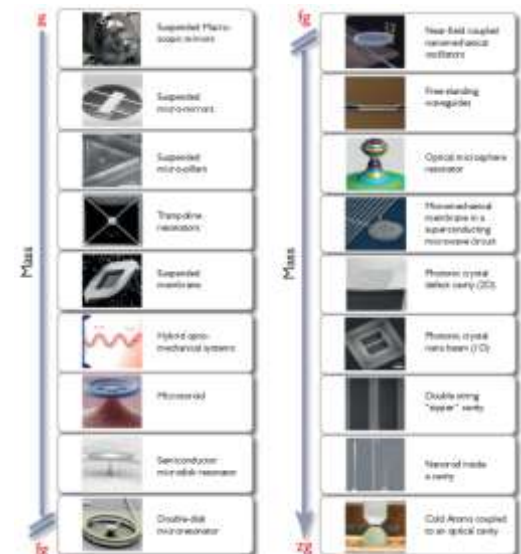


mechanical frequencies
15 MHz up to 380 MHz

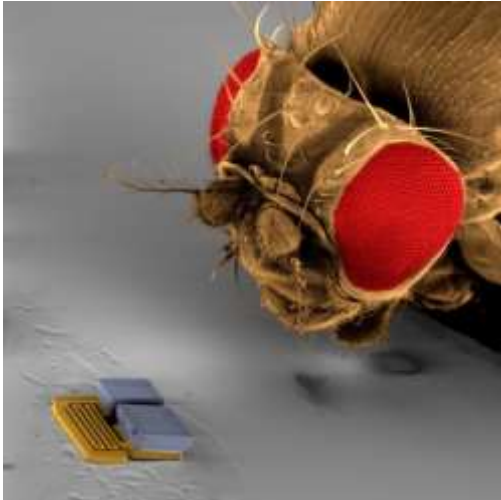
Applications: Opto-mechanical coupling



Aspelmeyer *et al.* Rev. Mod. Phys. **86** (2014)
DOI: 10.1103/RevModPhys.86.1391



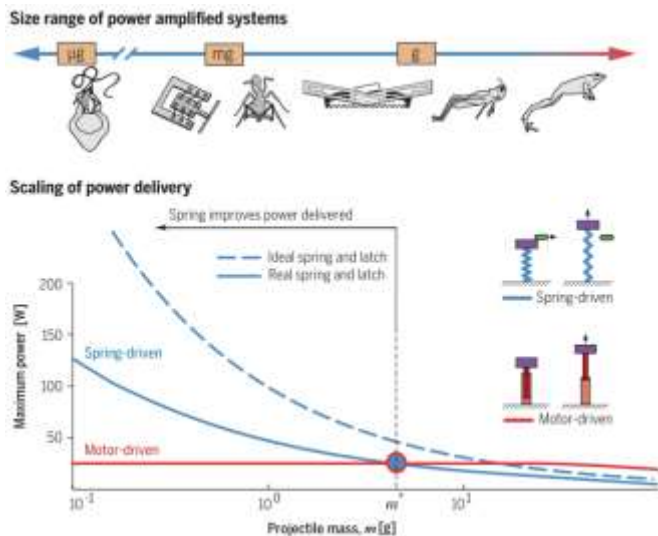
Nanosoccer RoboCup 2009 Winner



ETH Zurich, <http://patapsco.nist.gov>

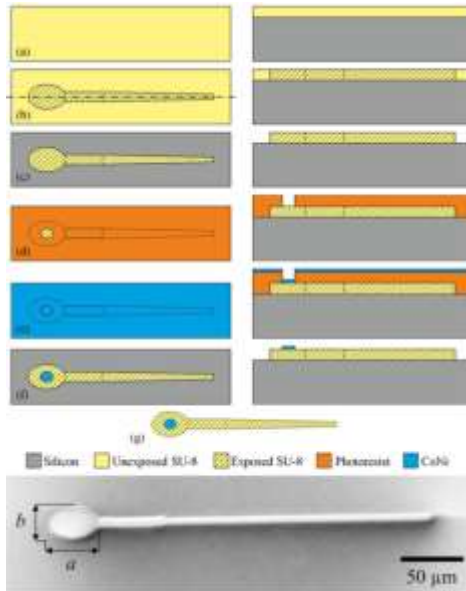


2010 NIST Mobile Microrobotics Challenge
<http://www.youtube.com/watch?v=B3u13jZtgmk>

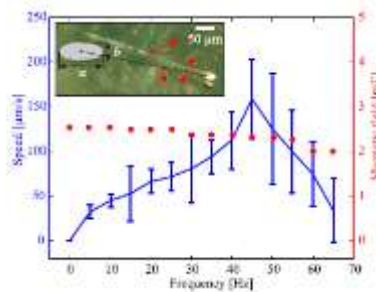


Ilton *et al.* Science **360** (2018)
DOI: 10.1126/science.aao1082

Nano Robots?



MagnetoSperm



A. Zettl, University of California. C. <http://www.descoopera.org>

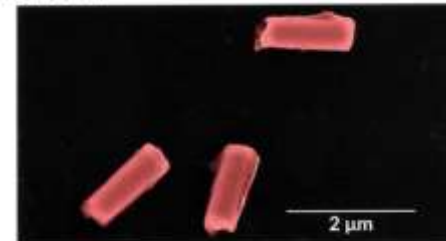
Nanorobots clean blood

Researchers at the US-based University of California San Diego have developed ultrasound-powered robots that swim through blood to remove harmful bacteria and toxins.

Stunning SEM imagery provides insight to these proof-of-concept nanorobots that could offer a safe and efficient way to detoxify and decontaminate biological fluids.

Professor Joseph Wang from NanoEngineering at UC San Diego Jacobs School of Engineering and colleagues fabricated the nanorobots by coating gold nanowires with a hybrid of platelet and red blood cell membranes.

This hybrid cell membrane coating allows the nanodevices to perform the tasks of platelets and red blood cells. Platelets bind bacteria while red



blood cells absorb and neutralise the toxins produced by these organisms. Crucially, the gold body of the nanorobots responds to ultrasound, which gives the devices the ability to 'swim' up to 35 micrometers per second in blood.

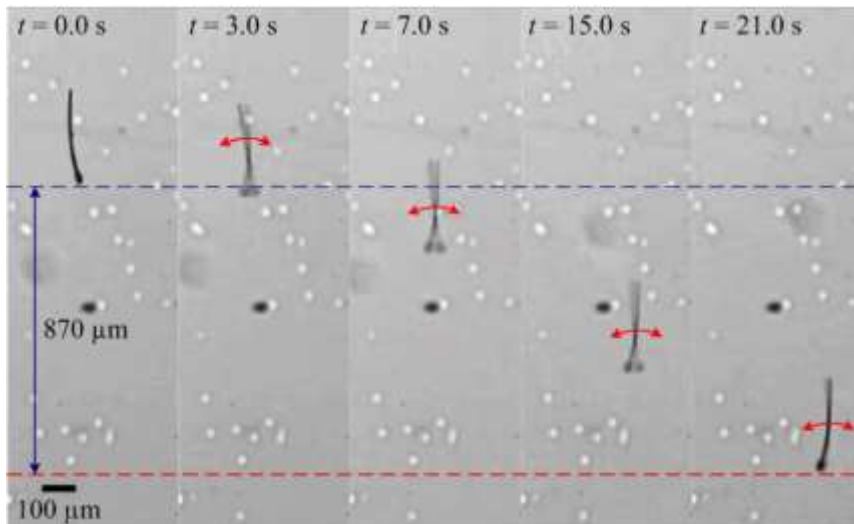
Research is published in *Science Robotics*.

Coloured SEM image of nanorobots coated in hybrid platelet and red blood cell membranes. Credit: NanoEngineering at Jacobs School of Engineering, UC San Diego.

Li *et al.* *Science Robotics* 2 (2017)
DOI: 10.1126/scirobotics.aam6431



Bath University. <http://people.bath.ac.uk>



Kahlil *et al.* *Applied Physics Letters* 104 (2014)
<http://dx.doi.org/10.1063/1.4880035>