Plasmon Resonances in Linear Array of Coupled Silver Nanowires

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ABSTRACT
In this paper, theoretical study of plasmon resonant coupling in a finite linear array of infinite-long silver nanowires is presented. The spectral response and optical near fields are considered. It was shown red-shifting of plasmon resonance with increasing of the number of nanowires in the array and optical field enhancement for closely spaced nanowires. Theory is based on the Mie series expansion.
Keywords: plasmons, nanowires, noble metals, Mie's theory.

1. INTRODUCTION

Plasmonic structures and their optical fields have been the subject of significant interest in recent years. Using resonators composed of negative permittivity materials such as plasma can form the basis of effective small-size antenna elements [1]. Plasmonic covers near their plasma resonance can make the object nearly invisible to an external observer [2]. Various elements such as plasmonic waveguides [3], subwavelength resonators [4] and optical nanoantennas [5] have been studied recently. Plasmonic structures of different shapes (nanowires, nanorods, nanospheres, nanoshells) are provided by various fabrication techniques.

The objective of this paper is to analyze the plasmonic resonances in finite array of silver wires with nanometer-scale radii.

2. PROBLEM FORMULATION AND RESULTS

We consider a linear chain of N identical infinite-long silver cylindrical nanowires with radii a and separation distance d. Transversal electric (H-polarized) plane wave illuminates the structure. The illumination direction and schematic diagram of the structure is presented in the inset in Fig. 1. We present internal and external fields using Mie's series expansions

$$H(\rho_j,\varphi_j)=\sum_{s=-\infty}^{+\infty} a_s^{(j)} J_s(\bar{k}\rho_j)e^{is\varphi_j} \text{ (inside each nanowire),} \quad (1)$$

$$H(\rho_j,\varphi_j)=\sum_{j=1}^{N}\sum_{s=-\infty}^{+\infty} \bar{a}_s^{(j)} H_s^{(2)}(k\rho_j)e^{is\varphi_j}+e^{-ikx} \text{ (in outer space).} \quad (2)$$

Here (ρ_j,φ_j) are set of N polar systems of coordinates, associated with each nanowire ($j=1...N$), time dependence is $e^{i\omega t}$, $\bar{k}=\bar{n}\,\omega/c$, $k=\omega/c$, x-axis is directed along the major axis of the structure with origin at the midpoint.

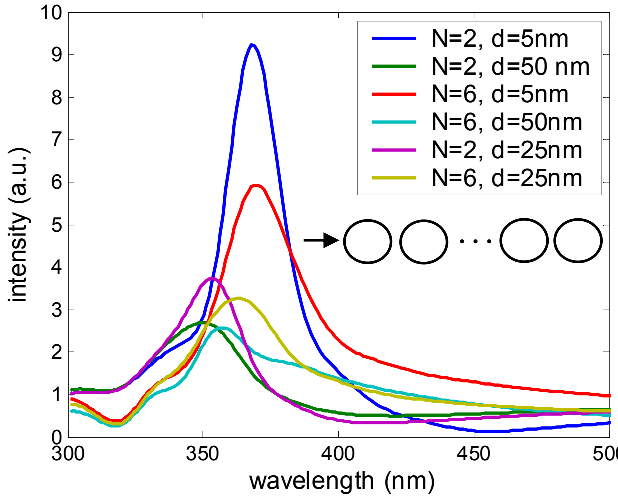

Figure 1. Normalized intensity of the scattered field in the midpoint of the array of N silver nanowires with 25nm radii.

Unknown coefficients $a_s^{(j)}$ and $\overline{a}_s^{(j)}$ are found from the boundary conditions, requiring the tangential components of the total electric and magnetic fields to be continuous at each nanowire's surface. Using the addition theorem for Bessel functions we arrive at an infinite system of algebraic equations that can be truncated in order to provide a controlled numerical precision.

To investigate spectral response we plot normalized intensity of the optical field in the midpoint of the structure versus the wavelength (Fig. 1). We study plasmonic coupling of the N silver nanowires (results are presented for the case $a = 25$ nm) with separation distance $d = 5$, 25 and 50 nm. For the refractive index $\overline{n} = n' - in''$ we use the experimental data obtained by Jonson and Christie [6] for bulk silver. For distant nanowires ($d = 50$ nm) it is observable surface plasmon excited at $\lambda = 350$ nm ($N = 2$) and at $\lambda = 363$ nm ($N = 6$). With decreasing of the separation distance $d = 25$ nm we observe red-shifting of the plasmonic resonance to $\lambda = 353$ nm ($N = 2$) and to $\lambda = 363$ nm ($N = 6$). For smaller separation distance ($d = 5$ nm) a dramatic field enhancement between nanowires is seen. Resonance peak is sharper for closely spaced nanowires. It should be added that for closely spaced nanowires splitting of plasmon resonances occurs that has been described in details in [7].

Figure 2 visualizes the ability of array of silver nanowires to guide light due to the coupling of surface plasmons (illumination along to the major axis).

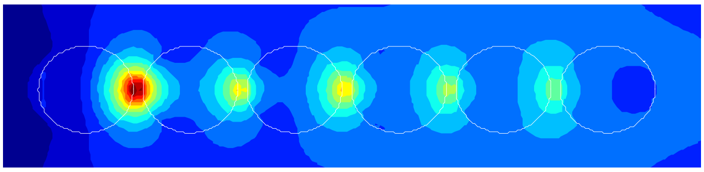

Figure 2. Near field distribution of plane wave scattering on array of silver nanowires (a = 25 nm, d = 5 nm).

3. CONCLUSIONS

Theoretical study of plasmon resonances in a finite linear array of infinite-long silver nanowires is presented. The attention is focused on the spectral response and optical near fields. Spectral shift toward longer wavelength upon the growing of the number of nanowires in an array has been shown. Dramatic field enhancement between closely spaced nanowires is demonstrated.

ACKNOWLEDGEMENTS

Authors are thankful to the Ukrainian National Target Program "Nanotechnologies and Nanomaterials", and the State Agency for Science, Ukraine for the support of this research.

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