

# Scattering of Light by Multilayered Cylindrically Periodic Arrays of Metal-Coated Nanocylinders

Haiyang Cao<sup>1</sup>, Kiyotoshi Yasumoto<sup>1</sup>, Yunfei Liu<sup>1</sup>, Vakhtang Jandieri<sup>2</sup> and Dan Zhang<sup>1</sup>

<sup>1</sup>College of Information Science and Technology, Nanjing Forestry University, Nanjing 210037, China

<sup>2</sup>General and Theoretical Electrical Engineering (ATE), Faculty of Engineering, University of Duisburg-Essen, D-47048 Duisburg, Germany

**Abstract** - Light scattering by the metal-coated nanocylinders symmetrically distributed on a circular cylindrical surface with multilayered structure is analyzed by using a semi-analytical method based on the T-matrix and generalized reflection and transmission matrices for cylindrical waves. The surface plasmon resonances observed in the spectral responses of the scattered field are numerically investigated.

**Index Terms** — Metal-coated nanocylinders, multilayered structure, surface plasmons, resonant scattering

## 1. Introduction

With a rapid development of nanoscience and nanotechnology, the interaction of light with nanoscaled objects remains as an important topic in recent years because of its wide range applications to optical sensors, imaging, and integrated photonic devices. The studies of the interaction are organized in many different ways [1], being dependent on the dimensionality of the objects and exciting sources.

In this paper, we investigate a two-dimensional scattering and guidance of TE polarized light by a multilayered cylindrically periodic array of metal-coated dielectric nanocylinders by using a semi-analytical method [2]. In this approach, the scattered fields in near field region to far field region of the cylindrical array structure can be accurately calculated by using the T-matrix of the nanocylinder in isolation and the generalized reflection and transmission matrices for the cylindrical waves. As a model of multilayered structures, we take a two-layered or three-layered structure with three or four nanocylinders on each layer. The spectral responses of the scattering and absorption cross section of the cylindrical structure and associated near field distributions are numerically investigated. It is shown that the light wave with a particular wavelength can be guided through the localized plasmon resonances on each nanocylinder when the size of the cylinder and their separation distance are optimized.

## 2. Formulation of The Problem

The cross sectional of  $N$ -layered cylindrical arrays formed by  $M$  metal-coated dielectric nanocylinders periodically distributed on each of concentric circular cylindrical surfaces is shown in Fig.1. The structure is located in the free space. The cylindrical array on the circular ring with radius  $R_\nu$  is labeled as the  $\nu$ -th layer. The coaxial nanocylinder consists of a circular dielectric core with radius  $r_2$  and a metal layer

of thickness  $r_1 - r_2$ . Material constants of the coating metal and dielectric core are denoted by  $(\epsilon_M, \mu_0)$  and  $(\epsilon, \mu_0)$ , respectively and  $(\rho_j, \phi_j)$  denotes the local coordinate for the  $j$ -th nanocylinder. The cylindrical structure is illuminated by a TE ( $H_z, E_x, E_y$ ) polarized light of unit amplitude with the incident angle  $\varphi^i$ .

The scattering problem is semi-analytically formulated using the  $T$ -matrix of a circular cylinder in isolation, the reflection and transmission matrices of a cylindrical array based on the cylindrical harmonics expansion, and the generalized reflection and transmission matrices for a cylindrically layered structure. The details of formulation process and analytical procedure are presented in [2],[3].

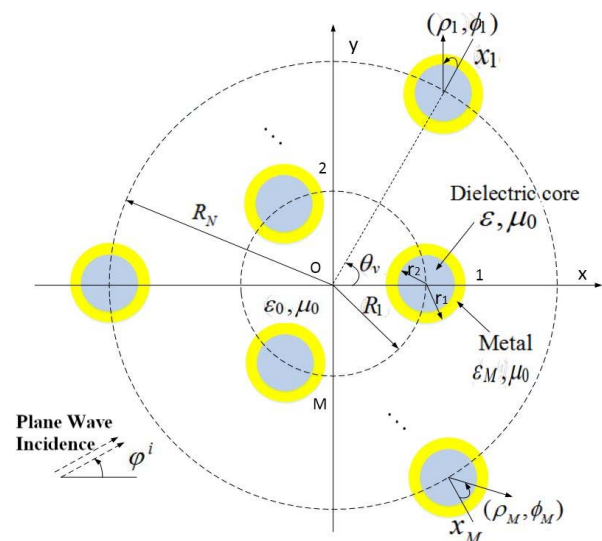


Fig.1. Cross-sectional view of multilayered cylindrically periodic arrays of metal-coated nanocylinders illuminated by a TE ( $E_x, E_y, H_z$ ) polarized plane wave.

## 3. Numerical Results and Discussions

Although a substantial number of numerical examples could be generated, we study here a two-layered structure with three nanocylinders on each layer which is illuminated by multiple plane waves propagating in different directions. The structural parameters are chosen to be  $r_1 = 60nm$ ,  $r_2 = 45nm$ , and  $\epsilon/\epsilon_0 = 2.25$ . We assumed silver ( $Ag$ ) for the coating metal and evaluated its dispersive permittivity  $\epsilon_M(\lambda)$  using the Drude-Lorentz model [4].

Firstly, we calculated the spectral responses of the scattering and absorption cross sections of the cylindrical structure. Although the results are not shown here due to limited page space, we found that the spectral responses have resonance peaks at several wavelengths which are related to the localized surface plasmon resonances. The near field distributions of  $|H_z|$  calculated for such resonant wavelengths are plotted in Figs. 2, 3, and 4.

Fig.2 shows the near field distribution for  $\lambda=348nm$  where the radii of the first layer and second layer are  $R_1 = 72 nm$  and  $R_2=196.7nm$ . Note that the gap width between two nearby cylinders is  $4.7nm$ . The empty circles with white lines indicate the locations of 6 cylinders. The exciting source is a pair of plane waves with unit amplitude propagating in the direction with  $\phi_1^i = 60^\circ$  and  $\phi_2^i = 300^\circ$ , respectively. The white arrows in the figure show the directions of the incidence of plane waves. We can see that the cylinders located on the two arms are strongly coupled through the excitation of gap plasmons, whereas the incident excitations are not effectively transferred to the cylinders on the remaining arm. Fig.3 shows the near field distribution of  $|H_z|$  for  $\lambda=604nm$ , where the array structure and excitation condition are the same as those in Fig. 2. For this wavelength, the surface plasmon fields localized around the inner boundary of the metal layer are excited on the cylinders located on the two arms, then combined through the coupling with the gap plasmons, and finally guided to the second cylinder on the remaining arm. The field distribution of Fig. 3 suggests that an optical beam may be transmitted beyond the diffraction limit by using the interaction of localized surface plasmons. Fig. 4 shows the near field distribution of  $|H_z|$  for  $\lambda=958nm$  when excited by a triplet of plane waves propagating in the directions of  $\phi_1^i=60^\circ$ ,  $\phi_2^i=180^\circ$ , and  $\phi_3^i=300^\circ$ , respectively. We can see that a very strong plasmon field is excited in the gap region located at the

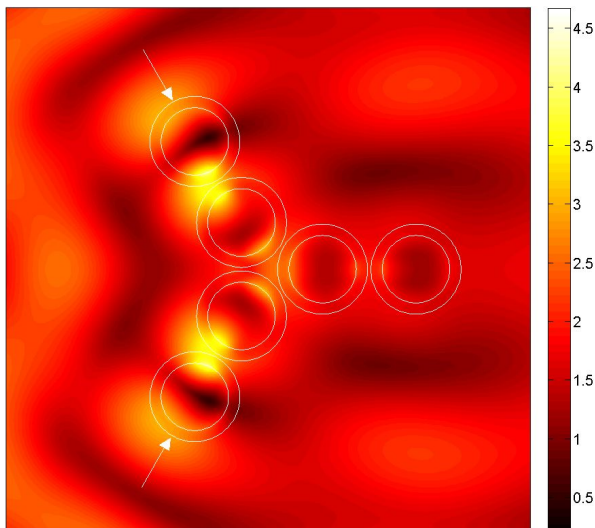


Fig.2. Near field distribution of  $|H_z|$  for a two-layered structure with 3 metal-coated cylinders in each layer. The layer radii are  $R_1 = 72 nm$  and  $R_2=196.7nm$ . The wavelength is  $\lambda=348nm$ . The excitation is a pair of plane waves propagating in the direction of  $\phi_1^i = 60^\circ$  and  $\phi_2^i = 300^\circ$ .

center of the cylindrical structure. The surface plasmon fields excited on the cylinders in each arm are guided through the gap plasmon interactions and resonantly combined in the center of the structure.

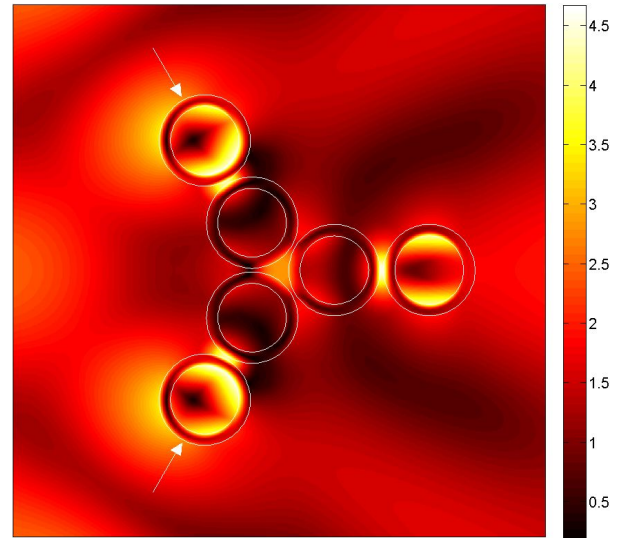


Fig.3. Near field distribution of  $|H_z|$  for  $\lambda=604nm$ . Others are the same as those in Fig. 2.

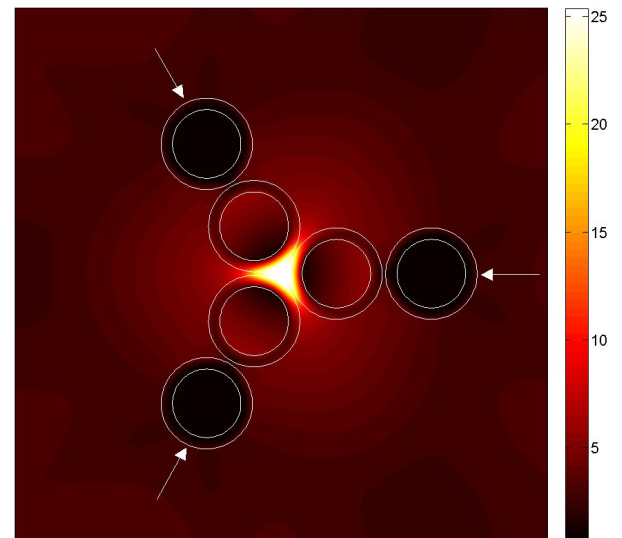


Fig.4. Near field distribution of  $|H_z|$  for  $\lambda=958nm$ . The excitation is a triplet of plane waves propagating in the directions of  $\phi_1^i=60^\circ$ ,  $\phi_2^i=180^\circ$ , and  $\phi_3^i=300^\circ$ , respectively. Others are the same as those in Fig. 2.

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