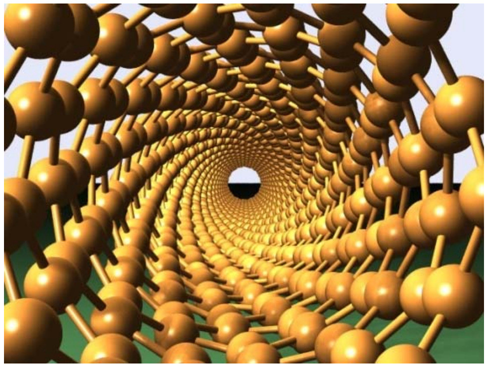
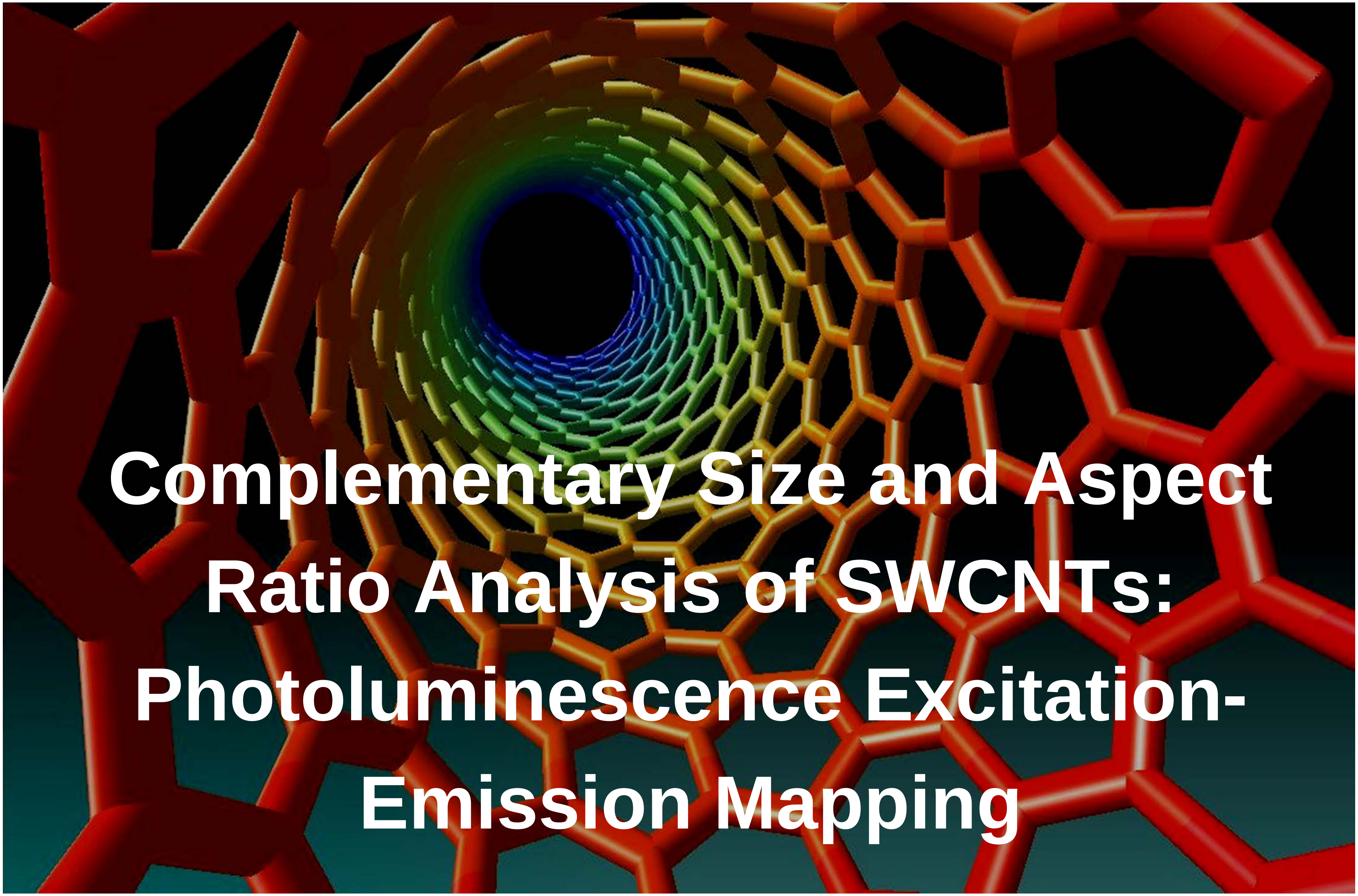
Carbon Nanotube Analysis



Particle Analysis: Jeffrey Bodycomb, Ph.D.

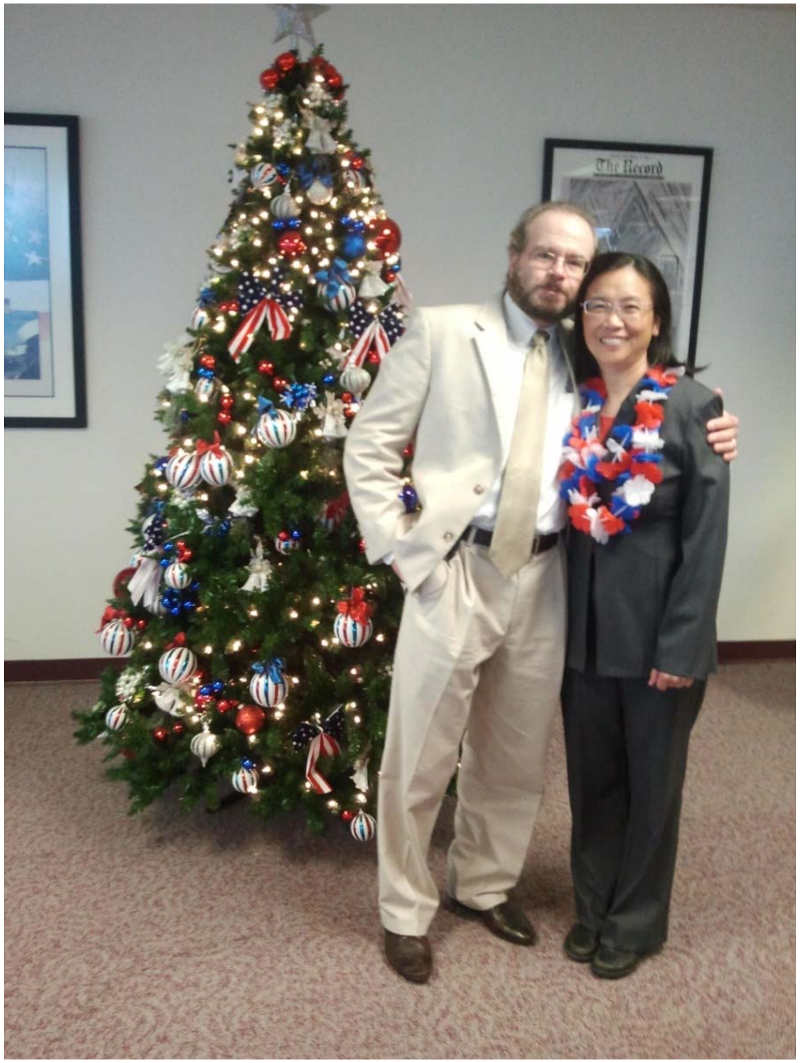
Fluorescence: Adam Gilmore, Ph.D.

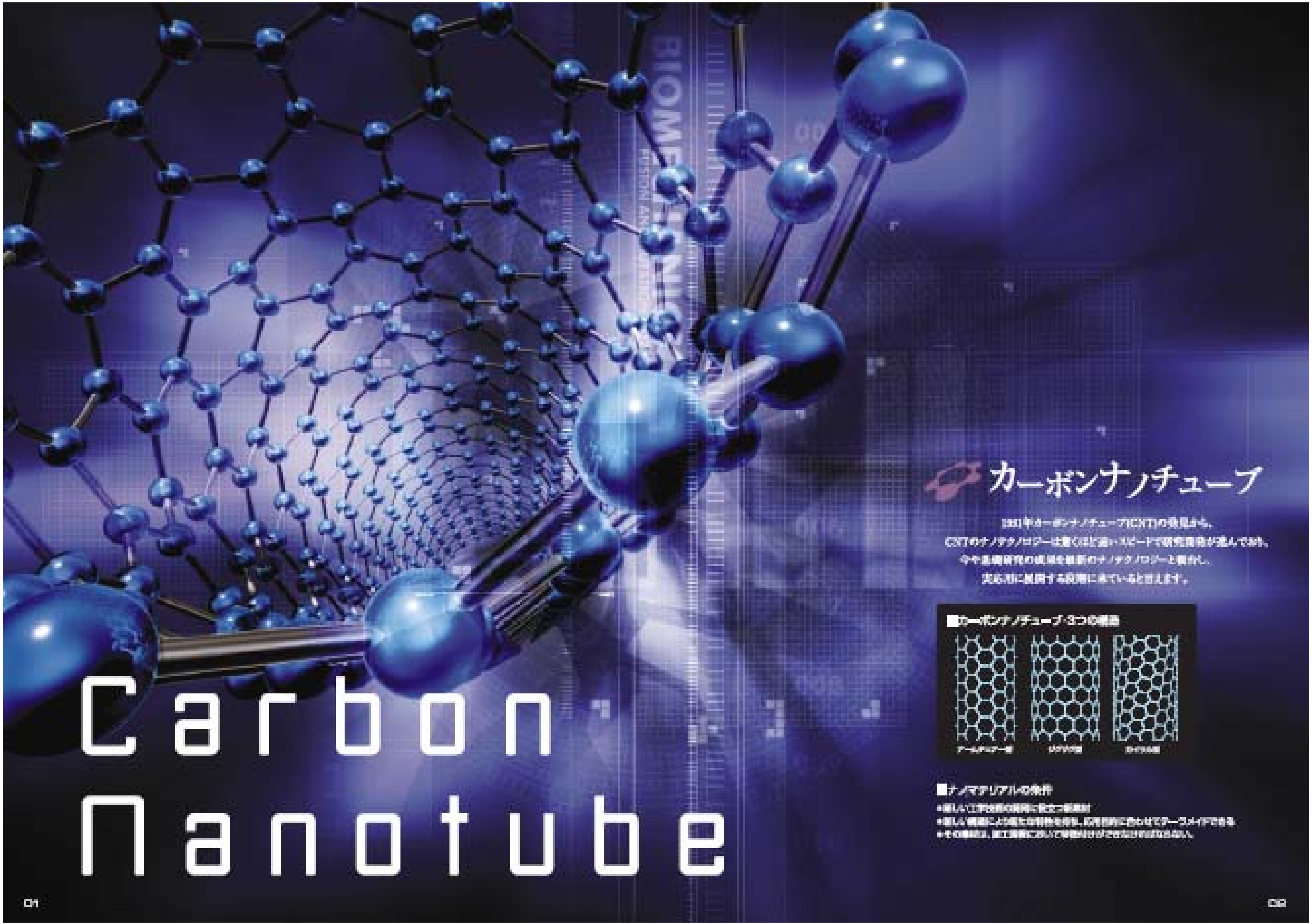


Complementary Size and Aspect Ratio Analysis of SWCNTs: Photoluminescence Excitation-Emission Mapping

Adam M. Gilmore, Fluorescence Product Manager

Me and My Wife

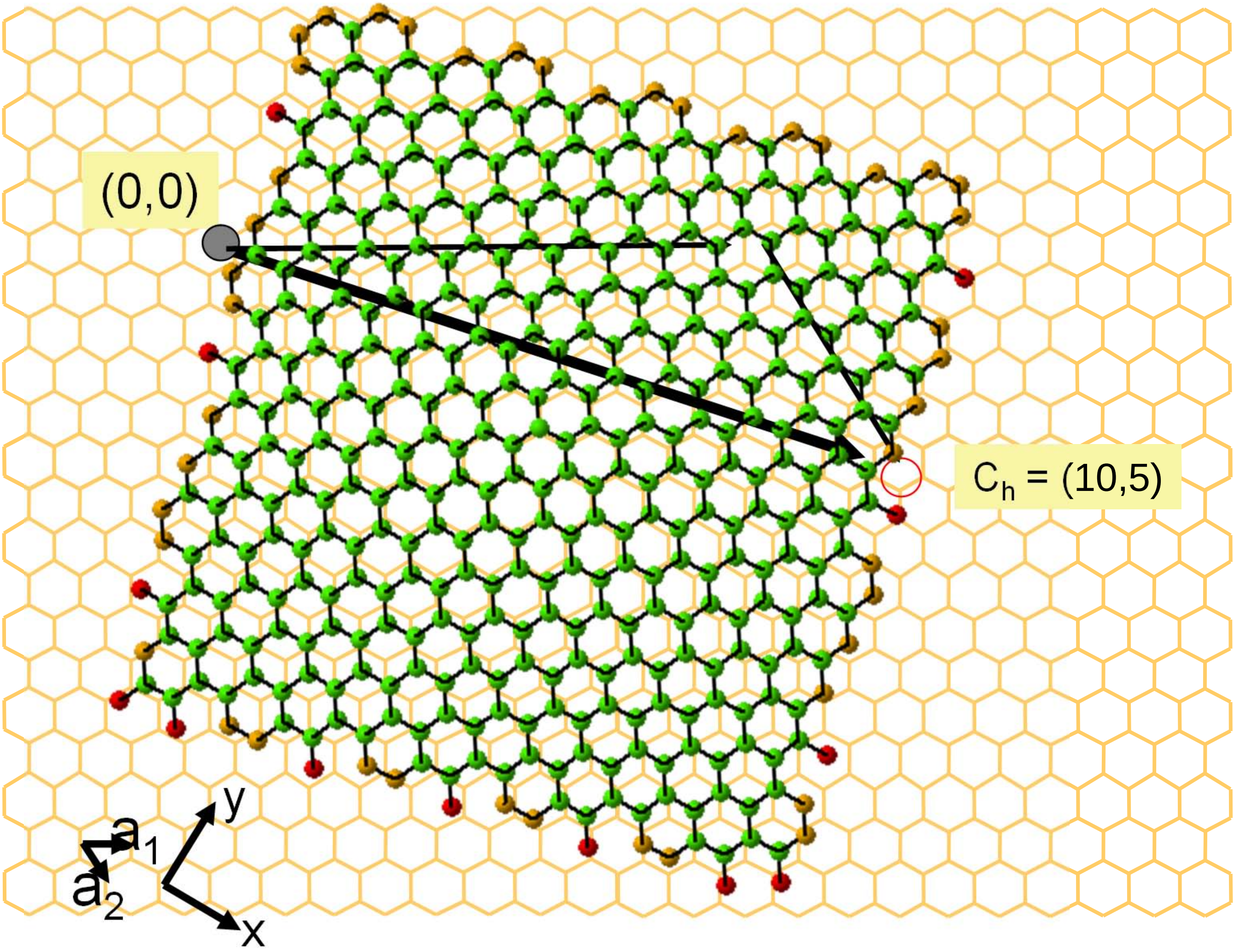




Carbon Nanotube

カーボンナノチューブ

SWCNTs are Graphene Roll-ups



Why are SWCNTs Significant?

2 Major SWCNT families:

- 2/3 =Semiconducting:
  - photo- and electro-luminescence (PL/EL),
  - field-effect transistors (FETs)
  - Precise size and bandgap selection for device engineering
  - Bright, non-blinking PL/EL for chemical and biological sensing
    - NIR emission- fits ideally in biological window
  - Faciliate dense transistor networks
- 1/3 =Metallic:
  - high electric and thermal conductivity, efficient connectors
  - Faciliate transparent conductive films (TCFs)
  - Enhanced efficiency photovoltaic materials

SWCNTs Hot News Flashes

- Effects of Gamma radiation characterized, show promise for medical apps and sterilization
- CNTs can divert heat from current flow in devices
- CNTs enhance photoacoustic imaging of tumours
- SWCNTs may replace ITO in solar cells
- Strain paint-stress changes shape and absorbance-emission spectra-aircraft etc..
- Sub-10 nm SWCNT transistors more efficient than predicted by models

SWCNTs: More Big News in 2012

- Discovery of how sonication shortens and damages SWCNTs
- Not all tubes are cylindrical they can be flattened, like graphene, as long as their diameter is wide enough (> 2 nm)
- Chiral selection possible by growth on stainless steel wires
- Selective dispersion methods improved for chiral selection.

Photoluminescence: PL

- *Def:* Subsequent emission of light from a material caused by light it had previously absorbed.
- Semiconductor PL: Light emission from around the semiconductor material’s bandgap energy level excited by absorption of light energy above the material’s bandgap energy level.

Quantum Confinement Effect

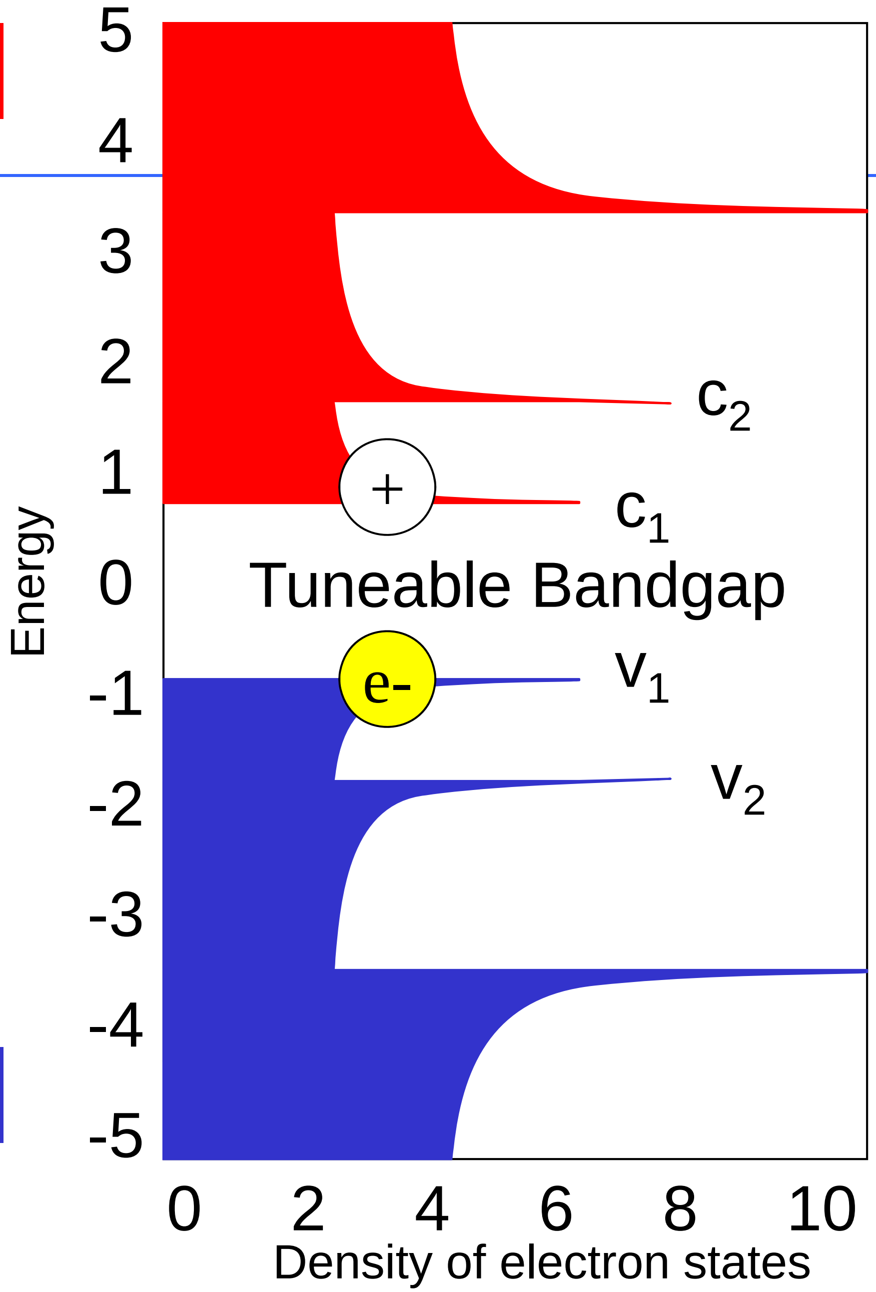
- The major principle defining the relationship between a nanoparticles' physical diameter and it's bandgap energy

- The 'Bohr-Exciton Radius' for a bulk semiconductor material can be defined is the physical distance (in nm) between the electron and it's hole across the bandgap.

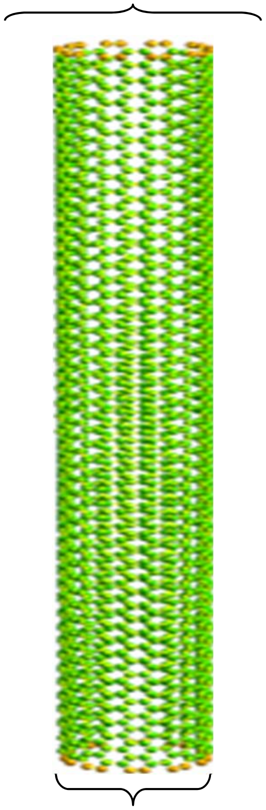
- When the diameter of a nanoparticle of a material is smaller than it's 'Bohr-Exciton Radius' the nanoparticle's bandgap is inversely related to the diameter of the nanoparticle due to 'quantum confinement'.

Conduction

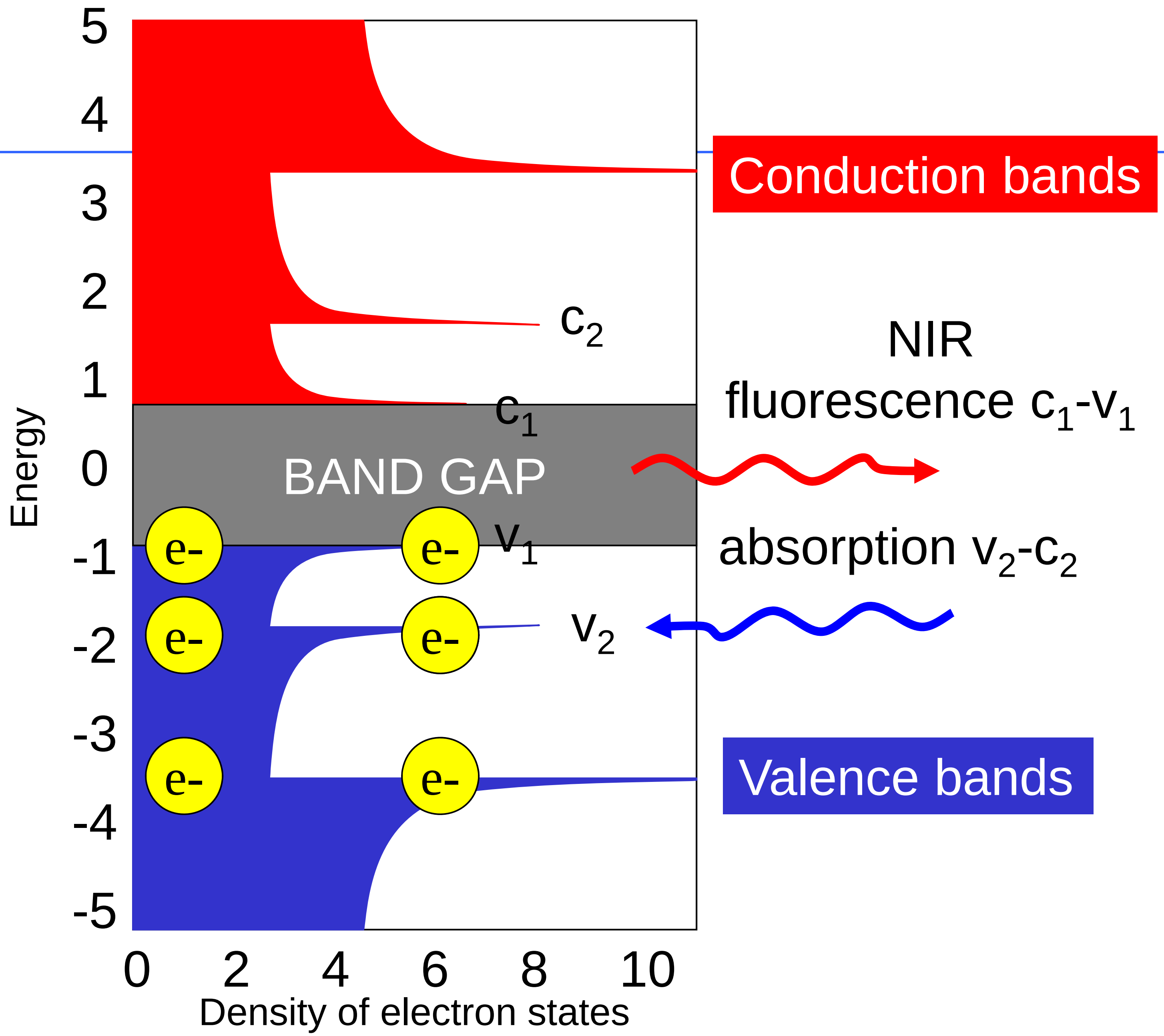
Valence



Exciton Bohr Radius



d_t Radius



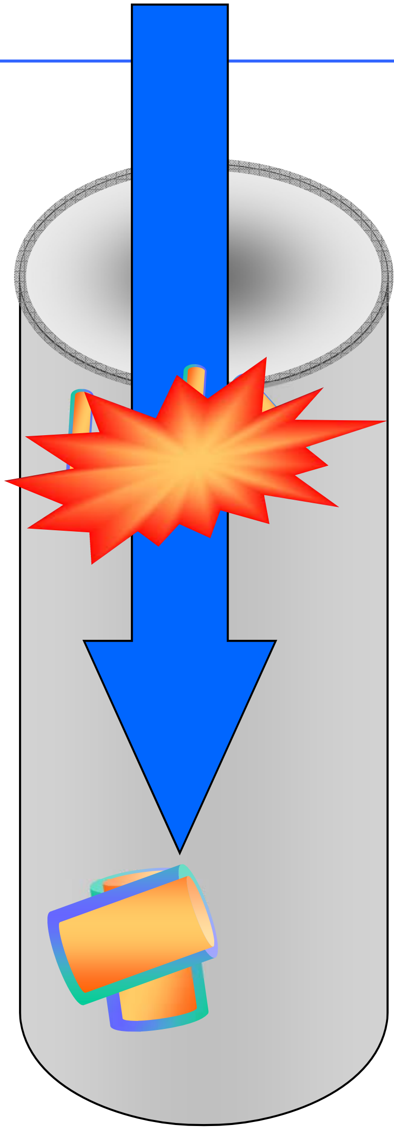
Conduction bands

NIR fluorescence c_1-v_1

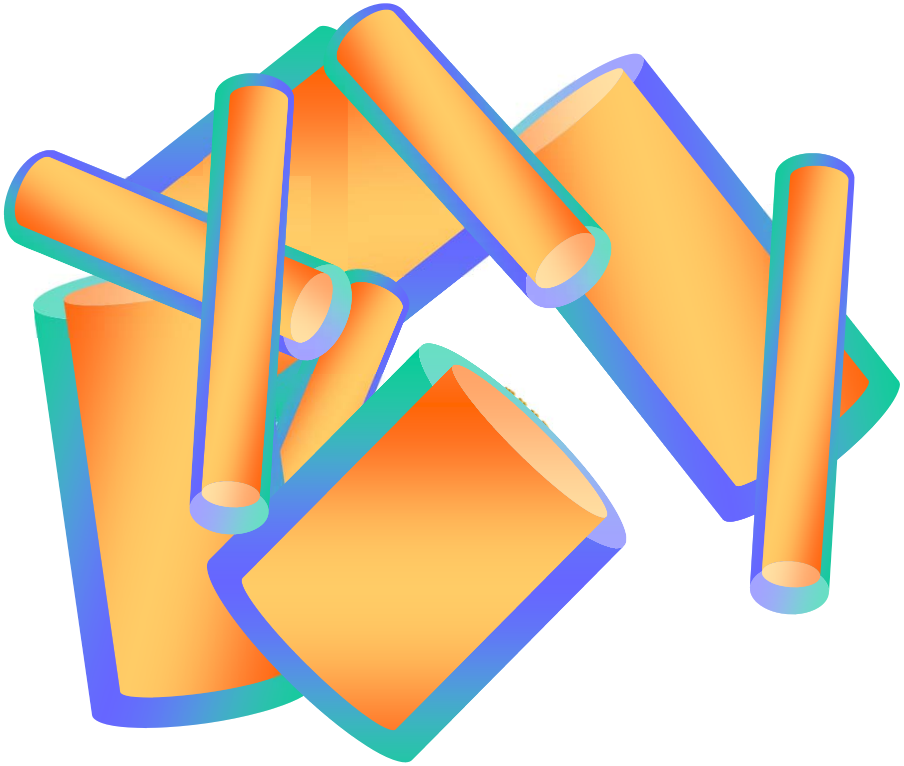
absorption v_2-c_2

Valence bands

Suspension of SWNTs for PL



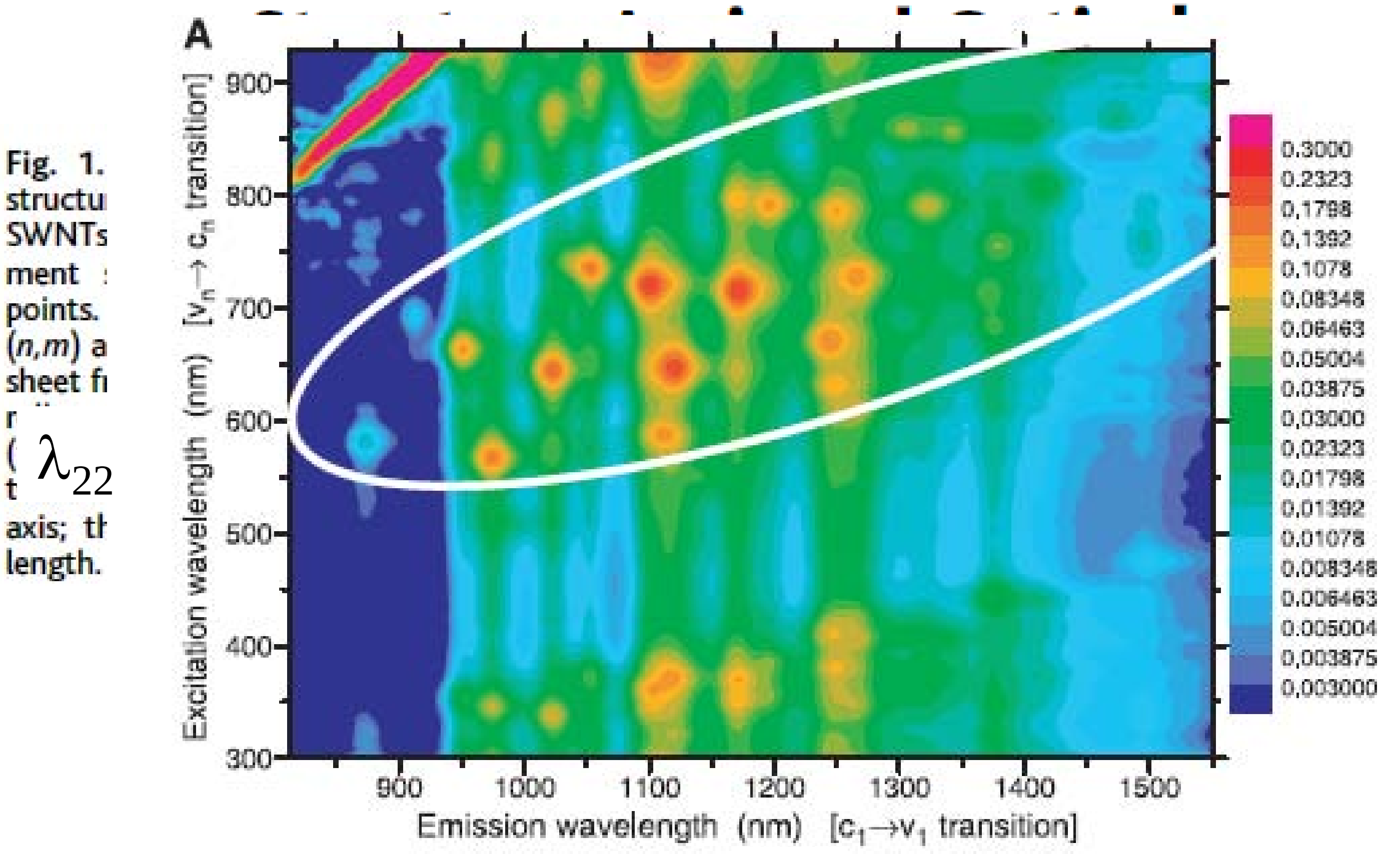
1. Nonfluorescent SWNT-SDS aggregates are sonicated
2. Single SWNTs are suspended
3. Centrifugation separates fluorescent SWCNTs



M. J. O'Connell et al., Science 297 (2002) 593

S. M. Bachilo *et al.*, Science 298 (2002) 2361.

PL Characterization of SWNTs



Bachilo et al. (2002) Sc λ_{11} e 298:2361-2363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  - Steady State- 10 ms
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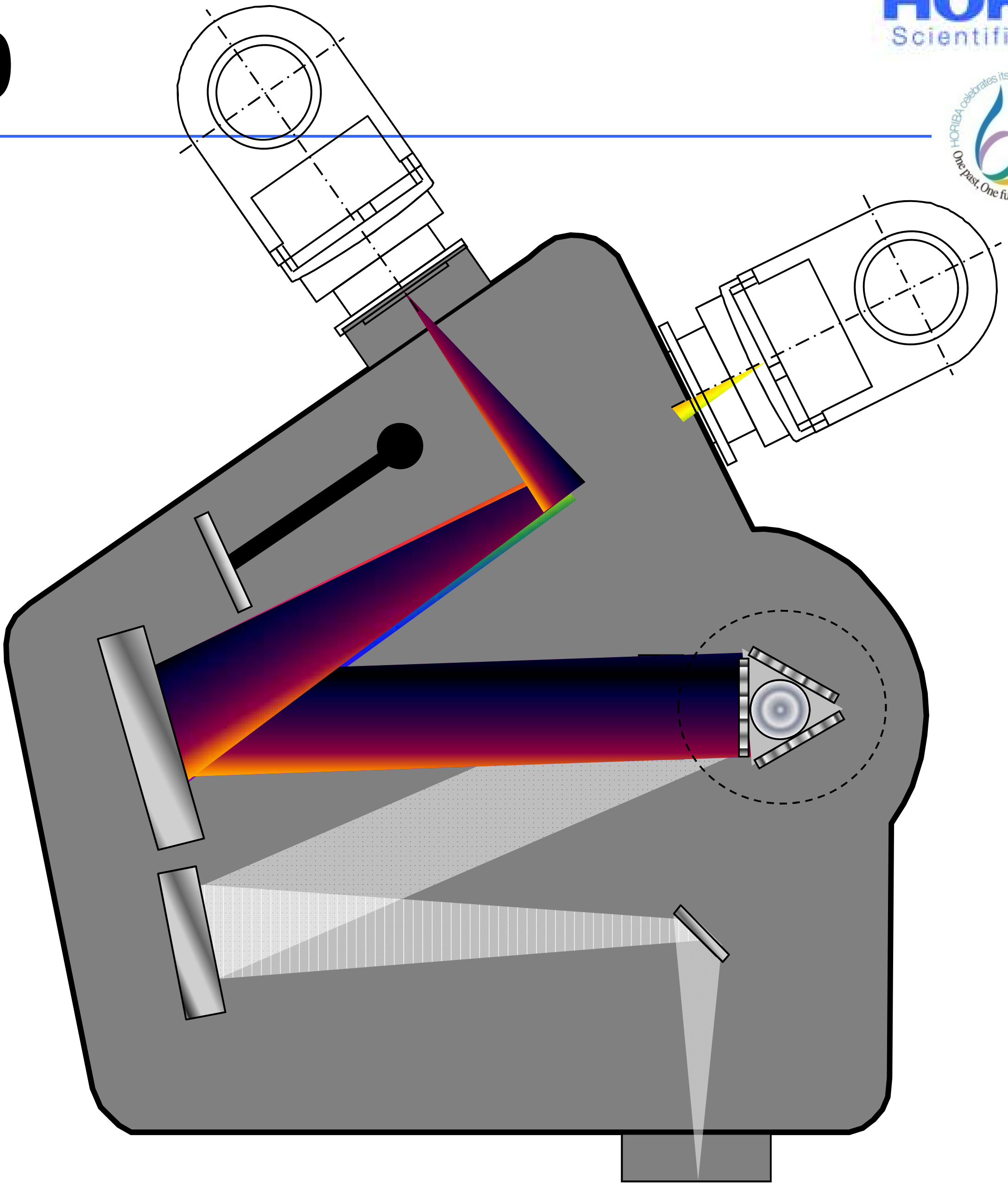
  - MCS-20 ns
- Microchannel Plate PMTs
  - 5 ps TCSPC

Kinematic Grating Turret
200 nm – 3000 nm



Single Walled Carbon Nanotubes (SWCNTs)

- SWCNTs can be characterized using photoluminesence spectroscopy for:
  - Diameter
  - Helical twisting (chirality)
  - Length
  - Bundling-(SWCNT to SWCNT interactions)

PL Yields Multidimensional Data

- Diameter:
  - absorbance and emission peaks correlate according to quantum confinement rules, smaller SWCNTs higher energy
- Helical twisting (chirality):
  - absorbance and emission peak energies are also influenced secondarily, and nonlinearly according to the SWCNT families
- Length:
  - intensity of absorbance extinciton and emisison intensity correlate.
- Bundling:
  - energy transfer from smaller (donor) to larger (acceptor) diameter SWCNTs influences relationship between absorbance and emission peak intensities.

Energy Transfer in Bundles

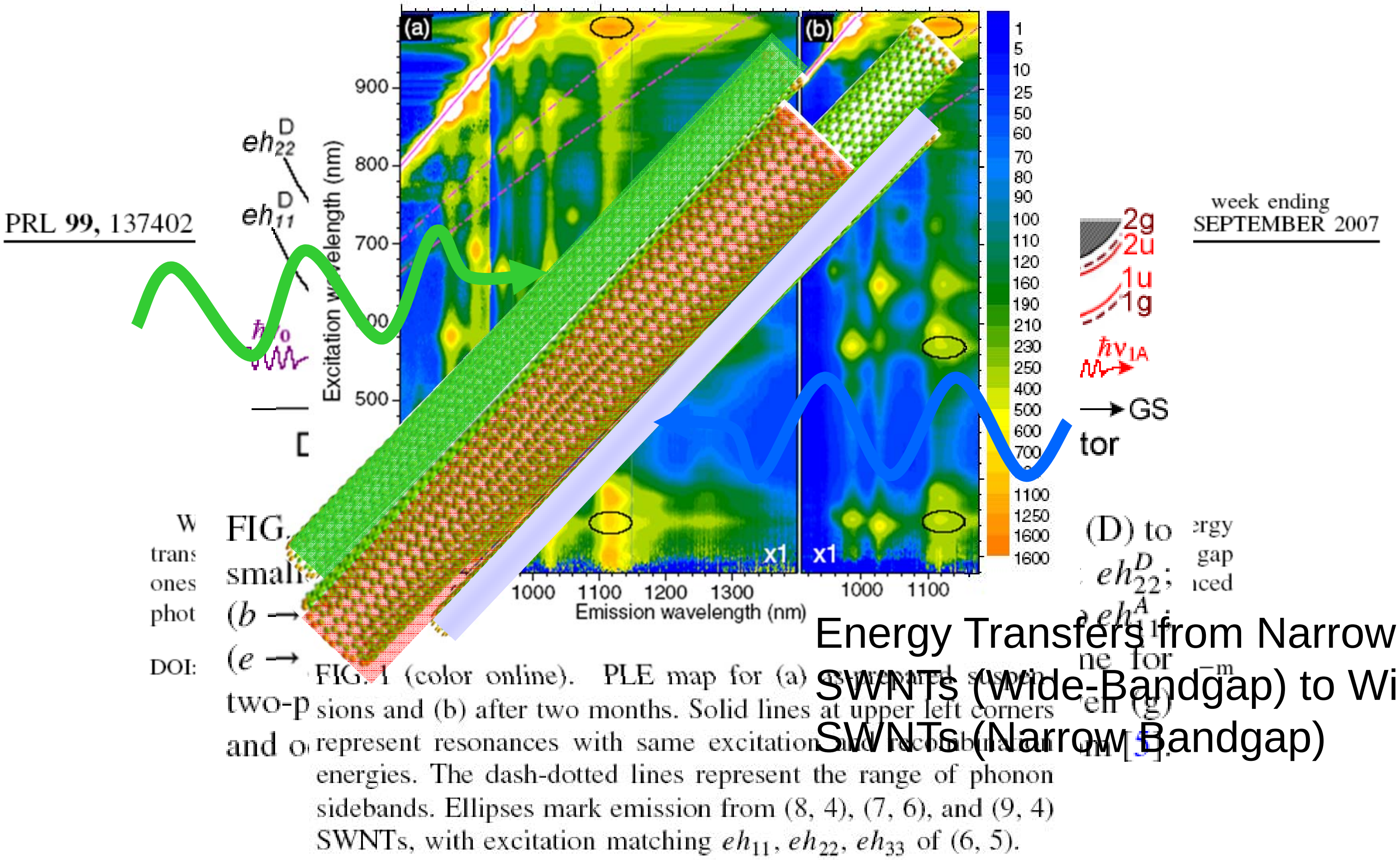
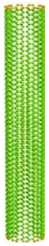
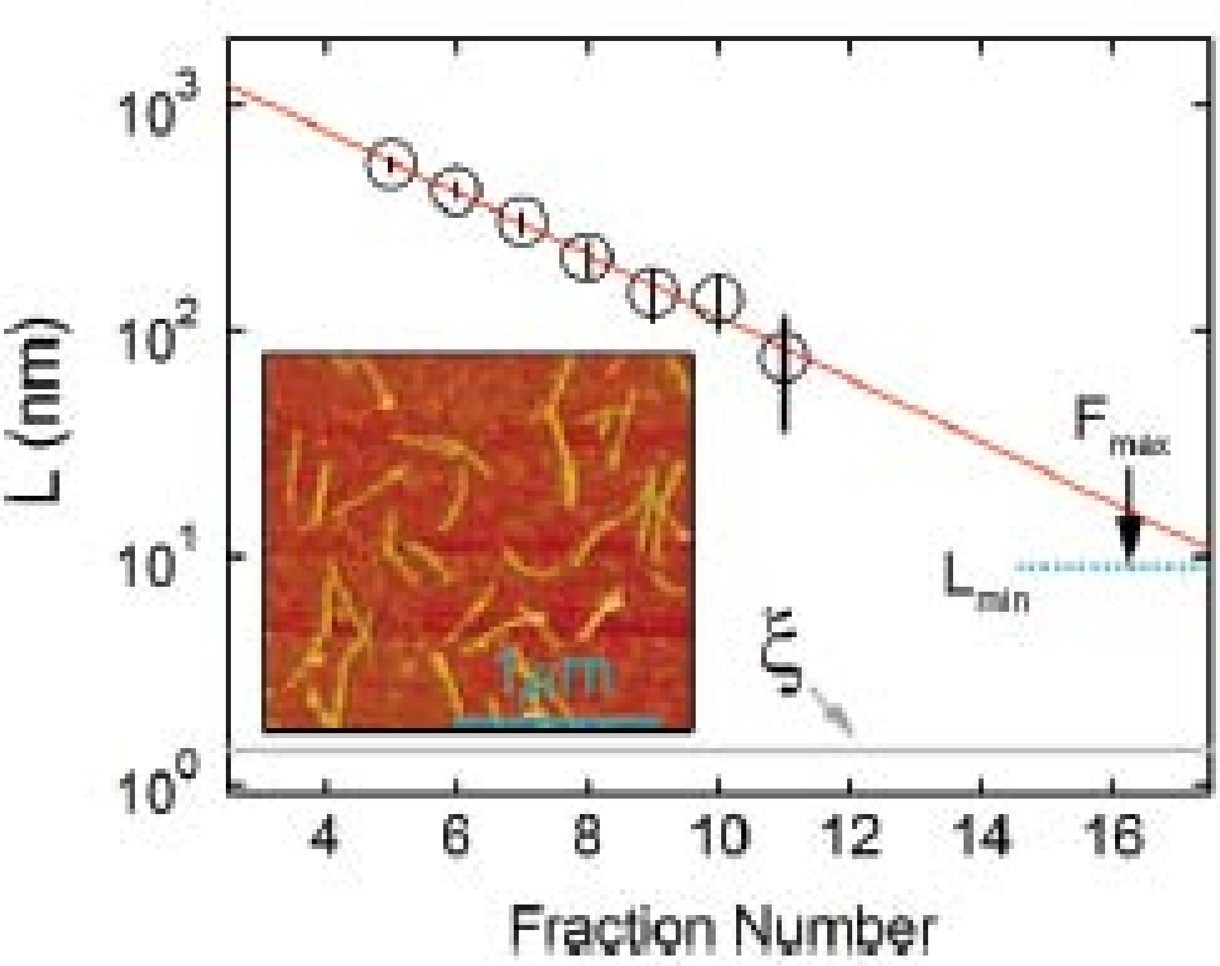


FIG. 1 (color online). PLE map for (a) as-prepared suspensions and (b) after two months. Solid lines at upper left corners represent resonances with same excitation and recombination energies. The dash-dotted lines represent the range of phonon sidebands. Ellipses mark emission from (8, 4), (7, 6), and (9, 4) SWNTs, with excitation matching eh_{11}, eh_{22}, eh_{33} of (6, 5).

Energy Transfers from Narrow SWNTs (Wide-Bandgap) to Wider SWNTs (Narrow Bandgap)

Length Dependent SWCNT PL





SWCNT Absorbance Spectra

A.4 Results

Length-Dependent Opt

ICLES

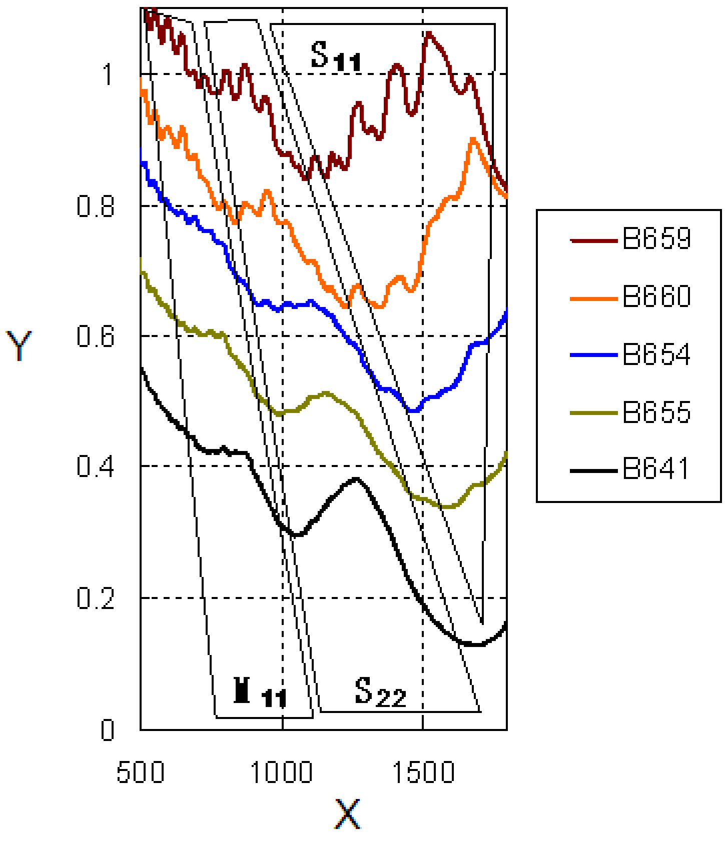


Figure 2. Optical ab

Key

X Wavelength (nm)

Y Absorbance (arb. unit)

Figure A.2 — The absorption spectra of SWCNT samples dispersed in 1% (mass fraction) SC-D_2O solvent.

The Nanolog®-EXT

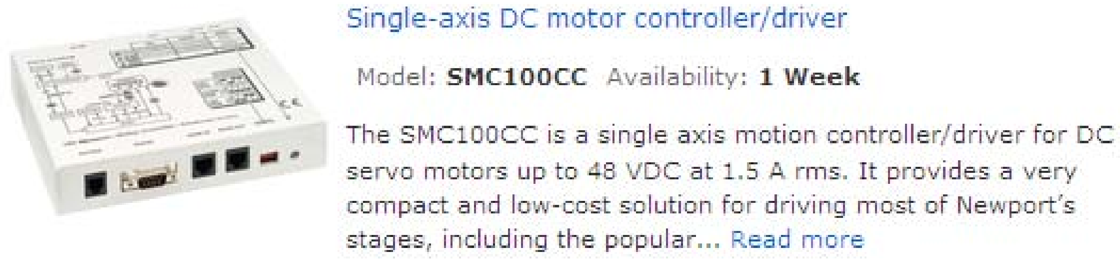
- Deeper NIR Excitation and Emission ranges are needed for larger diameter SWCNTs
- Larger diameter SWCNTs with small bandgaps are important for device manufacturing.

Essential Components:

1. Tunable Mainframe CW TiS Laser
2. Extended InGaAs Array (1100-2200 nm)

Newport 3900S Power Ti-S Laser

- Tuning from 700-1000 nm
- Useful for SWCNTs from 1.3 – 2.2 nm
- The only light source compatible with extended InGaAs array for large diameter SWCNTs



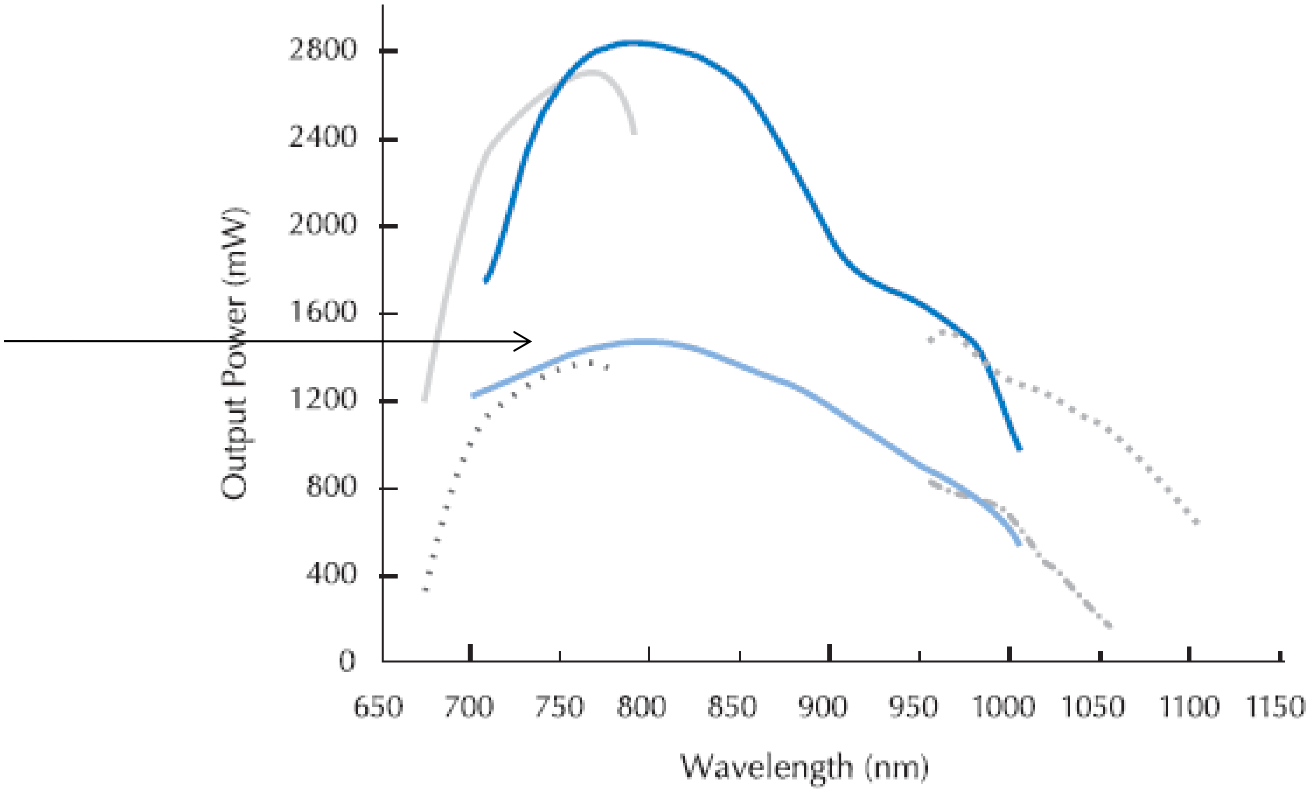
Single-axis DC motor controller/driver

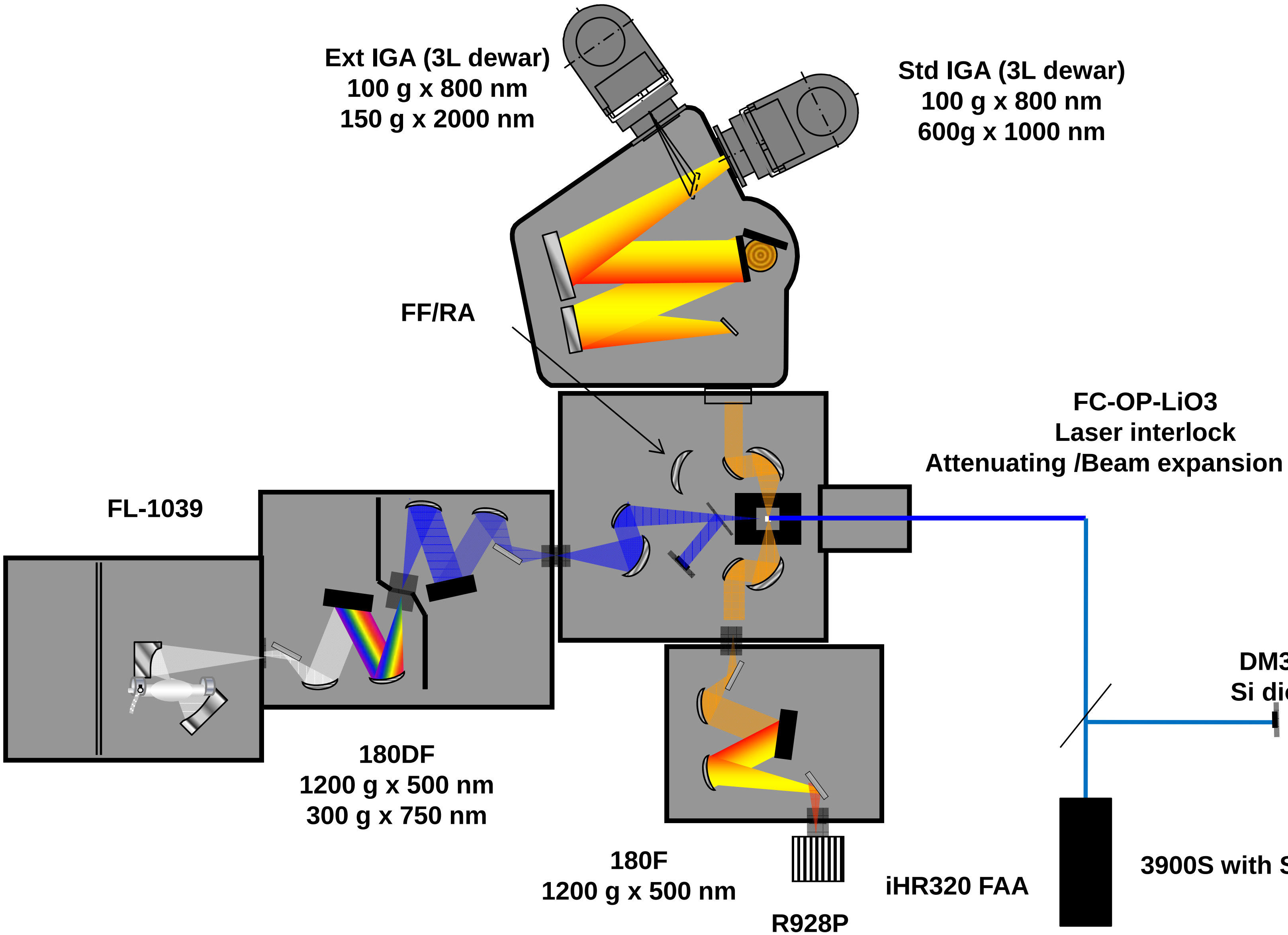
Model: **SMC100CC** Availability: **1 Week**

The SMC100CC is a single axis motion controller/driver for DC servo motors up to 48 VDC at 1.5 A rms. It provides a very compact and low-cost solution for driving most of Newport's stages, including the popular... Read more

HORIBA Tuning Software with SMCC100 Stepper Motor Controller

3900S 5W Pump Power





Ext IGA (3L dewar)
100 g x 800 nm
150 g x 2000 nm

Std IGA (3L dewar)
100 g x 800 nm
600g x 1000 nm

FF/RA

FC-OP-LiO3
Laser interlock
Attenuating /Beam expansion optics

FL-1039

DM303
Si diode

180DF
1200 g x 500 nm
300 g x 750 nm

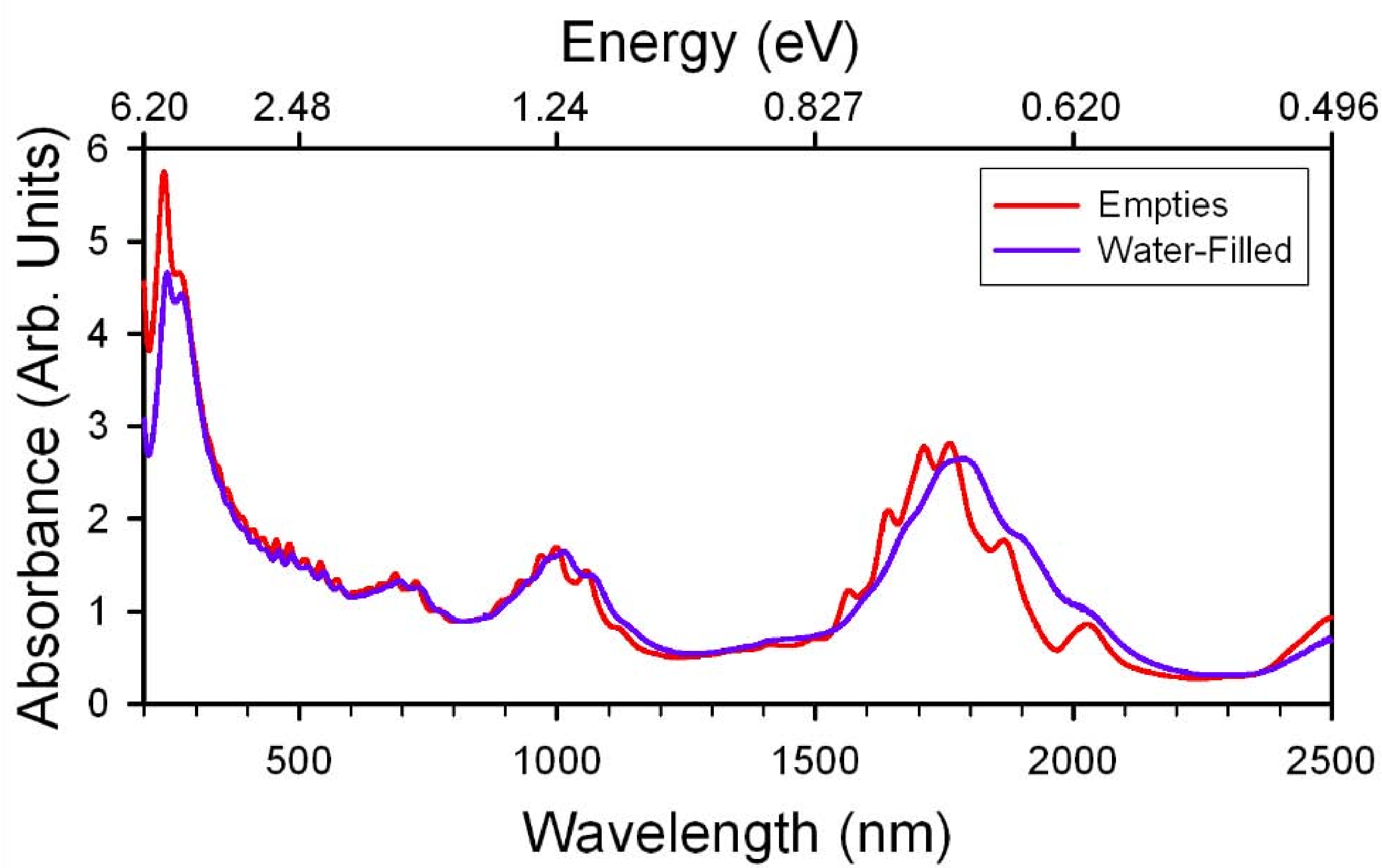
180F
1200 g x 500 nm

iHR320 FAA

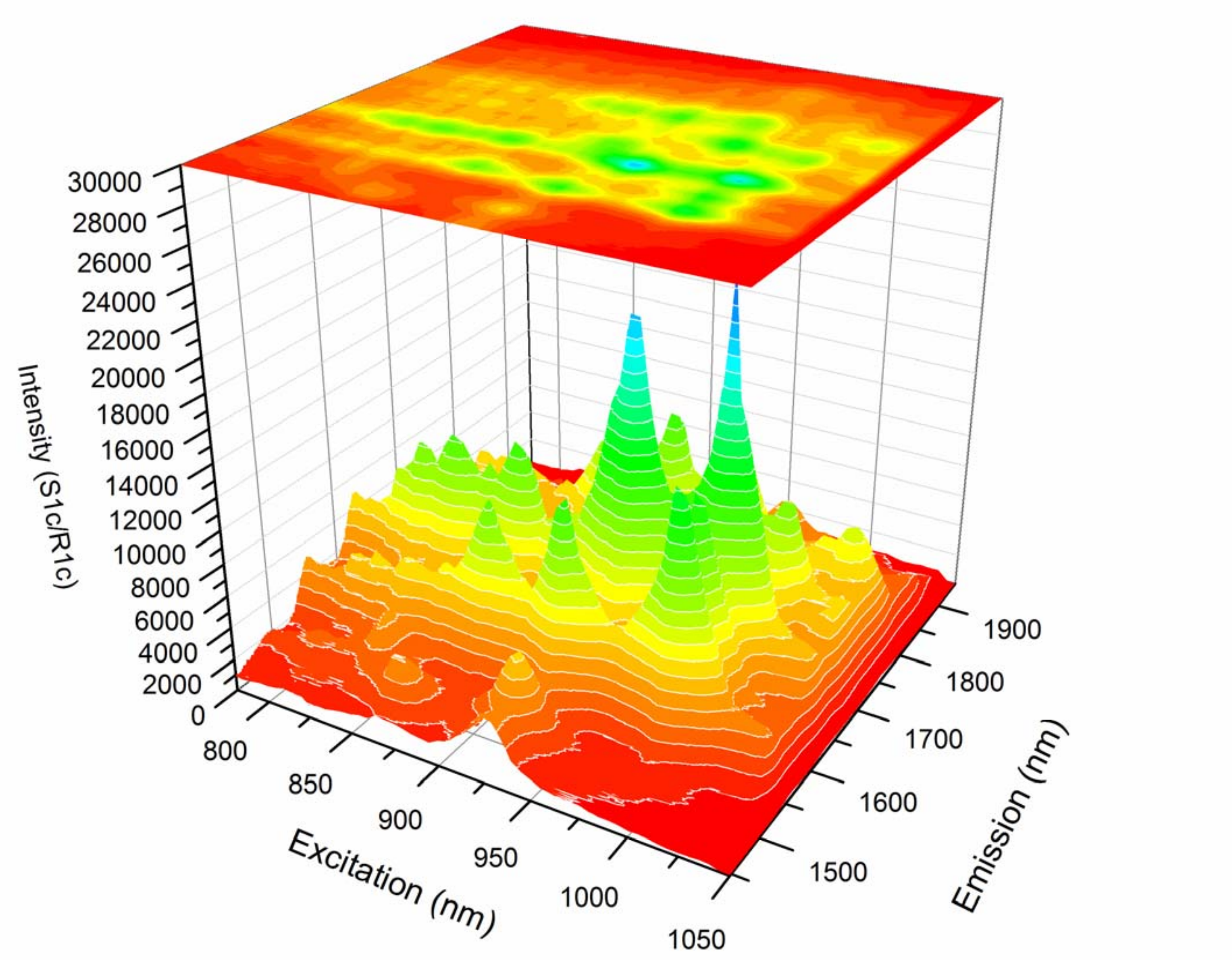
3900S with SMCC100

R928P
(290-850 nm)

Large Dia. SWCNT Absorbance



Large Diameter SWCNTs EEM



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Nanosizer®

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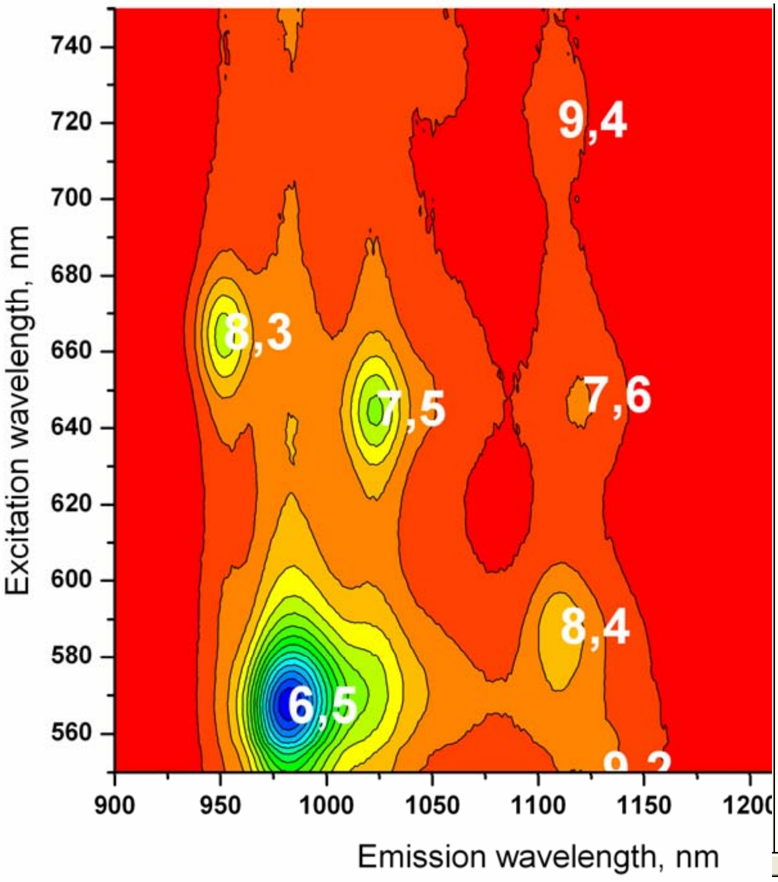
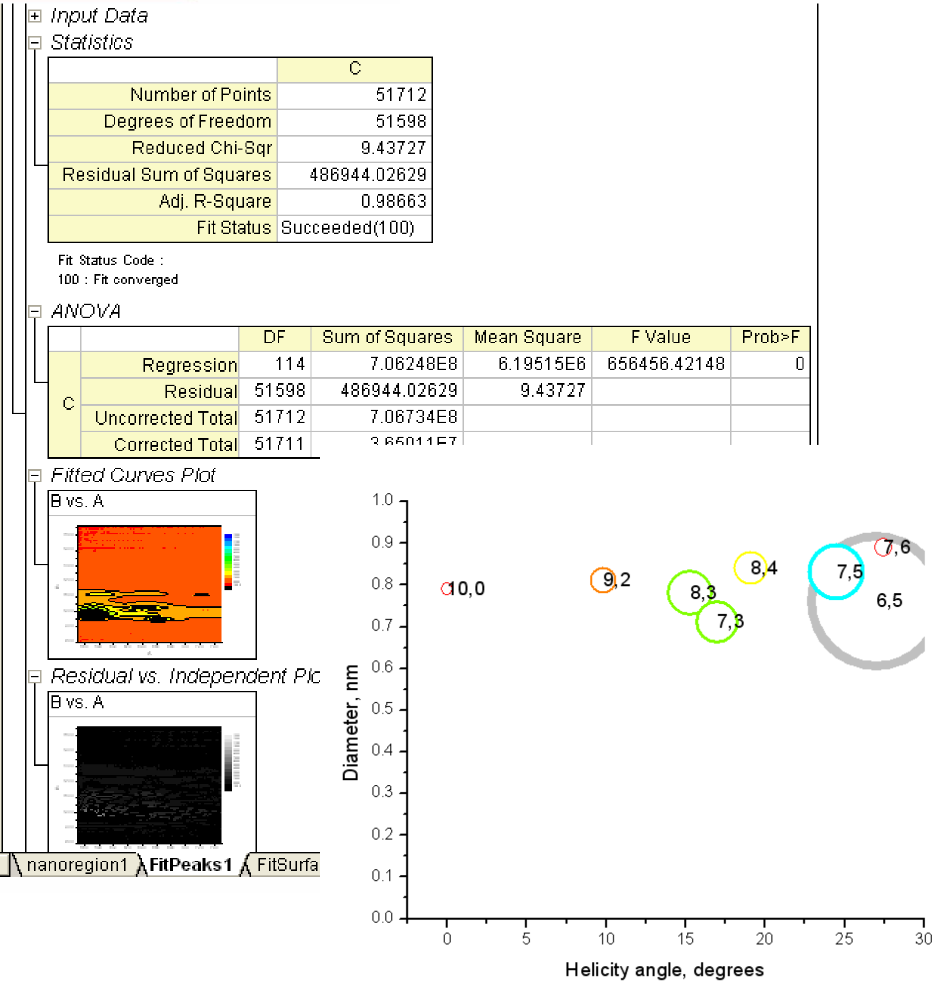




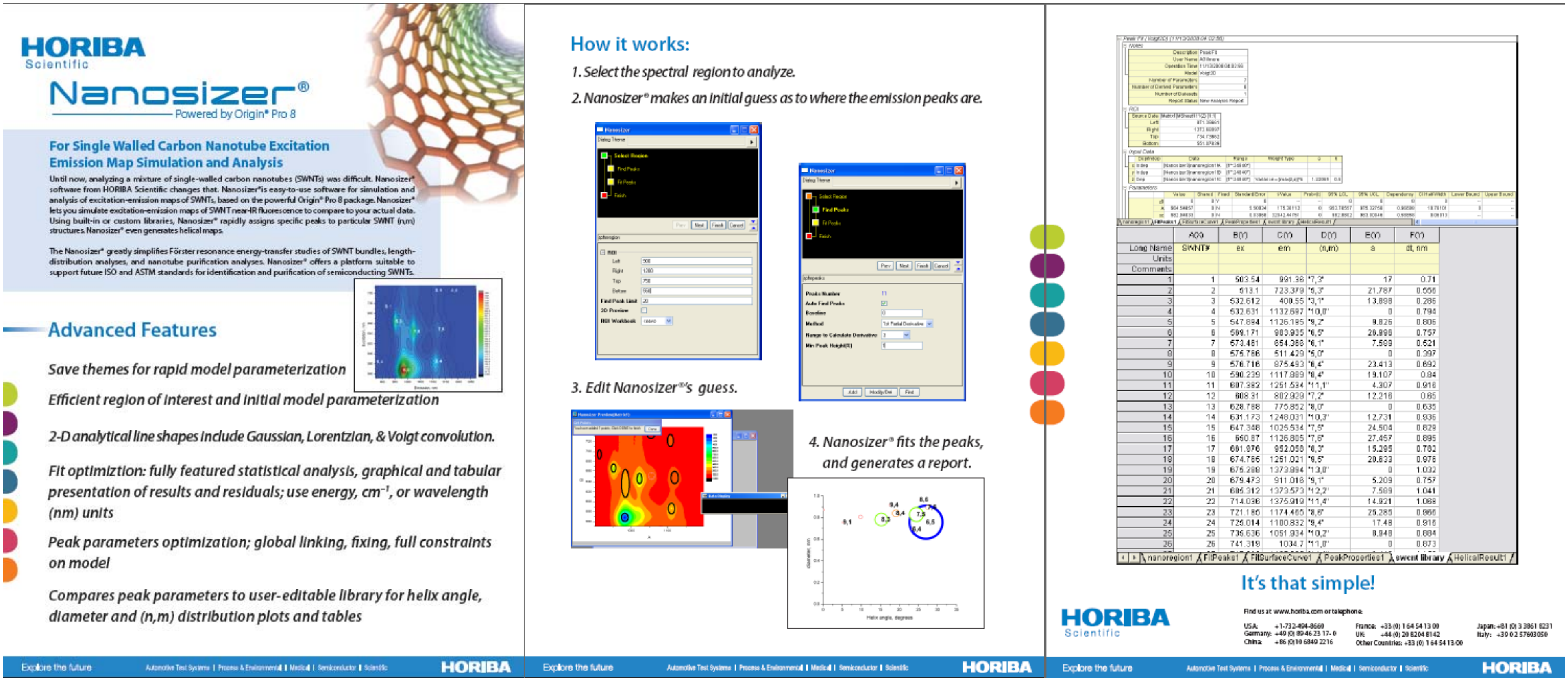
	C
Number of Points	51712
Degrees of Freedom	51598
Reduced Chi-Sqr	9.43727
Residual Sum of Squares	486944.02629
Adj. R-Square	0.98663
Fit Status	Succeeded(100)

Fit Status Code :
100 : Fit converged

ANOVA

		DF	Sum of Squares	Mean Square	F Value	Prob>F
C	Regression	114	7.06248E8	6.19515E6	656456.42148	0
	Residual	51598	486944.02629	9.43727		
	Uncorrected Total	51712	7.06734E8			
	Corrected Total	51711	3.65011E7			

Nanosizer®



For Single Walled Carbon Nanotube Excitation Emission Map Simulation and Analysis

Until now, analyzing a mixture of single-walled carbon nanotubes (SWNTs) was difficult. Nanosizer® software from HORIBA Scientific changes that. Nanosizer® is easy-to-use software for simulation and analysis of excitation-emission maps of SWNTs, based on the powerful Origin® Pro 8 package. Nanosizer® lets you simulate excitation-emission maps of SWNT near-IR fluorescence to compare to your actual data. Using built-in or custom libraries, Nanosizer® rapidly assigns specific peaks to particular SWNT (n,m) structures. Nanosizer® even generates helical maps.

The Nanosizer® greatly simplifies Förster resonance energy-transfer studies of SWNT bundles, length-distribution analyses, and nanotube purification analyses. Nanosizer® offers a platform suitable to support future ISO and ASTM standards for identification and purification of semiconducting SWNTs.

Advanced Features

- *Save themes for rapid model parameterization*
- *Efficient region of interest and initial model parameterization*
- *2-D analytical line shapes include Gaussian, Lorentzian, & Voigt convolution.*
- *Fit optimiztion: fully featured statistical analysis, graphical and tabular presentation of results and residuals; use energy, cm⁻¹, or wavelength (nm) units*
- *Peak parameters optimization; global linking, fixing, full constraints on model*
- *Compares peak parameters to user-editable library for helix angle, diameter and (n,m) distribution plots and tables*

How it works:

1. Select the spectral region to analyze.

2. Nanosizer® makes an initial guess as to where the emission peaks are.

3. Edit Nanosizer®'s guess.

4. Nanosizer® fits the peaks, and generates a report.

	A(X)	B(Y)	C(Y)	D(Y)	E(Y)	F(Y)
Long Name	SWNT#	ex	em	(n,m)	a	dt, nm
Units						
Comments						
1	1	503.54	991.36	"7,3"	17	0.71
2	2	513.1	723.379	"5,3"	21.787	0.556
3	3	532.612	400.55	"3,1"	13.898	0.286
4	4	532.631	1132.687	"10,0"	0	0.794
5	5	547.894	1126.195	"9,2"	9.826	0.806
6	6	569.171	983.935	"6,5"	26.996	0.757
7	7	573.461	654.366	"6,1"	7.589	0.621
8	8	575.766	511.429	"5,0"	0	0.397
9	9	576.716	875.493	"6,4"	23.413	0.692
10	10	590.239	1117.889	"8,4"	19.107	0.84
11	11	607.382	1251.534	"11,1"	4.307	0.916
12	12	608.31	802.929	"7,2"	12.216	0.65
13	13	628.788	775.852	"8,0"	0	0.635
14	14	631.173	1248.031	"10,3"	12.731	0.936
15	15	647.348	1025.534	"7,5"	24.504	0.829
16	16	650.87	1126.805	"7,6"	27.457	0.895
17	17	661.976	952.058	"8,3"	15.295	0.782
18	18	674.766	1251.021	"9,5"	20.633	0.976
19	19	675.288	1373.894	"13,0"	0	1.032
20	20	679.473	911.016	"9,1"	5.209	0.757
21	21	686.312	1373.573	"12,2"	7.589	1.041
22	22	714.036	1375.919	"11,4"	14.921	1.068
23	23	721.185	1174.465	"8,6"	25.285	0.966
24	24	726.014	1100.832	"9,4"	17.48	0.916
25	25	735.636	1051.934	"10,2"	8.948	0.884
26	26	741.319	1034.7	"11,0"	0	0.873

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SWCNTs: TOP TEN STORIES

NEWSREEL 2011-2012

Engineers build first sub-10-nm carbon nanotube transistor

February 1, 2012 by Lisa Zyga feature

9-nm CNT transistor with electron microscope images. Image credit: Franklin, et al. ©2012 American Chemical Society

Enlarge

(PhysOrg.com) -- Engineers have built the first carbon nanotube (CNT) transistor with a channel length below 10 nm, a size that is considered a requirement for computing technology in the next decade. Not only can the tiny transistor sufficiently control current, it does so significantly better than predicted by theory. It even outperforms the best competing silicon transistors at this scale, demonstrating a superior current density at a very low operating voltage.

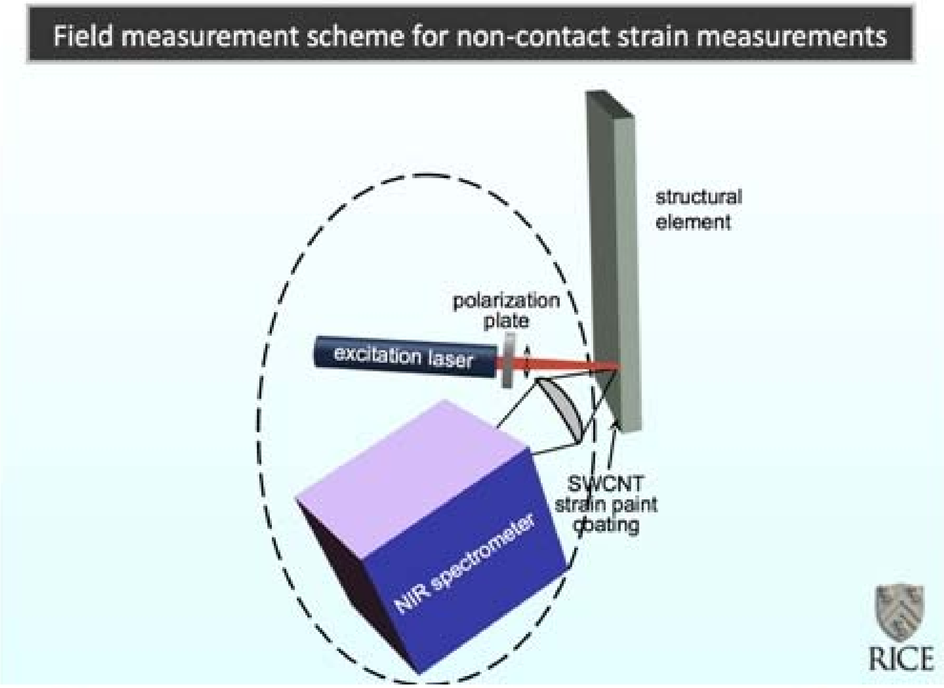
Published on June 22, 2012 at 7:09 AM

By Cameron Chai

Using carbon nanotubes, Rice University scientists, Bruce Weisman and Satish Nagarajaiah, have developed a new class of paint named 'strain paint,' which is capable of detecting strain in airplanes, bridges and buildings.

The researchers believe that their strain paint will be helpful in detecting deformations in structures such as airplane wings. This composite coating can be read with the help of a handheld infrared spectrometer. The study findings have been reported online in Nano Letters, a journal of the American Chemical Society.

Using this novel paint, it is possible to detect the signs of deformation in a material much earlier than the impact becomes detectable to the naked eye, and most importantly without contacting the structure. Moreover, the nanotube-based system is capable of measuring strain along any direction and at any spot.



An illustration shows how polarized light from a laser and a near-infrared spectrometer could read levels of strain in a material coated with nanotube-infused paint invented at Rice University. (credit: Bruce Weisman/Rice University)

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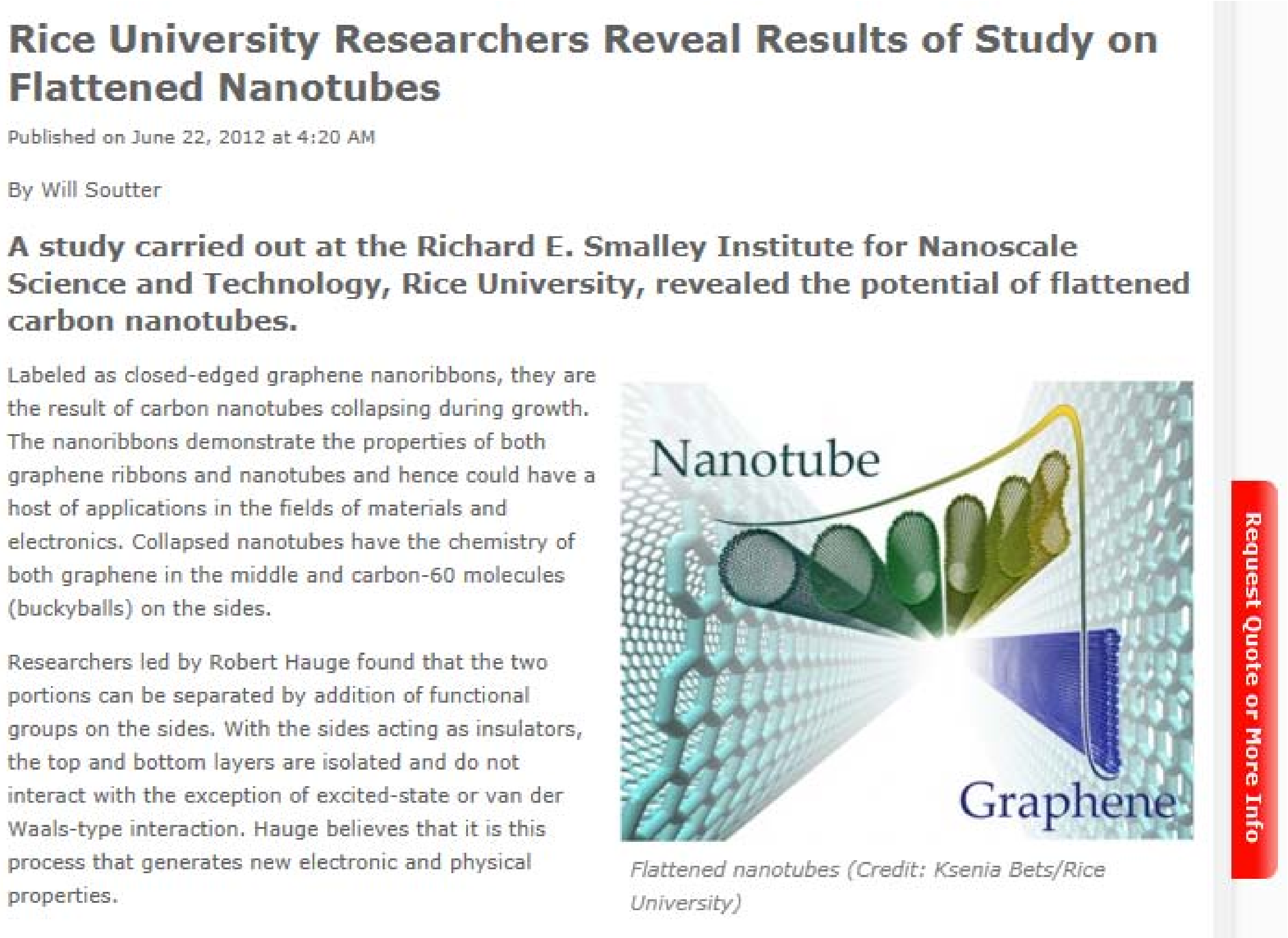


Rice University Researchers Reveal Results of Study on Flattened Nanotubes

Published on June 22, 2012 at 4:20 AM

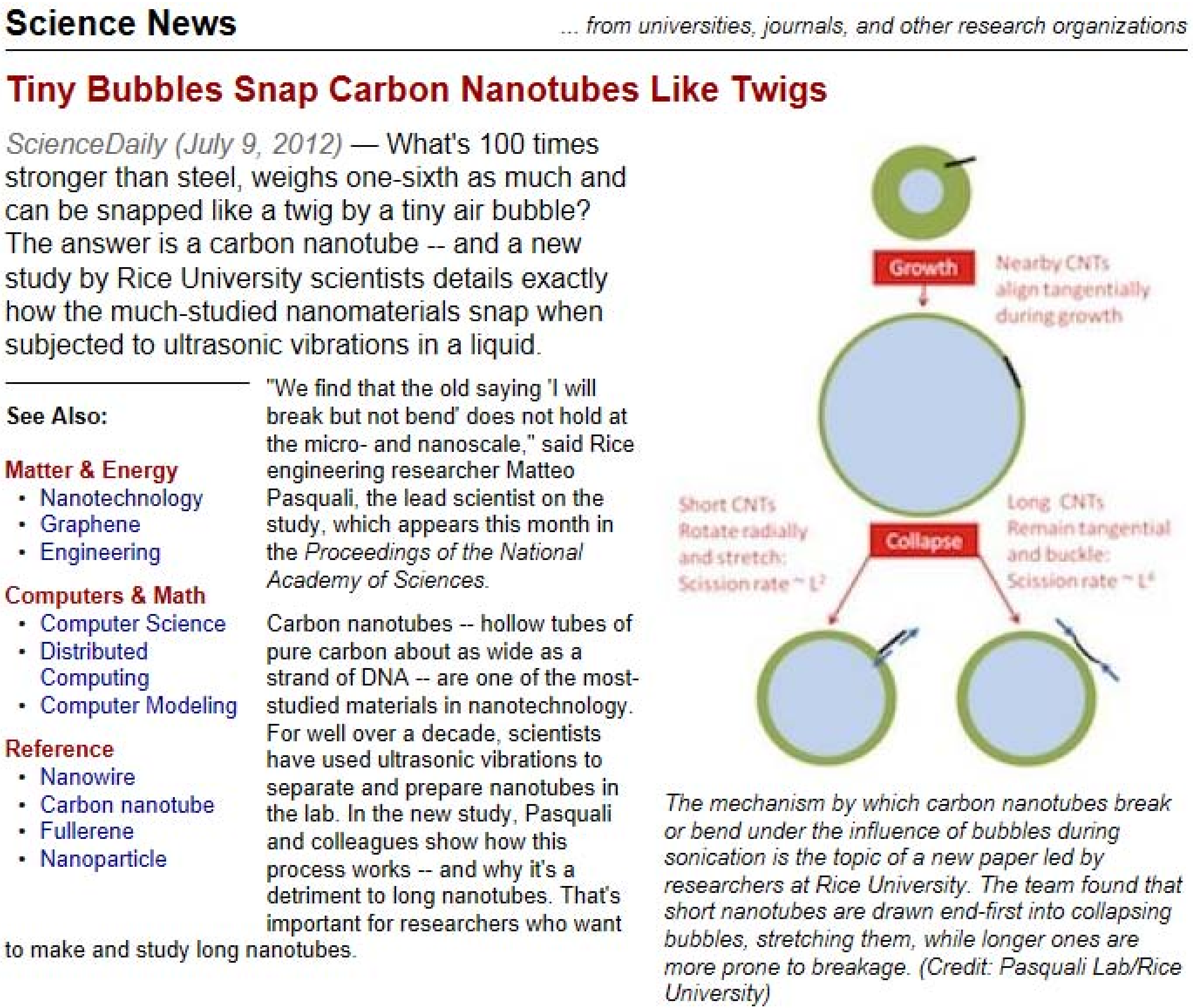
By Will Soutter

A study carried out at the Richard E. Smalley Institute for Nanoscale Science and Technology, Rice University, revealed the potential of flattened carbon nanotubes.

Labeled as closed-edged graphene nanoribbons, they are the result of carbon nanotubes collapsing during growth. The nanoribbons demonstrate the properties of both graphene ribbons and nanotubes and hence could have a host of applications in the fields of materials and electronics. Collapsed nanotubes have the chemistry of both graphene in the middle and carbon-60 molecules (buckyballs) on the sides.

Researchers led by Robert Hauge found that the two portions can be separated by addition of functional groups on the sides. With the sides acting as insulators, the top and bottom layers are isolated and do not interact with the exception of excited-state or van der Waals-type interaction. Hauge believes that it is this process that generates new electronic and physical properties.

Flattened nanotubes (Credit: Ksenia Bets/Rice University)



Science News *... from universities, journals, and other research organizations*

Tiny Bubbles Snap Carbon Nanotubes Like Twigs

ScienceDaily (July 9, 2012) — What's 100 times stronger than steel, weighs one-sixth as much and can be snapped like a twig by a tiny air bubble? The answer is a carbon nanotube -- and a new study by Rice University scientists details exactly how the much-studied nanomaterials snap when subjected to ultrasonic vibrations in a liquid.

See Also:

Matter & Energy
- Nanotechnology
- Graphene
- Engineering

Computers & Math
- Computer Science
- Distributed Computing
- Computer Modeling

Reference
- Nanowire
- Carbon nanotube
- Fullerene
- Nanoparticle

"We find that the old saying 'I will break but not bend' does not hold at the micro- and nanoscale," said Rice engineering researcher Matteo Pasquali, the lead scientist on the study, which appears this month in the *Proceedings of the National Academy of Sciences.*

Carbon nanotubes -- hollow tubes of pure carbon about as wide as a strand of DNA -- are one of the most-studied materials in nanotechnology. For well over a decade, scientists have used ultrasonic vibrations to separate and prepare nanotubes in the lab. In the new study, Pasquali and colleagues show how this process works -- and why it's a detriment to long nanotubes. That's important for researchers who want to make and study long nanotubes.

The mechanism by which carbon nanotubes break or bend under the influence of bubbles during sonication is the topic of a new paper led by researchers at Rice University. The team found that short nanotubes are drawn end-first into collapsing bubbles, stretching them, while longer ones are more prone to breakage. (Credit: Pasquali Lab/Rice University)

Carbon

Volume 50, Issue 11, September 2012, Pages 4294–4297

Letter to the Editor

Chiral-selective growth of single-walled carbon nanotubes on stainless steel wires

Maoshuai He[a], Pavel V. Fedotov[b], Elena D. Obraztsova[b], Ville Viitanen[c], Jani Sainio[c], Hua Jiang[d], Esko I. Kauppinen[d], Marita Niemelä[a], Juha Lehtonen[a]

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NANO RESEARCH
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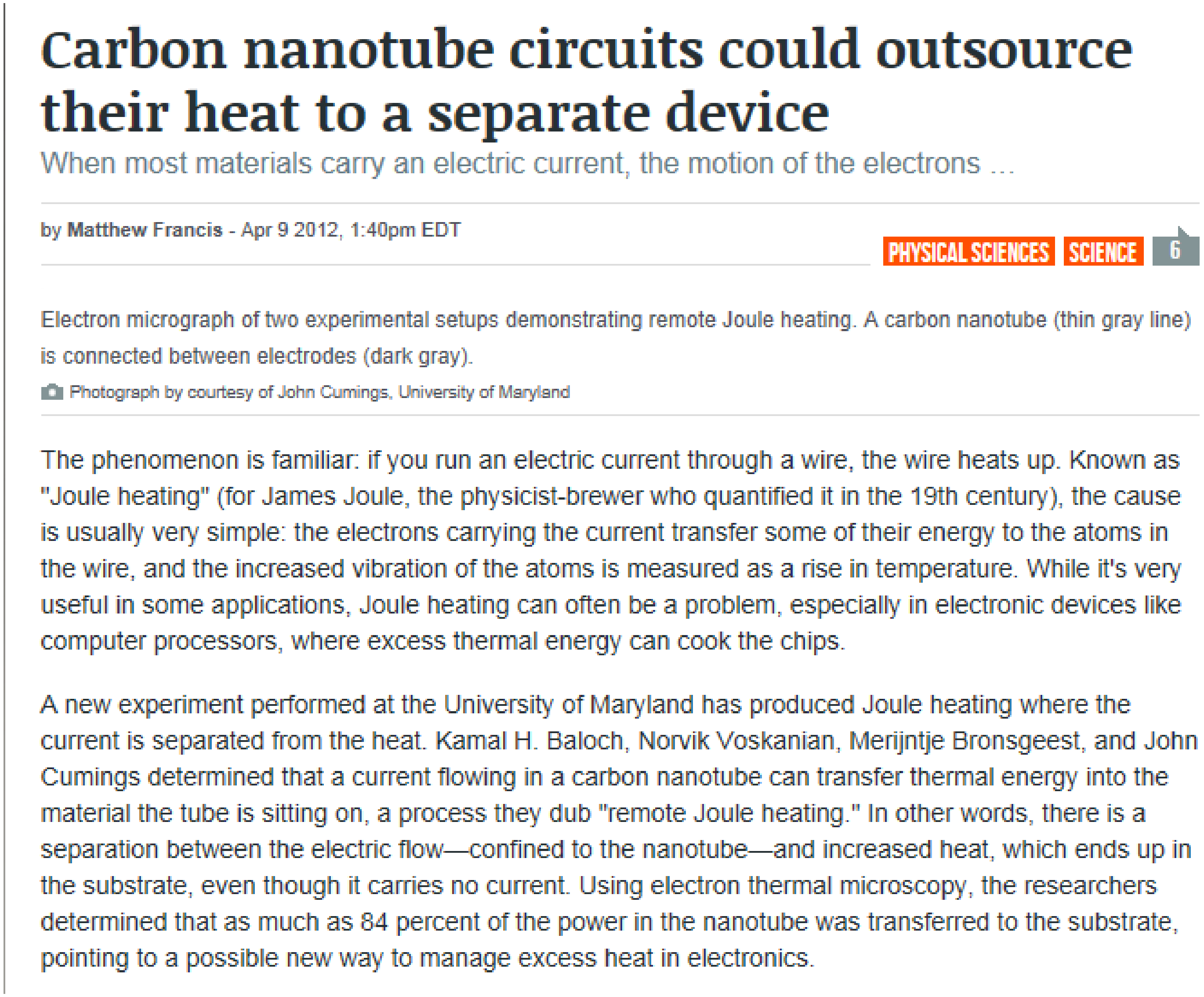
RESEARCH ARTICLE

Effects of gamma irradiation for sterilization on aqueous dispersions of length sorted carbon nanotubes

Jeffrey A. Fagan, Nancy J. Lin, Rolf Zeisler and Angela R. Hight Walker

Abstract

There is currently great interest in the potential use of carbon nanotubes as delivery vessels for nanotherapeutics and other medical applications. However, no data are available on the effects of sterilization methods on the properties of nanotube dispersions, the form in which most medical applications will be processed. Here we show the effects of gamma irradiation from a ^{60}Co source on the dispersion and optical properties of single-wall carbon nanotubes in aqueous dispersion. Samples of different length-refined populations were sealed in ampoules and exposed to a dose of approximately 28 kGy, a level sufficient to ensure sterility of the dispersions. In contrast to literature results for solid-phase nanotube samples, the effects of gamma irradiation on the dispersion and optical properties of the nanotube samples were found to be minimal. Based on these results, gamma irradiation appears sufficiently non-destructive to be industrially useful for the sterilization of nanotube dispersions.



Carbon nanotube circuits could outsource their heat to a separate device

When most materials carry an electric current, the motion of the electrons ...

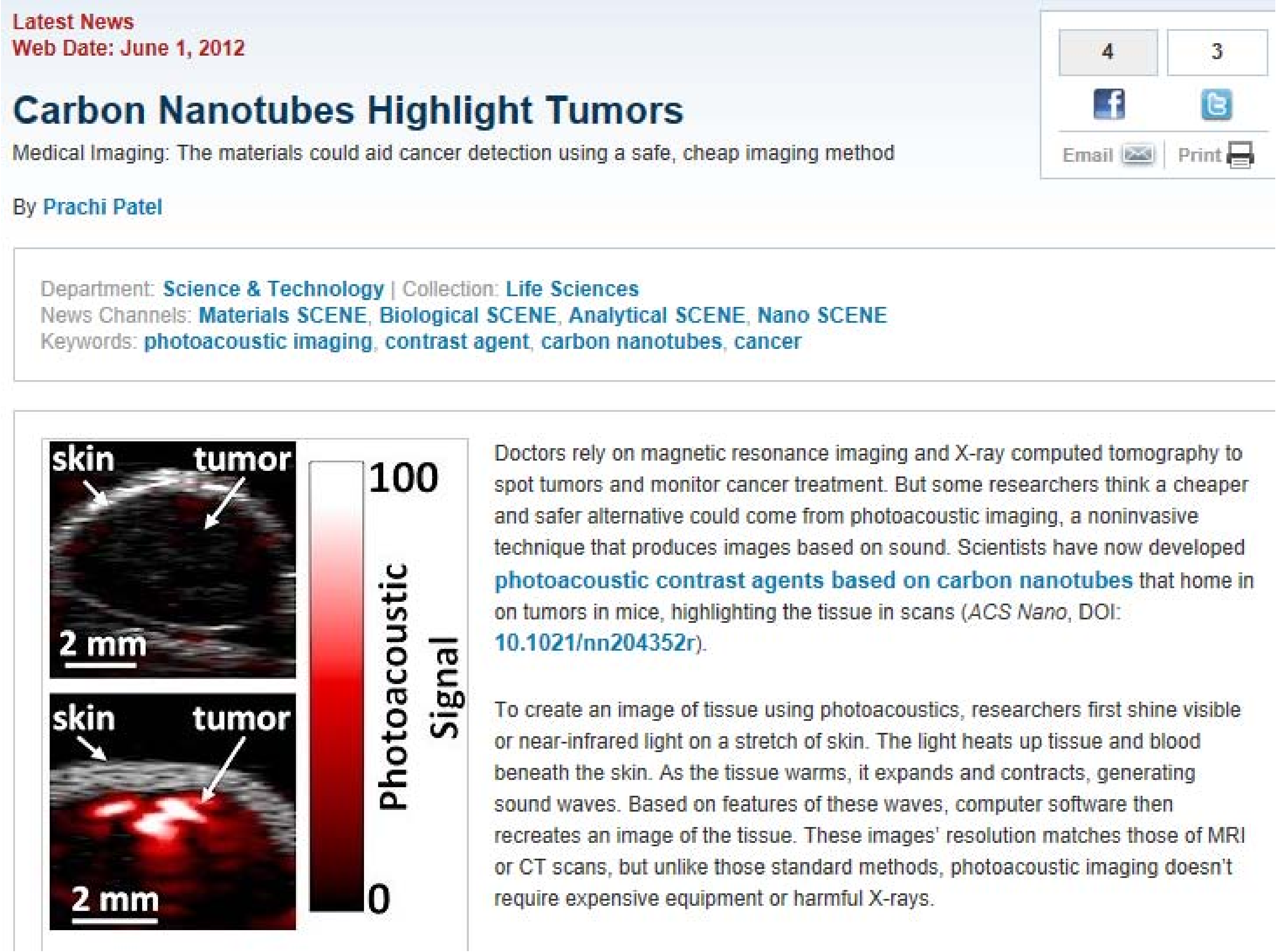
by **Matthew Francis** - Apr 9 2012, 1:40pm EDT

Electron micrograph of two experimental setups demonstrating remote Joule heating. A carbon nanotube (thin gray line) is connected between electrodes (dark gray).

Photograph by courtesy of John Cumings, University of Maryland

The phenomenon is familiar: if you run an electric current through a wire, the wire heats up. Known as "Joule heating" (for James Joule, the physicist-brewer who quantified it in the 19th century), the cause is usually very simple: the electrons carrying the current transfer some of their energy to the atoms in the wire, and the increased vibration of the atoms is measured as a rise in temperature. While it's very useful in some applications, Joule heating can often be a problem, especially in electronic devices like computer processors, where excess thermal energy can cook the chips.

A new experiment performed at the University of Maryland has produced Joule heating where the current is separated from the heat. Kamal H. Baloch, Norvik Voskanian, Merijntje Bronsgeest, and John Cumings determined that a current flowing in a carbon nanotube can transfer thermal energy into the material the tube is sitting on, a process they dub "remote Joule heating." In other words, there is a separation between the electric flow—confined to the nanotube—and increased heat, which ends up in the substrate, even though it carries no current. Using electron thermal microscopy, the researchers determined that as much as 84 percent of the power in the nanotube was transferred to the substrate, pointing to a possible new way to manage excess heat in electronics.



Latest News
Web Date: June 1, 2012

Carbon Nanotubes Highlight Tumors

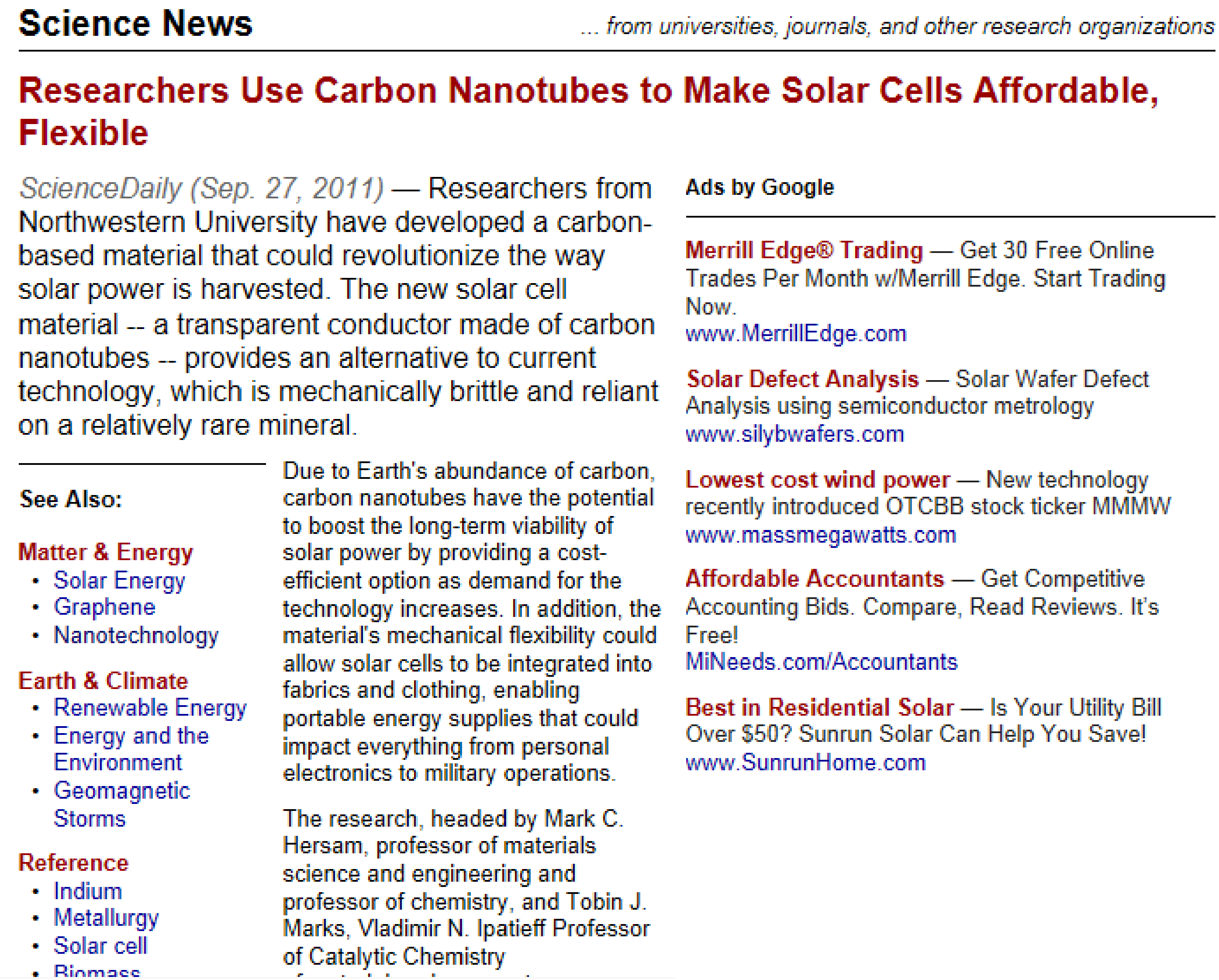
Medical Imaging: The materials could aid cancer detection using a safe, cheap imaging method

By Prachi Patel

Department: Science & Technology | Collection: Life Sciences
News Channels: Materials SCENE, Biological SCENE, Analytical SCENE, Nano SCENE
Keywords: photoacoustic imaging, contrast agent, carbon nanotubes, cancer

Doctors rely on magnetic resonance imaging and X-ray computed tomography to spot tumors and monitor cancer treatment. But some researchers think a cheaper and safer alternative could come from photoacoustic imaging, a noninvasive technique that produces images based on sound. Scientists have now developed photoacoustic contrast agents based on carbon nanotubes that home in on tumors in mice, highlighting the tissue in scans (*ACS Nano*, DOI: 10.1021/nn204352r).

To create an image of tissue using photoacoustics, researchers first shine visible or near-infrared light on a stretch of skin. The light heats up tissue and blood beneath the skin. As the tissue warms, it expands and contracts, generating sound waves. Based on features of these waves, computer software then recreates an image of the tissue. These images' resolution matches those of MRI or CT scans, but unlike those standard methods, photoacoustic imaging doesn't require expensive equipment or harmful X-rays.



Science News *... from universities, journals, and other research organizations*

Researchers Use Carbon Nanotubes to Make Solar Cells Affordable, Flexible

ScienceDaily (Sep. 27, 2011) — Researchers from Northwestern University have developed a carbon-based material that could revolutionize the way solar power is harvested. The new solar cell material -- a transparent conductor made of carbon nanotubes -- provides an alternative to current technology, which is mechanically brittle and reliant on a relatively rare mineral.

See Also:

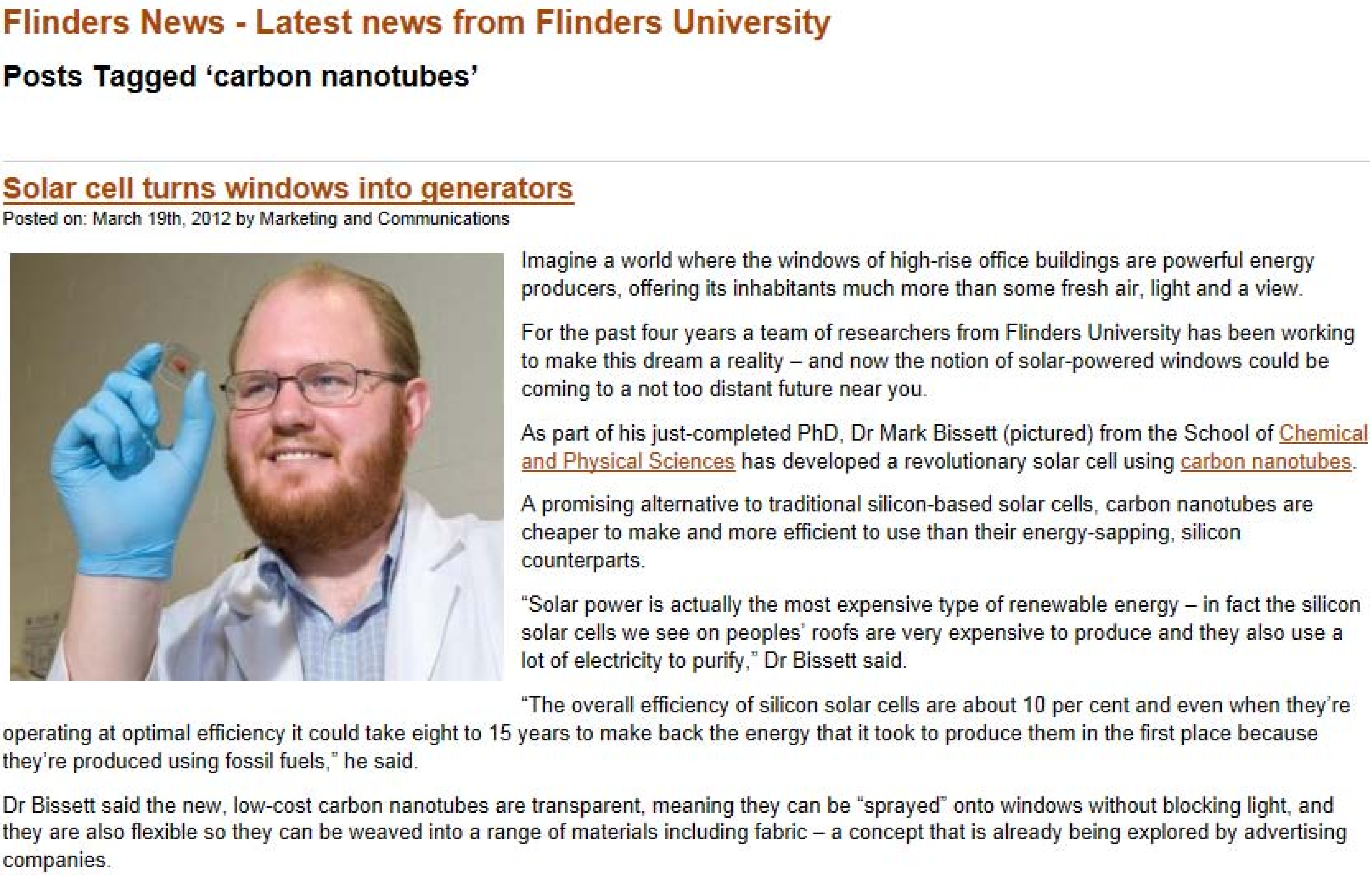
Matter & Energy
- Solar Energy
- Graphene
- Nanotechnology

Earth & Climate
- Renewable Energy
- Energy and the Environment
- Geomagnetic Storms

Reference
- Indium
- Metallurgy
- Solar cell
- Biomass

Due to Earth's abundance of carbon, carbon nanotubes have the potential to boost the long-term viability of solar power by providing a cost-efficient option as demand for the technology increases. In addition, the material's mechanical flexibility could allow solar cells to be integrated into fabrics and clothing, enabling portable energy supplies that could impact everything from personal electronics to military operations.

The research, headed by Mark C. Hersam, professor of materials science and engineering and professor of chemistry, and Tobin J. Marks, Vladimir N. Ipatieff Professor of Catalytic Chemistry



Flinders News - Latest news from Flinders University

Posts Tagged 'carbon nanotubes'

Solar cell turns windows into generators

Posted on: March 19th, 2012 by Marketing and Communications

Imagine a world where the windows of high-rise office buildings are powerful energy producers, offering its inhabitants much more than some fresh air, light and a view.

For the past four years a team of researchers from Flinders University has been working to make this dream a reality – and now the notion of solar-powered windows could be coming to a not too distant future near you.

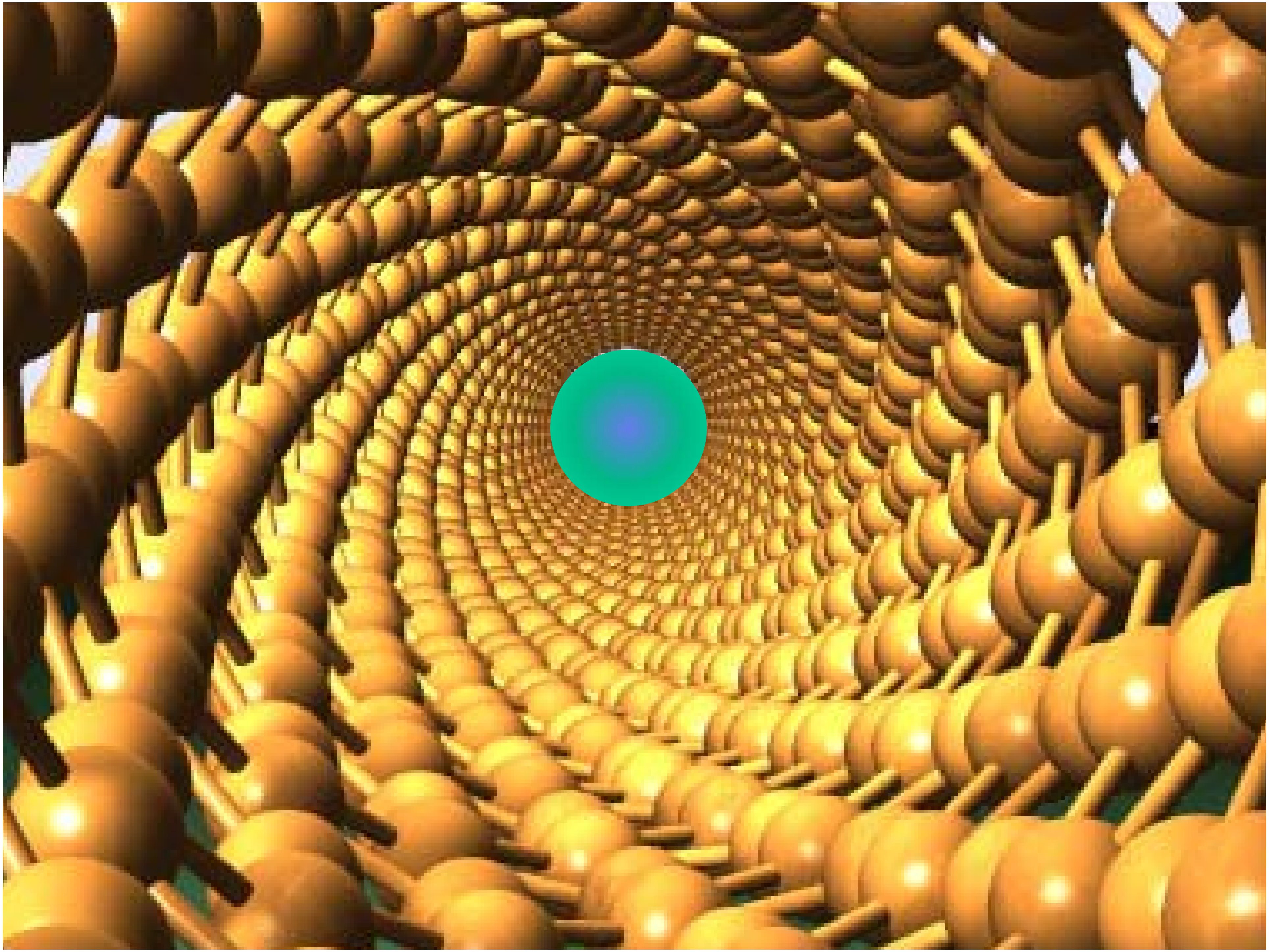
As part of his just-completed PhD, Dr Mark Bissett (pictured) from the School of Chemical and Physical Sciences has developed a revolutionary solar cell using carbon nanotubes.

A promising alternative to traditional silicon-based solar cells, carbon nanotubes are cheaper to make and more efficient to use than their energy-sapping, silicon counterparts.

"Solar power is actually the most expensive type of renewable energy – in fact the silicon solar cells we see on peoples' roofs are very expensive to produce and they also use a lot of electricity to purify," Dr Bissett said.

"The overall efficiency of silicon solar cells are about 10 per cent and even when they're operating at optimal efficiency it could take eight to 15 years to make back the energy that it took to produce them in the first place because they're produced using fossil fuels," he said.

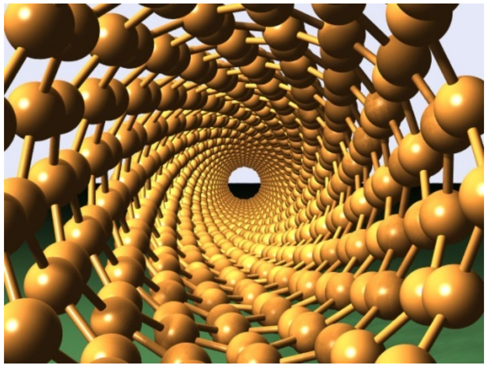
Dr Bissett said the new, low-cost carbon nanotubes are transparent, meaning they can be "sprayed" onto windows without blocking light, and they are also flexible so they can be weaved into a range of materials including fabric – a concept that is already being explored by advertising companies.



HORIBA

Scientific

Carbon Nanotube Analysis



Particle Analysis: Jeffrey Bodycomb, Ph.D.
Fluorescence: Adam Gilmore, Ph.D.

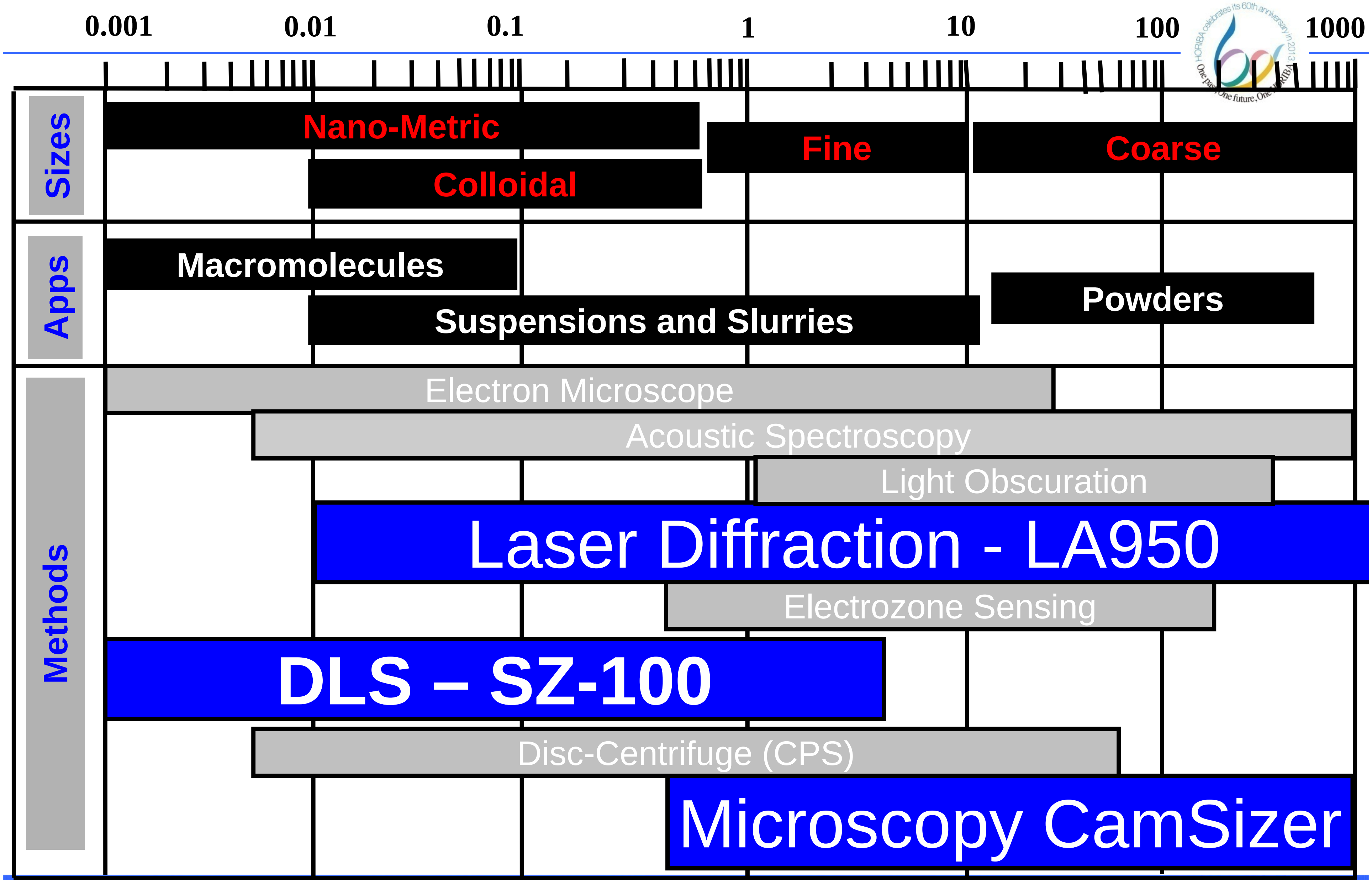
What is Dynamic Light Scattering?

- Dynamic light scattering refers to measurement and interpretation of light scattering data on a <u>microsecond</u> time scale.
- Dynamic light scattering can be used to determine
  - Particle/molecular size
  - Size distribution
  - Relaxations in complex fluids

Other Light Scattering Techniques

- Static Light Scattering: over a duration of ~1 second. Used for determining particle size (diameters greater than 10 nm), polymer molecular weight, 2nd virial coefficient, R_g.
- Electrophoretic Light Scattering: use Doppler shift in scattered light to probe motion of particles due to an applied electric field. Used for determining electrophoretic mobility, zeta potential.

Particle Diameter (µm)



Sizes

Nano-Metric

Colloidal

Fine

Coarse

Apps

Macromolecules

Suspensions and Slurries

Powders

Methods

Electron Microscope

Acoustic Spectroscopy

Light Obscuration

Laser Diffraction - LA950

Electrozone Sensing

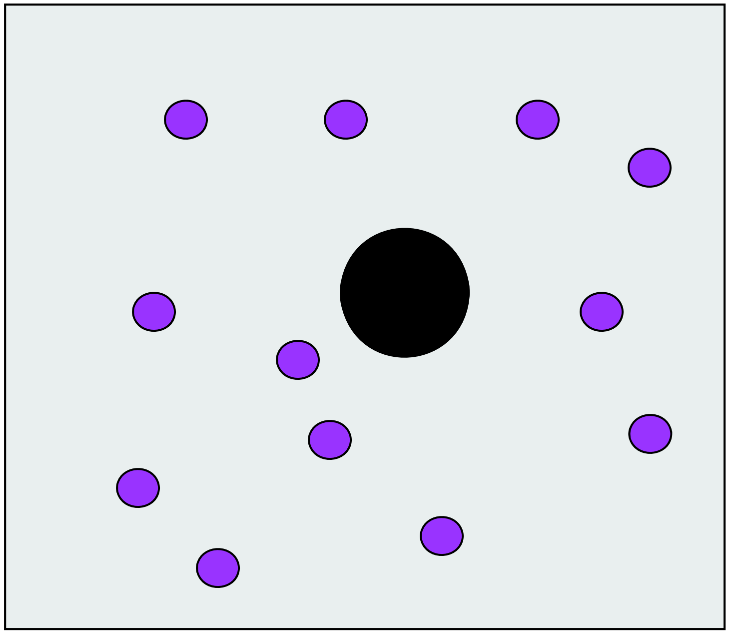
DLS – SZ-100

Disc-Centrifuge (CPS)

Microscopy CamSizer

Brownian Motion

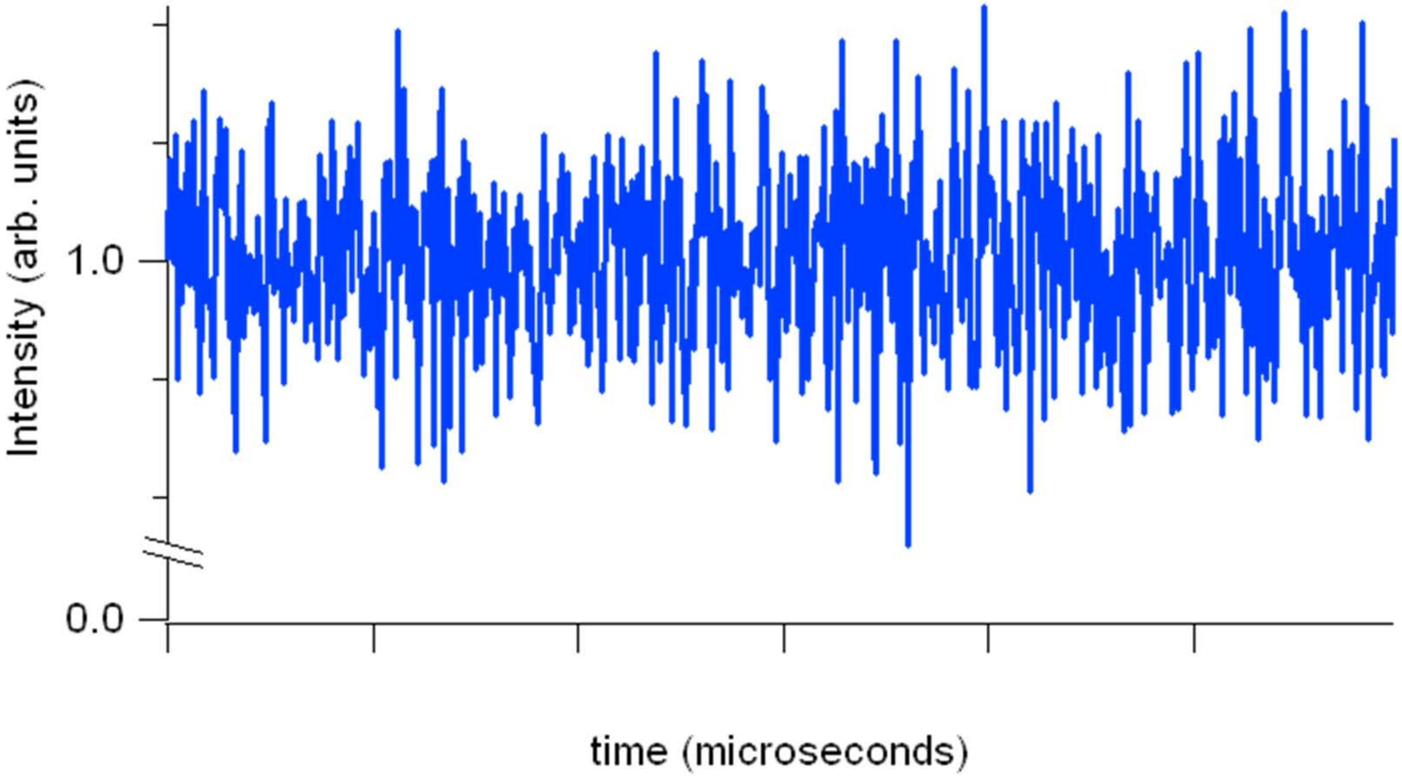
Particles in suspension undergo Brownian motion due to solvent molecule bombardment in random thermal motion.



- Brownian Motion
  - Random
  - Related to Size
  - Related to viscosity
  - Related to temperature

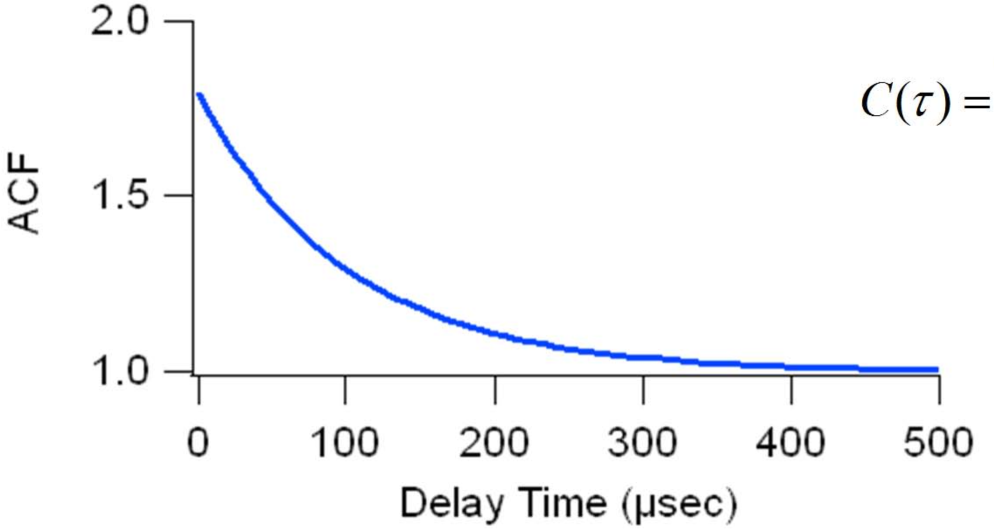
DLS signal

- Random motion of particles leads to random fluctuations in signal (due to changing constructive/destructive interference of scattered light.



Correlation Function

- Random fluctuations are interpreted in terms of the autocorrelation function (ACF).



$$C(\tau)=\frac{\int_0^T I(t)I(t+\tau)dt}{\langle I(t)I(t)\rangle}$$

$$C(\tau)=1+\beta\exp(-2\Gamma\tau)$$

Gamma to Size

$$\Gamma = D_m q^2$$

$$q = \frac{4\pi n}{\lambda} \sin\left(\theta / 2\right)$$

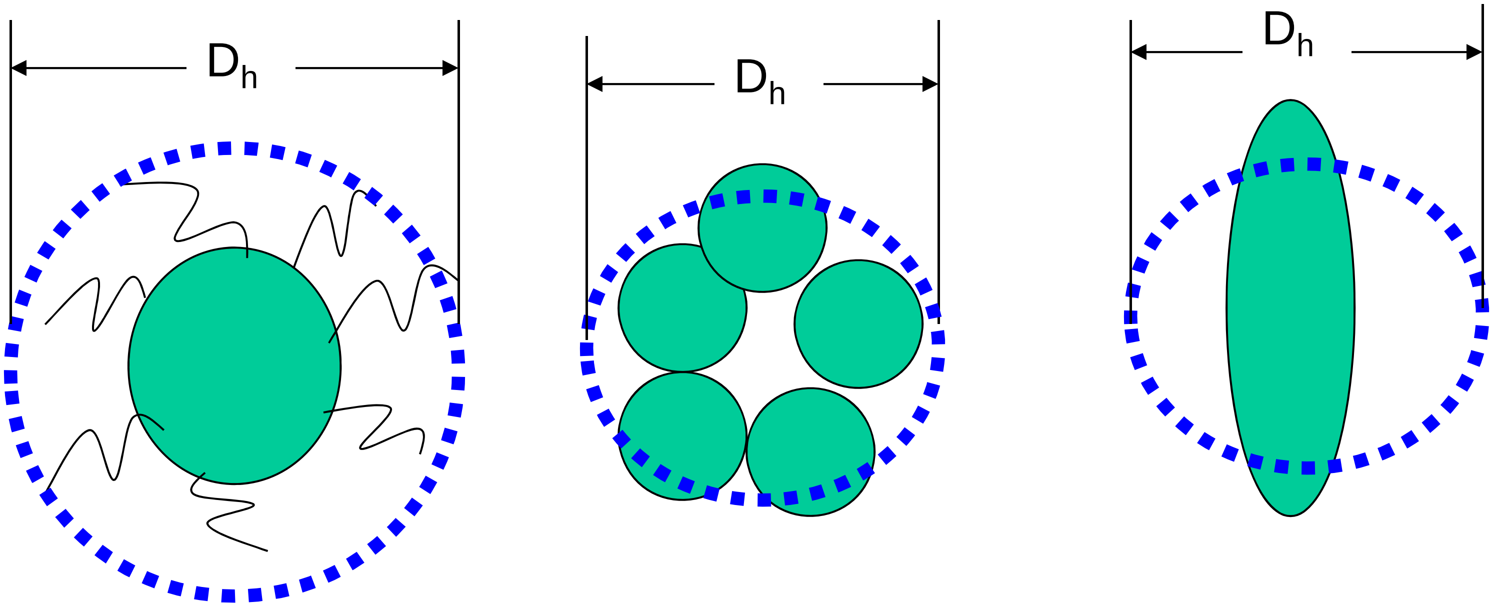
$$D_h = \frac{k_B T}{3\pi\eta(T) D_t}$$

Note effect of temperature!

Γ decay constant
D_t diffusion coefficient
q scattering vector
n refractive index
λ wavelength
θ scattering angle
D_h hydrodynamic diameter
η viscosity
k_B Boltzman's constant

What is Hydrodynamic Size?

- DLS gives the diameter of a sphere that moves (diffuses) the same way as your sample.

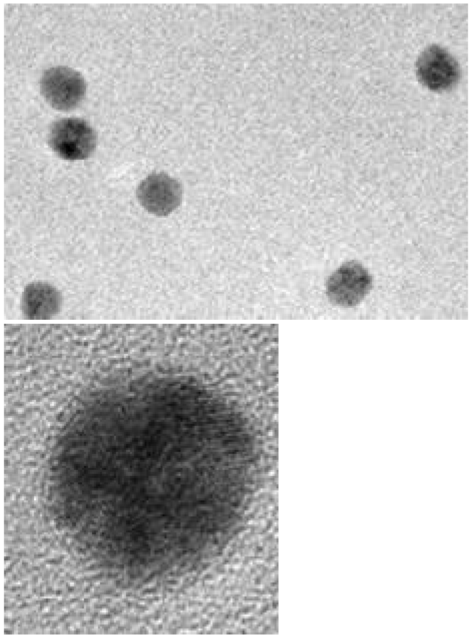


Hydrodynamic Size

- The instrument reports the size of sphere that moves (diffuses) like your particle.
- This size will include any stabilizers bound to the molecule (even if they are not seen by TEM).

Gold Colloids

Technique	Size nm
Atomic Force Microscopy	8.5 ± 0.3
Scanning Electron Microscopy	9.9 ± 0.1
Transmission Electron Microscopy	8.9 ± 0.1
Dynamic Light Scattering	13.5 ± 0.1



SEM (above) and TEM (below) images for RM 8011

Why DLS?

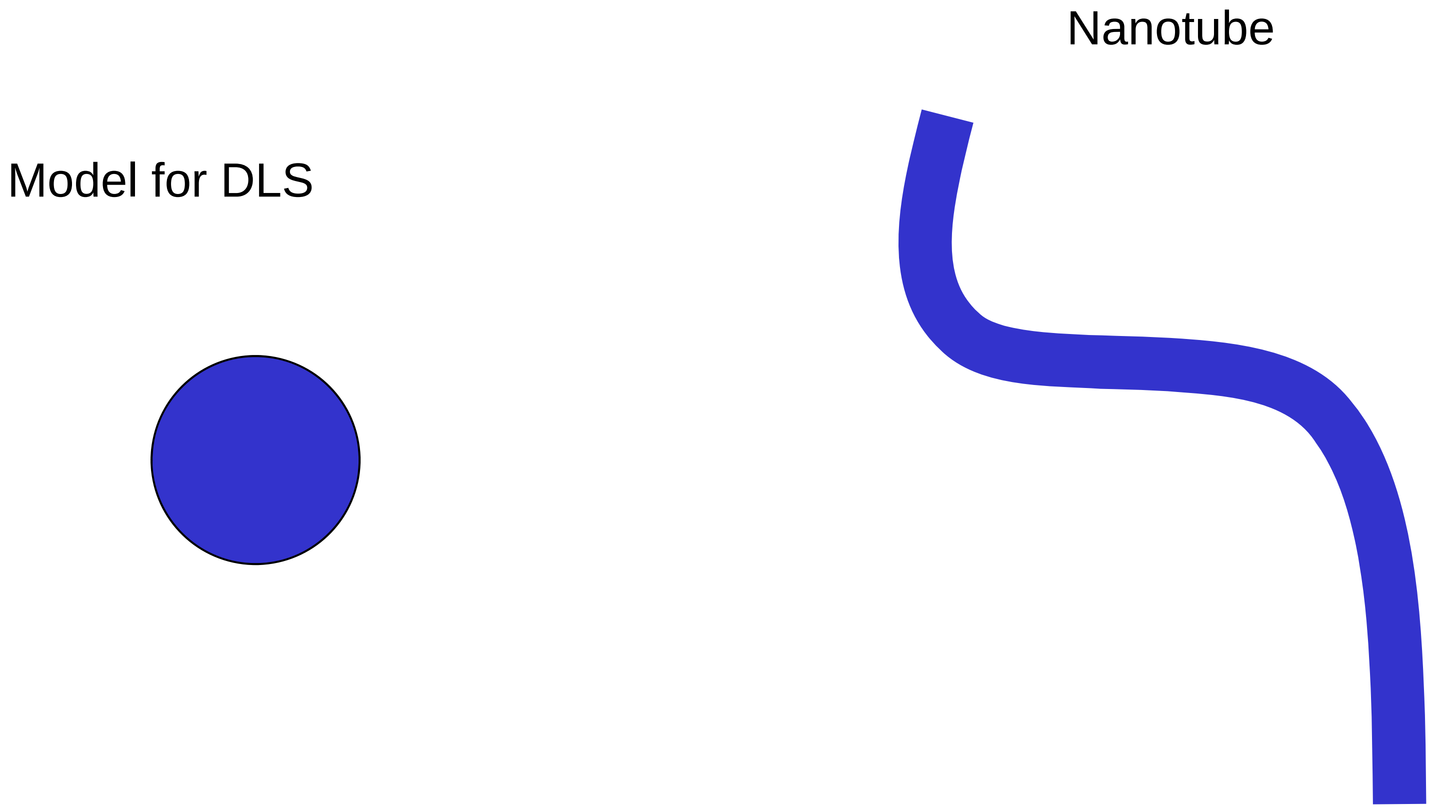
- Non-invasive measurement
- Requires only small quantities of sample
- Good for detecting trace amounts of aggregate
- Good technique for macro-molecular sizing

New Nanoparticle Analyzer

- Single compact unit that performs size, zeta potential, and molecular weight measurements.

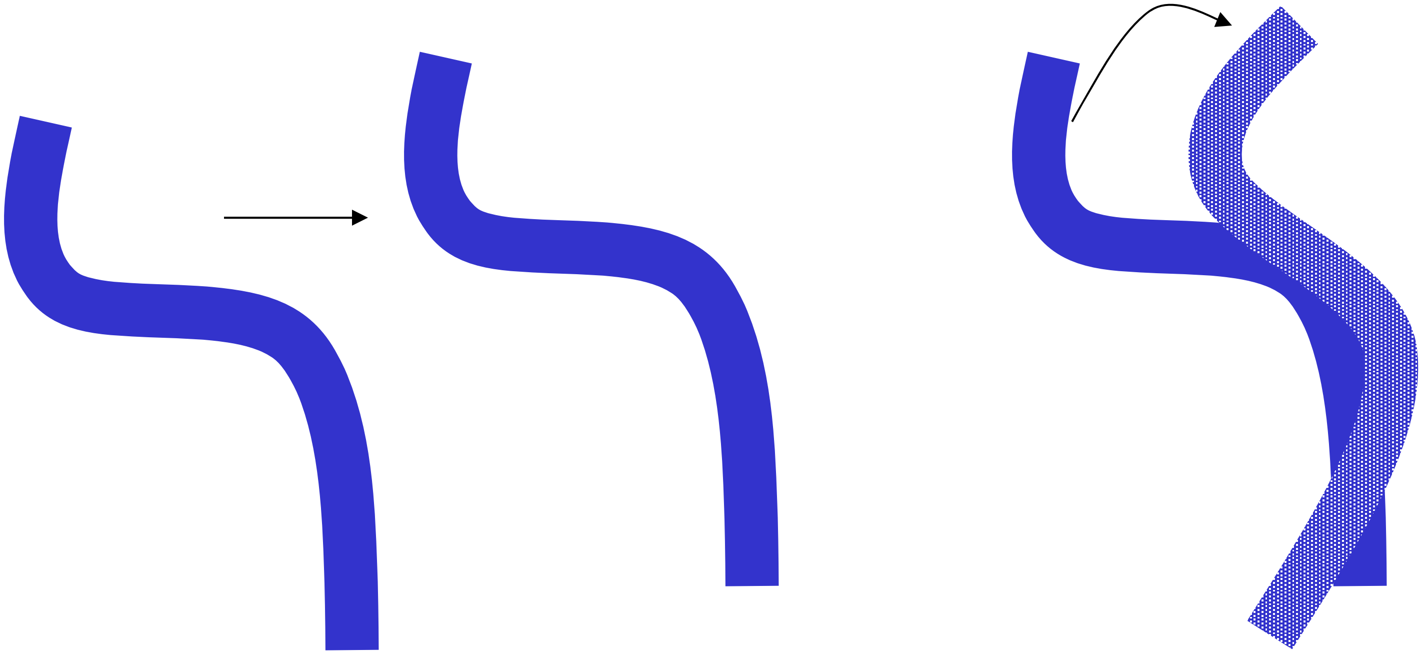
Carbon Nanotubes

- Nanotubes are not spheres….hence the “tube” in the name.



Motion of Carbon Nanotubes

- Two types of motion: Translation and rotation



- Here I ignore rotation

What to do?

- Recognize that big tubes diffuse slowly and recognize that DLS is a fast, easy size indicator.
- Try to match DLS data to model using some other information

$$D_t = \frac{k_B T}{3\pi\eta L}\left[\ln(L/d) + 0.32\right]$$

L= length
d=diameter

Nair, N., Kim, W., Braatz, R, and Strano, M. Langmuir 2008, 24, 1790-1795.

Measurement of Nanotubes

- Well characterized: We knew aspect ratio (1000) and diameter (0.7 to 0.9 nm) in advance
- Well dispersed: few if any aggregates
- Expect value between 97 and 125 nm using equation on previous slide
- Obtain a nice match.

	Z-avg. Diameter, nm
Repeat 1	115.0
Repeat 2	104.5
Repeat 3	105.3
Repeat 4	109.5
Repeat 5	115.2
Repeat 6	106.2
Average	**109.3**
Standard Deviation	4.8
Coefficient of Variation	4.4%

How to Measure with DLS?

- Ensure that the sample is well dispersed
- Ensure that the tubes are not colliding (dilute sample)
- Use results as an indicator of tube size (or aggregation if you are thinking about dispersion quality)

- Don’t blindly turn D_h into L

Other NanoSamples

- Nanometals
  - Nanogold
  - Nano Iron Oxide
- Nanorods
- Colloidal particles

Questions?
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Thank you

ありがとうございました

Cảm ơn

ขอบคุณครับ

谢谢

اشْكُر

Gracias

Grazie

Σας ευχαριστούμε

धन्यवाद

நன்றி

Tacka dig

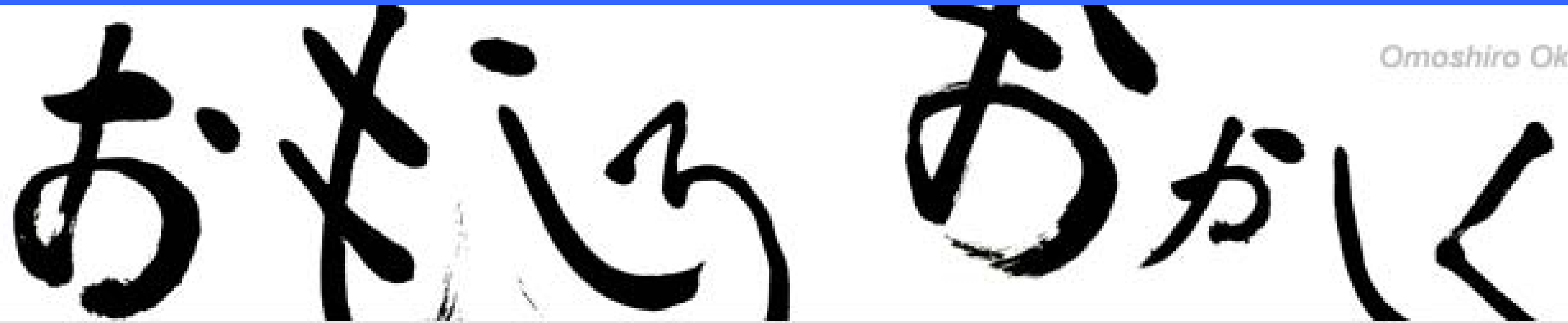
Danke

Merci

Obrigado

감사합니다

Большое спасибо



Omoshiro Okashiku