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Plasmonic Enhancing Nanoantennas for Photodetection

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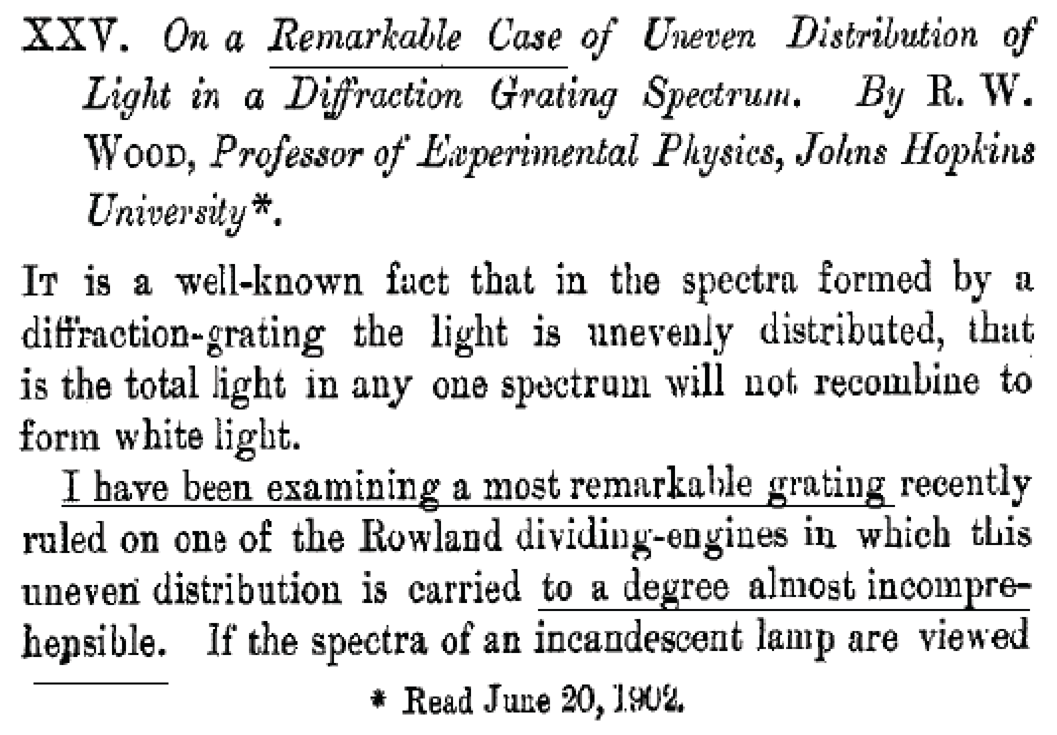
Some History

"new" or well-forgotten!

Surface-plasmon polaritons

Localized SP resonance



XXV. *On a Remarkable Case of Uneven Distribution of Light in a Diffraction Grating Spectrum.* By R. W. Wood, *Professor of Experimental Physics, Johns Hopkins University**.

It is a well-known fact that in the spectra formed by a diffraction-grating the light is unevenly distributed, that is the total light in any one spectrum will not recombine to form white light.

I have been examining a most remarkable grating recently ruled on one of the Rowland dividing-engines in which this uneven distribution is carried to a degree almost incomprehensible. If the spectra of an incandescent lamp are viewed

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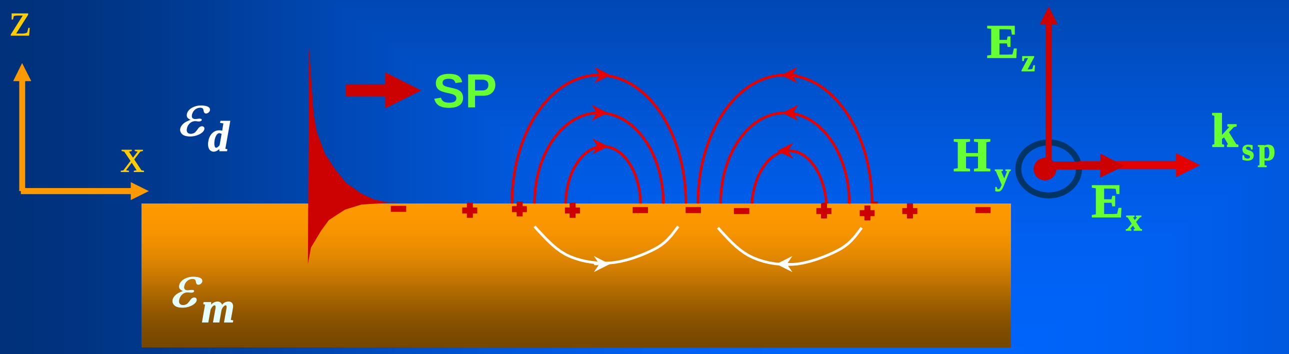
* Read June 20, 1902.

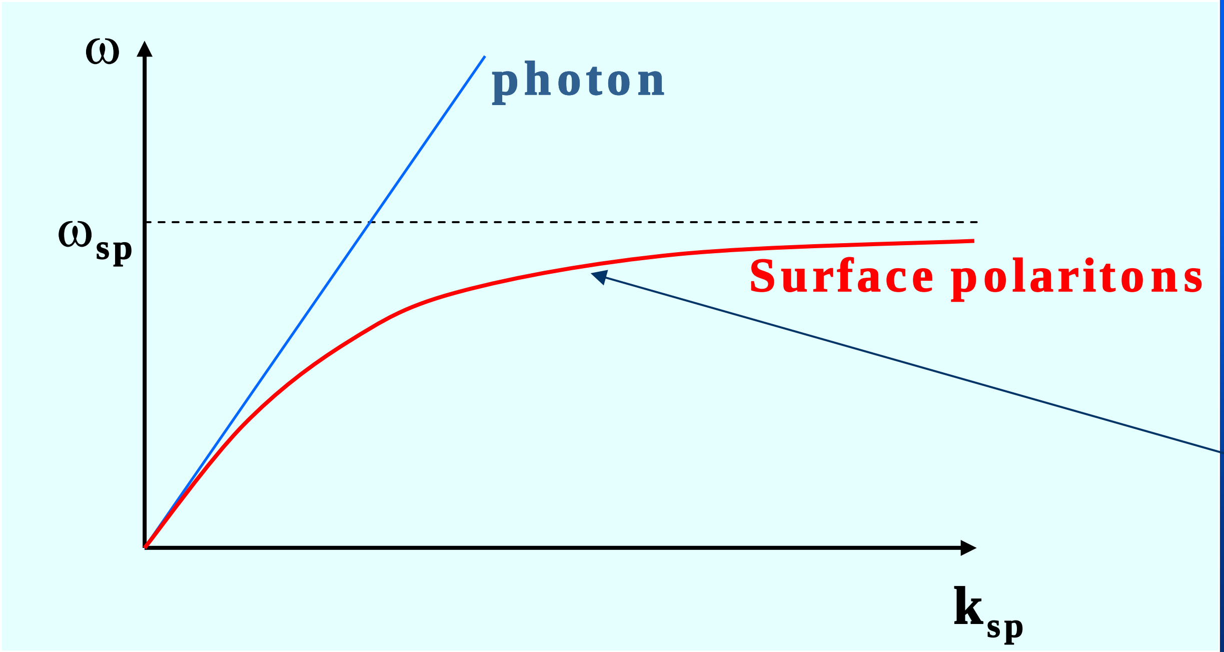
Plasmon resonances give to specific metallic nanoparticles a strong and well defined color.

R.W. Wood, Phil. Mag. 4, 396 (1902).

Surface-plasmon polaritons (SPPs) with optical ω-s and x-ray λ-s



$$k_{sp} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}}$$


Dispersion relation for SPPs.

$$\varepsilon_d \approx -\varepsilon_m$$

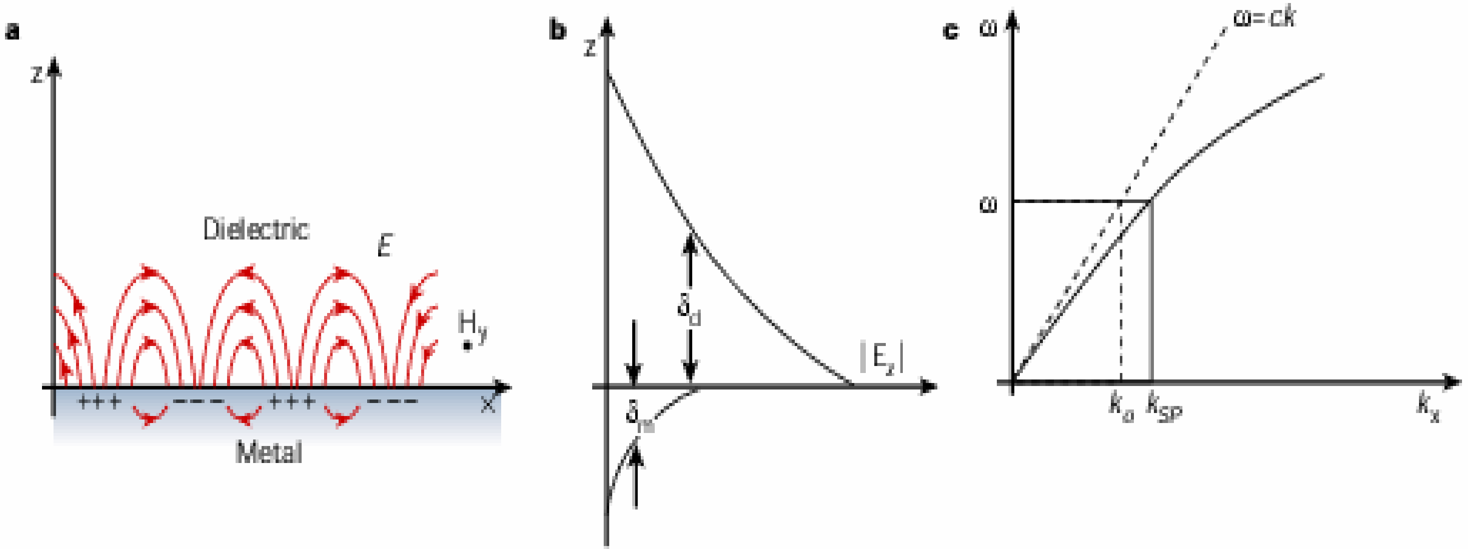
Optical ω

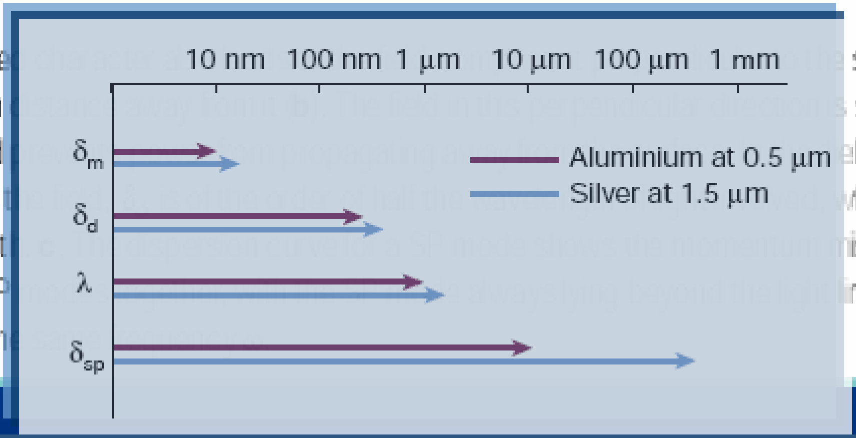
nm scale-λ

Box 1

Surface plasmon basics

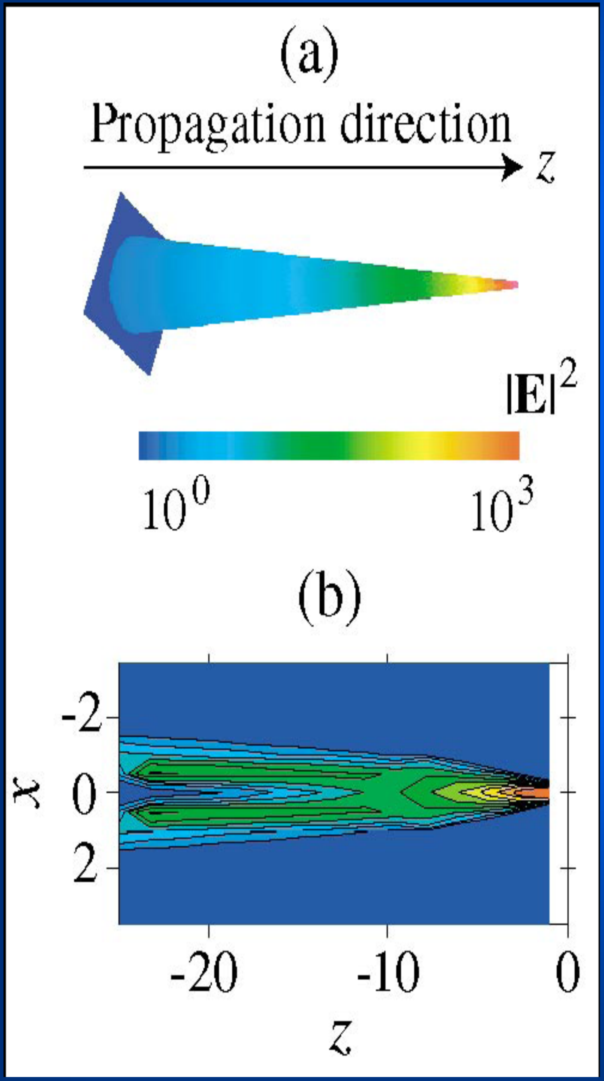
SPs at the interface between a metal and a dielectric material have a combined electromagnetic wave and surface charge character as shown in **a**. They are transverse magnetic in character (**H** is in the y direction), and the generation of surface charge requires an electric field normal to the surface. This combined character also leads to the field component perpendicular to the surface being enhanced near the surface and decaying exponentially with distance away from it (**b**). The field in this perpendicular direction is said to be evanescent, reflecting the bound, non-radiative nature of SPs, and prevents power from propagating away from the surface. In the dielectric medium above the metal, typically air or glass, the decay length of the field, δ_d, is of the order of half the wavelength of light involved, whereas the decay length into the metal, δ_m, is determined by the skin depth. **c**, The dispersion curve for a SP mode shows the momentum mismatch problem that must be overcome in order to couple light and SP modes together, with the SP mode always lying beyond the light line, that is, it has greater momentum ($\hbar k_{sp}$) than a free space photon ($\hbar k_0$) of the same frequency ω.

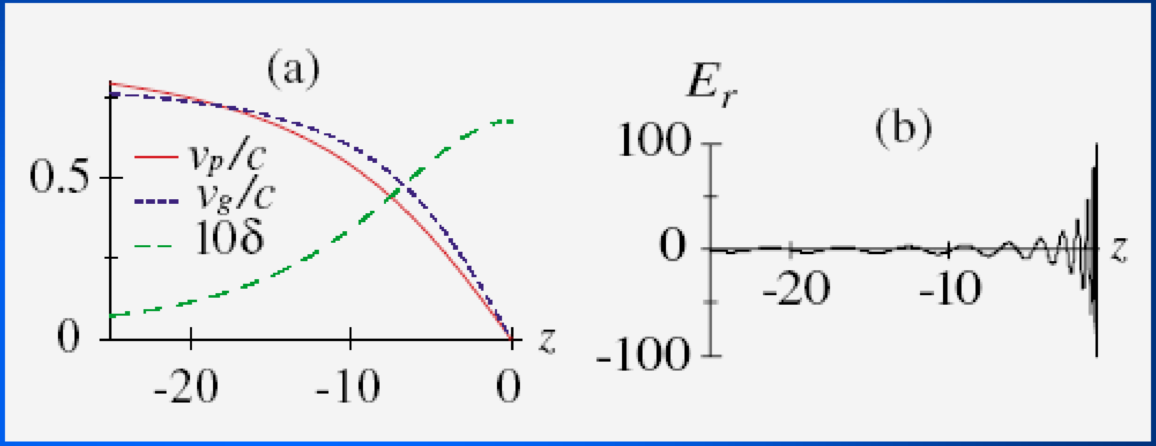


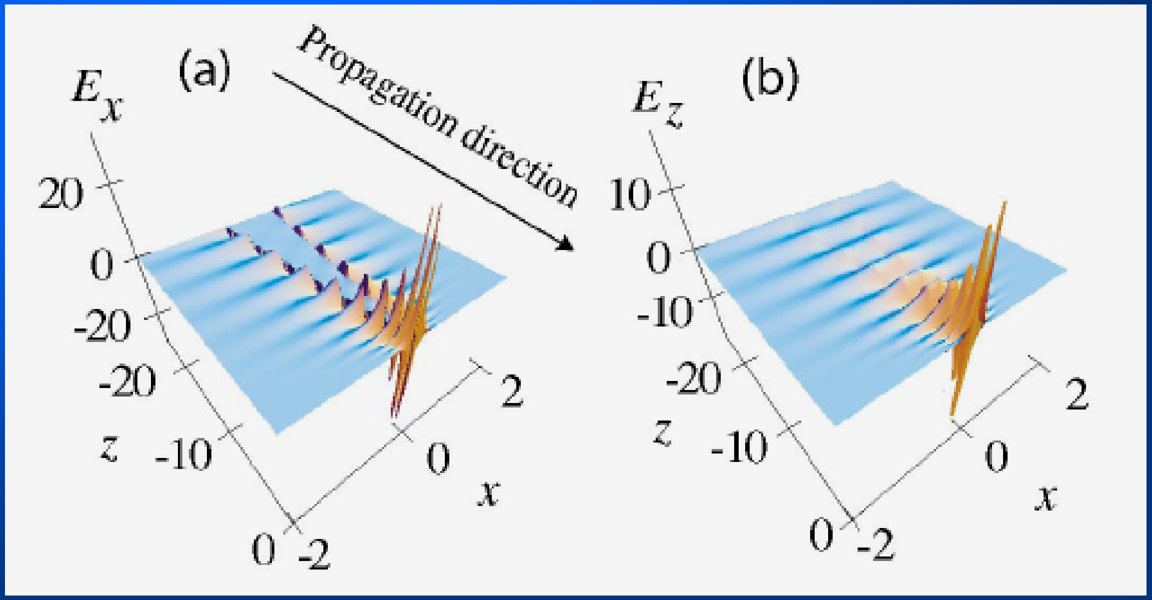


William L. Barnes, Alain Dereux & Thomas W. Ebbesen, Nature **424,** 824 (2003)

Nanofocusing of Optical Energy

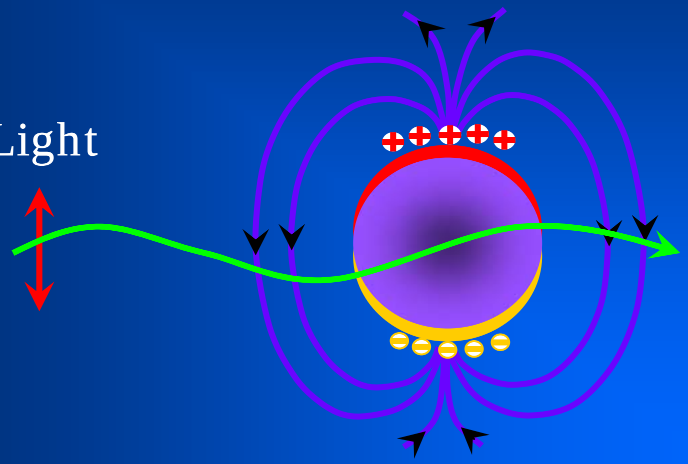






Mark I. Stockman, Phys. Rev. Lett. 93, 1374041 (2004)

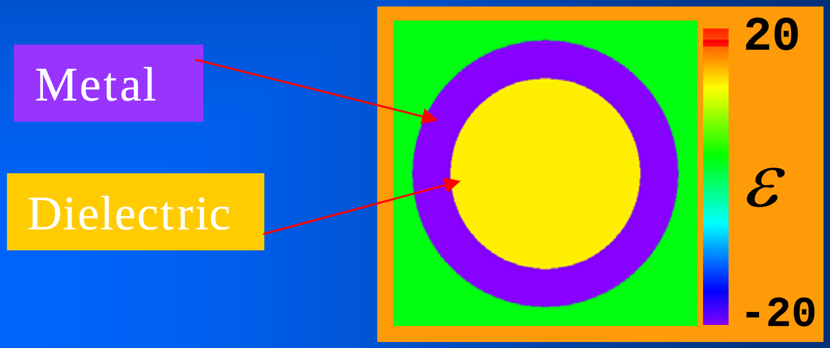
Localized Surface Plasmons



LSP represent collective oscillations of free electrons in small metal nanoparticles. They concentrate energy in three dimensions.

LSPR - Optical Nanoantenna

Optical Resonances of Nanoshell: Tunable LSPR



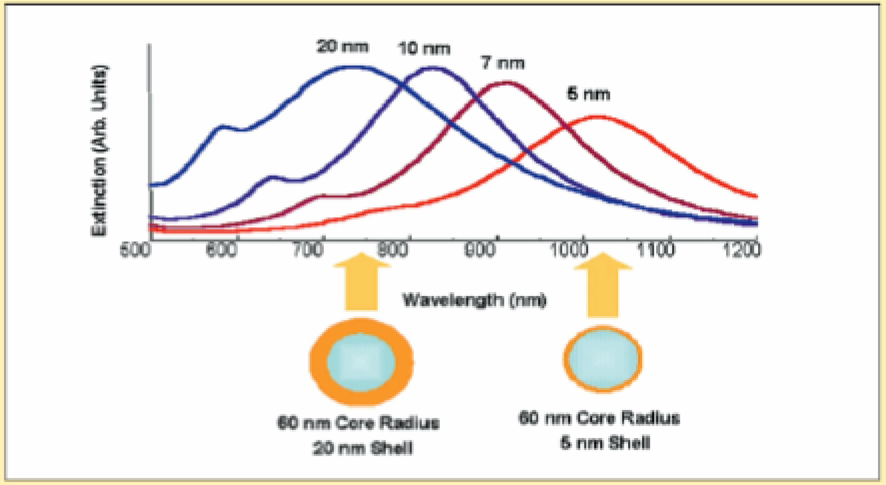
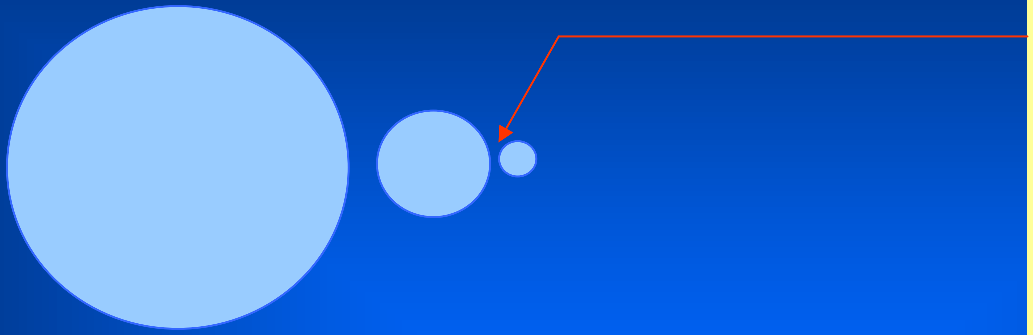


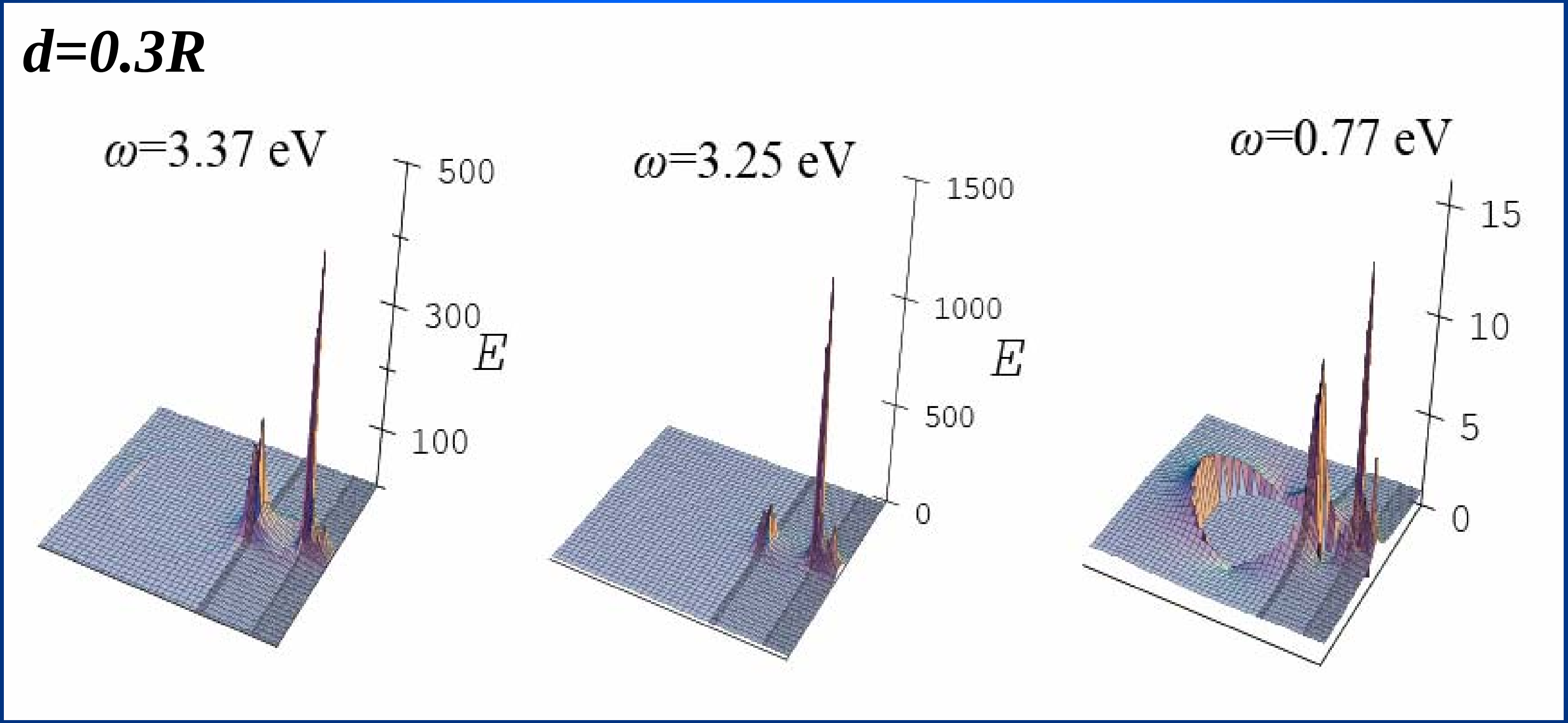
Figure 1. Calculated optical resonances of silica core, gold shell nanoshells over a range of core radius/shell thickness ratios.

Naomi Halas @ Rice University

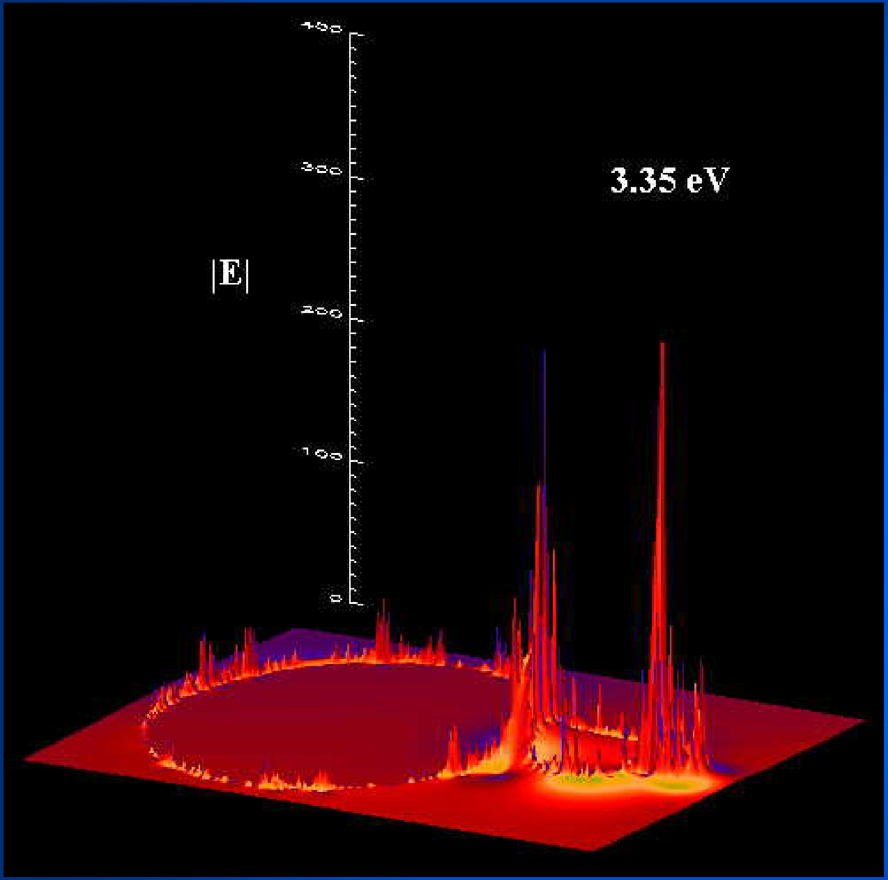
Local Fields for Silver 3-Sphere Nanolens

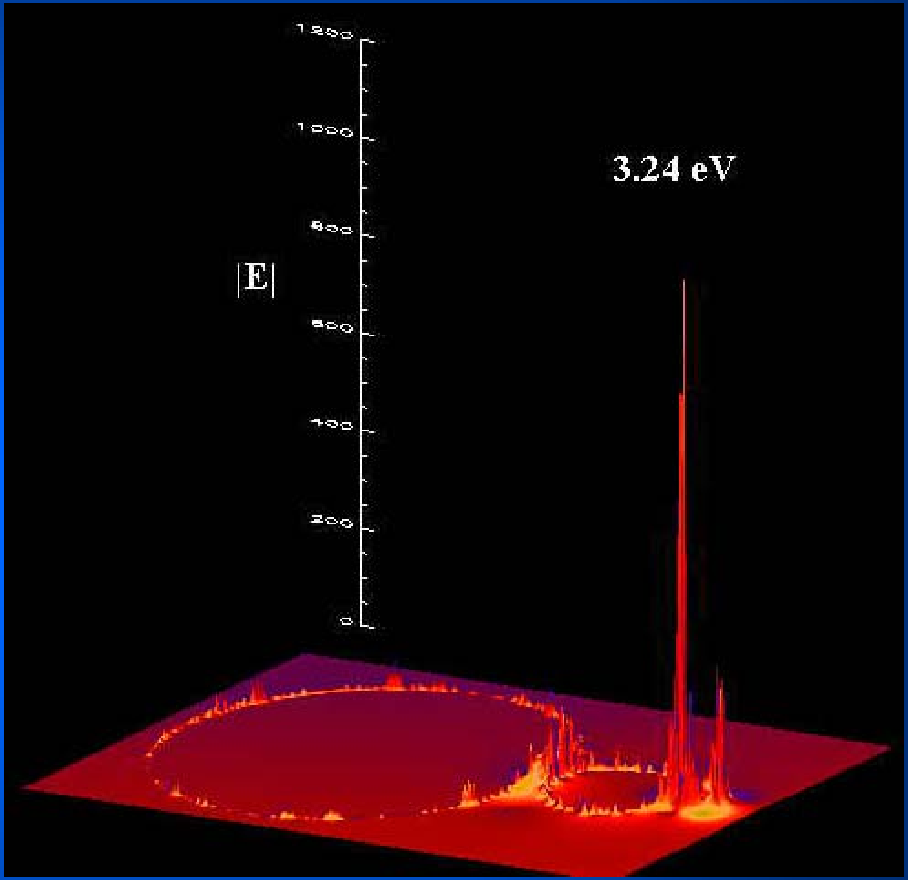


Giant local fields in the minimum gap: Nanoscale localization of optical energy

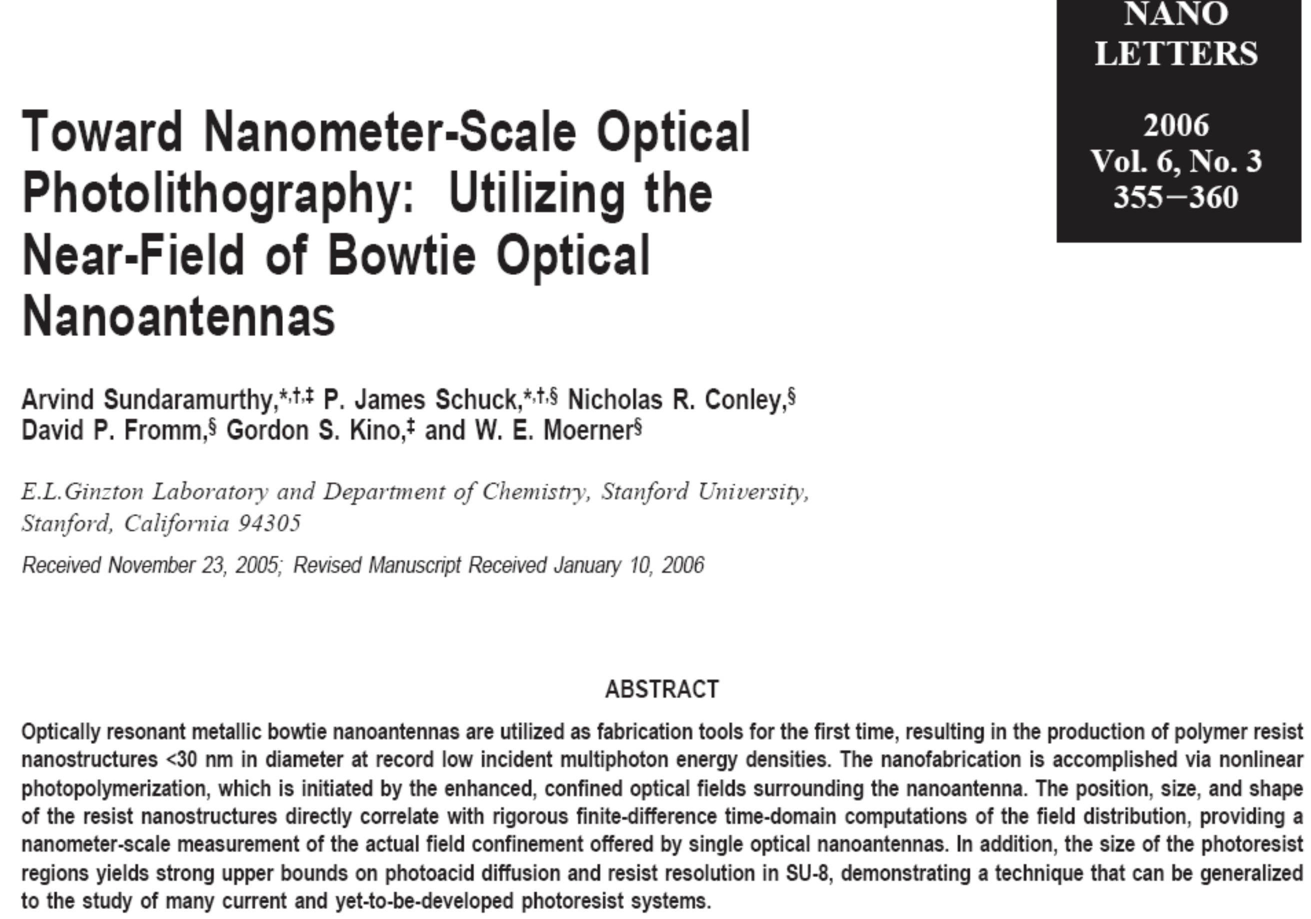


K. Li, M. I. Stockman, and D. J. Bergman, Phys. Rev. Lett. 91, 227402 (2003).





C. Oubre and P. Nordlander (Private Communication).



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Toward Nanometer-Scale Optical Photolithography: Utilizing the Near-Field of Bowtie Optical Nanoantennas

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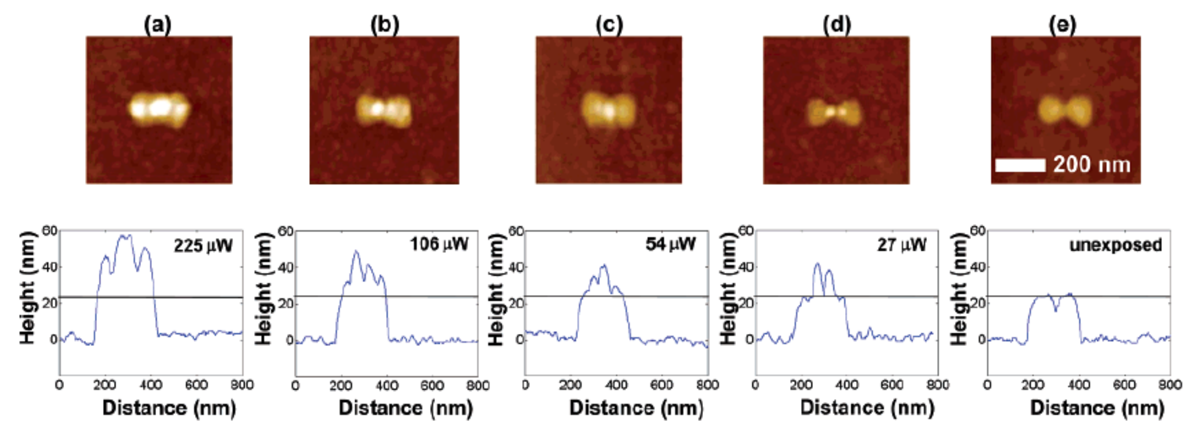
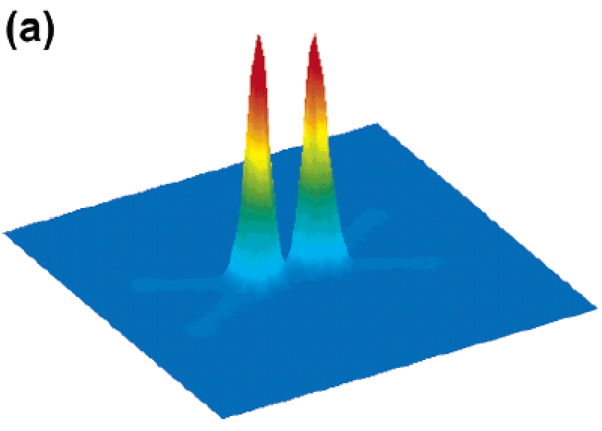
ABSTRACT

Optically resonant metallic bowtie nanoantennas are utilized as fabrication tools for the first time, resulting in the production of polymer resist nanostructures <30 nm in diameter at record low incident multiphoton energy densities. The nanofabrication is accomplished via nonlinear photopolymerization, which is initiated by the enhanced, confined optical fields surrounding the nanoantenna. The position, size, and shape of the resist nanostructures directly correlate with rigorous finite-difference time-domain computations of the field distribution, providing a nanometer-scale measurement of the actual field confinement offered by single optical nanoantennas. In addition, the size of the photoresist regions yields strong upper bounds on photoacid diffusion and resist resolution in SU-8, demonstrating a technique that can be generalized to the study of many current and yet-to-be-developed photoresist systems.

Bowtie Optical Nanoantenna

Bowtie antennas, consisting of two metallic triangles facing tip to tip that are separated by a small gap.





(a) Color surface plot of FDTD-calculated $|I|^2$ ($|E|^4$)

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Nano-antennas for optoelectronics and nanophotonics

Javier Alda, José Manuel López-Alonso, and José María Rico-García

Nano-antennas, designed to detect light in the visible, infrared, and beyond, may be used in polarimetric imaging systems, optical sensors, and for other applications.

The evolution of the design of radio and microwave antennas has allowed new, diverse, and ubiquitous applications of great added value, ranging from global positioning systems to cellular-phone networks. Scaling these designs down towards optical wavelengths has faced two main practical restrictions. On one hand, until recently there have been technological and fabrication issues. On the other, they could not compete against the prevailing semiconductor-based emitters (light-emitting diodes, laser diodes) and detectors (PIN detectors, avalanche photo diodes, etc.). It is now a time of new opportunity for optical or nano-antennas.[1]

An optical antenna, also called an antenna-coupled optical detector, is the marriage of two clearly distinguishable elements working conjointly: a metallic antenna structure that collects the optical radiation, and a transducer that turns the received power into an electric signal.[2] Each of these elements can be optimized

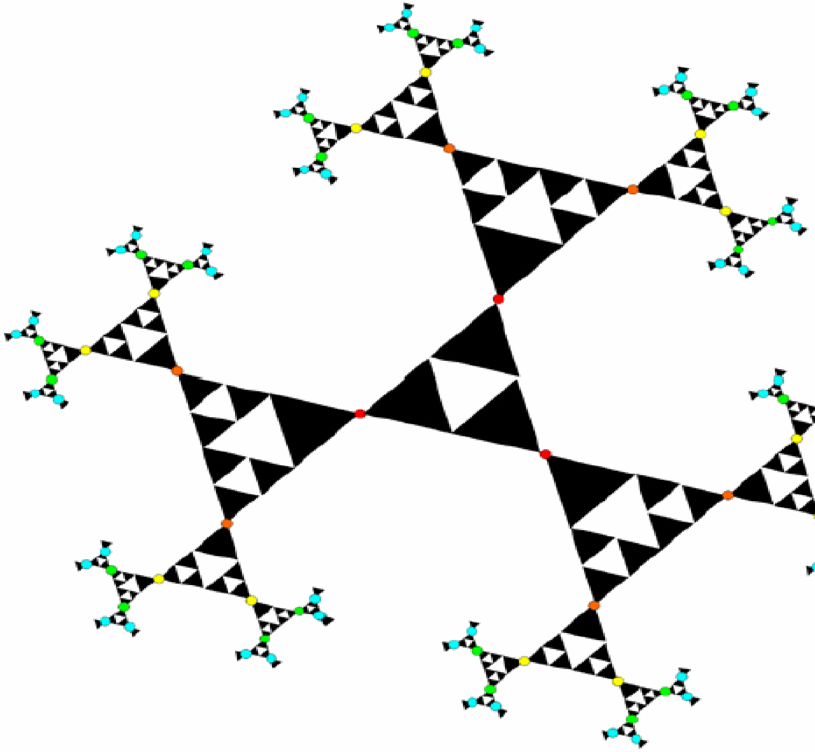

Figure 1. *This fractal bow-tie antenna array is designed to detect five bands centered at wavelengths of λ_0, $2\lambda_0$, $4\lambda_0$, $8\lambda_0$, and $16\lambda_0$.*

Conclusion

The Plasmonic waveguides intercept the energy of the excitation radiation by a large area and propagate it as surface plasmon polaritons to a small IR photodetector.

The plasmonic nanoantennas (Nanoshell, Nanolens and Bowtie) are capable of producing very high local fields in small volumes. They may be used to improve signal characteristic of IR photodetectors.

Thank you