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Short Communication

FDTD studies of EM field enhancement in silver nano cylinders arranged in triangular geometry

Prabhat Behere*, S. K. S. M. Ajay Ram, V. Sai Muthukumar and K. Venkataramaniah

Department of Physics, Sri Sathya Sai University, Sri Sathya Sai Vidya Giri, Prasanthi Nilayam, India, 515134.

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Metallic nano structures exhibit interesting optical properties due to the coupling of surface plasmon resonances with the electromagnetic fields. Metal nano particles exhibit dramatic field enhancement in the vicinity of the nano particle which can be further increased by near field coupling between closely spaced particles. In this paper, we study a system made of 3 nano cylinders placed at the vertices of an equilateral triangle. Near field optical responses of the system of silver nano cylinders interacting with the incident plane wave was simulated by finite difference time domain (FDTD) method in the visible light region. We attempt to study influences of the radius of the nano cylinders and inter-particle distances on the resonances.

Key words: Plasmons, FDTD, silver nano cylinder.

INTRODUCTION

Enhancement and confinement of electromagnetic fields is an important problem in nano photonics. Metallic nano structures exhibit interesting optical properties due to the coupling of surface plasmon resonances with the electromagnetic fields (Bohren and Huffman, 1983). Hence metal nano structures have potential applications in photonic and plasmonic devices (Ohtsu et al., 2002).

Light scattering by single sub-wavelength spherical metallic particle was studied analytically by Mie as early as 1908 (Mie, 1908). Interaction of light with single non regular metallic particles have been investigated both numerically (Tominaga and Tsai, 2002) and experimentally (Jin et al., 2002). Nano particles with low symmetric geometries exhibit dramatic field enhancement in the vicinity of the nano particle. This enhancement can be further increased by near field coupling between closely spaced particles (Kottman and Martin, 2002).

Various arrangements of the particles give rise different complex surface plasmon resonances. Local field enhancement of linear arrays of identical Ag nano particles has been studied by Sweatlock et al., (2005) and exhibits 5000 fold enhancement. Ming-Yaw Ng et al. (2006) studied the field enhancement in 3 pair arrays of silver nano cylinders in which particle-particle interaction as well as pair-pair interaction was studied.

In this paper, we study a nano cylinder structure made of 3 nano cylinders placed at the vertices of an equilateral triangle. Near field optical responses of the system interacting with the incident plane wave was simulated by finite difference time domain (FDTD) method in visible light region. A FDTD solver called MEEP was used for the FDTD calculations. Influences of the radius of the nano cylinders and inter-particle distances on the local field enhancement are investigated in this paper.

Simulation model

2 dimensional FDTD methods (Taflove, 1995) is used to investigate the near field optical responses of the triangular system of nano cylinders. Figure 1 shows the geometric configuration of the nano cylinders. The inter particle distance is varied as 10 and 20 nm. The structure is illuminated with a y-polarised plane wave traveling in x-direction at a wavelength of 459 nm. The dispersion behaviour of silver was simulated by Lorentz dispersion model (Skinner and Byrne, 2006).

The imaginary part of the permittivity is influenced by the size of the nano particles. Nevertheless, the experimental results agree well with theoretical calculations based on Mie theory with the bulk dielectric constant, in particular for particles with radius greater than 20 nm

*Corresponding author. E-mail:prabhatbehere2811@gmail.com. Tel.: +91-8555-286324.

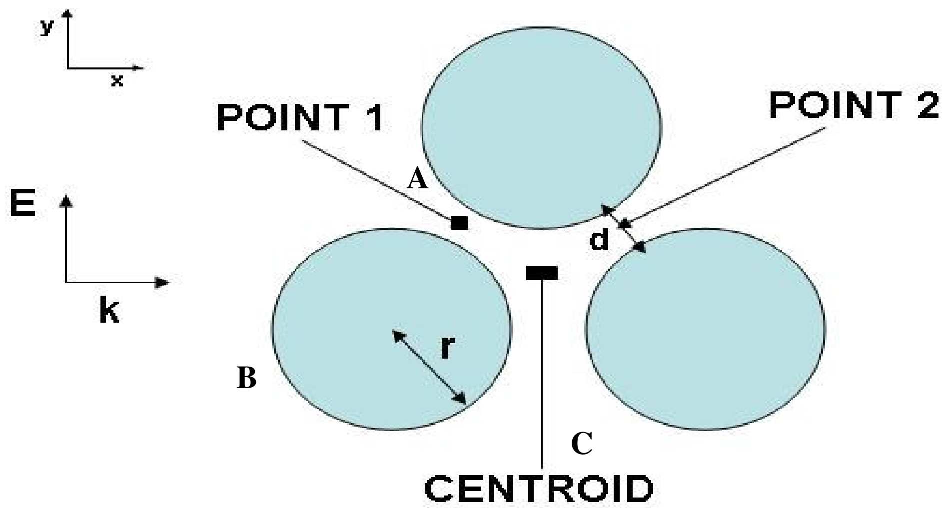

Figure 1. Simulation model: d is the interparticle distance and r is the radius of the cylinder. Point 1 and point 2 are the midpoints of line joining the centre of cylinders A and B and cylinders A and C respectively.

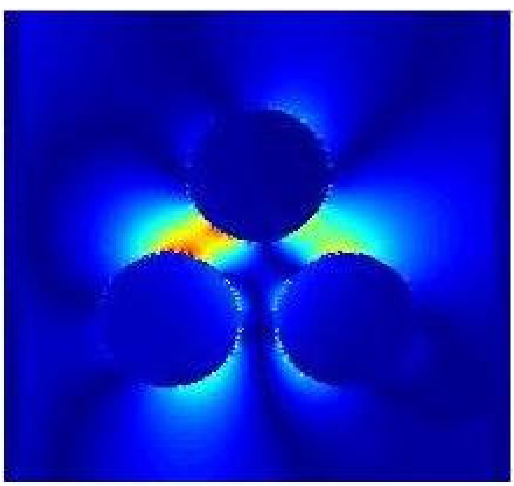

Figure 2. TM mode near field distribution around the system with d = 20 nm and r = 40nm and λ = 459 nm.

(Charle et al., 1998). Hence for the present work, fre-quency dependent optical constant is set to the bulk experimental data (Palik, 1985).

The cylinders are labeled as A, B and C for convenient reference. Also fields at point 1 (midpoint of AB), point 2 (midpoint of AC) and the centroid (of the triangle ABC) are considered for discussion (shown in Figure 2).

The computational region is 600 by 600 nm and the grid size is 1 nm. The error in the computation can be reduced by reducing the grid size. This is verified by comparing the computations at different grid sizes.

RESULTS AND DISCUSSION

Response of sub-wavelength particles is often modeled in quasi static approximation where it can be assumed that all the points of the particle respond simultaneously to an incoming excitation field (Novotny and Hecht, 2006). The inter-particle interaction can be taken to be a dipole-dipole interaction. The dipole approximation is valid only for small particles and with increasing radius the higher order terms contribute to the interaction.

The near field intensity is maximum at the surface of the cylinder and the field inside the particle dies down exponentially within the skin depth. There is an EM coupling between 2 particles giving rise to field enhancement in the gaps between them. The amount of coupling is dependent on the radius, inter-particle distance and wavelength. In this paper we are interested in the study of coupling between the particles which are not placed parallel to the incident polarization.

Figure 2 gives the intensity image of the system with the incident excitation field. The radius of the particles is varied from 20 to 70 nm keeping the inter-particle distance constant at 20 nm. Figure 3 show the plot of average intensity at 3 different points of interest (specified in Figure 1) with varying radius in the cylinders.

The intensity at the centroid is interestingly almost constant for all radii. Here, we have a point of low intensity surrounded by a region of high intensity. For point 1 there is a gradual increase of intensity till 43 nm. A similar behaviour is observed at point 2 with the resonance occurring at smaller radius. Since the amount of field passing into the triangle reduces with increasing radius, the intensity at point 2 falls off rapidly.

A similar study was done for particle separation of 10 nm which is shown in Figure 4. At point 1 there is a resonance peak at 35 nm and point 2 at 30 nm. The field at the centroid is constant over all the radii even in this case. The strongest field enhancement at point 1 occurs due to plasmon resonance. But when compared with the

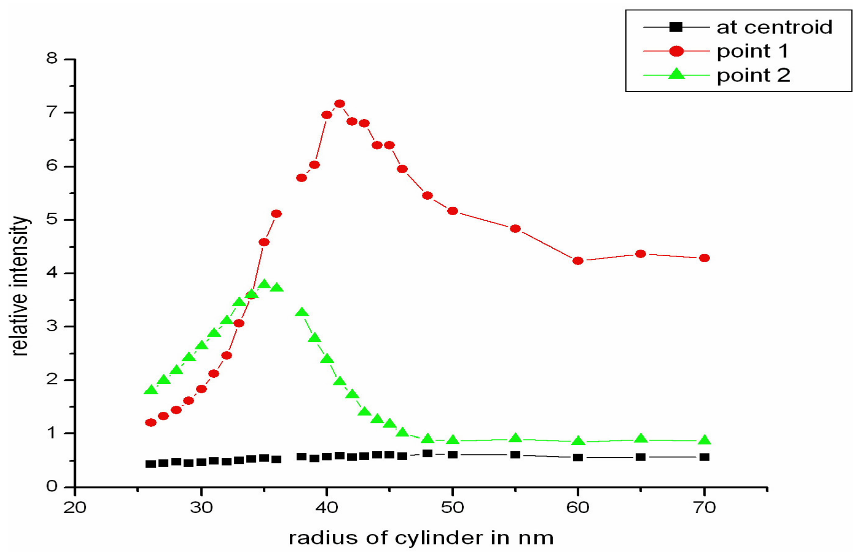

Figure 3. Average intensity (in arbitrary units) Vs radius of the nano cylinders particle separation = 20 nm.

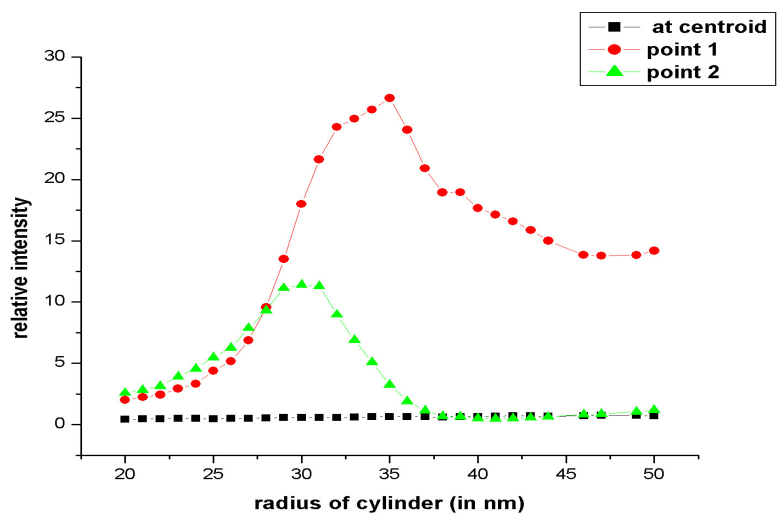

Figure 4. Average intensity (in arbitrary units) Vs radius of the nano cylinder. Particle separation = 10 nm

results of the previous works by Ming-Yaw Ng et al. (2006) where they studied the resonances with the incident polarization parallel to the coupling direction, there is a shift in the resonant radius from 36 to 43nm for a separation of 20 nm.

The behavior is similar to the results obtained by Brandl et al., (2006) where a similar arrangement of 3 nano particles was considered instead of nano cylinders as in this case. There is similar field enhancement in both the works with very small enhancement at the centroid. Here we consider coupling which is not parallel to the plane of oscillation. Then, we expect contribution from higher order multipoles and not just dipoles. These contributions are more pronounced at larger radii as is evident from the shift of resonance towards larger radius. Also, when the inter-particle distance is reduced to 10 nm there is a shift to lower radii owing to strong coupling. In Brandl et al. (2006), symmetric field enhancements were observed both at point 1 and point 2 with the interparticle separation being 1 nm. But in this paper an inter particle separation of 20 and 10 nm was considered.

The difference between the 2 peaks (intensity at point 1 and 2) in the 20 nm case is about 8 nm and the difference in the 10 nm case is about 5 nm. With lesser interparticle distances both the peaks get closer and tend towards symmetric behavior. The behavior of the 3 cylinder

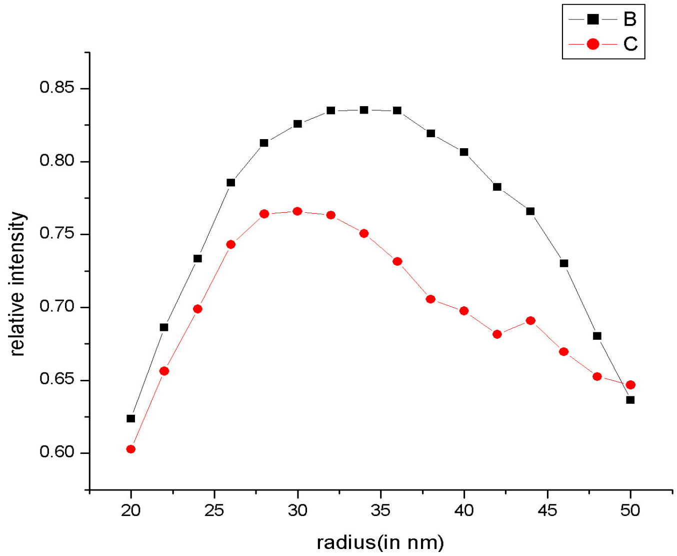

Figure 5. Average Intensity (in arbitrary units) Vs radius of the nano cylinder. 2 cylinder geometry and particle separation = 20nm.

arrangement is different from the 2 cylinder arrangement. To study the effect of the third cylinder, simulation was done with the 2 cylinder geometry in which one of the particles was removed from the triangular geometry. 2 configurations were studied with cylinder A and cylinder B (shown in Figure 2) in one case and cylinder A and cylinder C in the other. The inter particle distance was maintained at 20 nm. The field at the midpoint was plotted as a function of radius in Figure 5. It is evident from Figure 3 and Figure 5 that in the 3 particle case the resonance peak is sharper and also there is a peak shift towards larger radii. The behavior of the 2 particle system with the particles arranged parallel to the incident polarization is done in Ming - Yaw Ng et al. (2006).

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