Modeling of photonic nanojet emission from spherical nanoparticles using the 3D multiple multiplole method

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Spherical micro and nano particles with different refractive indices under plane wave illumination have been studied by using the 3D multiple multipole (MMP) method. The intensity distribution that emerges in the vicinity of the particle's rear boundary (with respect to its plane wave illumination) has resulted in a tightly focused photonic nanojet [1, 2]. The resulting beam waist significantly undergoes the diffraction limit, where the nanojet emission extends over several optical wavelengths without suffering from significant diffraction providing a pencil-like area of high optical intensity. In our contribution, we report on the optimization of both the dielectric material and the particle shapes (oblate ellipsoids) in order to maximize the power confinement in the nanojet. Different 3D-MMP models are applied and discussed.

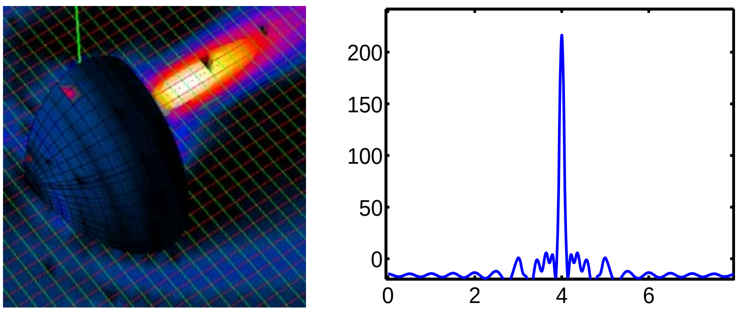

Fig.1: Nanojet emission from an oblate dielectric ellipsoidal particle (n=2) illuminated by a plane wave from the left (λ = 500 nm; E-polarization): a) The time-averaged Poynting field modeled with 3D ring multipoles b) The Radiation pattern (intensity distribution in the "focal plane" against the lateral extent given in µm) showing a beam waist of W_{FWHM}=120 nm for the particle's major and minor axis of R_x=5 µm and R_y=2.5 µm.

References

[1] Z. Chen, A. Taflove, *Opt. Express* 12, 1214-1220, 2004.

[2] T. Jalali, D. Erni, Ch. Hafner, *15th Int. Workshop on Optical Waveguide Theory and Numerical Modelling (OWTNM 2006)*, April 20-21, Varese, Italy, 2006.

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Modeling of Photonic Nanojet Emission from Spherical Nano Particles using the 3D Multiple Multiplole Method

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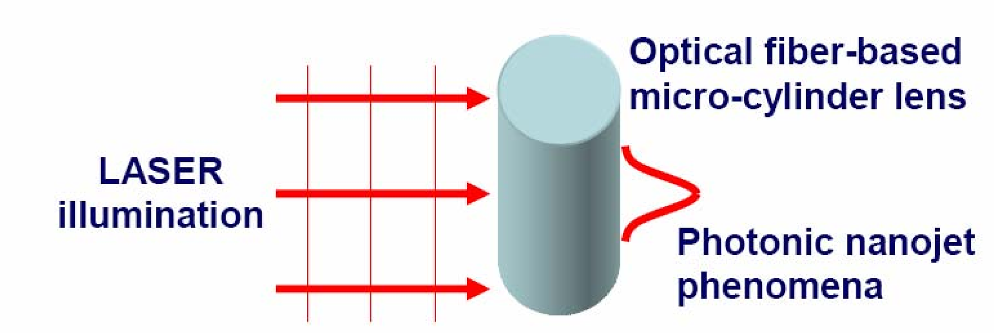
Introduction

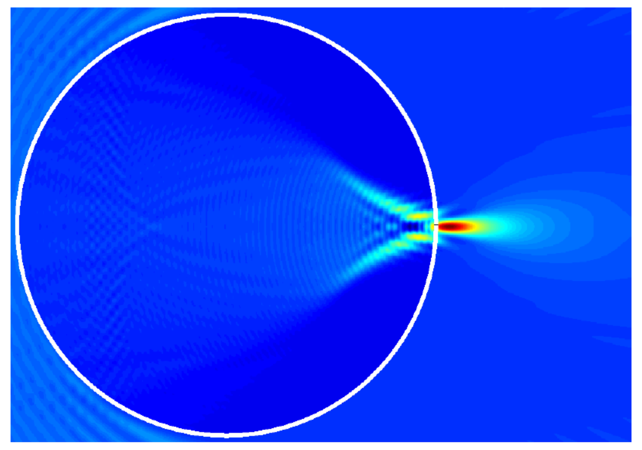
The properties of photonic nanojets could be a tool for detecting, differentiating and sorting nanoparticles, which is necessary for the field of nanobiotechnology. It may be used for study of individual nanometer scale intracellular components and macromolecular complexes and detection of individual viral particles. Photonic Nanojets open door to Visible-Light Ultramicroscopy by using visible light for detecting and imaging. Because of the whispering gallery mode resonances with high quality factors, this microspheres could be one choice for employing in tight-binding photonic devices such as coupled resonator optical waveguides.

Photonic Nanojet

The scattering theory of the TM polarization by a homogeneous prolate or oblate spheroid with any size and refractive index is considered. The electromagnetic field around a dielectric ellipse using Mie theory is obtained. The total field outside the ellipse is considered as the sum of the incident and scattered fields $E_t = E_i + E_s$. Four essential parameters play important role: particle refractive index, refractive index of the surrounding, the incident plane wave wavelength, the different radius the particle. The vector wave are obtained from solutions of the scalar wave equation that is separable in the spheroidal coordinate system (η, ξ, ϕ)

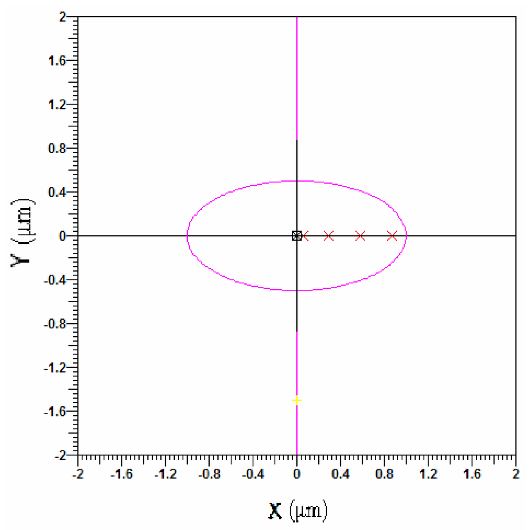
$$(\nabla^2 + k^2)\begin{Bmatrix}E\\H\end{Bmatrix} = 0 \quad \Rightarrow \quad \psi_{{}^e_o mn}^{(j)}(-ic;\eta, i\xi, \phi) = S_{mn}(-ic;\eta) R_{mn}^{(j)}(-ic; i\xi) \begin{matrix}\cos\\ \sin\end{matrix} m\phi,$$

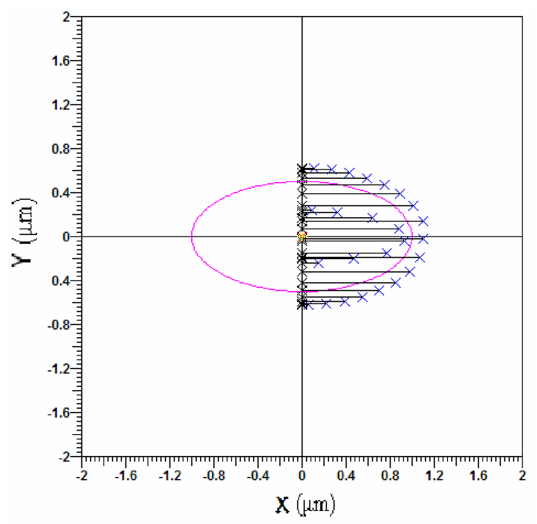




3D MMP Simulation

The Multiple Multipole Program (MMP) is a semi-analytic boundary method in the frequency domain that may provide highly accurate results. MMP solutions fast convergence help to have highly accurate results even in the close near field, i.e., where the nanojets are observed.

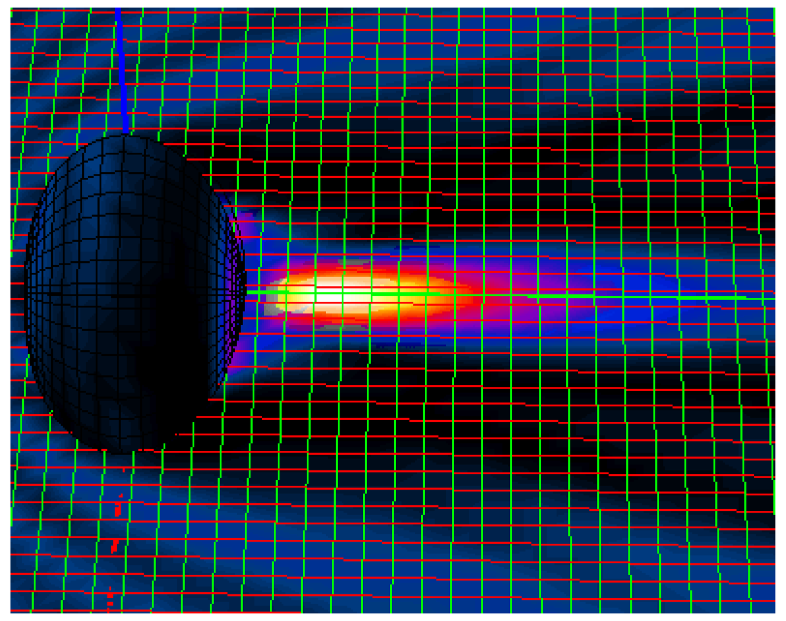


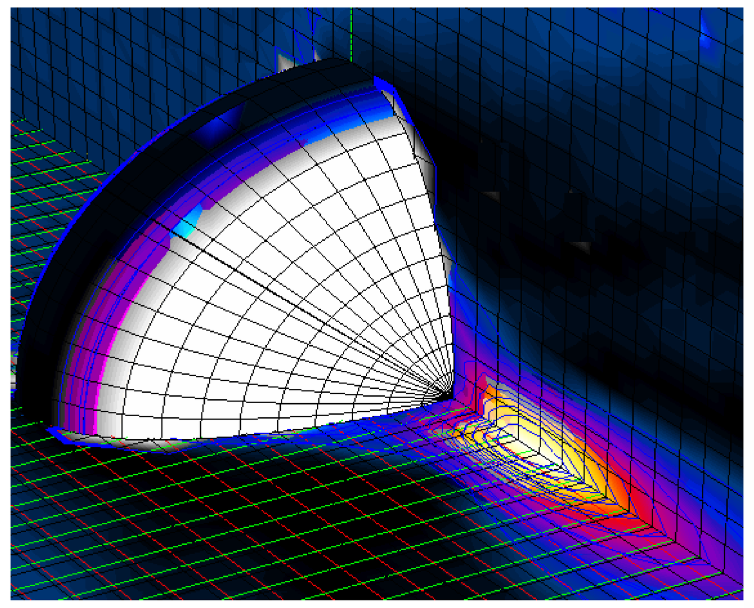


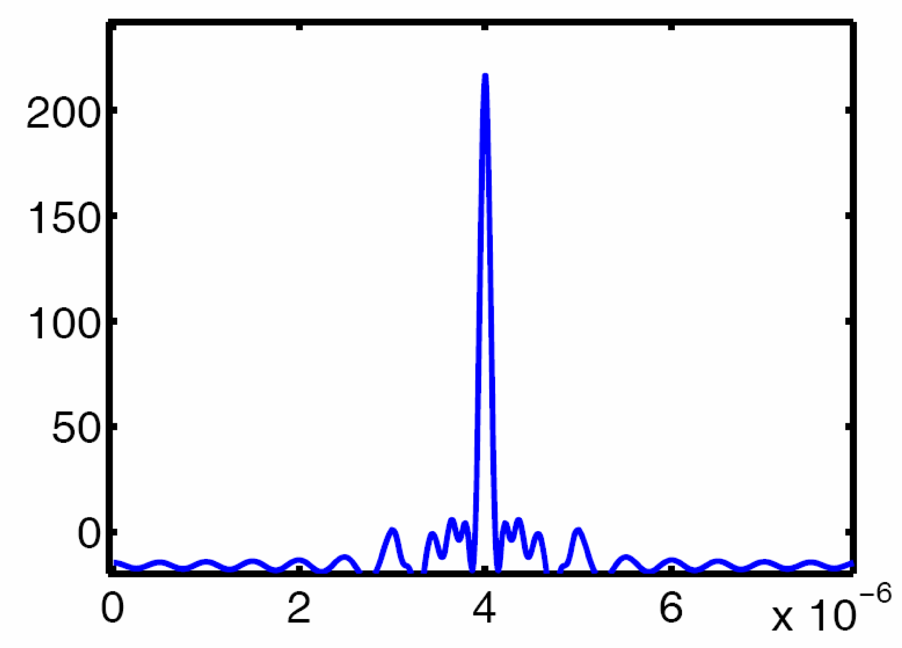
Excitation is plane wave. The boundary (ellipse , circle) in xy plane is defined. 2D multiplole expansions is set in a half of the shape, due to a symmetry. 3D shape is defined by rotate the 2D one. 3D ring multiploles is generated.

Results

In the case of an oblate ellipsoid, an ellipse is rotated around its short axis. The optimized parameters of 2D model namely R_x= 5 μm, R_y= 2.5 μm and n=2 are used to compute the waist size. The wais size is W_{FWHM}=120nm. The mismatching error is 1.27% for the ring multipoles ellipsoid and 53% for complex origin one.







Conclusion

3D MMP simulation has been done by using ring multipoles and complex origin and the difference between these two methods was compared. Comparison between obtale and prolate solution shows that they have nearly same waist for the same area, but the intensity for oblate by factor 1.5 is higher and the oblate one can be easily optimized for different major axis and refractive index. The waist is getting smaller by increasing major axis and refractive index. MMP method is difficult to set boundaries, sources and multipoles in correct positions, but as it is shown in the pervious section is quite fast and accurate.

References

[1] Z. Chen, A. Taflove, *Opt. Express* 12, 1214-1220, 2004.

[2] A. V. Itagi, W. A. Challener, *J. Opt. Soc. Am. A*, 22(12), 2847, 2005.

[3] Ch. Hafner, *Post-modern Electromagnetics*, John Wiley & Sons, Chichester, 1999.

[4] http://max-1.ethz.ch

[5] T. Jalali, D. Erni, Ch. Hafner, *15th Int. Workshop on Optical Waveguide Theory and Numerical Modelling (OWTNM 2006)*, April 20-21, Varese, Italy, 2006.