Optics at the Nanoscale: new scientific opportunities and multidisciplinary interactions

Naomi J. Halas

Department of Electrical and Computer Engineering

Department of Physics and Astronomy

Department of Chemistry

Department of Bioengineering

Rice University, Houston, TX, USA

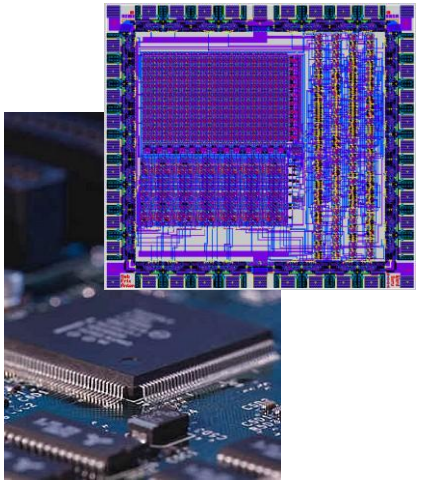
http://www.ece.rice.edu/~halas/

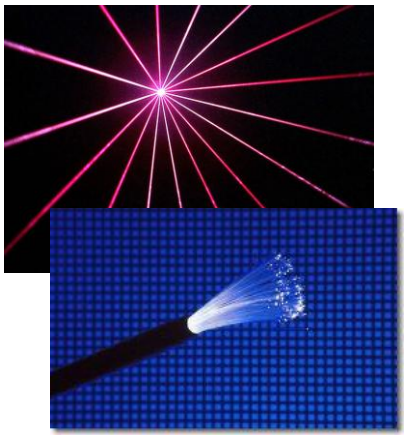
LAQNP LABORATORY FOR NANOPHOTONICS

NSF NNI Workshop,
Washington, DC, March 2011

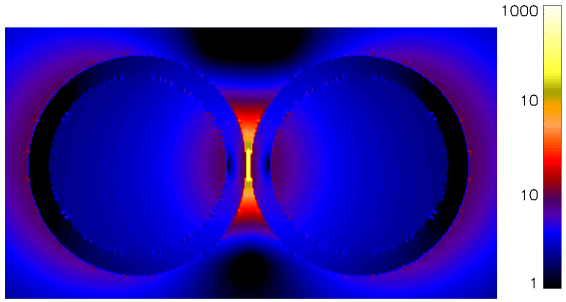
RICE

Nanophotonics: an emerging technology

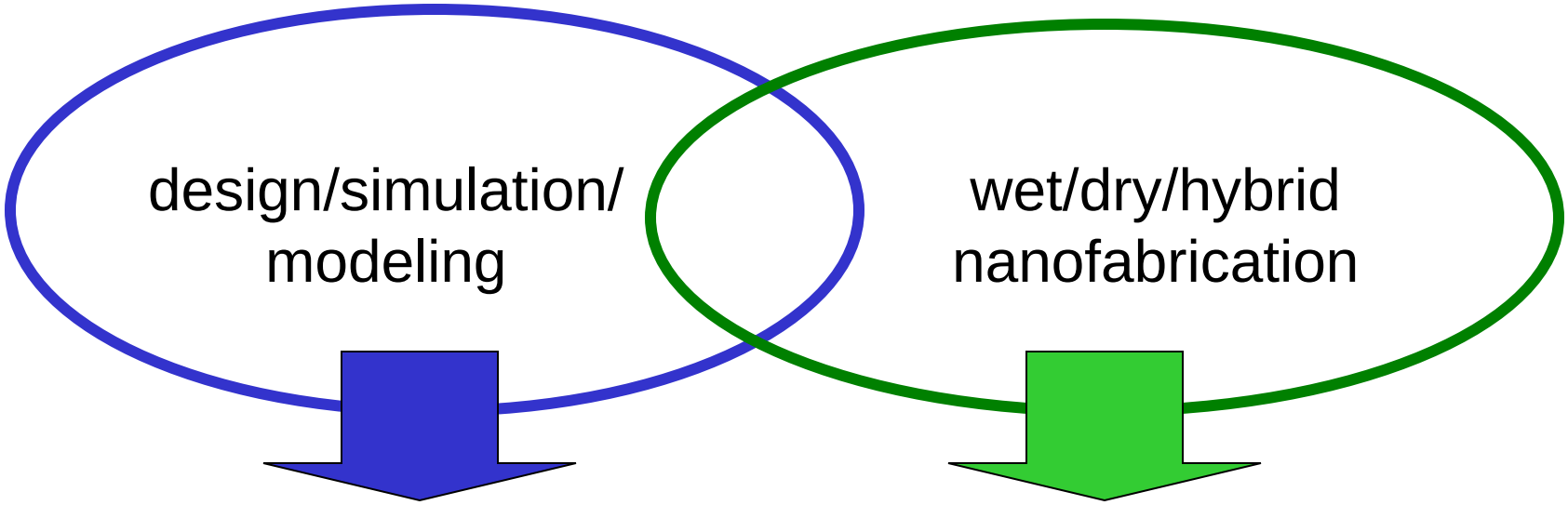




Optics at the nanoscale!



Nanoscale optics is *design driven*:

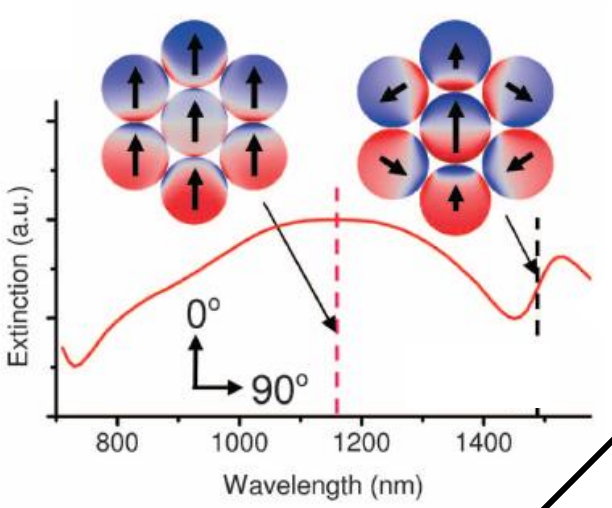


Finite-difference time domain,
Finite element methods
NEW: quantum effects (TDLDA)

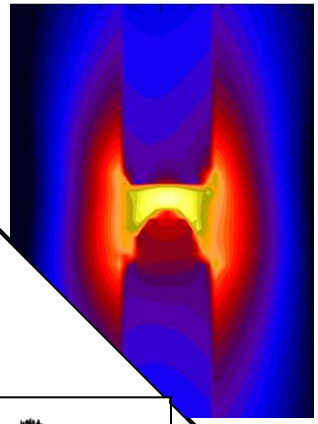
Chemistry,
Clean room nanofab,
Hybrid methods

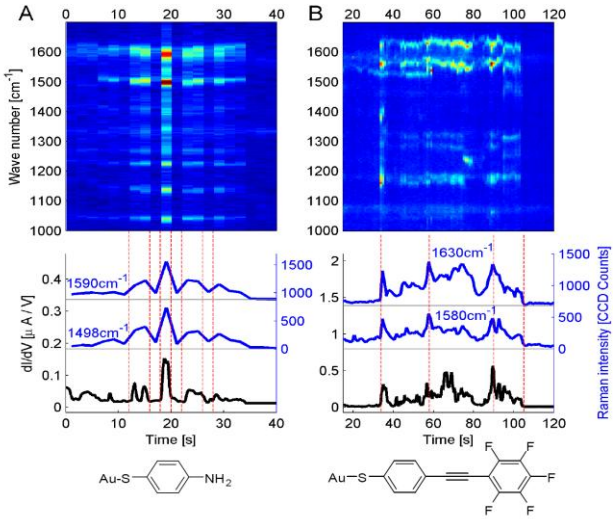
Plasmonics: optics at the nanometer scale

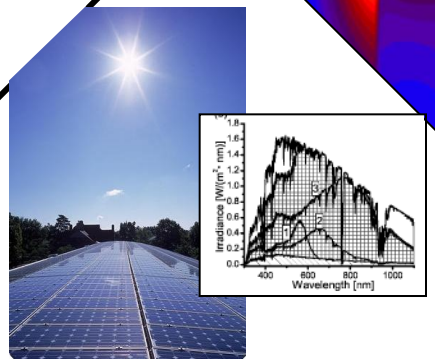
Plasmonics: Fundamental science of metallic nano-optical components



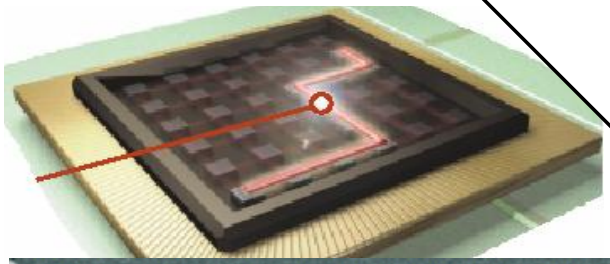
Plasmon-enhanced Spectroscopies for chemical & biodetection

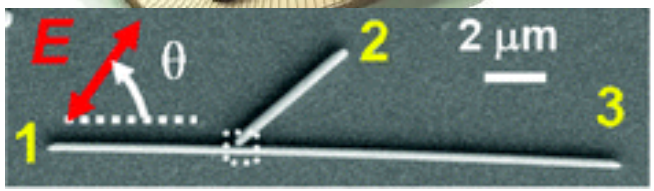




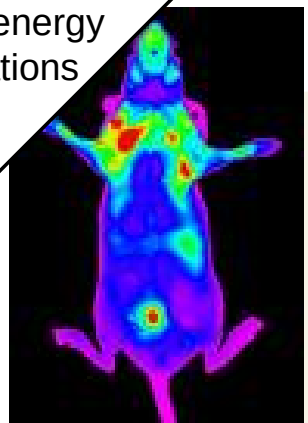


Light harvesting for solar energy applications

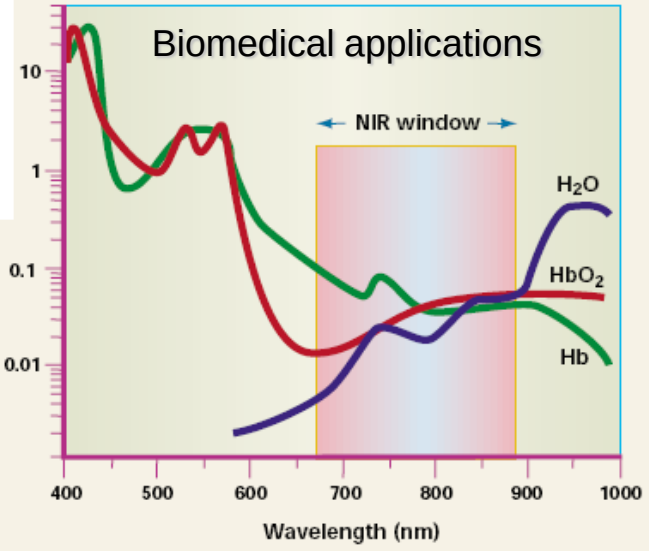




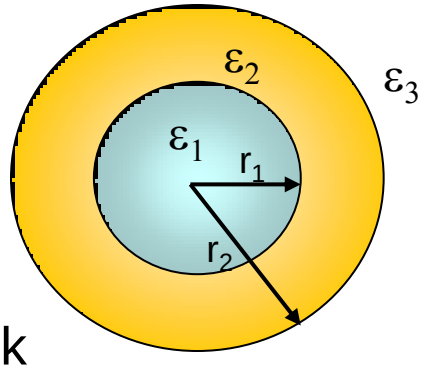
Optical interconnects in next-generation computer chips

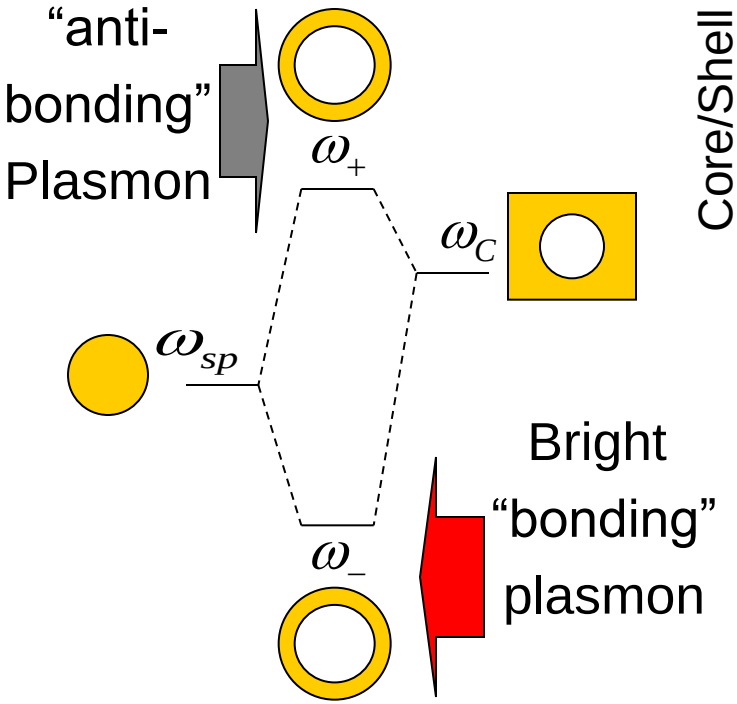


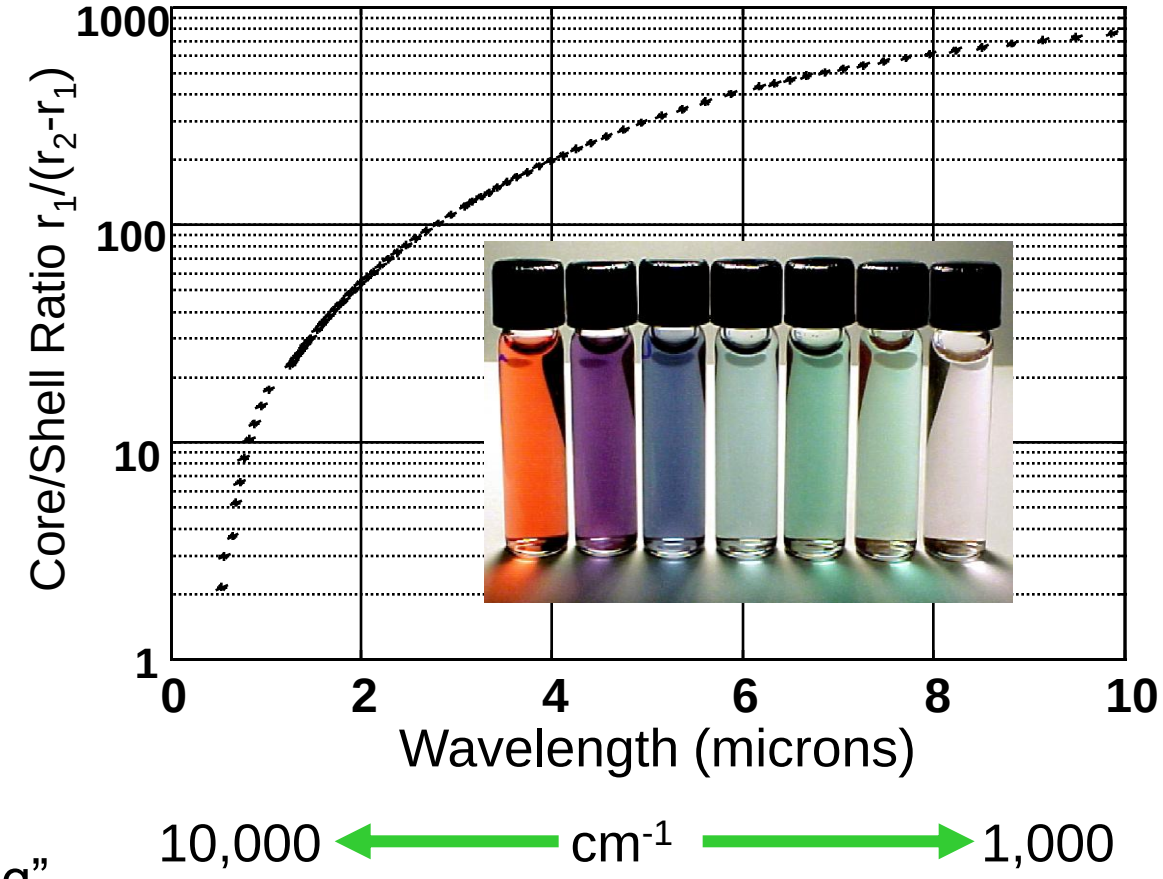
Biomedical applications



Nanoshell:
plasmon hybridization results in “tunable nanoparticle”





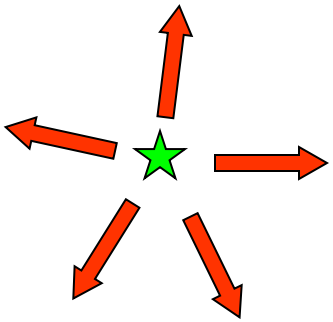


S. Oldenburg et al.,*CPL* **288**, (1998) 243-247.

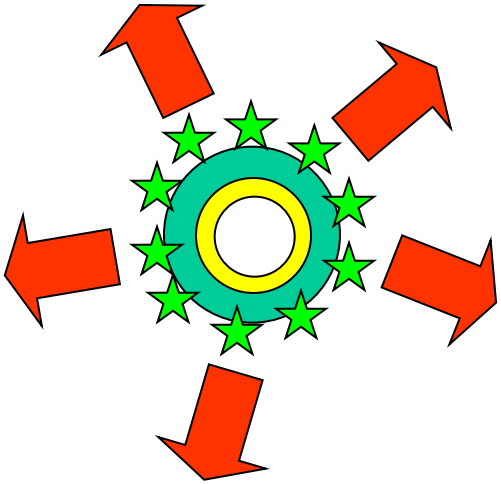
E. Prodan et al., ***Science* 302** (2003) 419-21.

Plasmonic nanoantennas for fluorescence enhancement

Indocyanine green (a.k.a. Cardio Green):
only FDA approved contrast agent for Fluorescent imaging, used worldwide



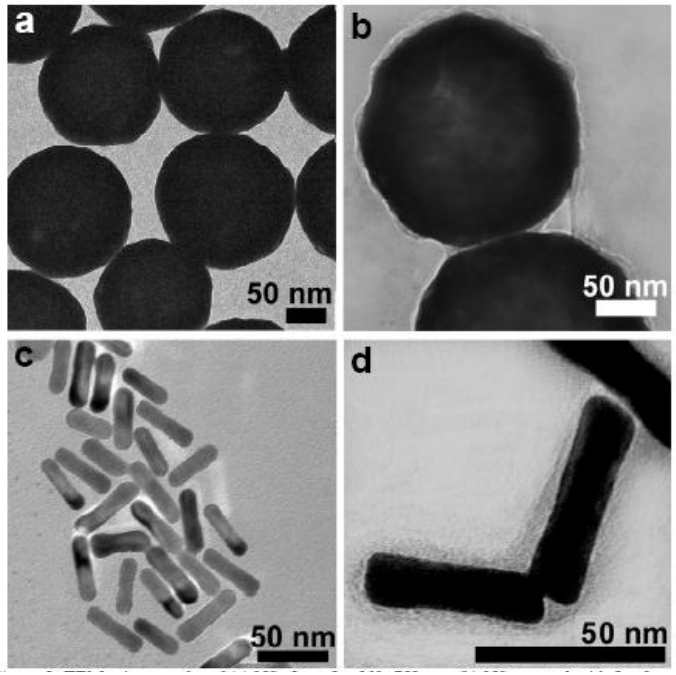
ICG
Weakly fluorescent
(Quantum yield < 2%)

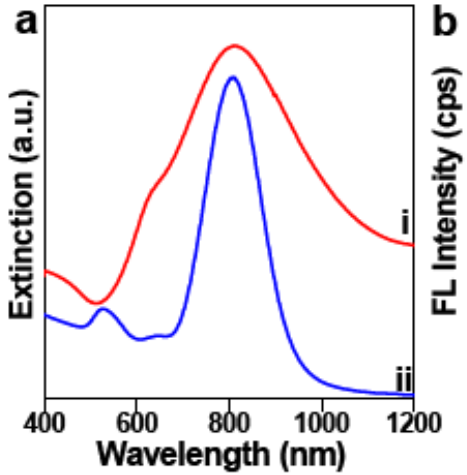


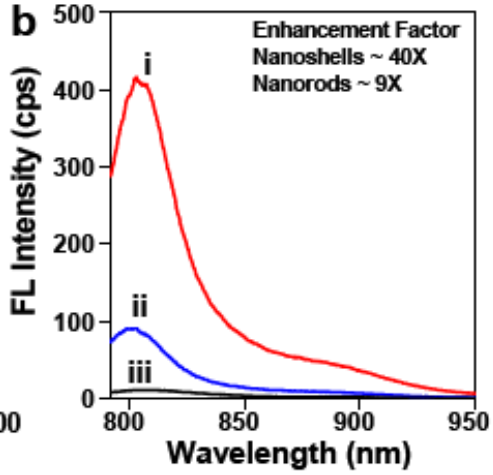
Nanoparticle “antenna”
Enhances ICG fluorescence
45X

Increase in Quantum Yield due to nanoparticles:

R. Bardhan et al., ACS Nano 3, 745-752 (2009).







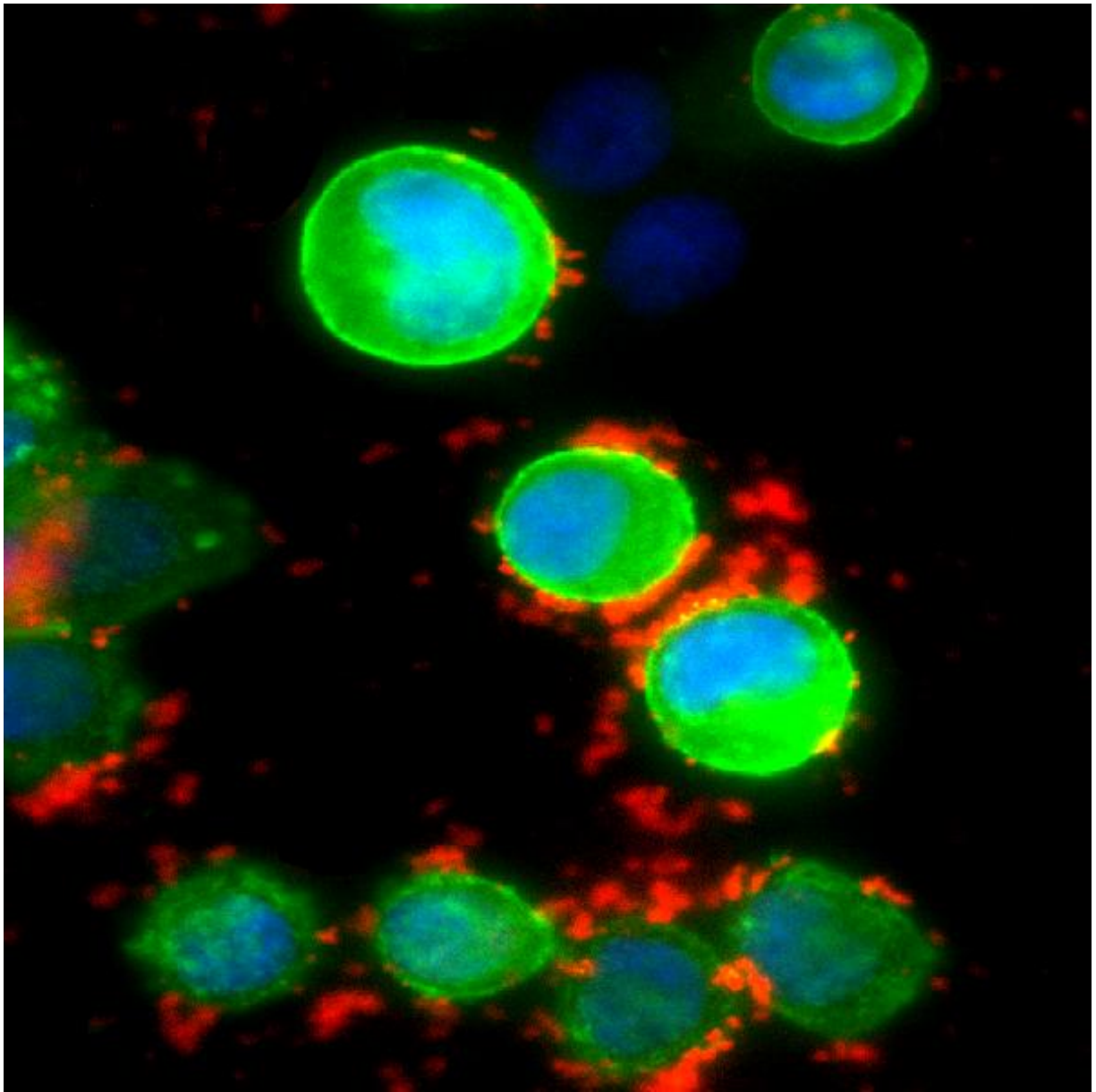
Sample	Q.Y.	Γ	k_{nr}
IR800	0.07	1.241×10^{8}	1.648×10^{9}
HSA-IR800	0.11	2.576×10^{8}	2.084×10^{9}
NRs-HSA-IR800	0.74	6.180×10^{9}	2.084×10^{9}
NSs-HSA-IR800	0.86	1.262×10^{10}	2.084×10^{9}

nanorods ➡

nanoshells ➡

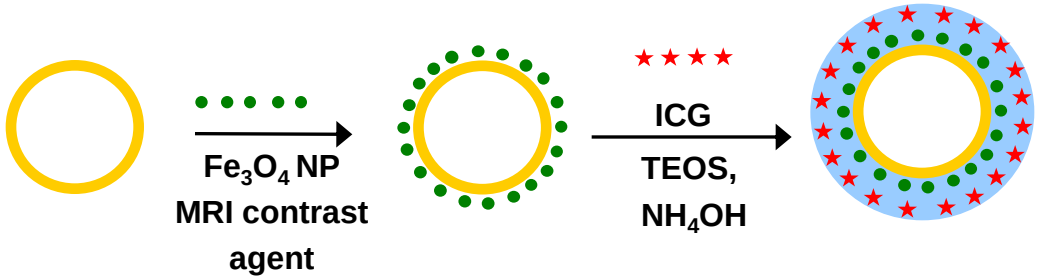
Targeted delivery to cells:

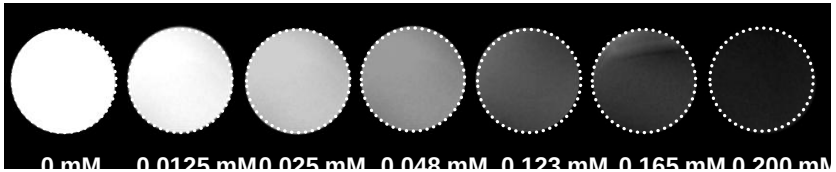
R. Bardhan et al., Advanced Functional Materials, 2009.



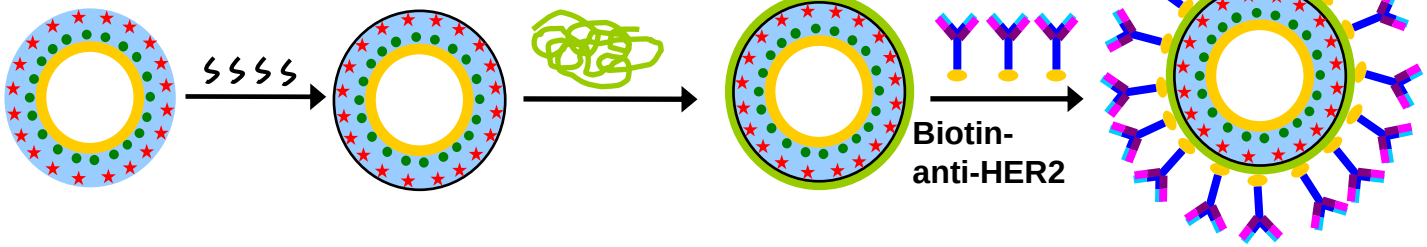
Fluorescence enhancement with MRI contrast agent:

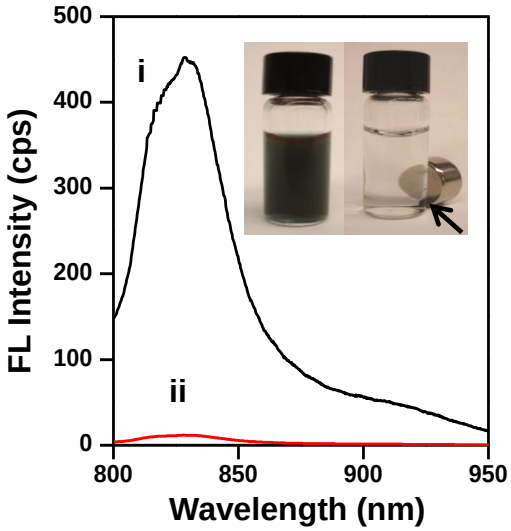
combines the high sensitivity of photons with
detailed anatomical information of MRI imaging

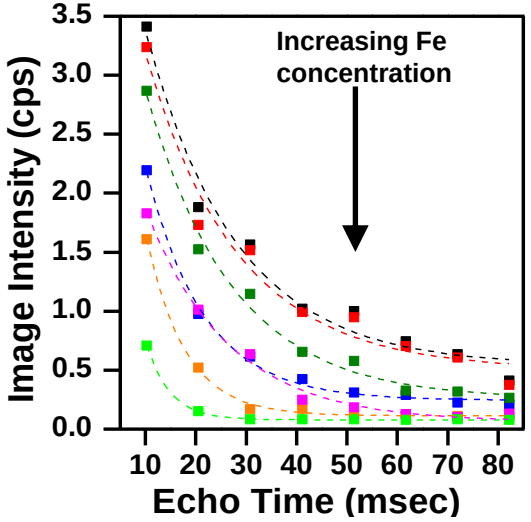


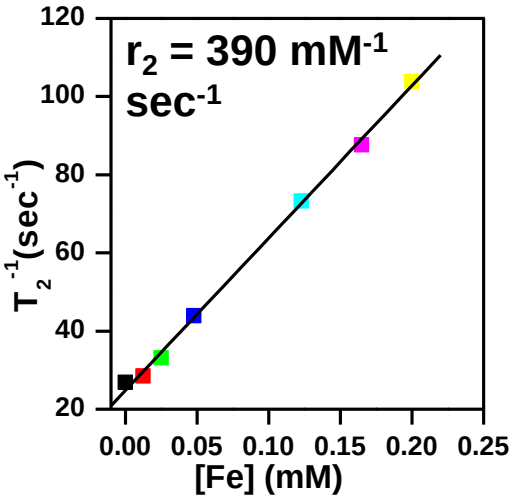


T_2 weighted images of Nanocomplexes:





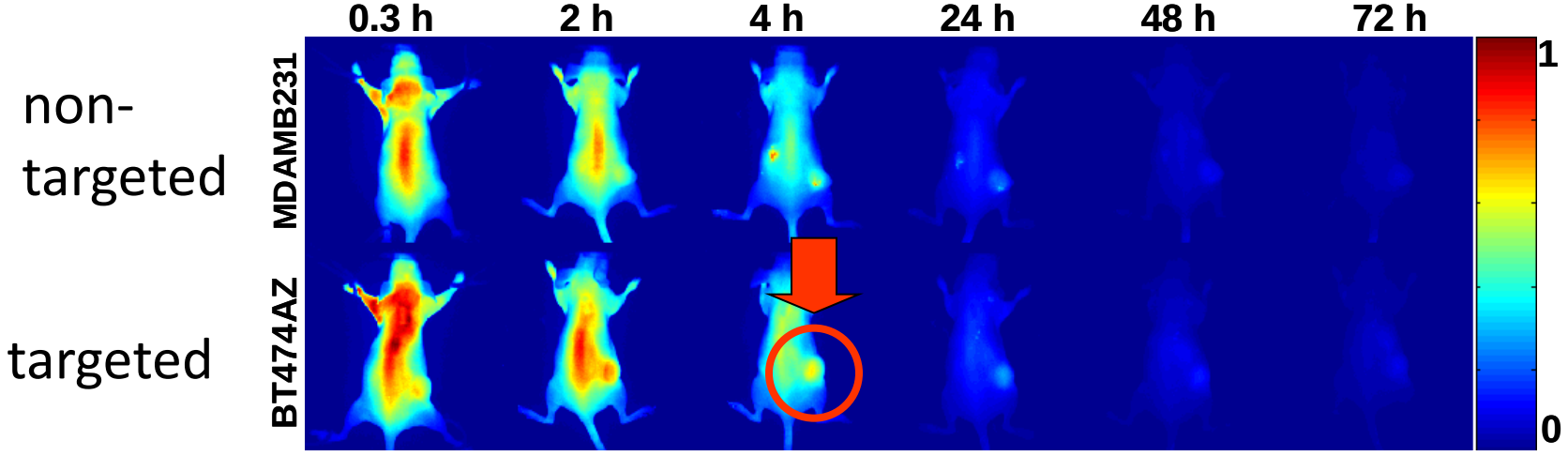




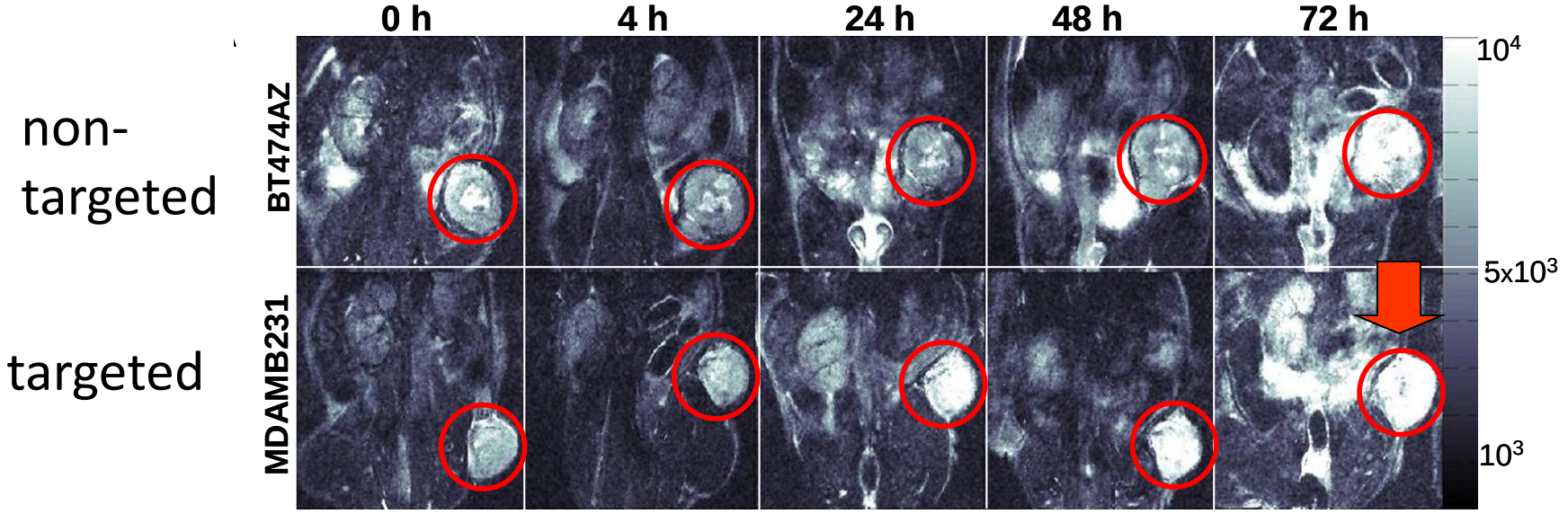
Real-time tracking of nanoparticles *in vivo*

R. Bardhan et al., NL10, 4920-4928 (2010).

Fluorescence imaging: high sensitivity

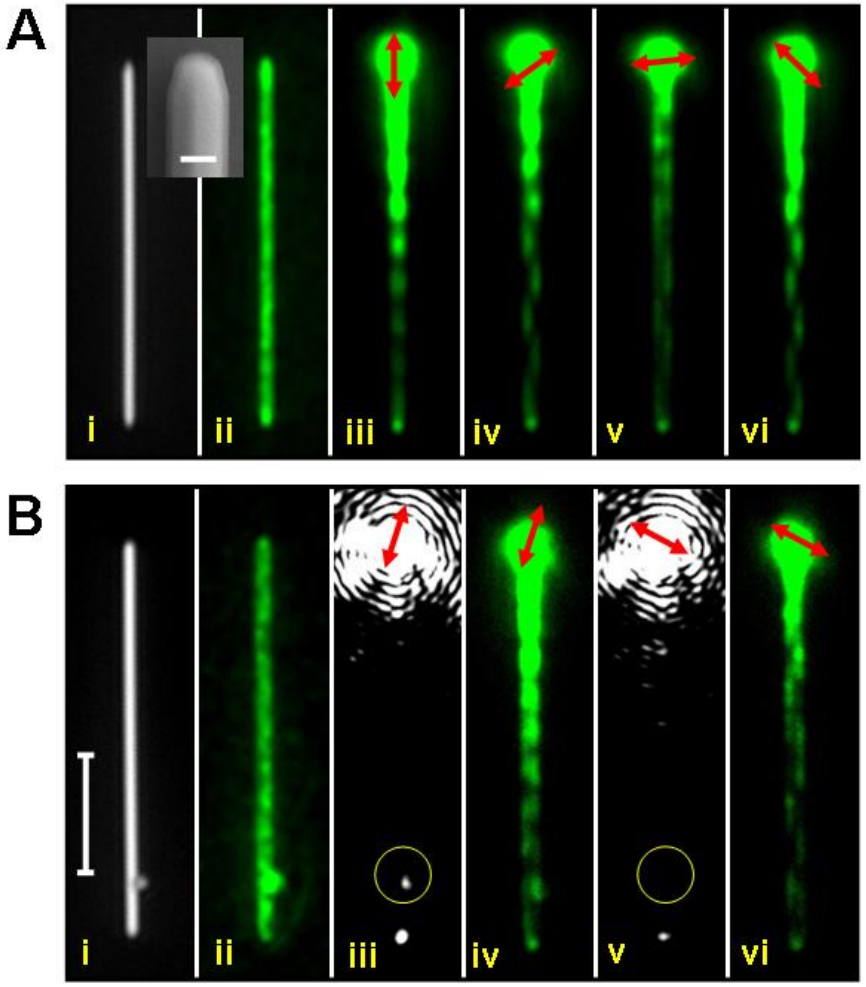


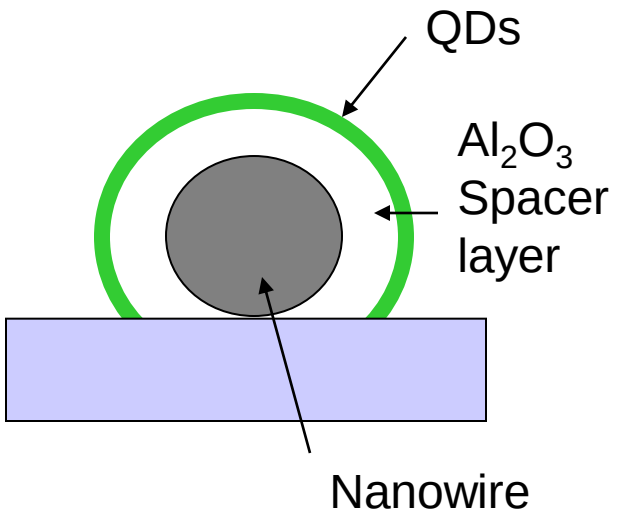
+MRI contrast: detailed, quantitative anatomical information

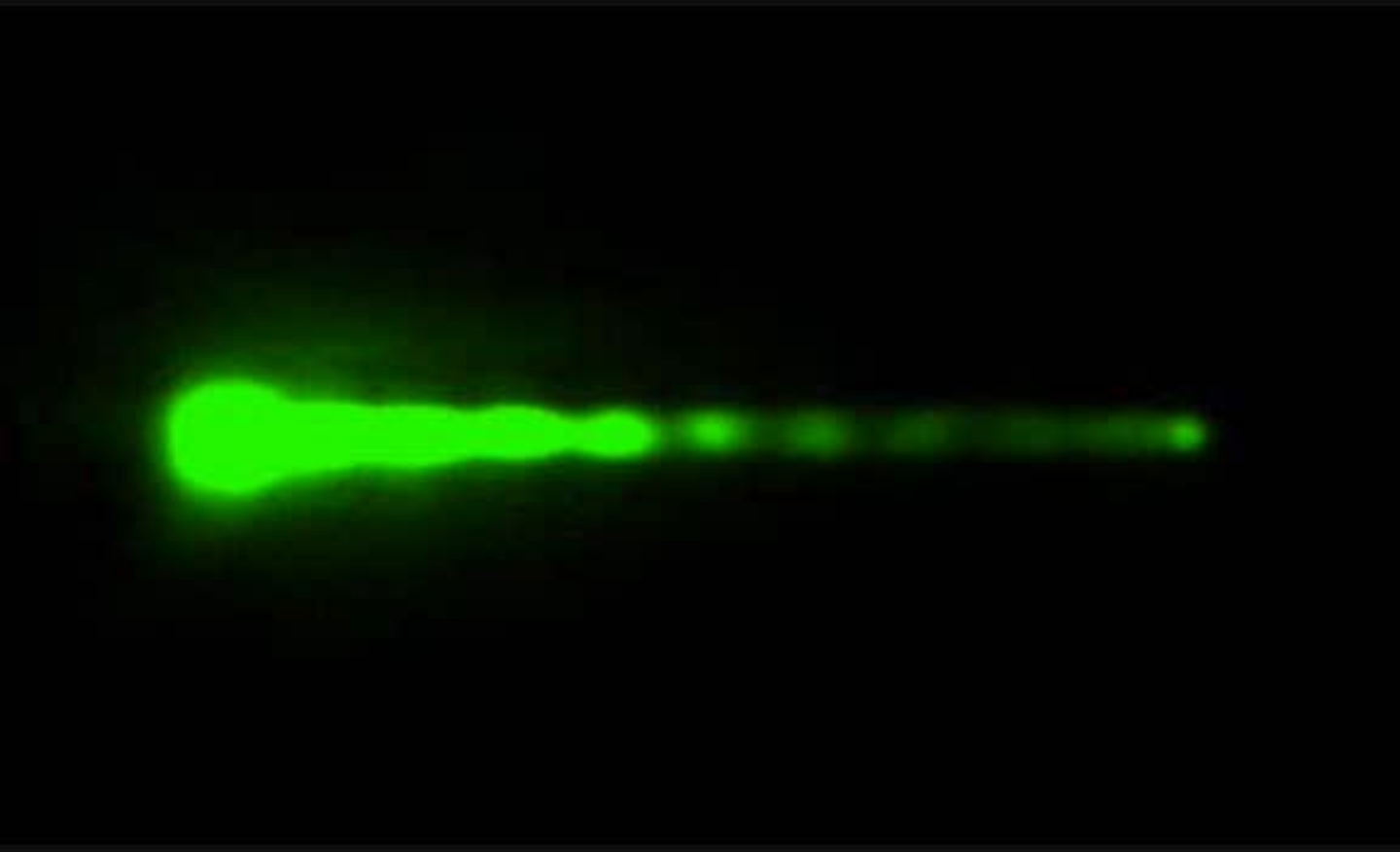


Quantum Dot-based Local Field Imaging in Silver Nanowire Networks

Hong Wei et al., NL 11, 471-5 (2011).

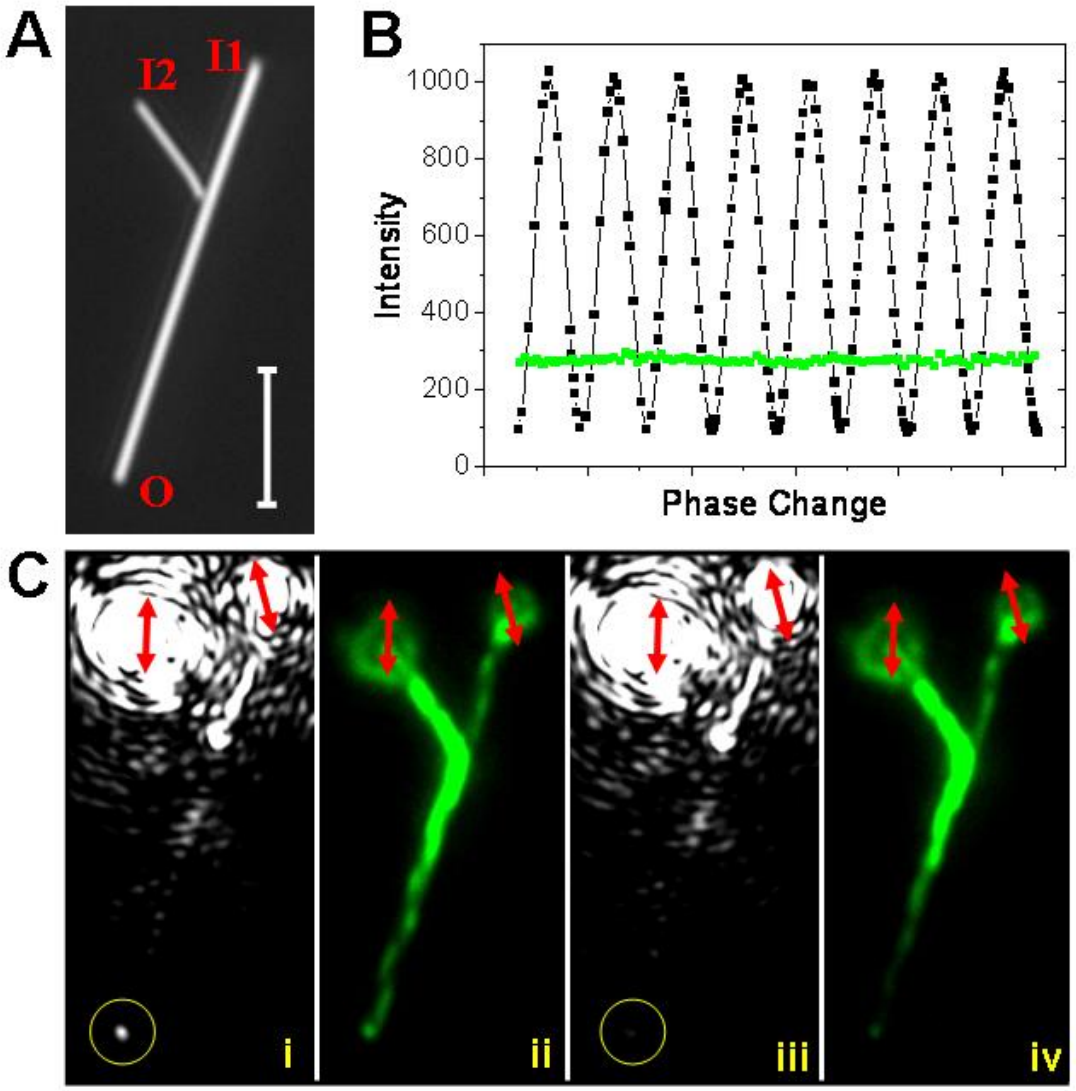




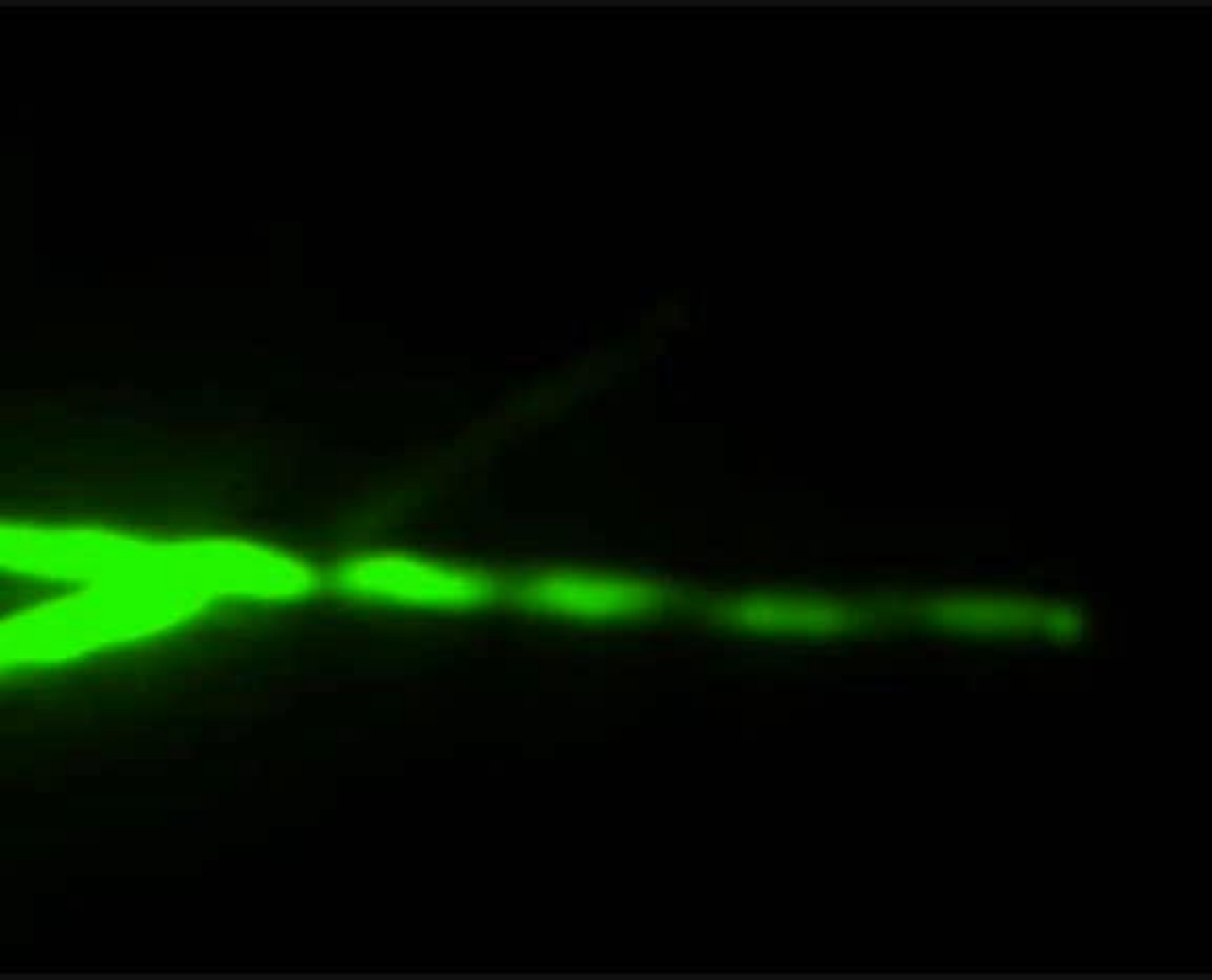


Plasmonic logic on Ag nanowire networks:

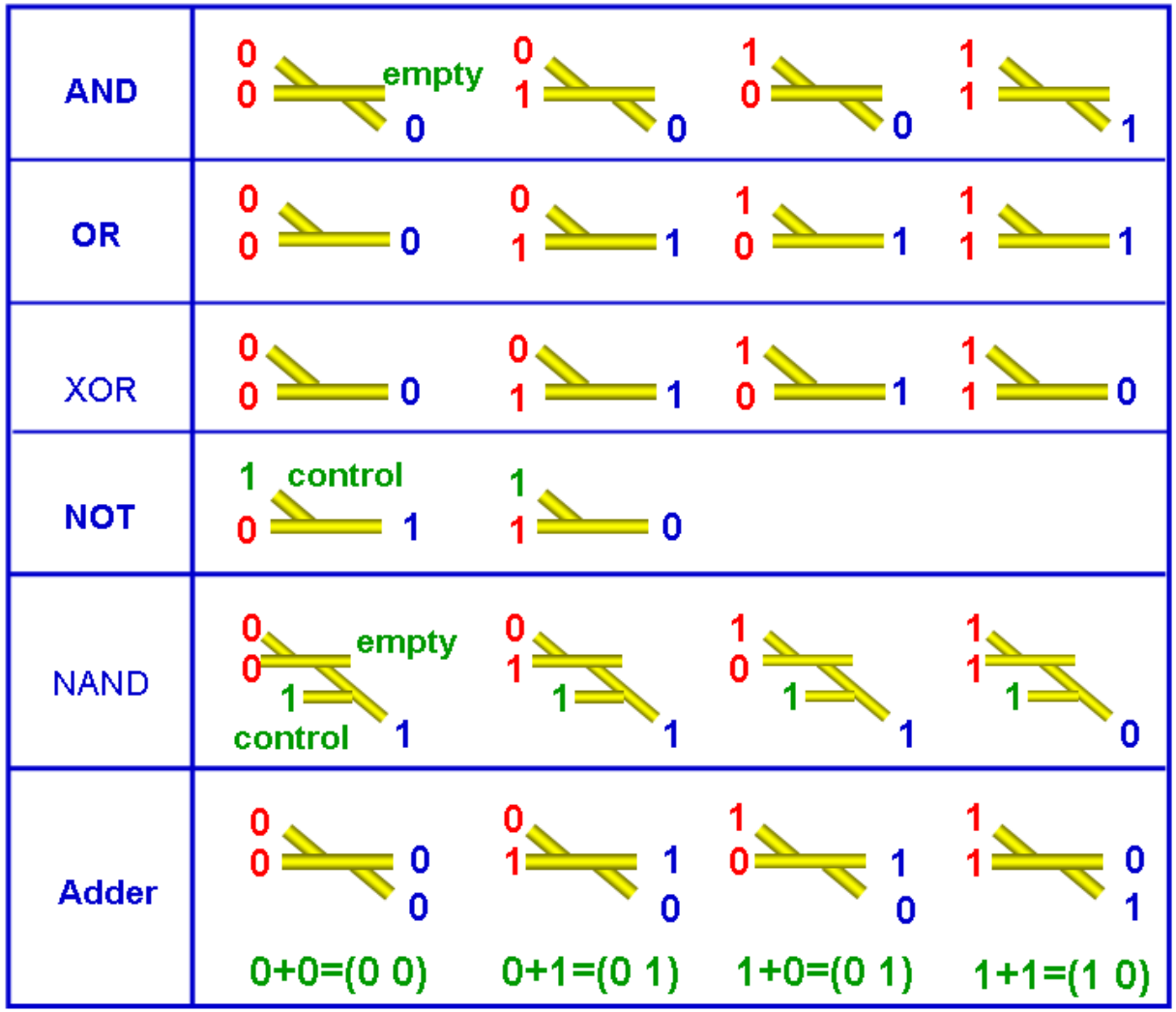
Hong Wei et al., NL 11, 471-5 (2011).



Relative phase or polarization at two inputs controls "on" or "off" at Output!

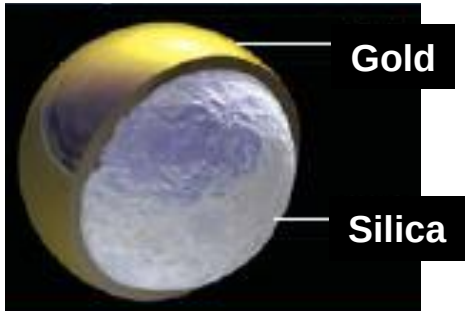


Boolean Logic in Ag Nanowire Networks:

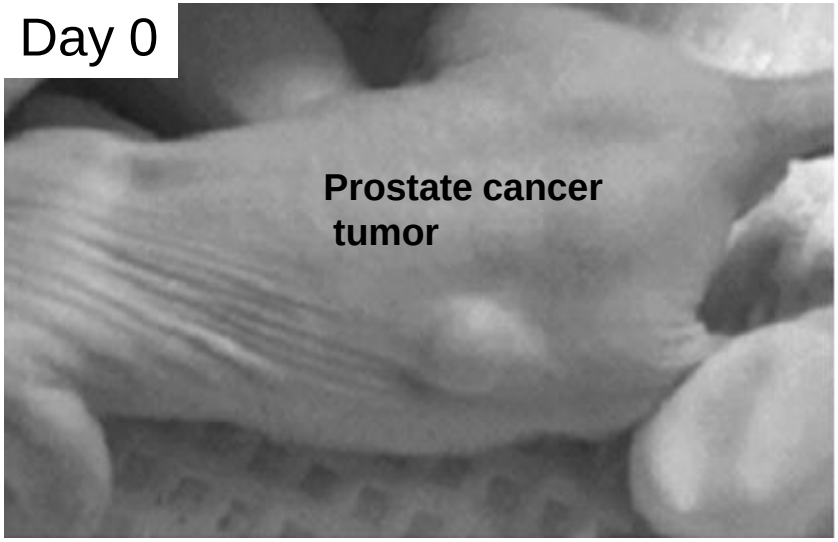


Nanoshell-based photothermal cancer therapy

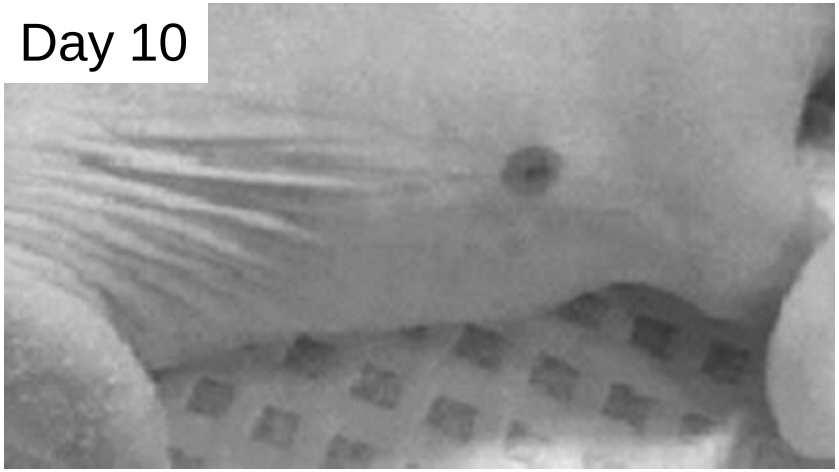
Currently in clinical trials: head & neck cancer, advanced prostate cancer

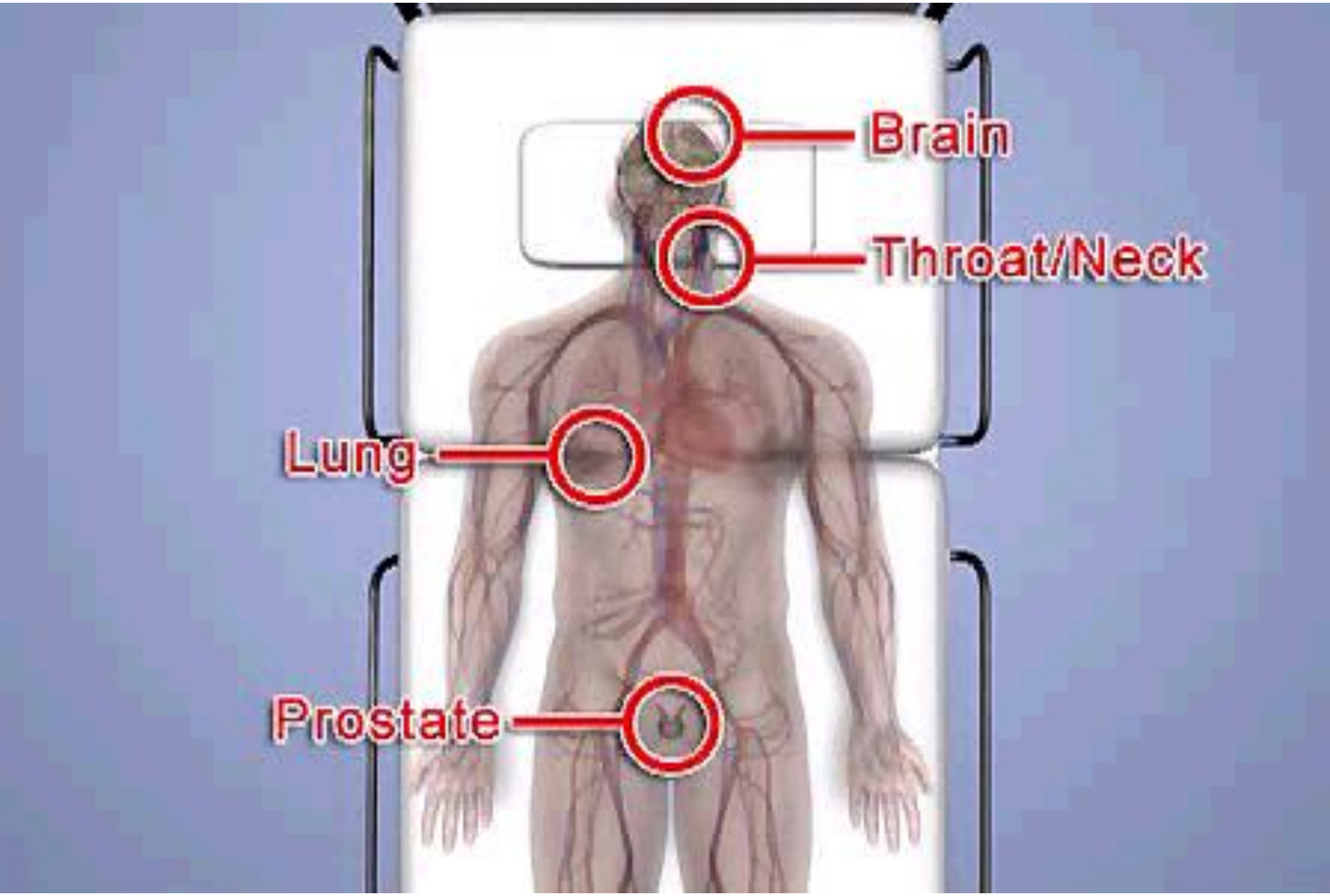


Day 0

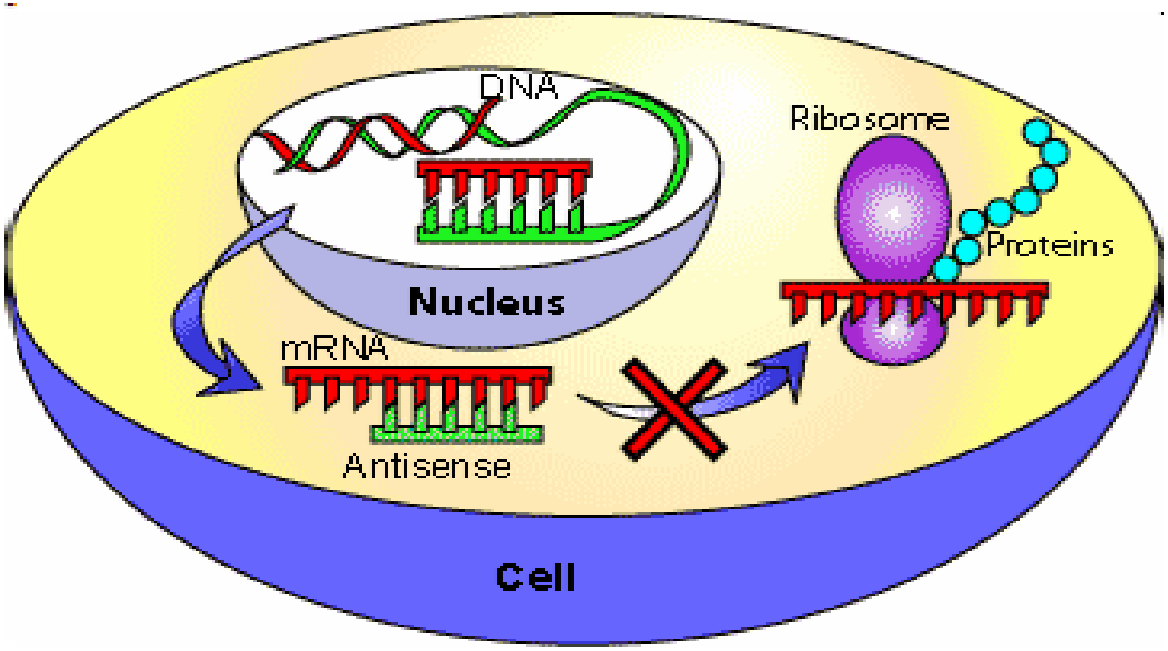


Day 10




Brain
Throat/Neck
Lung
Prostate

The challenges of gene delivery:



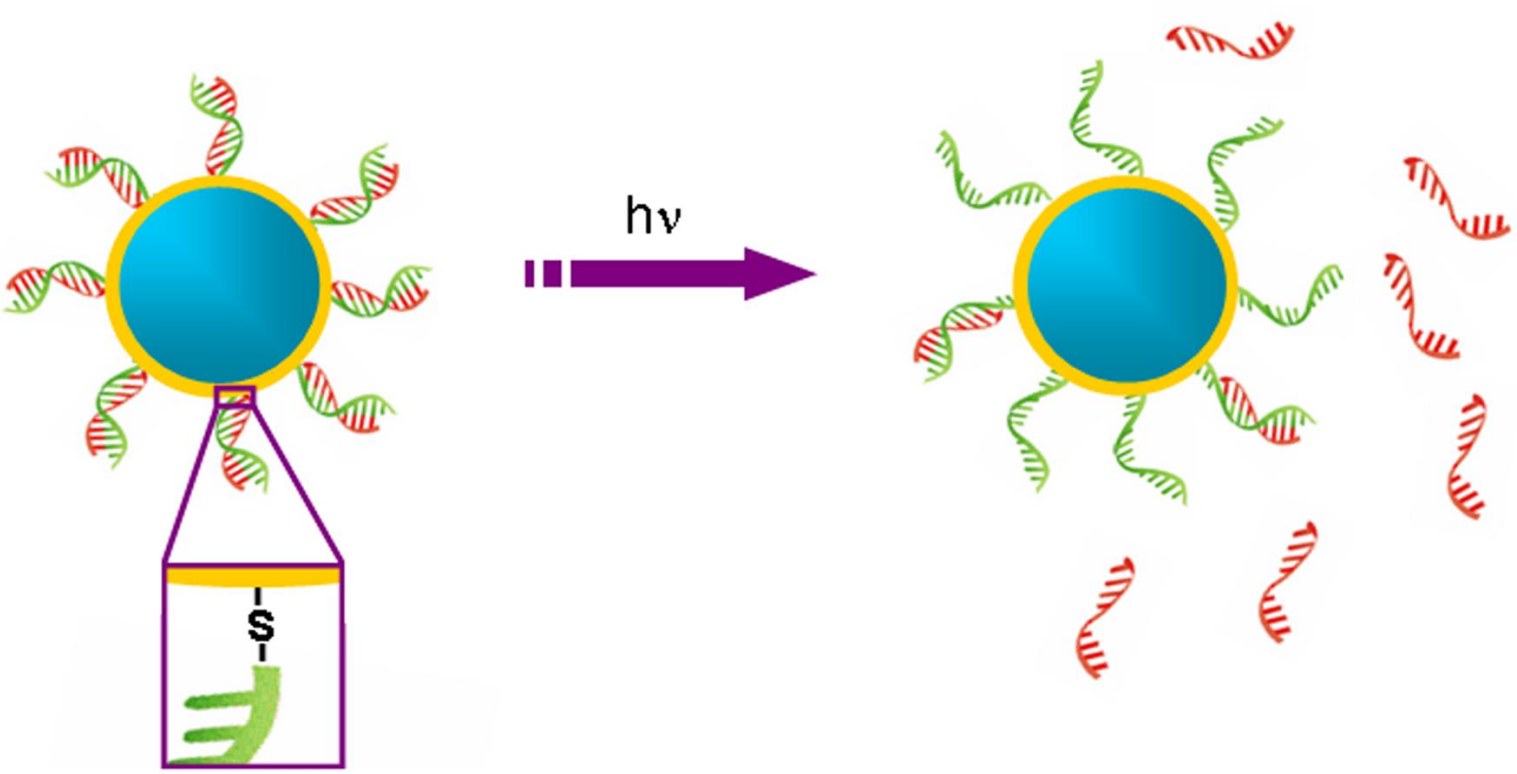
- DNA injected into bloodstream rapidly degraded by enzymes
- Isolated DNA not taken up by cells (endocytosis)
- Isolated DNA does not target specific cells of interest

Light-triggered plasmonic vectors for gene therapy

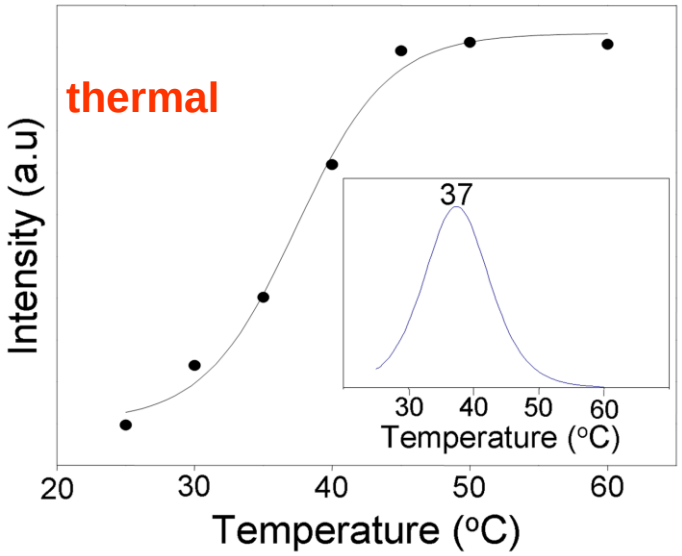
A. Barhoumi, et al., Chem. Phys. Lett. 482, 171-179 (2009)

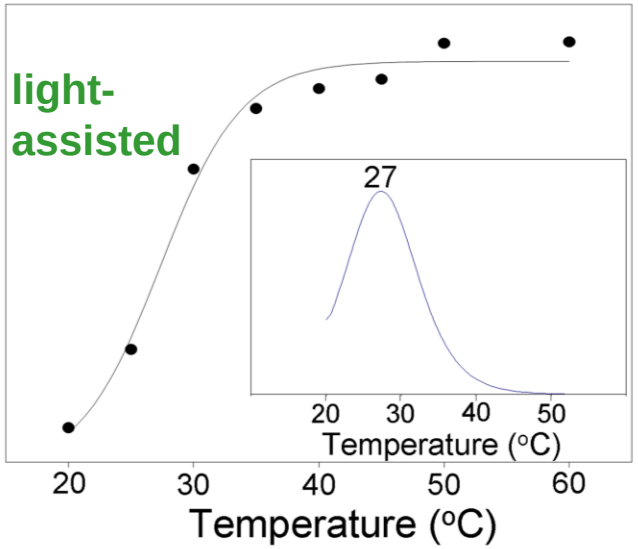
- **Inserting specific genes into cells controls the proteins expressed in cells, a therapeutic strategy for virtually all diseases**

- **Remote-controlled release of DNA, siRNA using low intensity near-IR light**

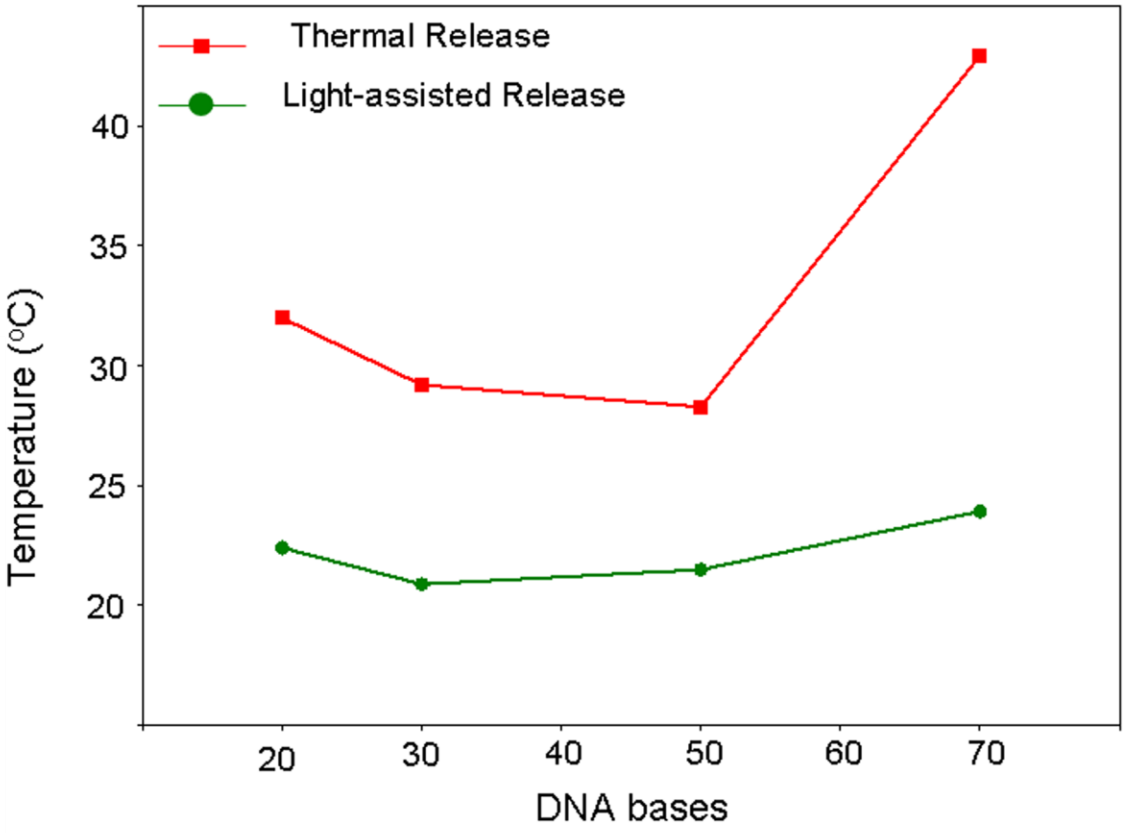


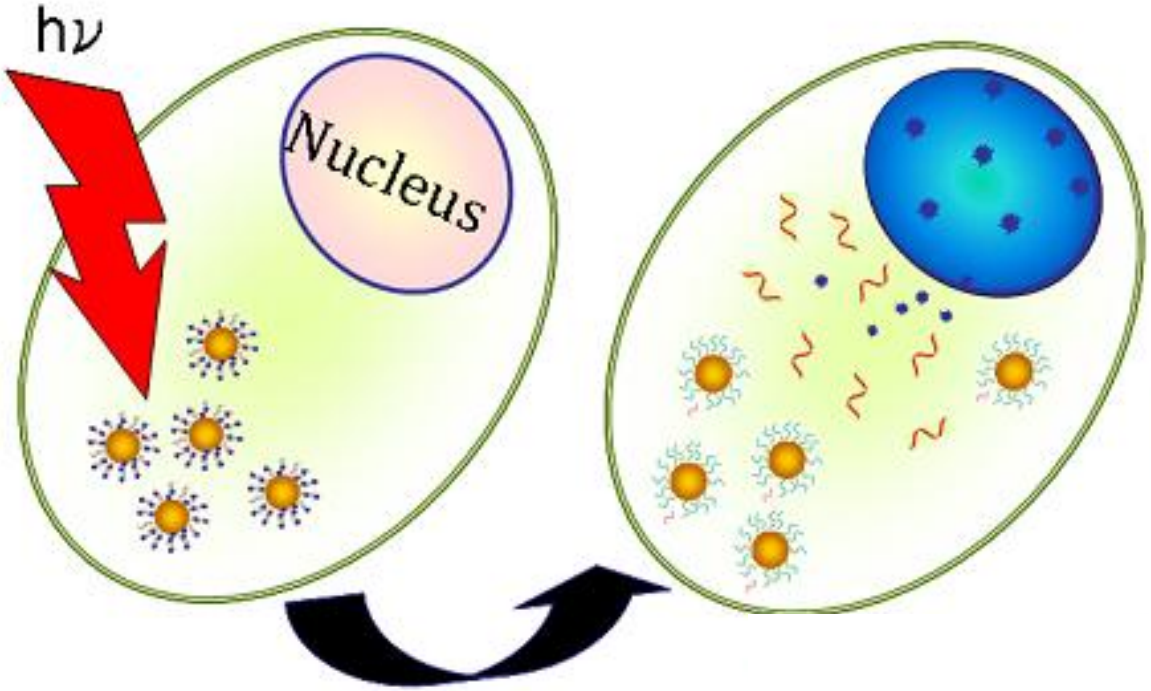
Thermal vs. light-assisted release

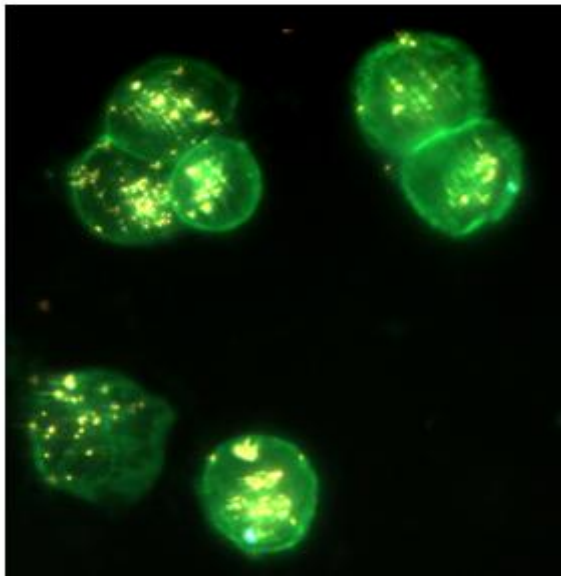




Gene release occurs at low light levels, minimal temperature rise and cells stay viable

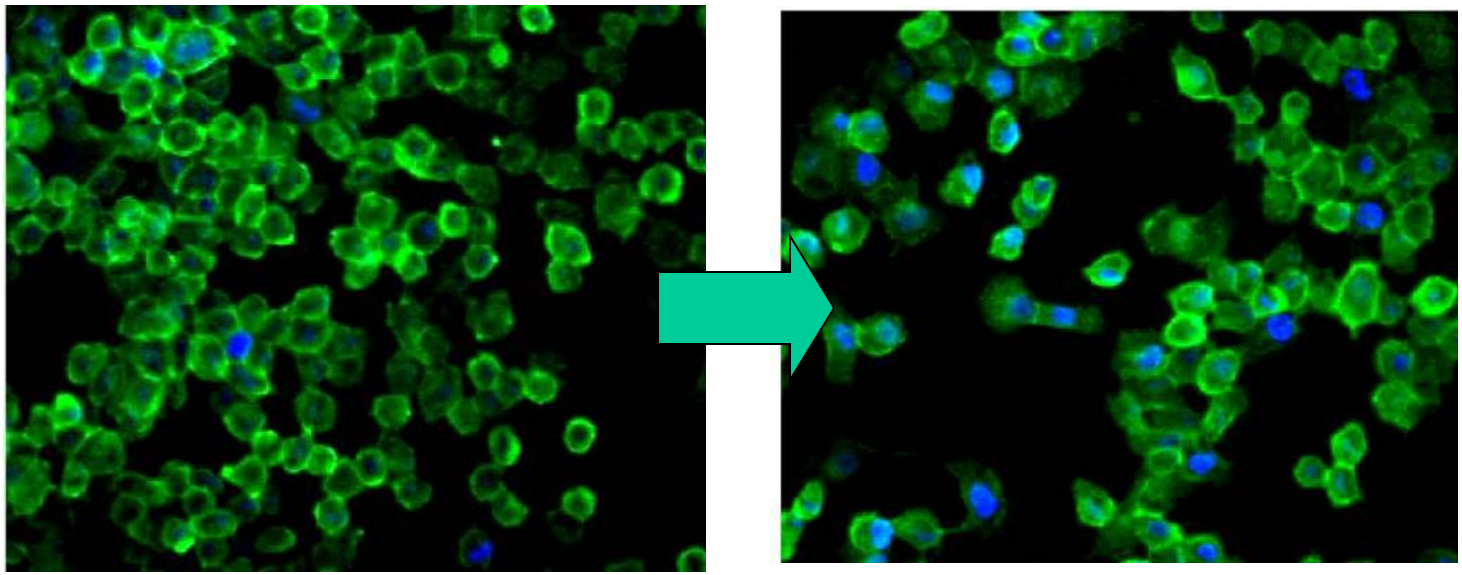






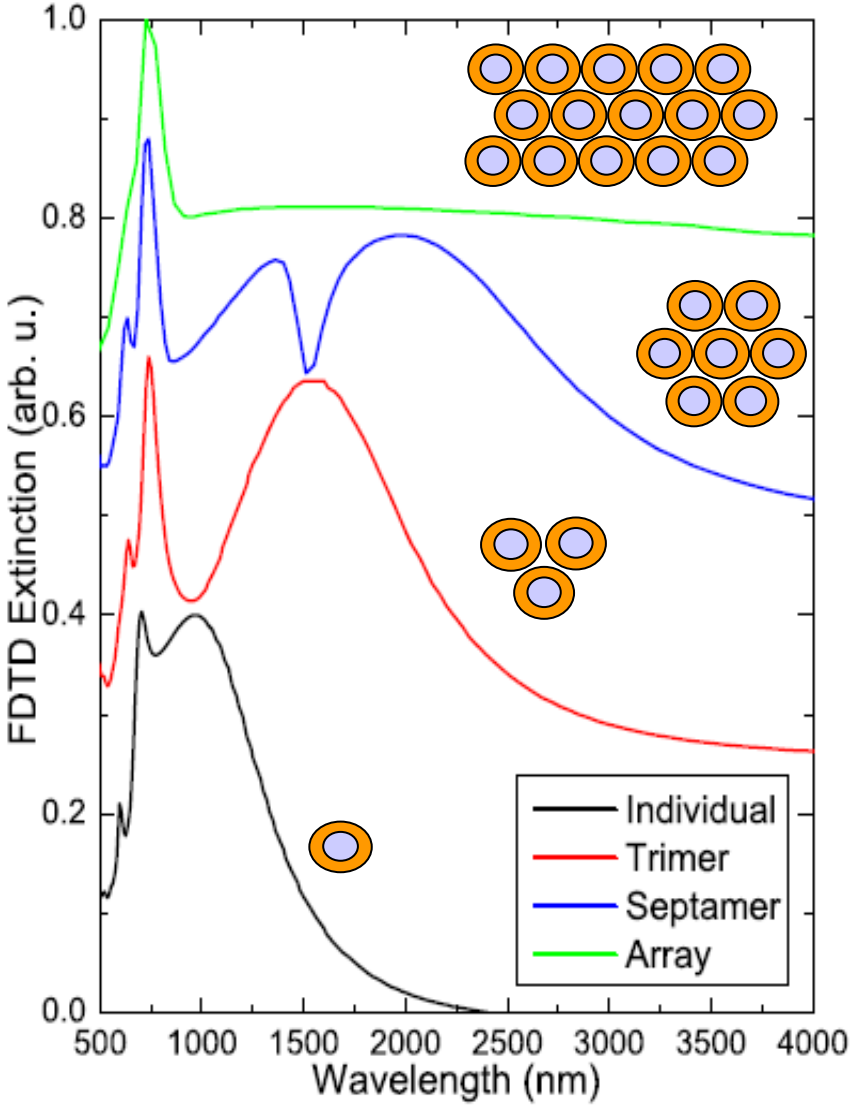
BEFORE

AFTER

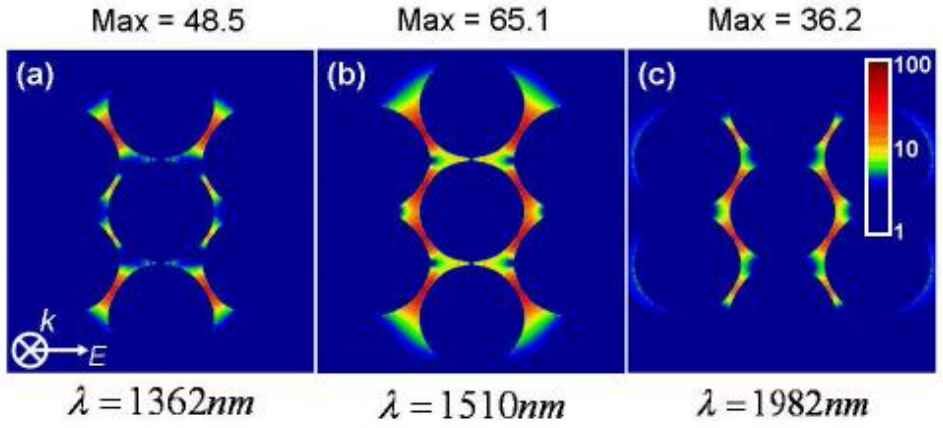


Nanoparticle clusters and arrays

Coherence provides a route to enhanced sensitivity in metamaterials!



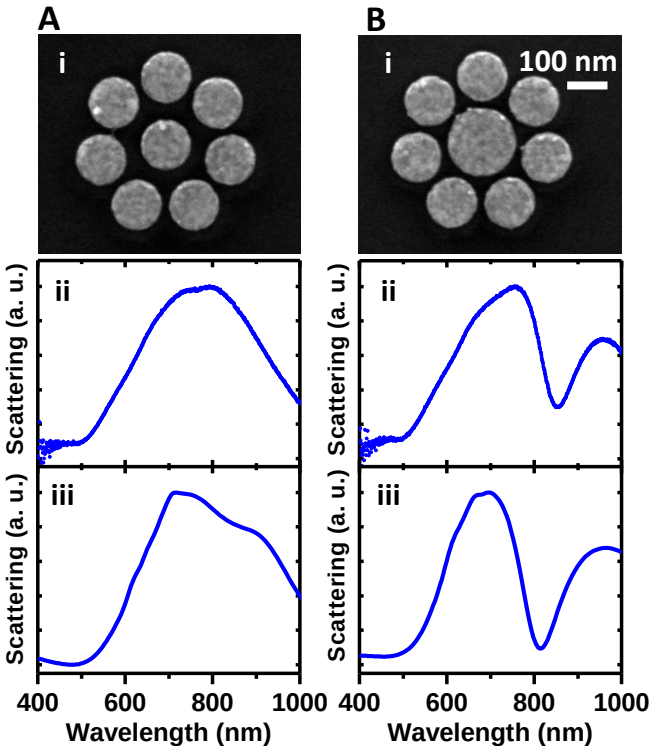
Fano resonance, Electromagnetically induced Transparency (EIT)

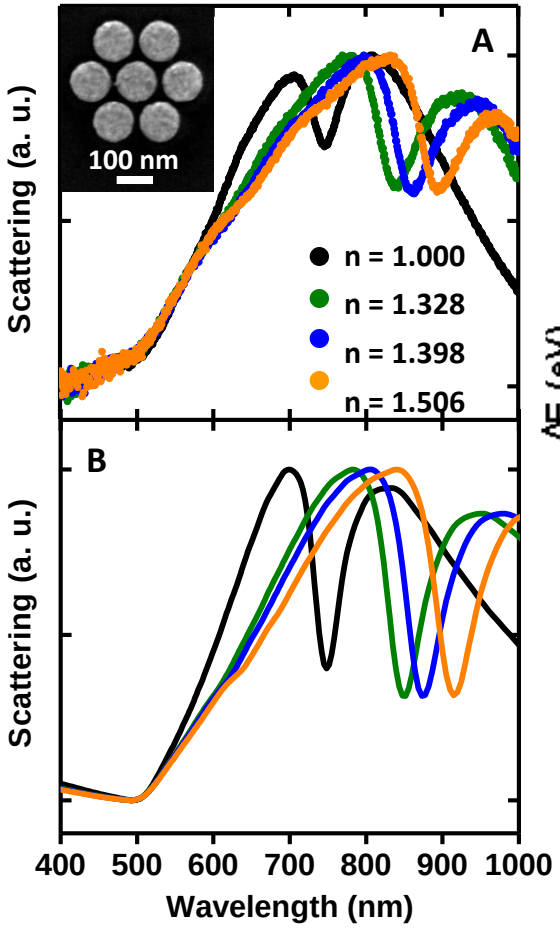


Most sensitive LSPR* sensor ever reported

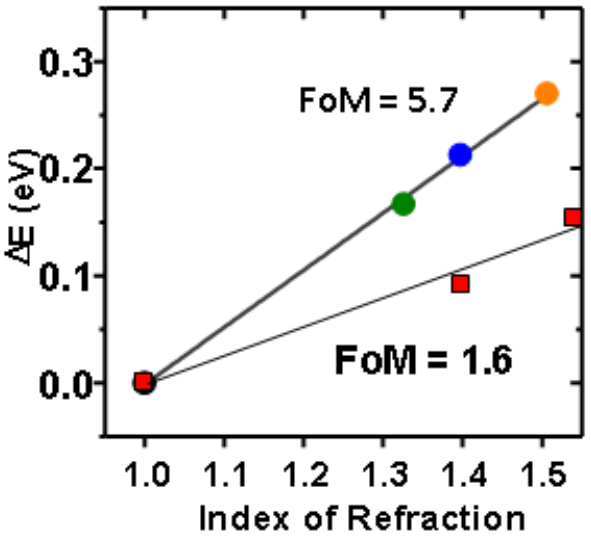
*Localized Surface Plasmon Resonance sensor

Jonathan A. Fan, et al., Science 328, 1135 (2010); Lassiter et al., NL, 2010.





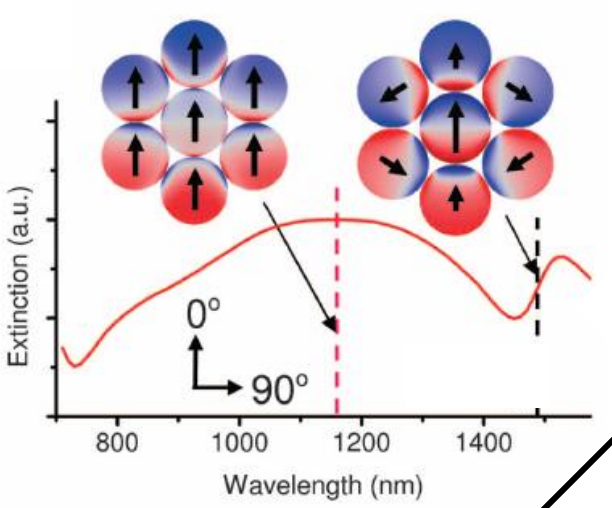
Compared to best Previously reported Active metamaterial!



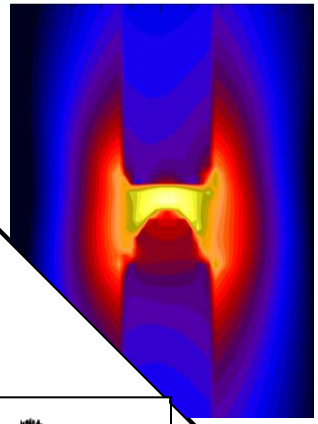
Coherence provides a route to enhanced sensitivity in metamaterials!

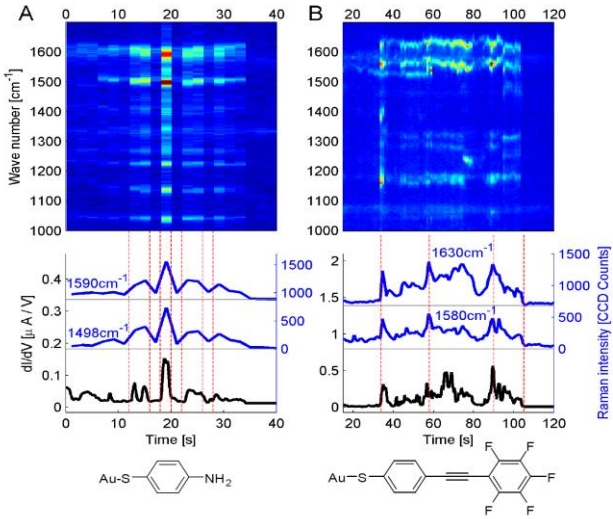
Plasmonics: optics at the nanometer scale

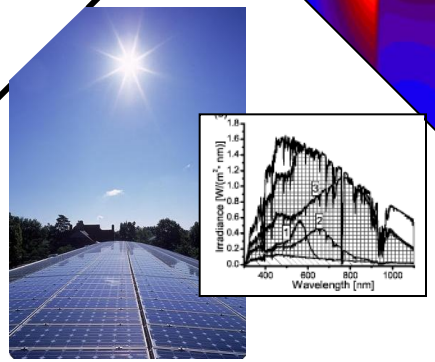
Plasmonics: Fundamental science of metallic nano-optical components



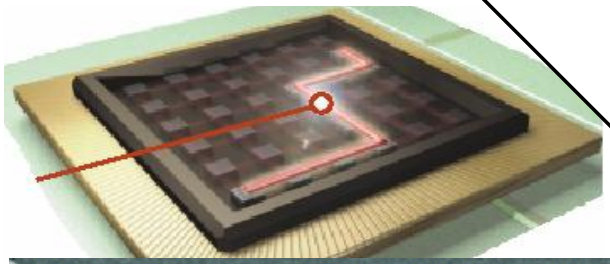
Plasmon-enhanced Spectroscopies for chemical & biodetection

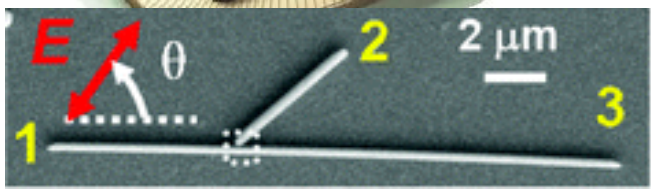




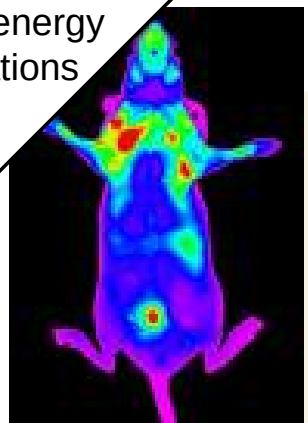


Light harvesting for solar energy applications





Optical interconnects in next-generation computer chips



Biomedical applications