Nano-Optic Tools and Materials

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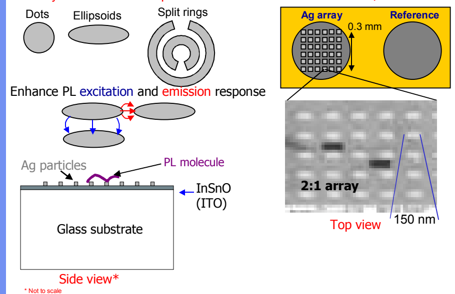
Abstract

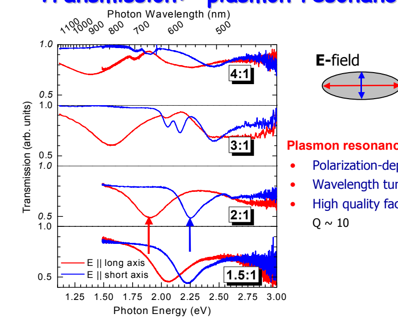
The emergence of modern nano-fabrication capabilities has ushered in many new nano-scale tools and materials with enhanced functionality. We have developed and investigated both an improved Near Field Scanning Optical Microscope (NSOM) probe and nano-structured optical materials. NSOM provides a powerful optical probe on the nanometer scale using tips formed on the end of optical fibers. Our recent developments in NSOM include novel tips with higher optical throughput, increased spatial resolution, and polarization control. These NSOM tips are being used to develop novel nano-structured materials for optical applications in the subwavelength spatial regime. Our nano-structured materials include regular arrays of silver nano-particles with grid spacing several hundred nanometers and an approximately 75 nm thickness and width. We have measured the far-field optical response of different arrays of identical particles which have an in-plane aspect ratio (length to width) from 1:1 to 4:1, which clearly demonstrate a resonance shift to lower (higher) energy with increasing aspect ratio for polarizations parallel to the long (short) axis. This work establishes the ability to tune optical resonance energies and widths in nanostructured materials with quality factors *Q* exceeding 10. One goal of this effort is the development of powerful new optical imaging capabilities and meta-materials with a negative index of refraction.

Nano particle Plasmonics

Nano-particle array samples



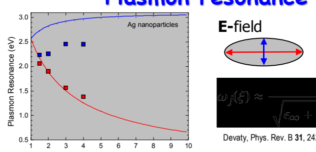
Transmission: plasmon resonance



Plasmon resonance

- Polarization-dependent
- Wavelength tunable
- High quality factor: Q ~ 10

Plasmon resonance



$$\omega_j(\xi) \approx \frac{\Omega_p}{\sqrt{\varepsilon_\infty + [P_j(\xi)^{-1} - 1]\varepsilon_h}}$$

Devaty, Phys. Rev. B 31, 2427 (1985)

Maxwell-Garnett effective dielectric

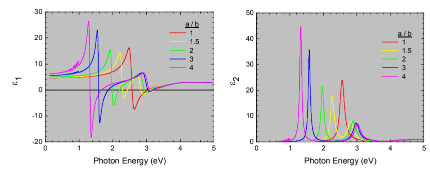
metallic spheres ε_i in dielectric host ε_h

$$(\bar{\varepsilon}_{eff}(\xi)) = \bar{\varepsilon}_h + \frac{f(\bar{\varepsilon}_i - \bar{\varepsilon}_h)\bar{\varepsilon}_h}{\bar{\varepsilon}_h + (1-f)(\bar{\varepsilon}_i - \bar{\varepsilon}_h)P_j(\xi)}$$

$$P_j(\xi) = \frac{1-\xi^2}{2\xi^3}\left[\log\left(\frac{1+\xi}{1-\xi}\right) - 2\xi\right]$$

$$\xi = \sqrt{1-(b/a)^2}$$

Model dielectric constant ε

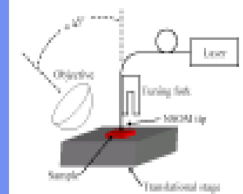


- EMT Model predicts plasmon behavior: metallic Ag parameters
- Plasmon resonance tunable with NP aspect ratio
- Negative dielectric constant: $\varepsilon_1 < 0$

NSOM

Near Field Scanning Optical Microscopy

NSOM investigation of nano-structures



NSOM characteristics

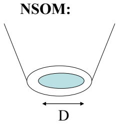
- 20 nm spatial resolution
- Spectroscopy
- Polarization resolved

NSOM Applications

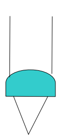
- Optronic devices probed
- Hot spot antenna structures probed
- Florescence probed
- Photo-conductive response of carbon nano-tubes
- Photovoltaic response of p-n junctions

Optical spatial resolution

	Image	Confocal
Far field optics:	$\Delta x \cong \frac{0.5\lambda}{\sin(\theta_{max})}$	$\Rightarrow \frac{0.35\lambda}{\sin(\theta_{max})}$
Solid Immersion lens:	$\Delta x \cong \frac{0.5\lambda}{n\sin(\theta_{max})}$	$\Rightarrow \frac{0.35\lambda}{n\sin(\theta_{max})}$
NSOM:	$\Delta x \cong D$	

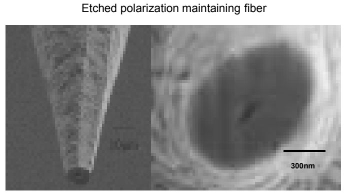


focusing element



High optical throughput NSOM tips

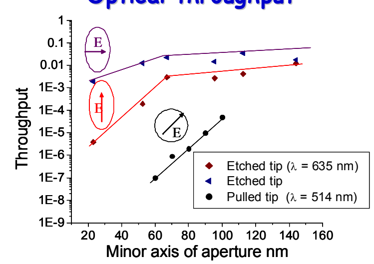
Etched polarization maintaining fiber



SEM image of uncoated probe (a). Preferential etching leads to non-circular plateau. SEM image of the tip after FIB milling (b). The aperture has dimensions of about 55 nm by 225nm.

V. Adiga, D. Schmadel, H.D. Drew, Appl. Opt., in press

Optical throughput



Far field throughput as a function of minor axis dimension. For comparison the throughputs of pulled tips are also shown.

V. Adiga, D. Schmadel, H.D. Drew, Appl. Opt., in press

Conclusions

- Developed novel NSOM polarization maintaining probe tips – provide enhanced throughput and spatial resolution
- Arrays of silver nano-rods - fabricated and characterized in far-field spectroscopy
- Demonstrated high-Q, tunable plasmon resonances: polarization sensitive and dependent on the nano-rod aspect ratio
- Potential applications of nano-particles in metal enhanced fluorescence, nano-optronics, and meta-materials
- Nano-fabrication and nano-optical probes offer promise for novel optical materials