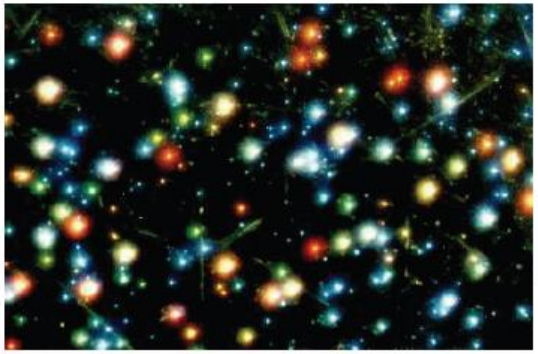
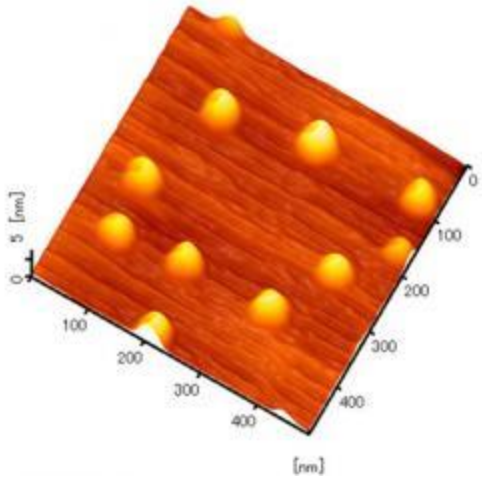
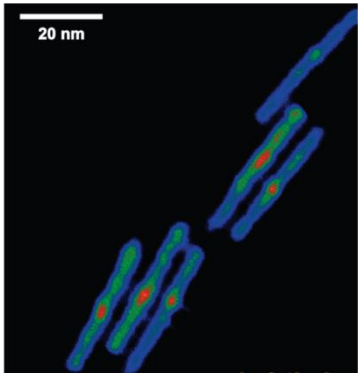
Nanoscience in the Classroom: Nanoparticles, light, and solar energy





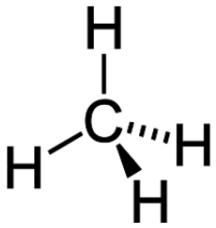


Prashant K Jain

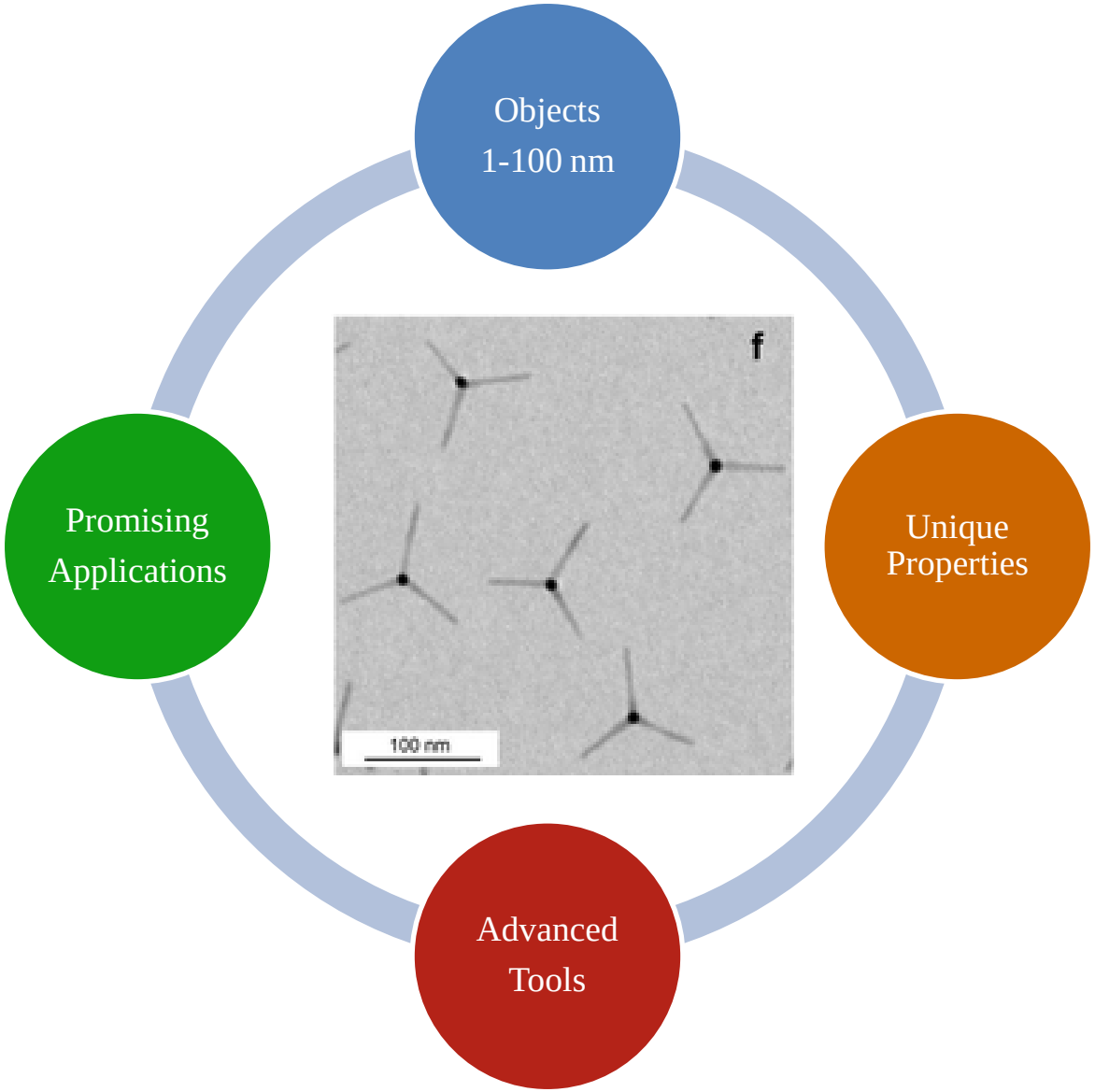
University of Illinois Urbana Champaign

Chemistry, Physics, & Beckman Institute

Nanoscience and Nanotechnology



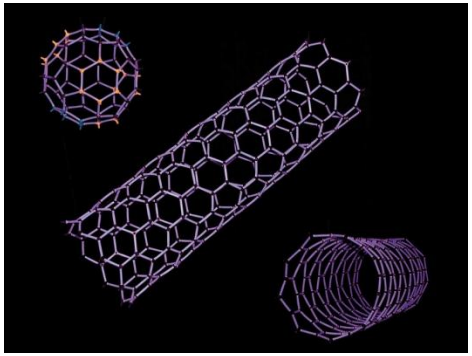
Molecule



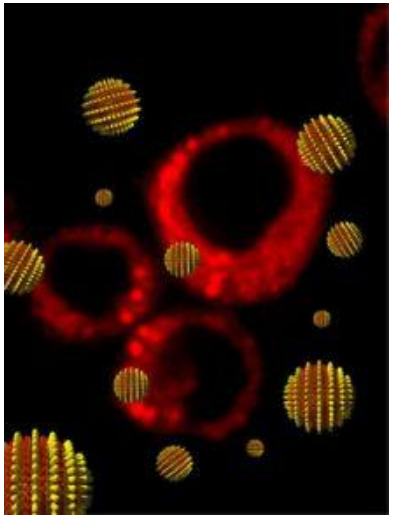
Bulk crystal

Why Do We Care About Structuring, Controlling, and Understanding Matter at the Nanoscale ?

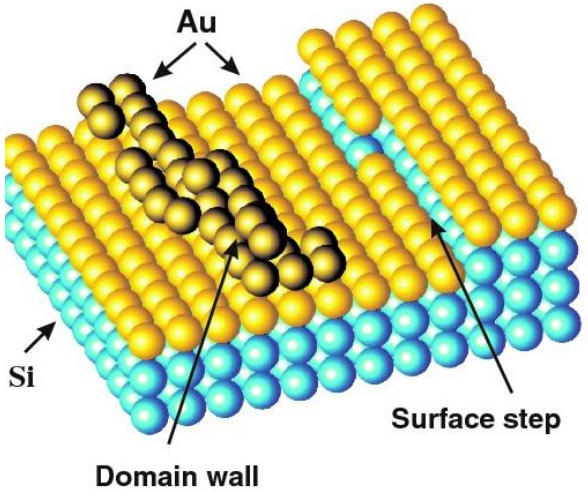
Novel Physics and Chemistry



New Processes and Materials

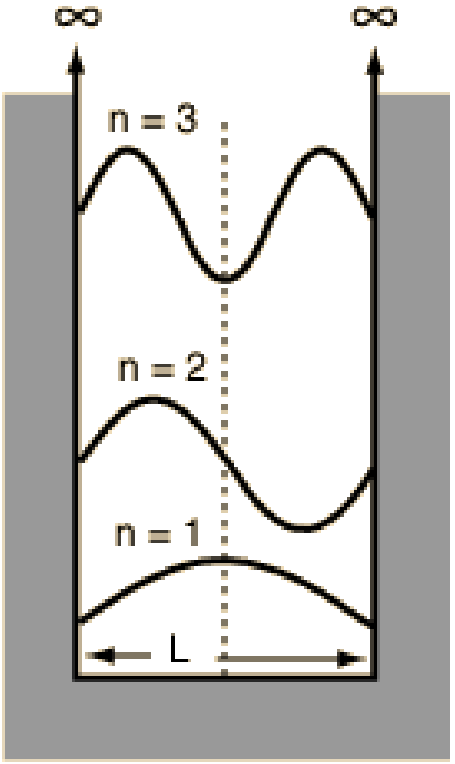


The right size for integration



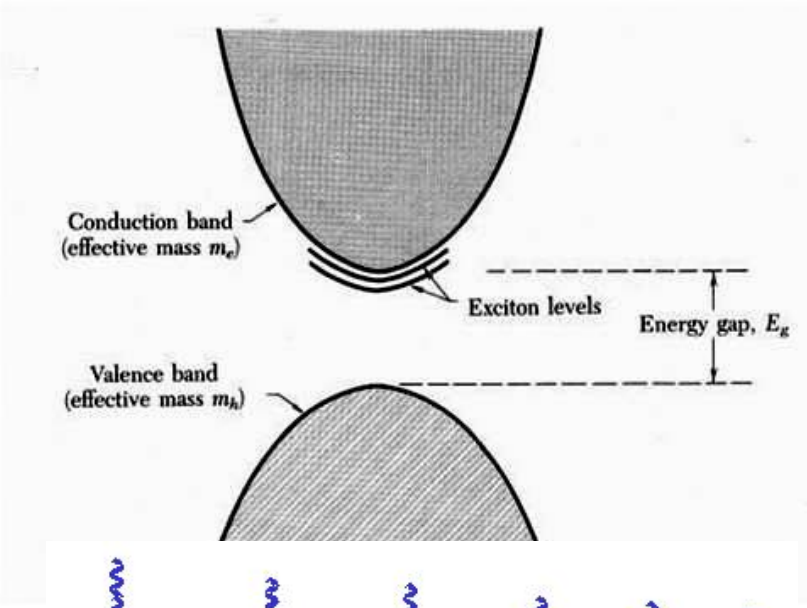
Surfaces and interfaces

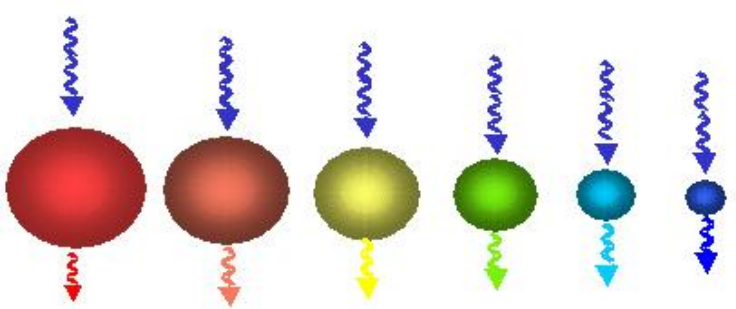
A Colorful Rendition of Quantum Mechanics



x = 0 at left wall of box.

$$\Psi(x) = A\sin kx, \quad \Psi(0) = \Psi(L) = 0$$





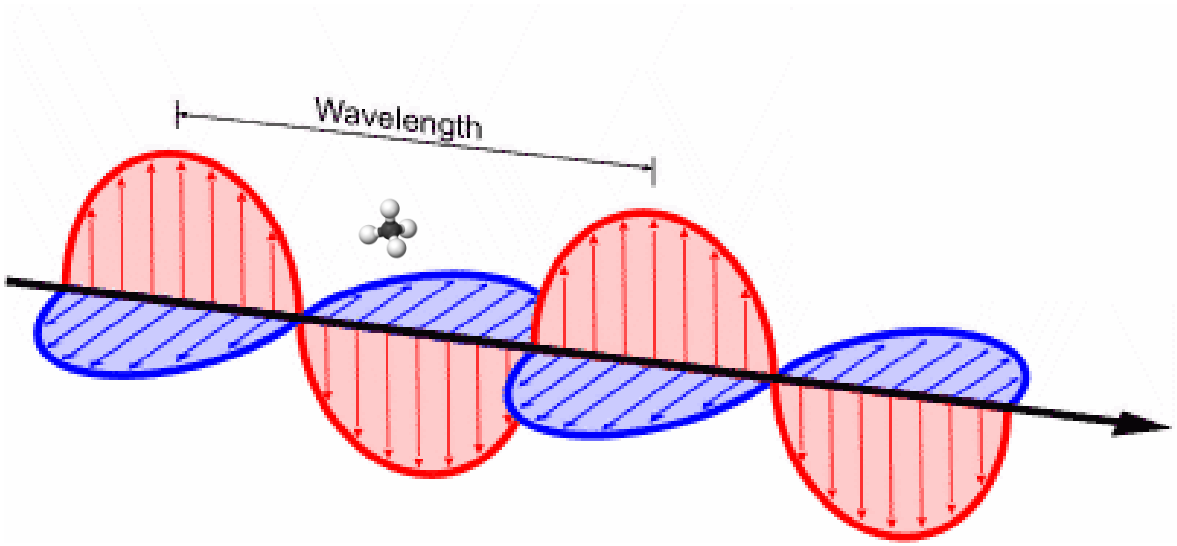
See work of Brus, Efros, Alivisatos, Bawendi

How I Found Nanoscience?

Prof. Mostafa A. El-Sayed, Regents Professor and Julius Brown Chair, Georgia Tech
Physical Chemist and spectroscopist, National Medal of Science 2008

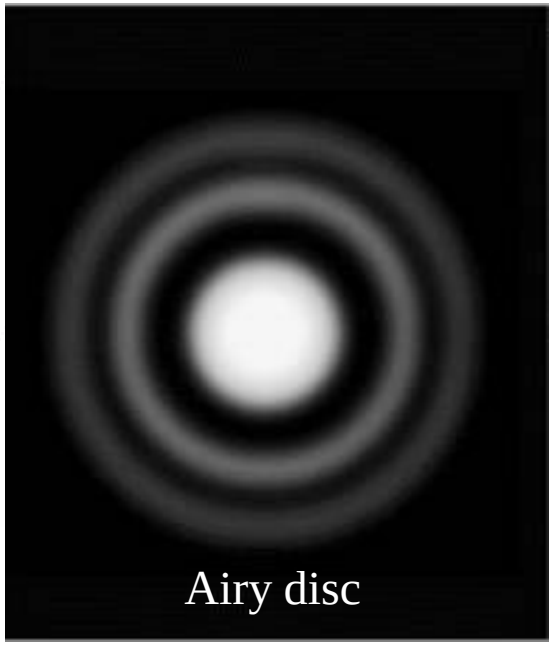
Interfacing to the molecular world using light

Biosensing, structure determination, solar cell or water splitting, optical data writing



A molecule and light

$a/\lambda << 1$

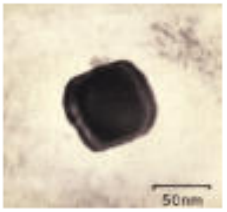


Brilliant Color from Metals on the Nanoscale

Luster decorated XVI century
Renaissance pottery, Gubbio, Italy

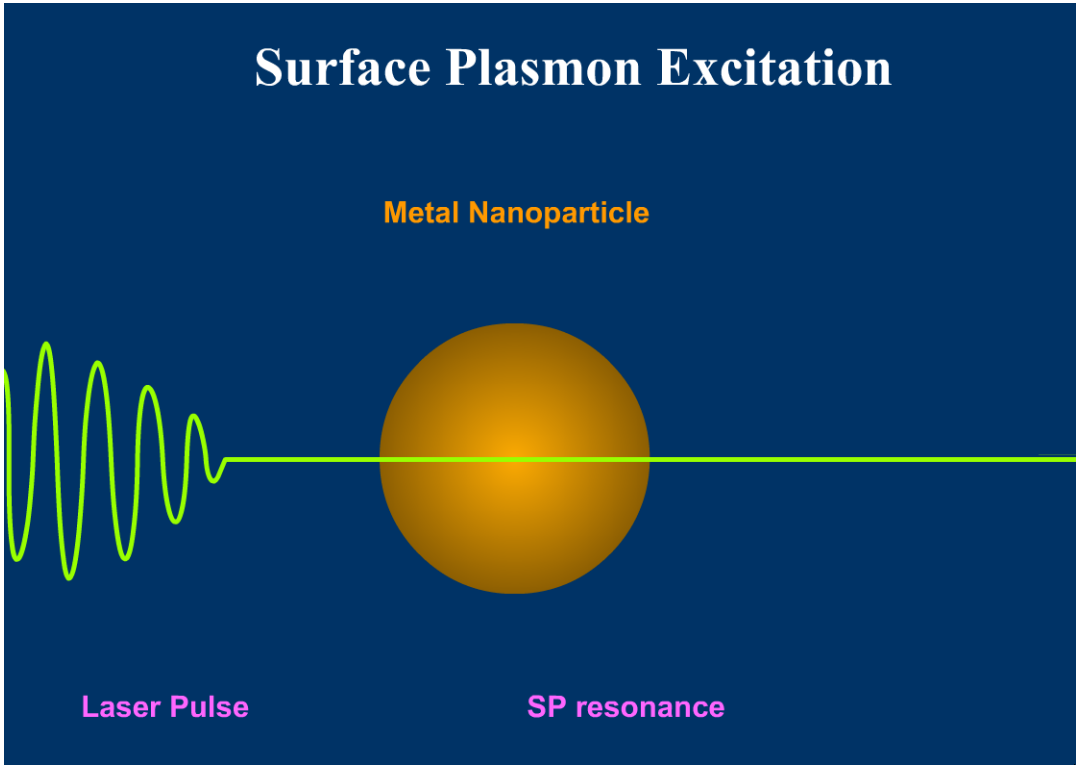
The Lycurgus Cup, Roman glass IV century

70% silver and 30 % gold



Padovani et al., *J. Appl. Phys*. 2003, 93, 10058 .

The Physics of Metal Nanoparticles



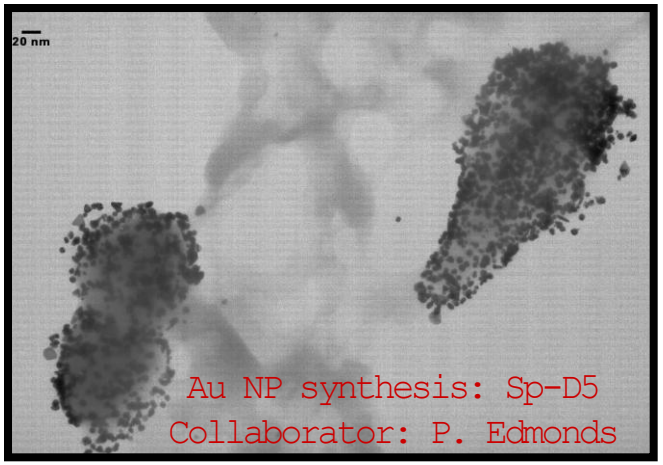
Light “confined” to the nanoscale by means of a resonant coherent free electron oscillation

Jain, Huang, El-Sayed, and El-Sayed , *Acc. Chem. Res.* 2008, 41, p1578

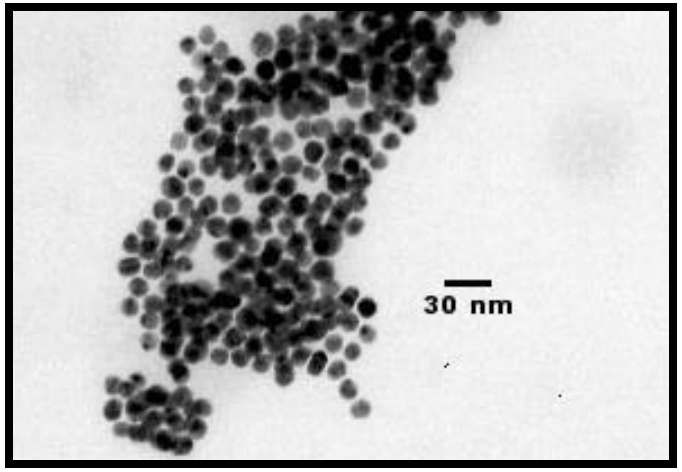
Synthesizing Metal Nanostructures

Reduction of Ionic Gold

Bacteria



Sodium Citrate (Turkevich/Frens)

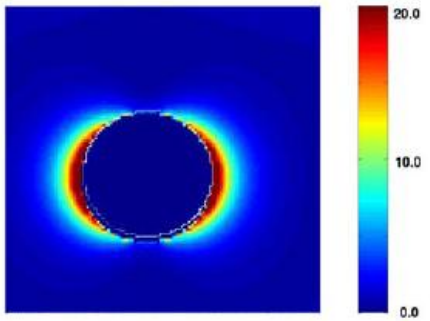


Average diameter: 13 nm

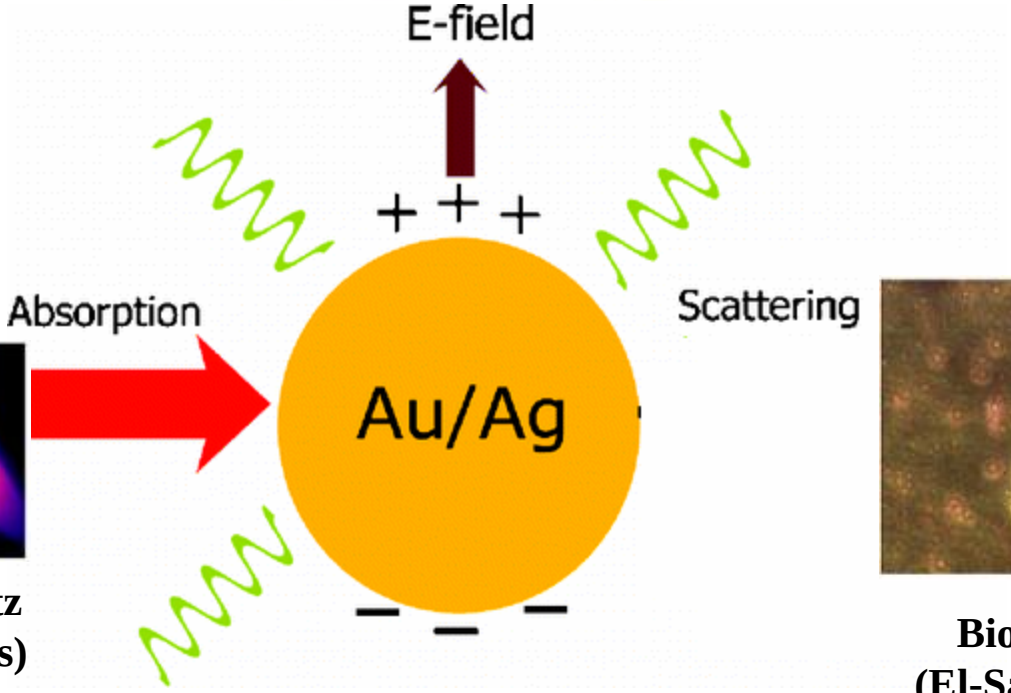
Michael Faraday's colloidal gold

Prashant K. Jain, Wei Qian, Mostafa A. El-Sayed, *J. Phys.Chem. B*, 110(1), 2006, 136-142.

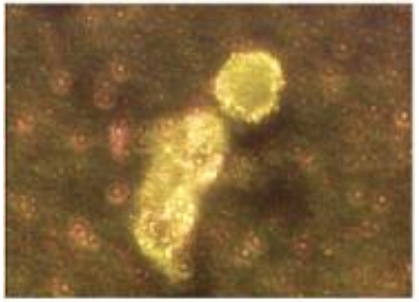
What can we do with this Confined Light?



Enhancement of light absorption in solar cells



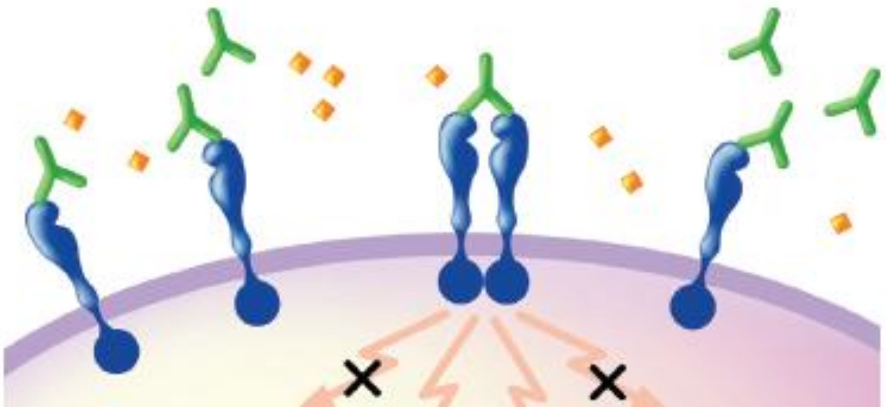
Cancer Therapy, Nanopartz (Halas and El-Sayed groups)



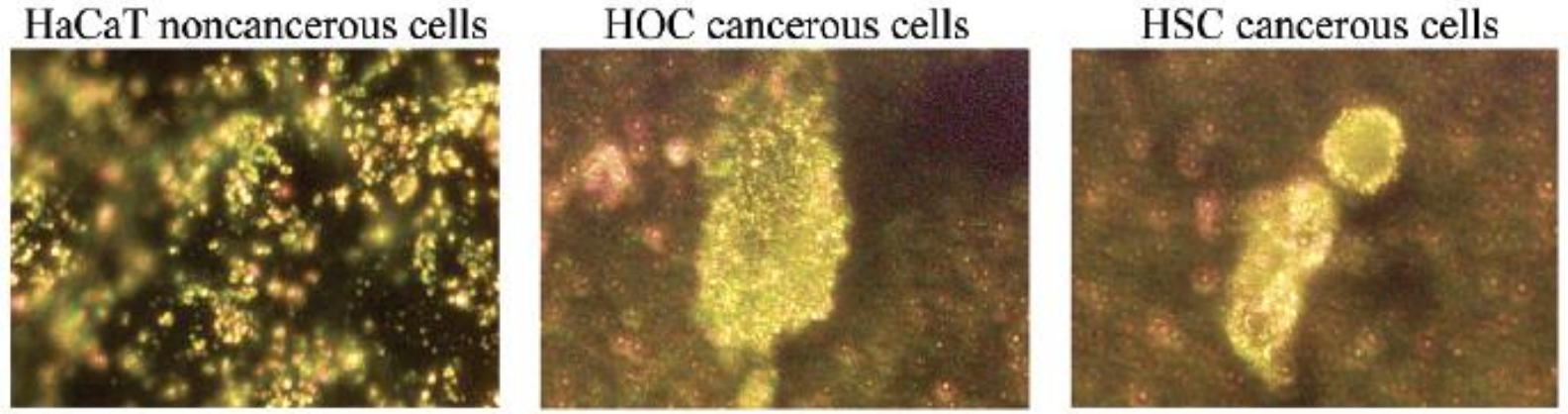
Bio-Imaging (El-Sayed group)

Huang, Jain, El-Sayed, El-Sayed, *Nanomedicine*, 2(5), 2007, 681; Jain, Lee, El-Sayed, El-Sayed, *JPCB*, 2006, 110, p7238,;

Targeting Cancer Cells Using Nanoparticle Bioconjugates



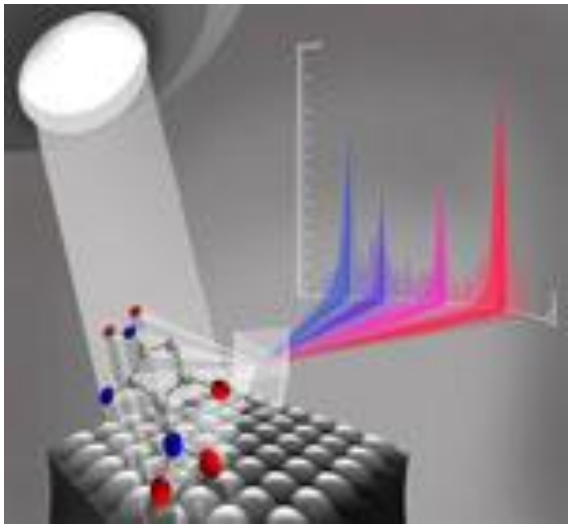
Epithelial Growth Factor Receptor over expressed on cytoplasmic membrane of most epithelial cancer cells. 35-nm Au nanoparticles are conjugated to anti-EGFR monoclonal antibodies for selective targeting.



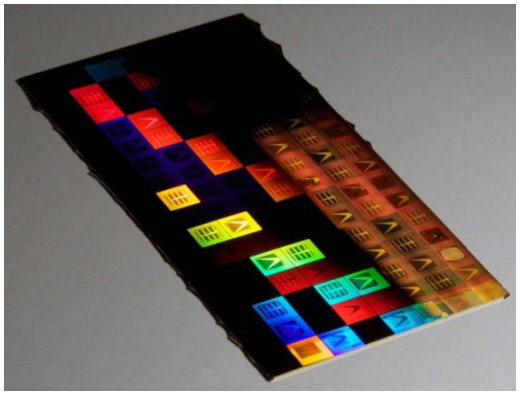
El-Sayed, I.H.; Huang, X., El-Sayed, M.A. *Nano Letters* **2005**, 5, 829.

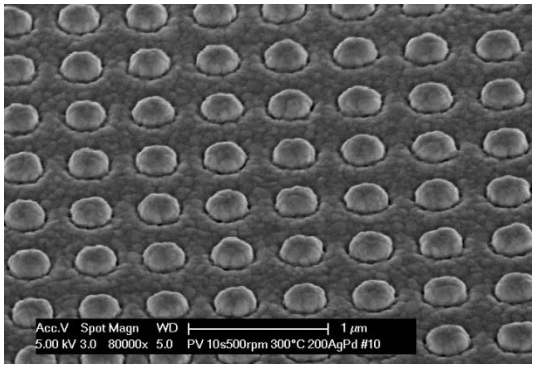
Novel Spectroscopy Using Confined Light

C. V. Raman and his spectrometer

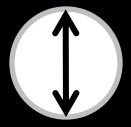


$\boldsymbol{E}^4$ or 10^6-10^7 enhancement of Raman



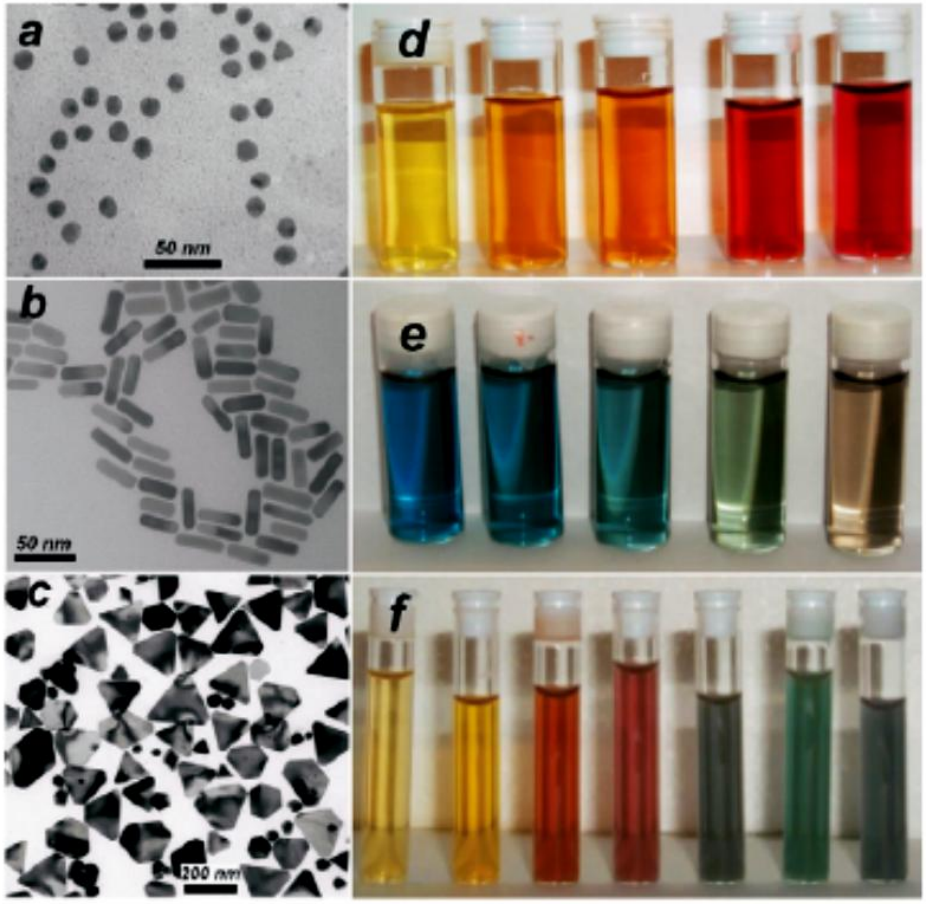


Atwater group: Ultrathin solar cells using light trapping abilities of metal nanostructures



polarizer

Size- and shape-dependent color

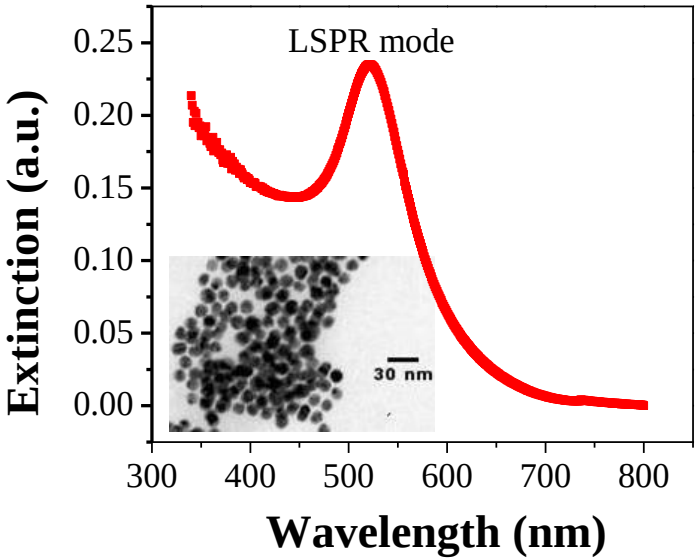


Ag, Au

Picture from Liz-Marzan, L. M., *Materials Today* (2004), **7** (2), 26

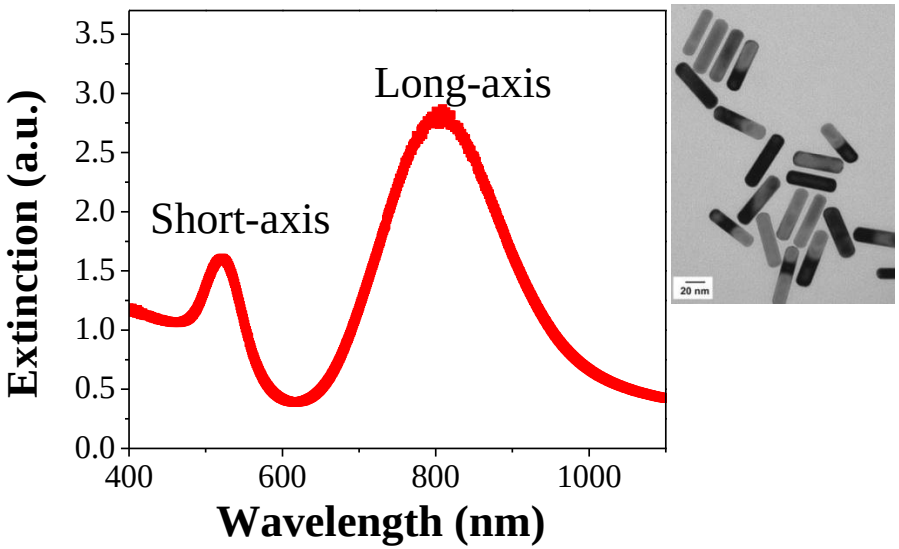
Shape Tunability of Properties at the Nanoscale

SPHERE

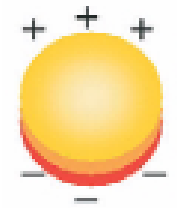


13-nm Au NS via citrate method

ROD



3.2 AR Au NRs via Murphy method



See work of Link and El-Sayed, Catherine Murphy

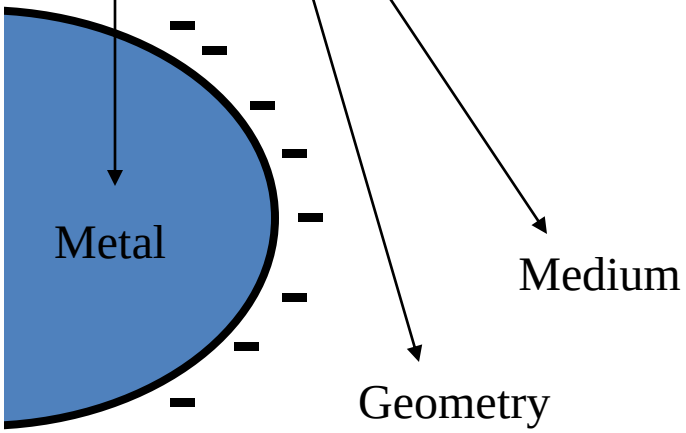
Color and quality of nanoscale confined light is size, shape, and medium dependent

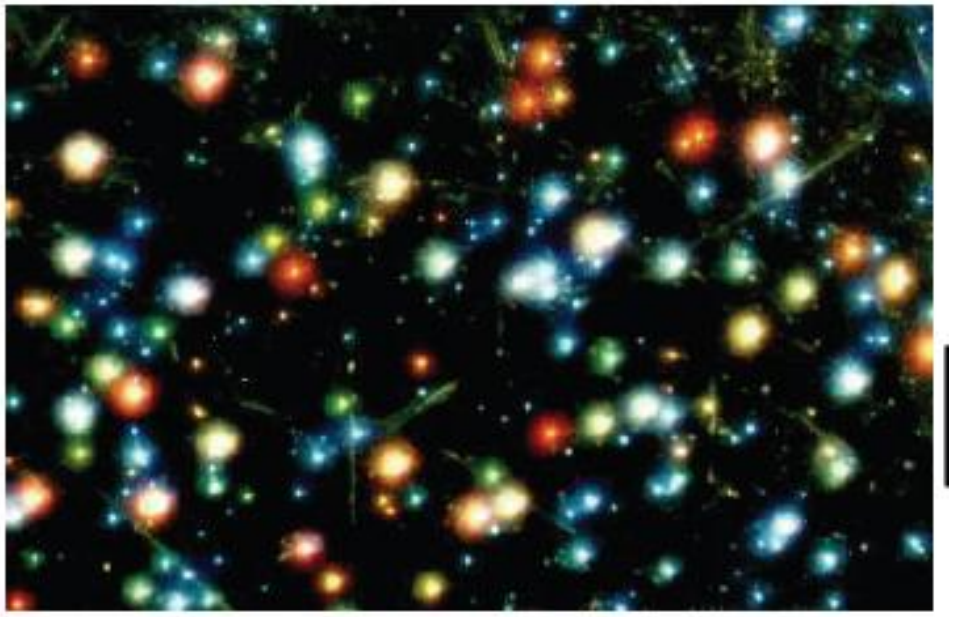
$$\alpha(\omega) = (1+\kappa)\varepsilon_0 V\left(\frac{\varepsilon(\omega)-\varepsilon_m}{\varepsilon(\omega)+\kappa\varepsilon_m}\right)$$

α = Polarizability of the metal sphere
ε_0 = Permittivity of free space
ε_m = Dielectric constant of medium
ε = Complex dielectric function of metal
κ = Geometric factor

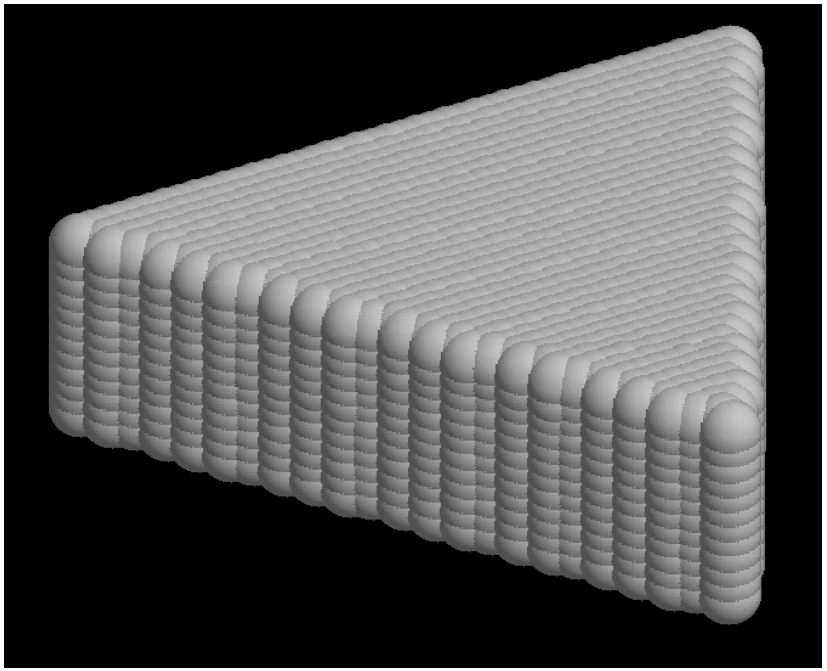
Max at ω_{lspr} where:

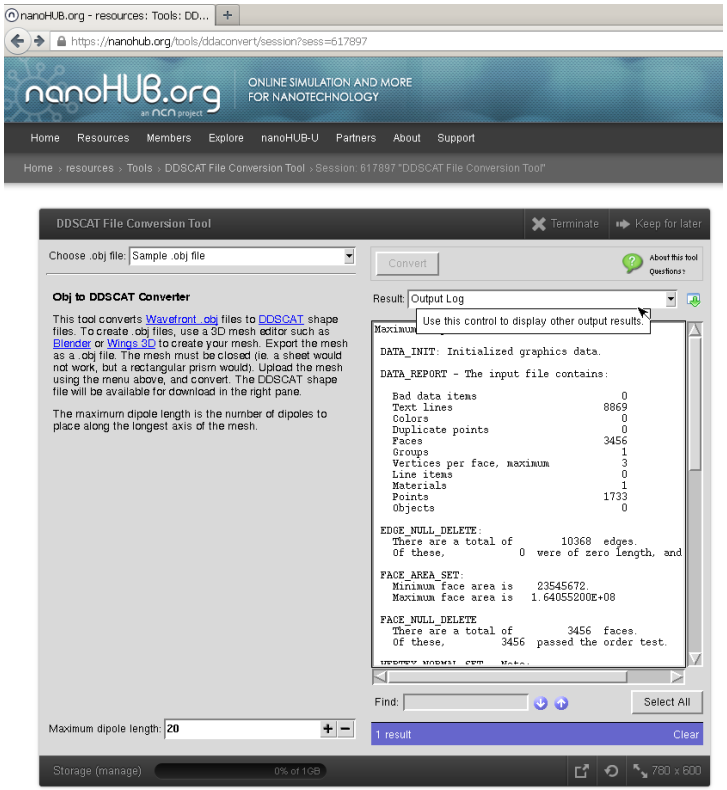
$$\varepsilon_r = -\kappa\varepsilon_m$$





Electrodynamic Simulations: Discrete Dipole Approximation





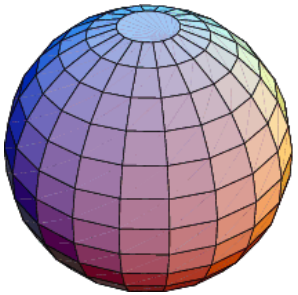
$$\boldsymbol{E}_{loc}(\boldsymbol{r}_i) = \boldsymbol{E}_{inc,i} + \boldsymbol{E}_{other,i} = \boldsymbol{E}_o \exp(i\,\boldsymbol{k}.\boldsymbol{r}_i - i\omega t) - \sum_{j \neq i} \boldsymbol{A}_{i,j}.\boldsymbol{P}_j$$

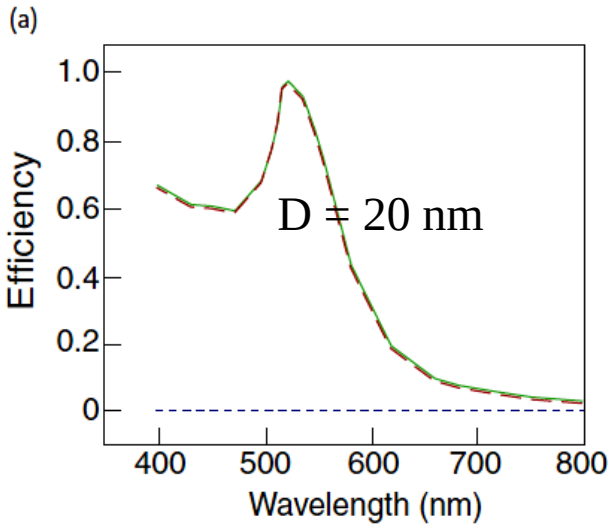
DDA includes finite-size retardation and multipolar effects and hence reproduces experiments better than quasistatic dipole models.

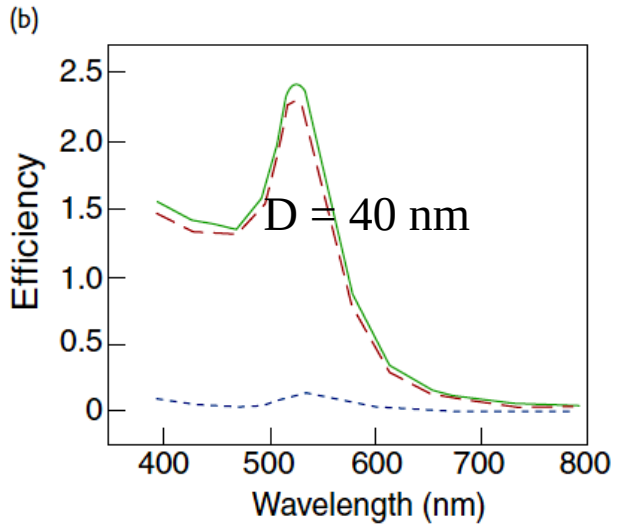
Draine, B. T.; Flatau, P. J. *J. Opt. Soc. Am. A* **1994**, *11*, 1491-1499 and Code: DDSCAT 6.1.

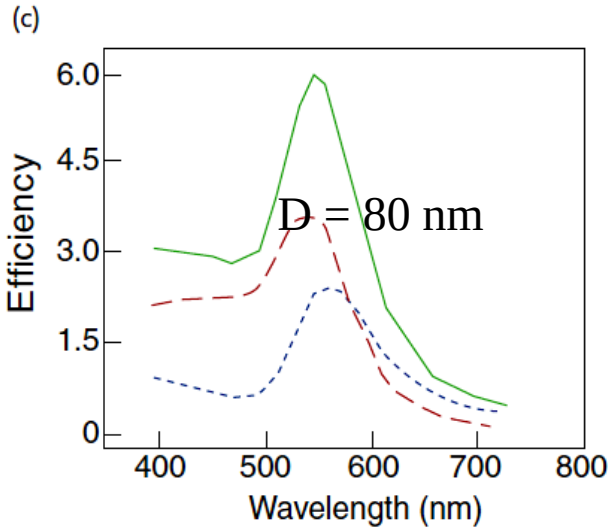
Role of Theory: Size Tunability of Optical Spectrum

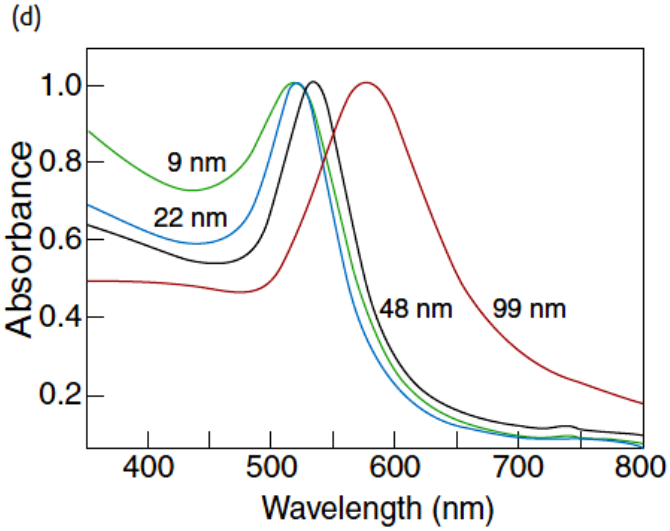
Mie theory





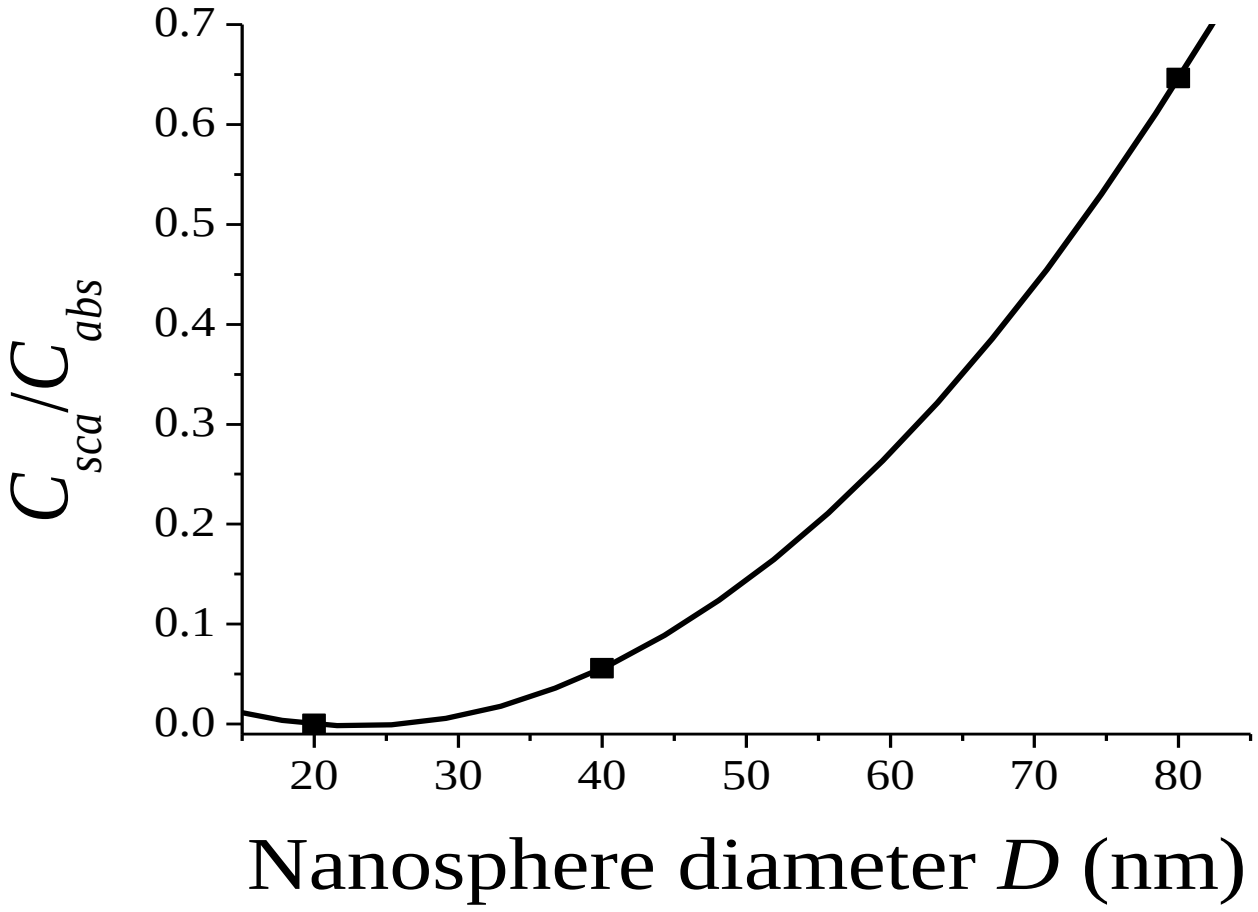


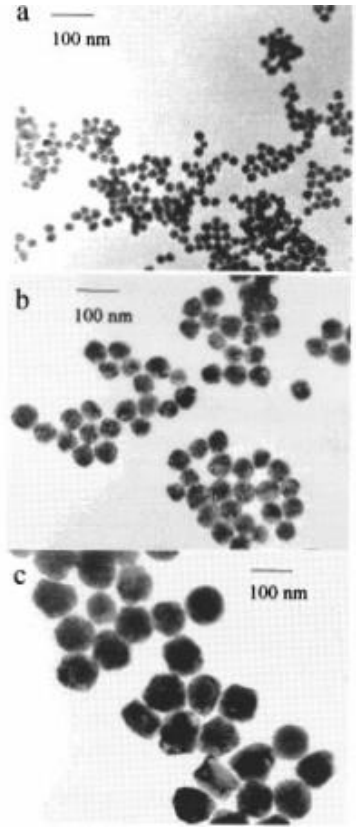




P. K. Jain, K. S. Lee, I. H. El-Sayed, M. A. El-Sayed, *J. Phys. Chem. B* 110(14), **2006**, 7238-7248.

Tuning Nanoparticle Size for Imaging/Therapy

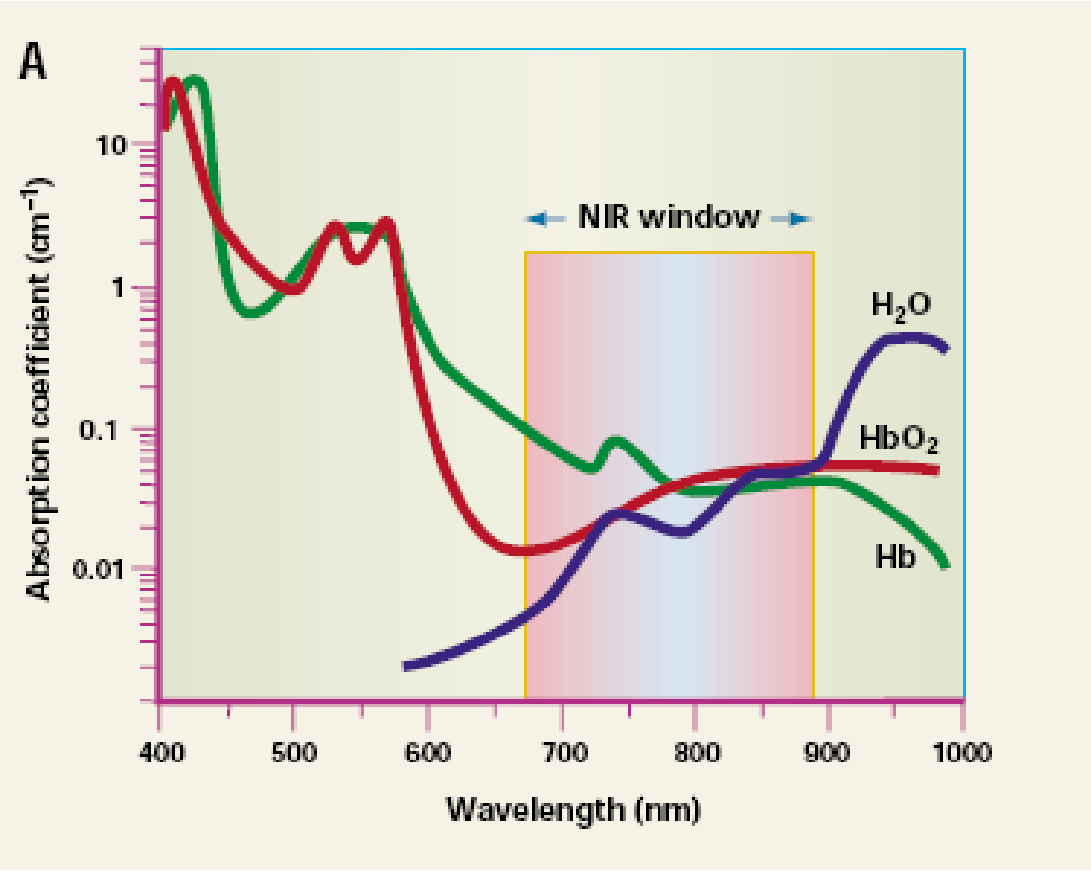




Link et al.

P. K. Jain, K. S. Lee, I. H. El-Sayed, M. A. El-Sayed, *J. Phys. Chem. B* 110(14), **2006**, 7238-7248.

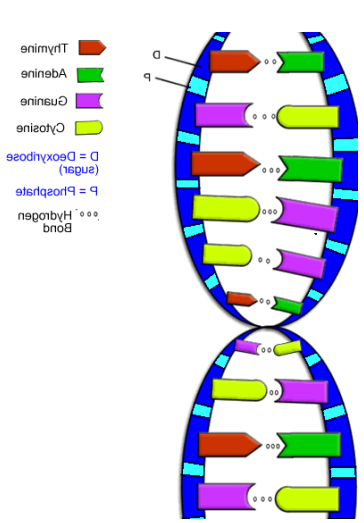
Biological Water Spectral Window in NIR

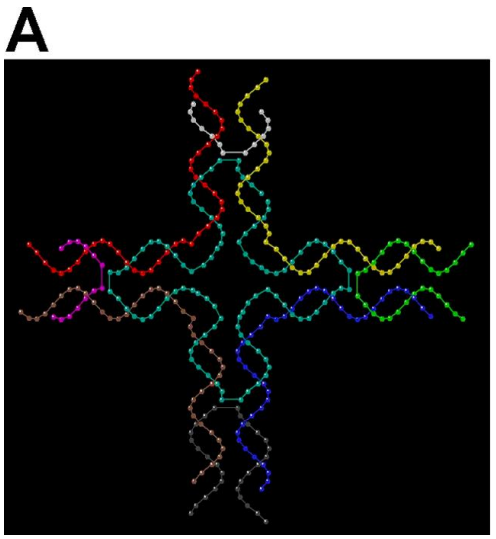


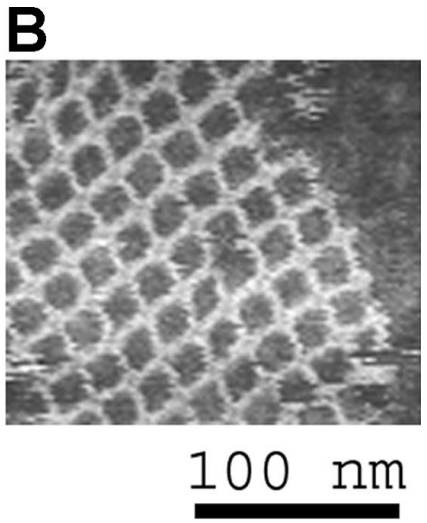
NIR light-resonant nanoparticles required for tissue penetration.

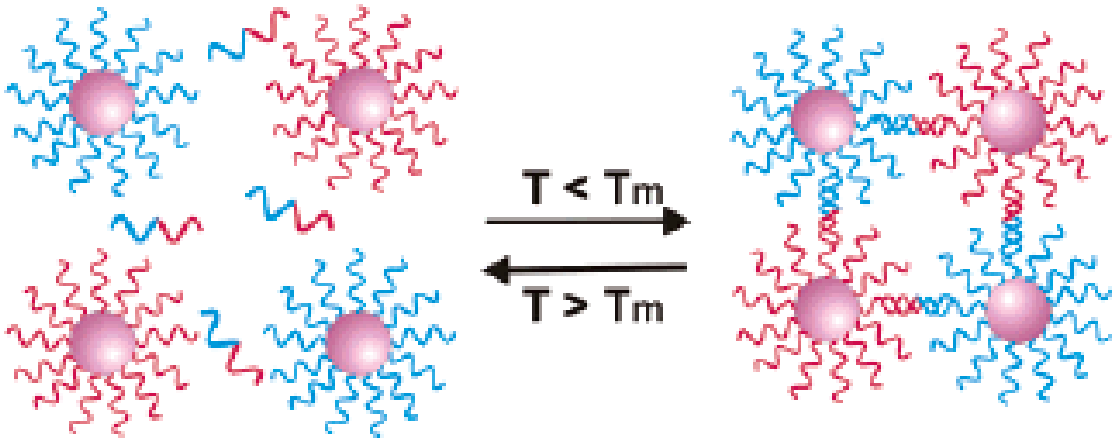
Weissleder, R., *Nat. Biotechnol.* 2001, 19, 316

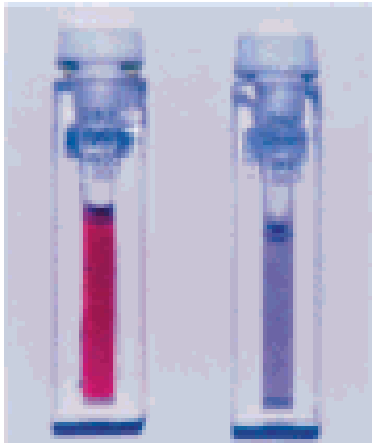
Self-assembly of nanostructures using molecular recognition





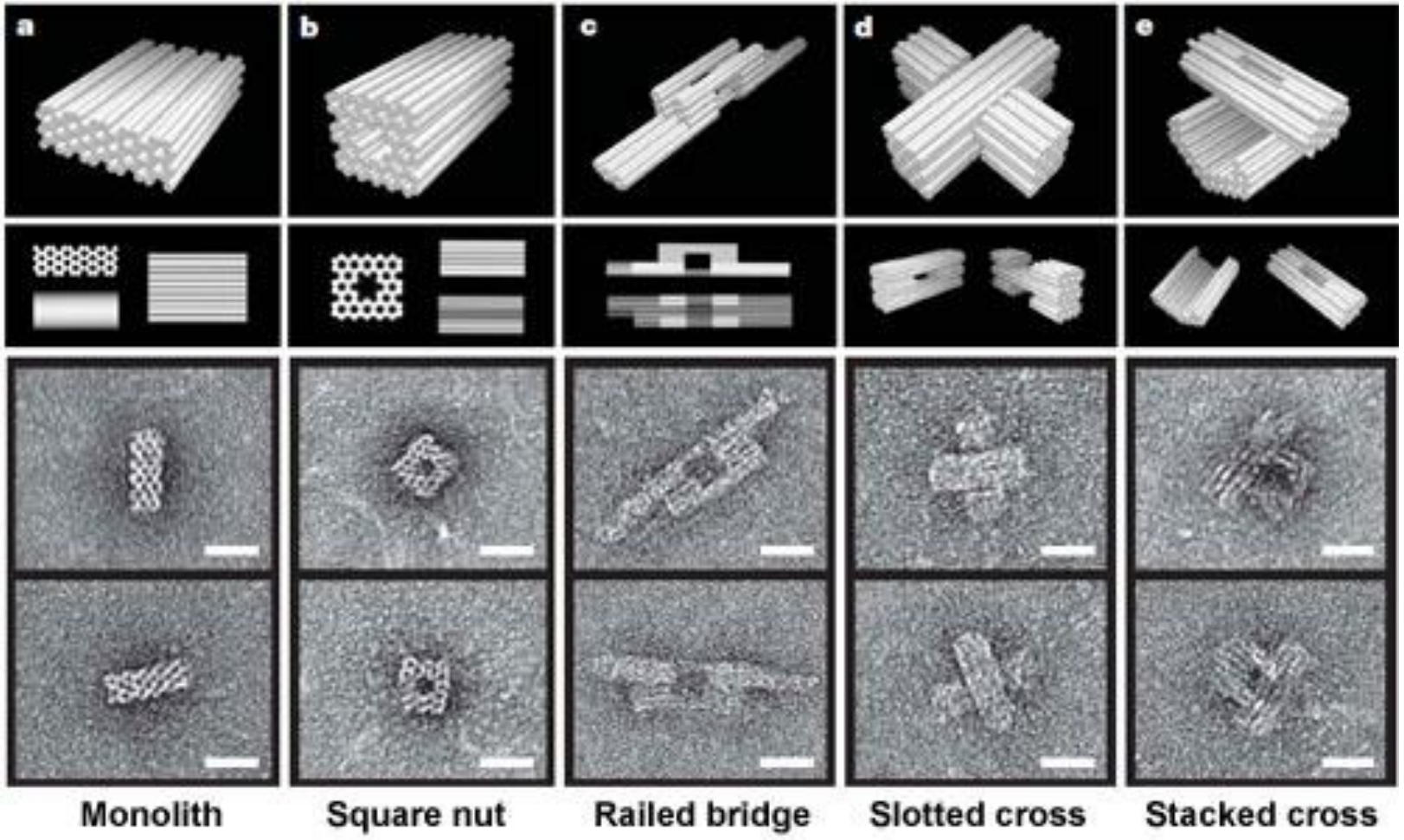






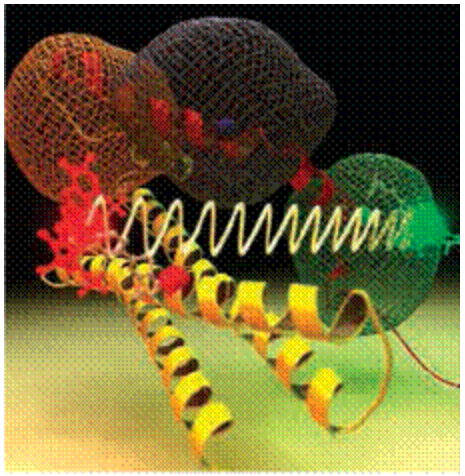
DNA Assembly method by Mirkin and coworkers

DNA Nanotechnology

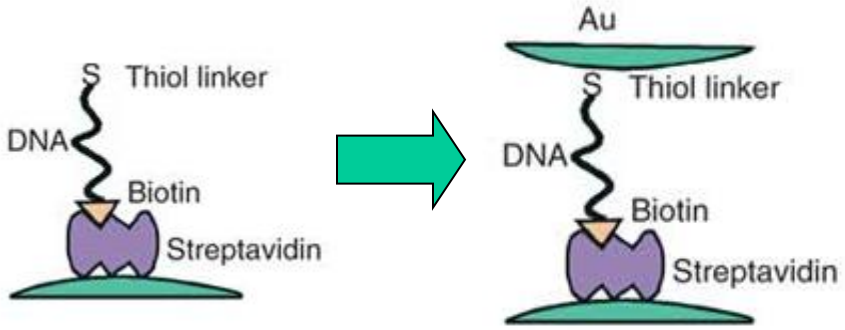


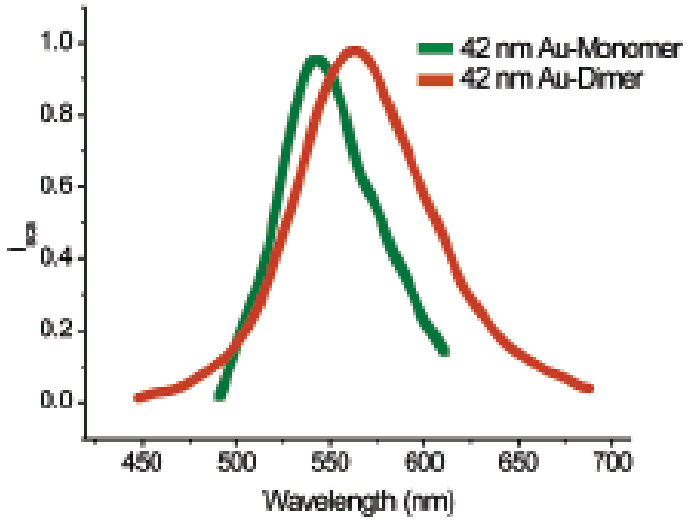
Shawn Douglas

Nanoscale Distance Rulers



R.F. Service, *Science*, 2005, 308, p1099



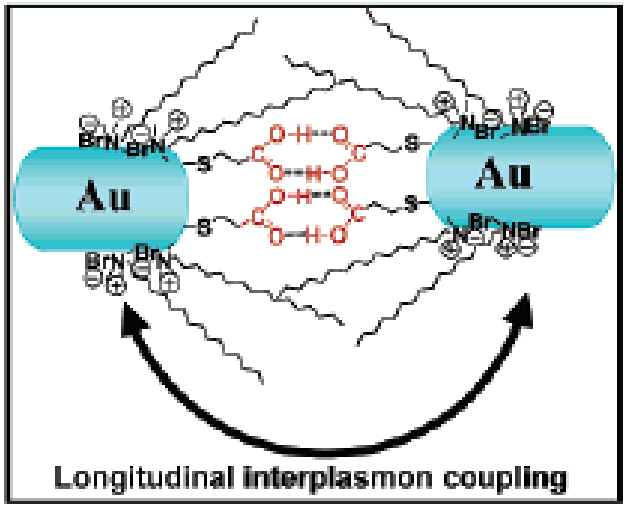


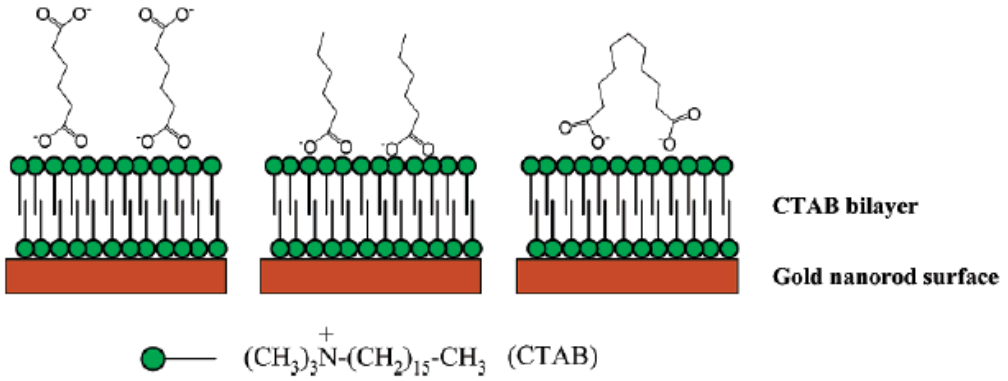
Change in spectral maximum → Readout for nanoscale distance and biomolecular activity

Plasmon field coupling can be used to measure nanoscale distances in biological systems

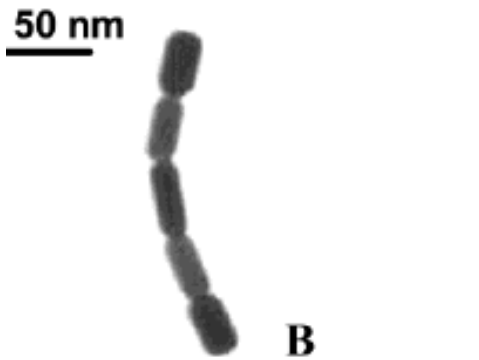
Sonnichsen, Reinhard, Liphardt, and Alivisatos, *Nature Biotech.* 2005, 23, p741

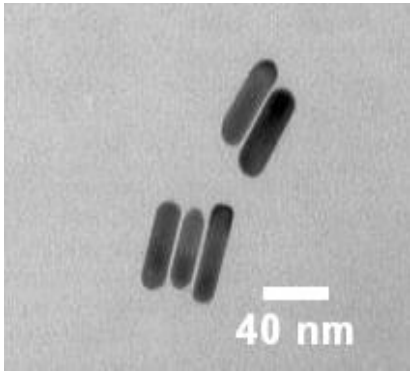
Controlled assembly of gold nanorods

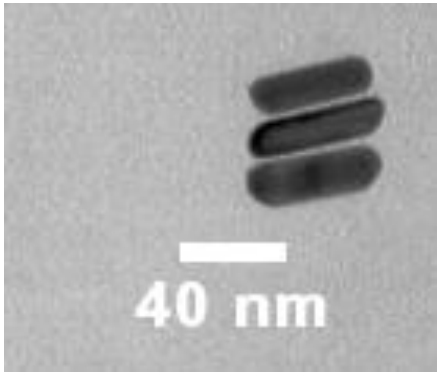




Orendorff, Hankins, & Murphy Langmuir, 2005, 21, p 2022.



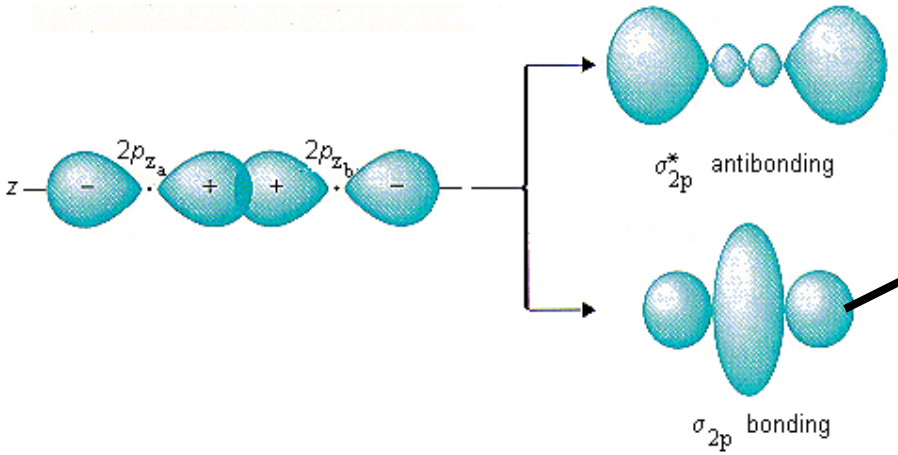


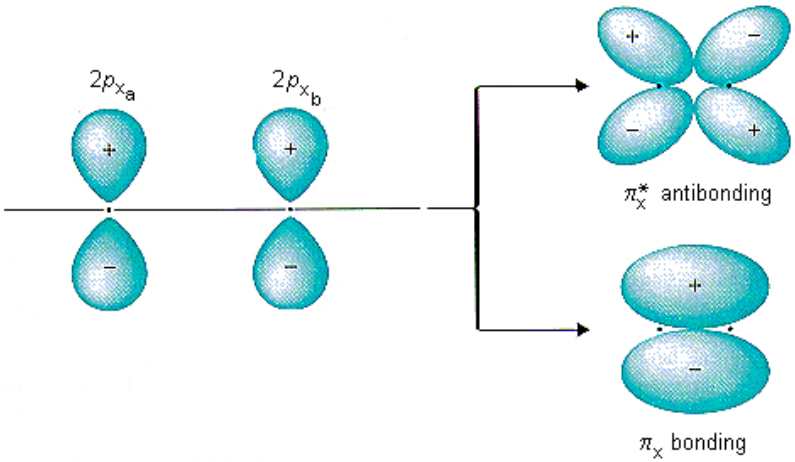


Jain, Eustis, and El-Sayed , *J. Phys. Chem. B*, 2006, 110, p18243.

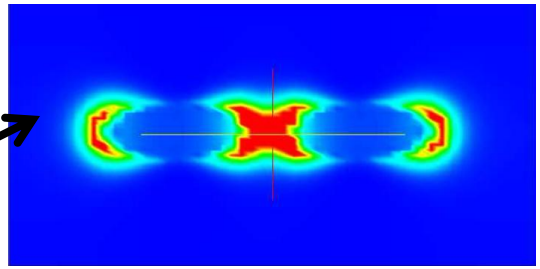
Just like electronic orbitals confined photons can hybridize too

MOLECULAR ORBITALS

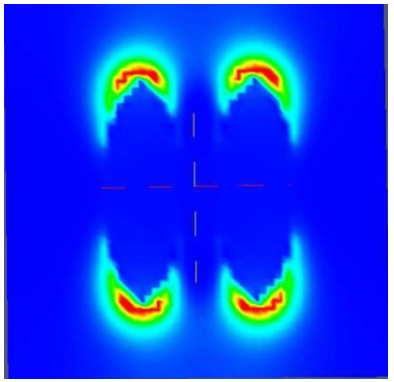




COUPLED PLASMONS



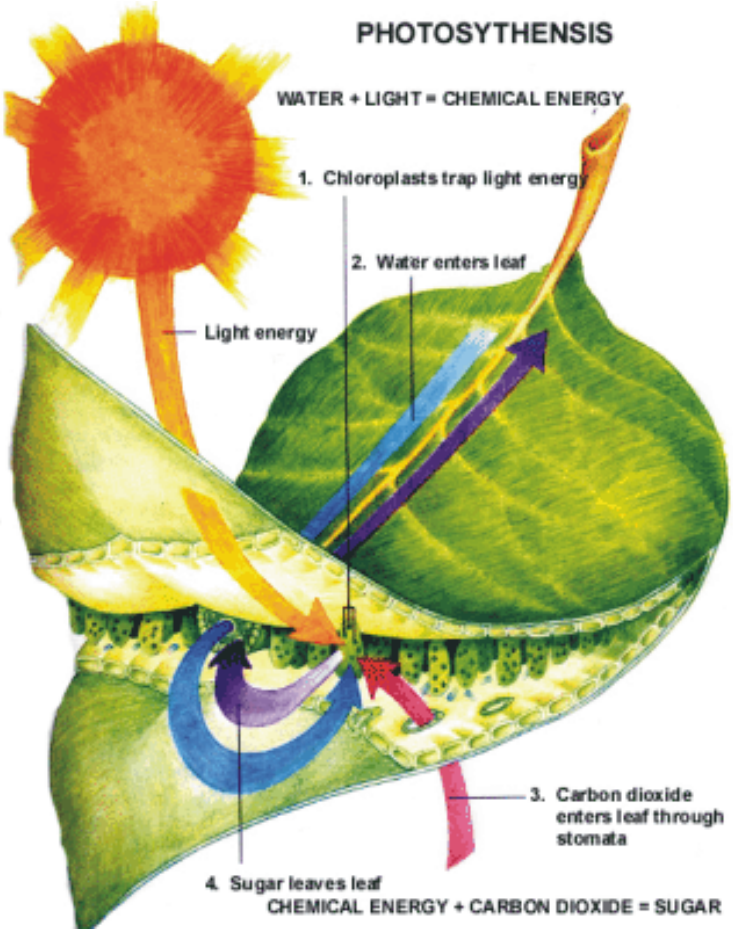
END-TO-END ↔



SIDE-BY-SIDE ↕

Using “nanoparticle molecules” to sculpt the field of the light

Renewable Energy and Photosynthesis

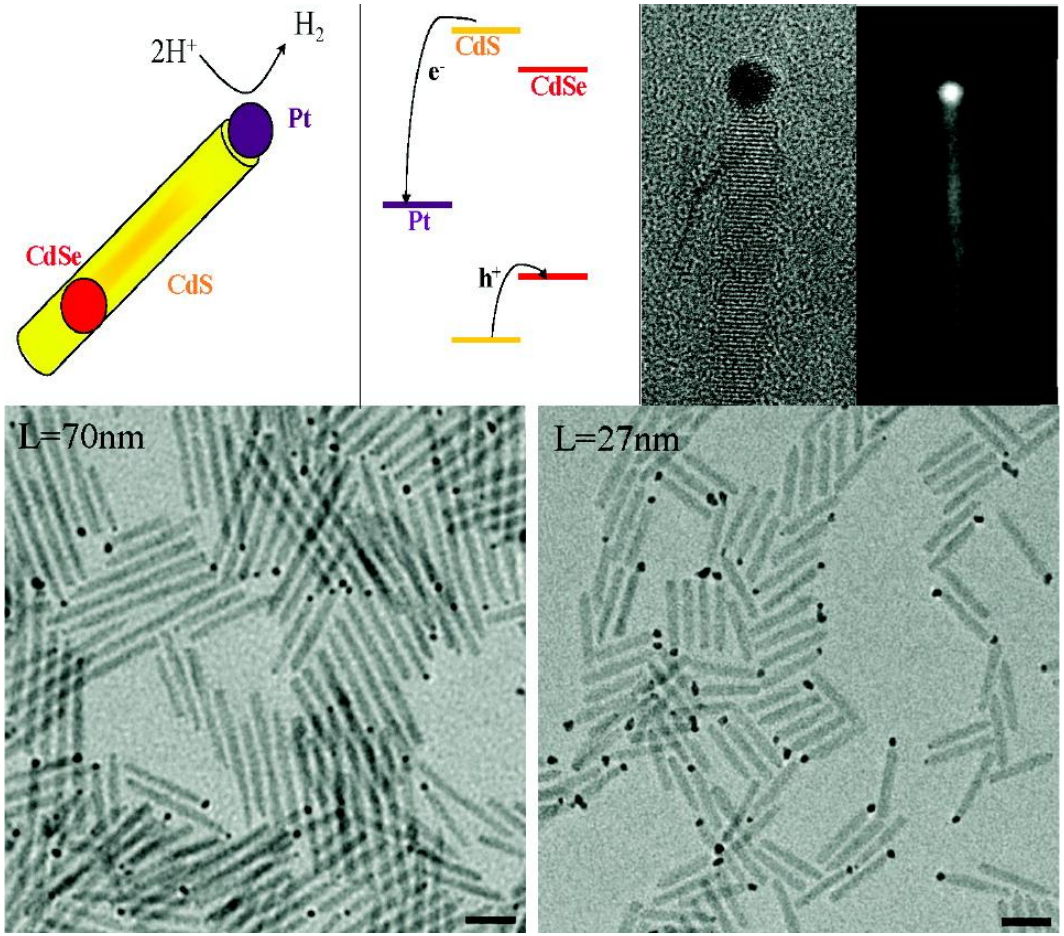


Sunlight and water: Abundant sources

Hydrogen: Fuel that can be stored and Transported

Can we use light energy to split water into hydrogen and oxygen efficiently?

Nanostructures for Artificial Photosynthesis



Courtesy: Lilac Amirav

Picture-perfect solar energy: Making Photographic Blueprints with the Sun

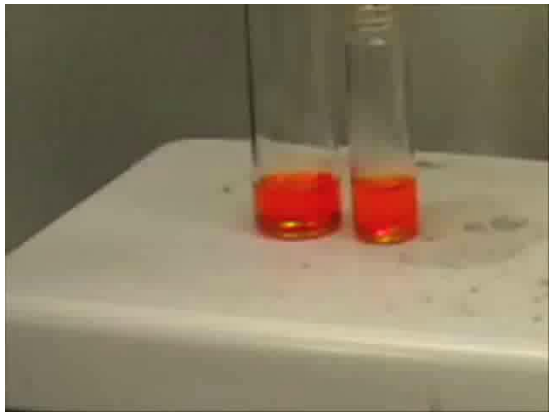
Picture-perfect solar energy: Making Photographic Blueprints with the Sun


March 17, 2010
Test Prep/Break
Writers' Workshop
Reading Zone
Math
Biographies

High Surface Access at the Nanoscale

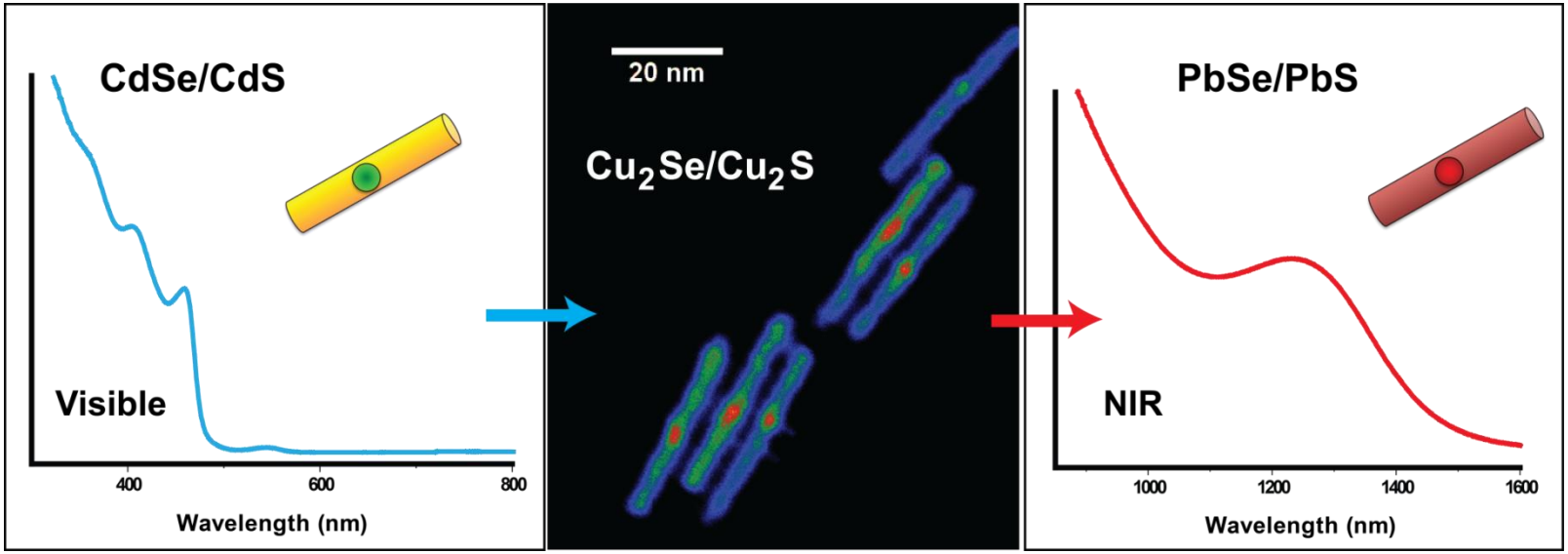
$(A^+B^- + C^+ \rightarrow C^+B^- + A^+)$

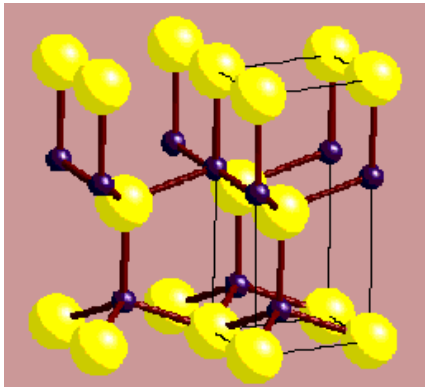
Son, Hughes, Yin, and Alivisatos, *Science*, 2004, 306**,** 1009

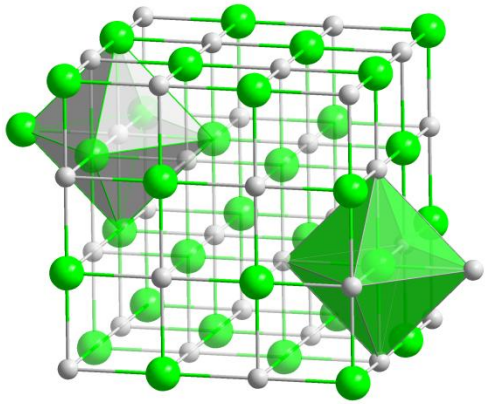


Courtesy: Bryce Sadtler

Templated Access to New Materials





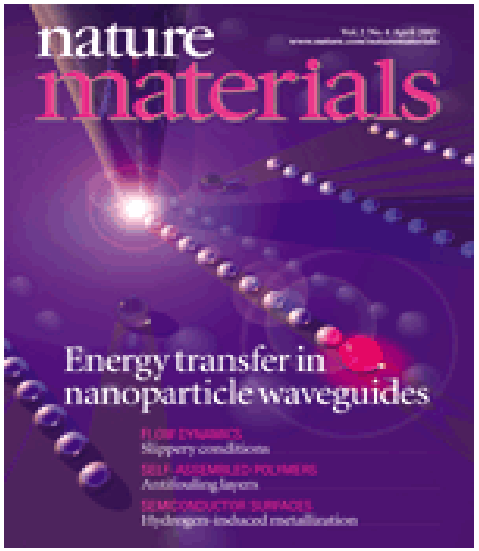


Wurtzite → c-axis

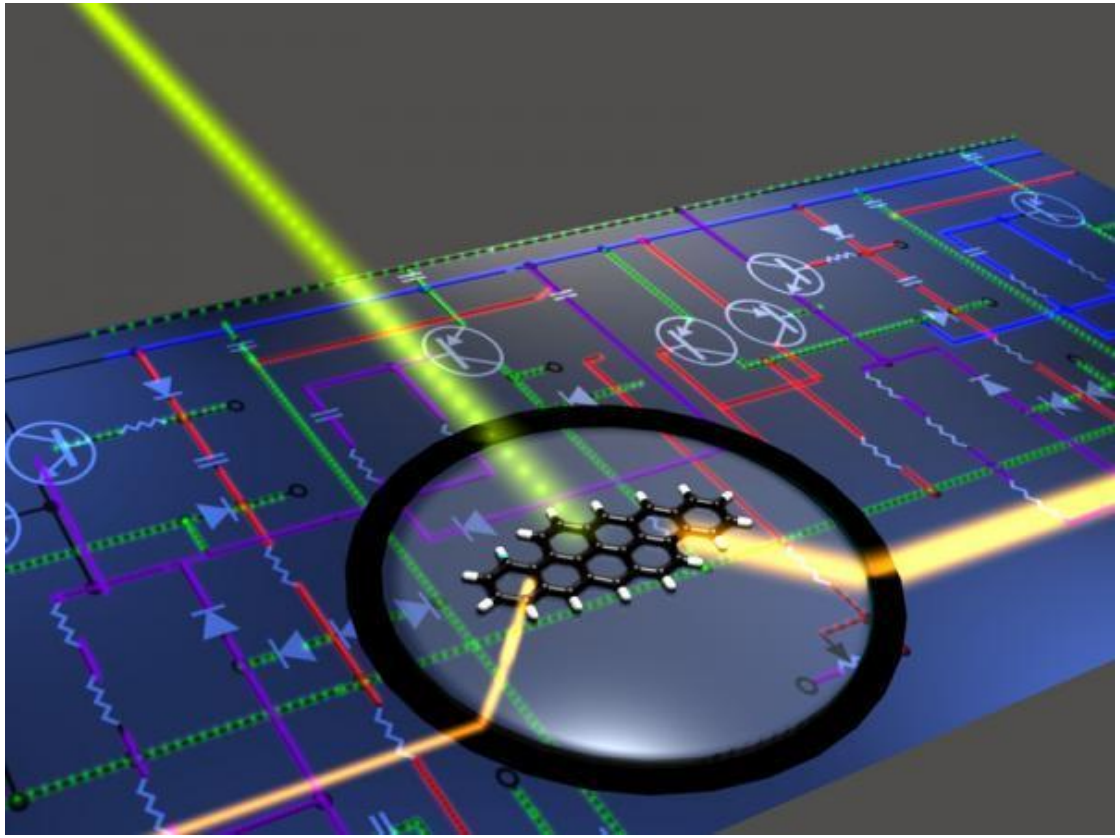
Rock-salt → symmetric

Jain*, Amirav*, Aloni, and Alivisatos, *JACS*, 2010, 132, p9997.

Using Photons Instead of Electrons For Computing

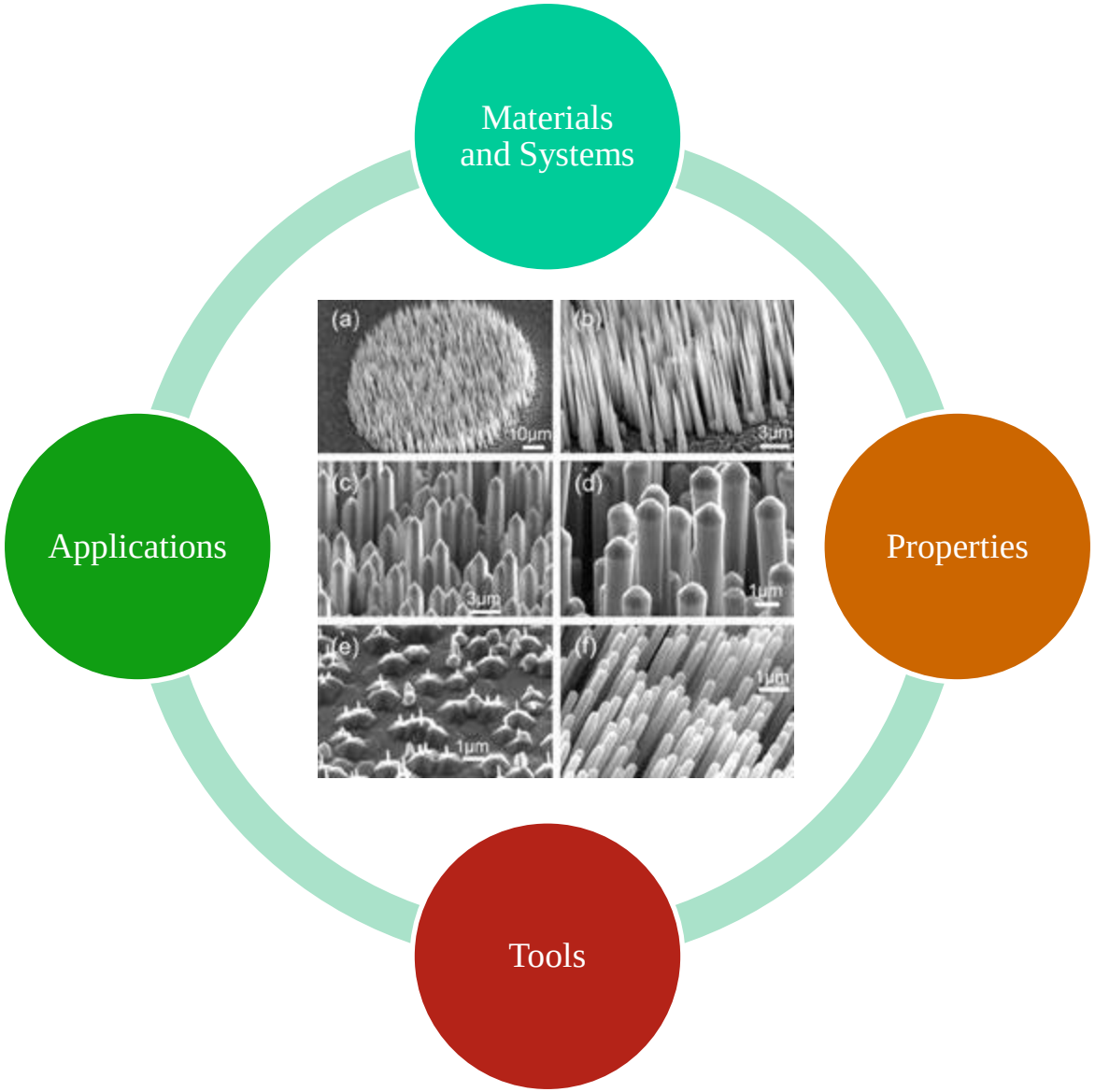


Coupling can be used to guide light in a nanoscale circuit

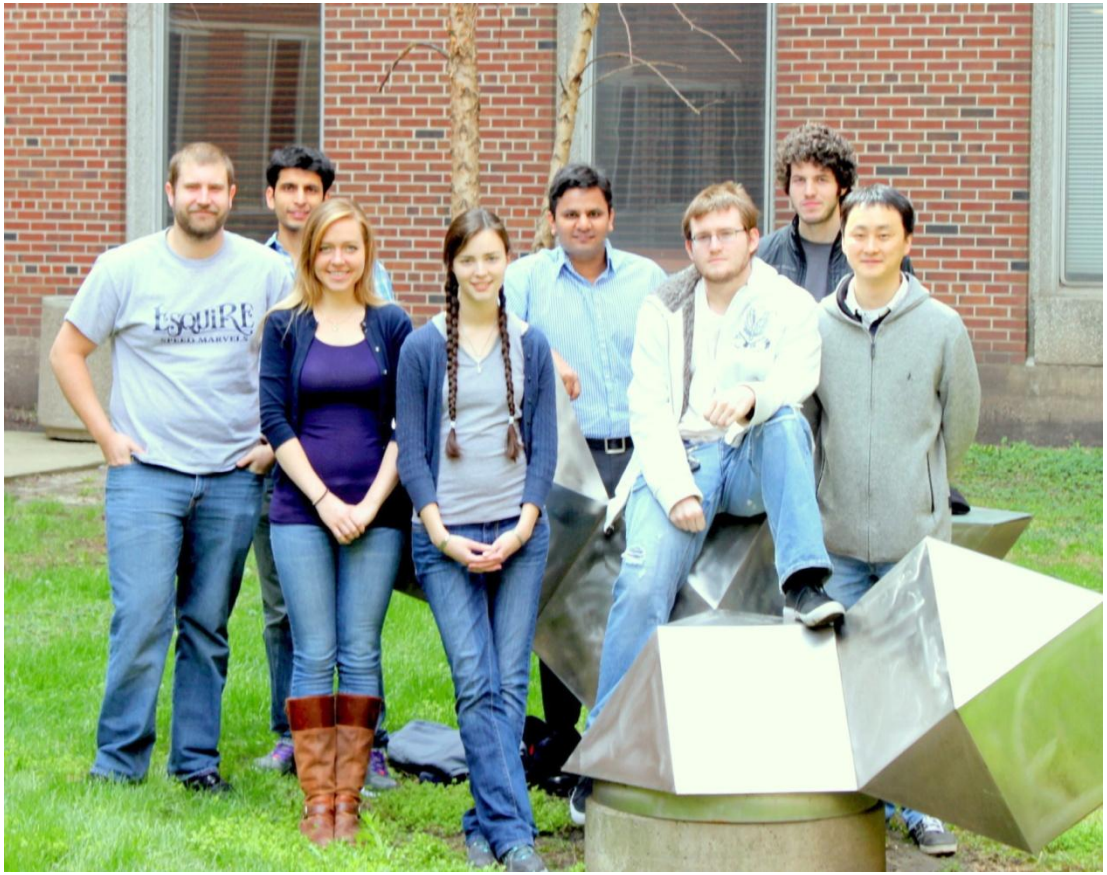


Lower heat generation, faster data transfer rates

Nanoscience



Acknowledgements



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Technology Review
TR35 The World's Top 35 Innovators Under 35

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