Super-Enhanced Optical Energy Concentration Through A Subwavelength Aperture Using A Photonic Nanojet

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Optical transmission through resonant subwavelength apertures in optically thick metal films have received an explosion of interest for their ability to overcome the diffraction limit of light and concentrate light efficiently into a subwavelength volume. This achievement has attracted the use of subwavelength apertures in numerous applications, i.e. in near-field optical microscopy, fluorescence correlation spectroscopy, nanoscale optical recording, optical lithography, ultra small photodetectors, novel nanoscale light source, and nonlinear optical processes, etc.

In a separate line of research, photonic nanojets have been discovered and proposed for a number of applications ranging from optical data disk storage to high-speed photodetectors. A photonic nanojet is a sub-wavelength (as small as $\lambda/3$) narrow electromagnetic beam that can propagate multiple wavelengths from the shadow-side surface of a dielectric sphere.

We present here a means to significantly compress the transverse width of a photonic nanojet by placing a plasmonic nano-aperture in its path. Three-dimensional (3-D) finite-difference time-domain (FDTD) modeling is used to demonstrate the superenhanced optical energy concentration capability of the photonic nanojet nano-aperture light-collection system.

Specifically, 3-D FDTD results demonstrate that a gold nano-aperture illuminated by a nanojet compresses the nanojet from $\lambda/3$ to $\lambda/6$, which corresponds for an incident wavelength, $\lambda = 633$ nm to a reduction of the intensity full-width at half-maximum (FWHM) from ~ 220 nm to ~ 140 nm. Further, we achieve an absorption enhancement factor of nearly 350 in a subwavelength volume of 0.004 μm^3 on the shadow-side of the gold nano-aperture for an incident wavelength, λ of 633 nm. The superenhanced, subwavelength concentration of light is achieved for both resonant and non-resonant plasmonic nano-apertures. This phenomenon may find utility in a wide range of applications, such as high-speed photodetectors, optical data storage, optical lithography, near-field optical microscopy, novel nanoscale light source, localized detection of embedded ultra-subwavelength inhomogeneity, fluorescence correlation spectroscopy, biosensors, etc.