Electromagnetic Simulation of a Gold Nano-Cylinder Chain

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Abstract— **The wavelength response of a gold nano-cylinder chain is investigated by using electromagnetic simulation. We discuss that the plasmonic resonant peaks can be tunable by varying the vibration direction of electrons and the distance between cylinders.**

Keywords— Localized surface plasmons, Gold nano-cylinder chain, Electromagnetic simulation

I. Introduction

Recently, metal nano-particle chains are expected in a lot of practical applications such as light antennas [1][2], plasmonic waveguides[3], bio sensors[4], and so on. The chain can localize light energy in nano domain, because the energy can be transmitted as LSP (Localized Surface Plasmons). In this paper, we analyze the wavelength response of a gold nano-cylinder chain for changing the vibration direction of electrons and the distance between cylinders.

II. Computational Model and Method

The computational model of the gold nano-cylinder chain is shown in Fig. 1. The chain consists of the five gold cylinders and they are arrayed linearly in equal intervals. The radius of the cylinder is 5nm and the distance between two cylinders is given by d. The vibration direction of electrons is assumed to be (a) vertical, (b) parallel, and (c) 45 degree inclined to the chain axis. Using a localized external source, LSP is excited in the C1 cylinder. The dispersion relation of gold is assumed as the Drude model

$$\varepsilon(\omega) = \varepsilon_\infty + \varepsilon_{\mathrm{D}}(\omega) \quad (1)$$

where ε_∞ is the relative permittivity at infinite frequency and ε_{D} is the relative permittivity of the Drude model. We apply the FDTD (Finite-Difference Time-Domain Method) method [5][6] to electromagnetic simulation. The motion of electrons is considered as the current density to solve the following auxiliary differential equation of the gold nano-cylinders:

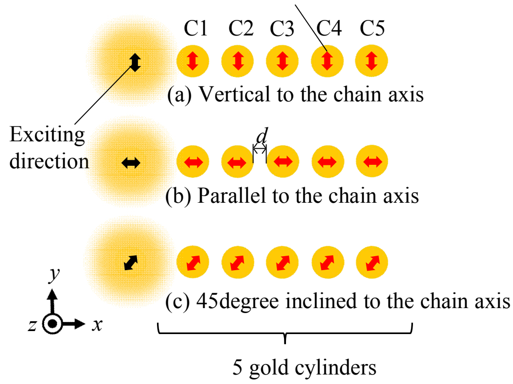

Fig.1. Computational model of the gold nano-cylinder chain

$$-j\omega m_e \mathbf{v} = e\mathbf{E} - \gamma\mathbf{v} \quad (2)$$

where $\mathbf{v}$ is the displacement vector, γ is the collision frequency, and m_e is the effective mass of electrons. Multiplying Eq. (2) by elementaly charge e and the electron density n_0, we obtain

$$-j\omega m_e \mathbf{J}_{\mathrm{D}} = \varepsilon_0 \omega_p^2 \mathbf{E} - \gamma \mathbf{J}_{\mathrm{D}} \quad (3)$$

where the polarization currents $\mathbf{J}_{\mathrm{D}}$, and the plasma frequency ω_p are given by

$$\mathbf{J}_{\mathrm{D}} = e n_0 \mathbf{v}, \quad \omega_p = \sqrt{\frac{n_0 e^2}{m_e \varepsilon_0}} \quad (4)$$

Applying the inverse fourier transform and the central difference scheme for (3), the differential equation for the polarization currents $\mathbf{J}_{\mathrm{D}}$ can be expressed as

$$\mathbf{J}_{\mathrm{D}}^{n+1} = C_{\mathrm{J1}} \cdot \mathbf{J}_{\mathrm{D}}^{n} + C_{\mathrm{J2}} \cdot \mathbf{J}_{\mathrm{D}}^{n-1} + C_{\mathrm{J3}} \frac{\mathbf{E}^{n+1} - \mathbf{E}^{n-1}}{2\Delta t} \quad (5)$$

where

$$C_{\mathrm{J1}} = \frac{4}{2\Delta t}, \quad C_{\mathrm{J2}} = \frac{2-\gamma\Delta t}{2+\gamma\Delta t}, \quad C_{\mathrm{J3}} = \frac{2\varepsilon_0 \omega_p^2 \Delta t^2}{2+\gamma\Delta t} \quad (6)$$

III. NUMERICAL RESULTS

Fig. 2 shows the wavelength responses of the nano-cylinder chain evaluated by the dipole moment in the C5 cylinder when the vibration direction of electrons is vertical to the chain axis. In the case of d = 10nm, the plasmonic resonant peak is found at 502.9 nm. The blue-shift of the plasmonic resonant peak at 449.9 nm is confirmed when the distance becomes shorter, i.e. d = 2 nm.

We investigate the wavelength responses when the vibration direction of electrons is parallel to the chain axis as shown in Fig. 3. In the case of d = 10 nm, the plasmonic resonant peak is at 564.5 nm. In the contrast with the vertical direction, the red-shift is observed at 700 nm when d = 2 nm.

To confirm the above interesting and important properties, the vibration direction of electrons is selected as 45 degree inclined to the chain axis. Fig. 4 is a plot of the wavelength response. Two large plasmonic resonant peaks are appeared, since two LSP modes of vertical and parallel directions are excited by the source. From these results, it indicates that the plasmonic resonant peaks are tunable by varying the vibration direction of electrons and the distance between cylinders.

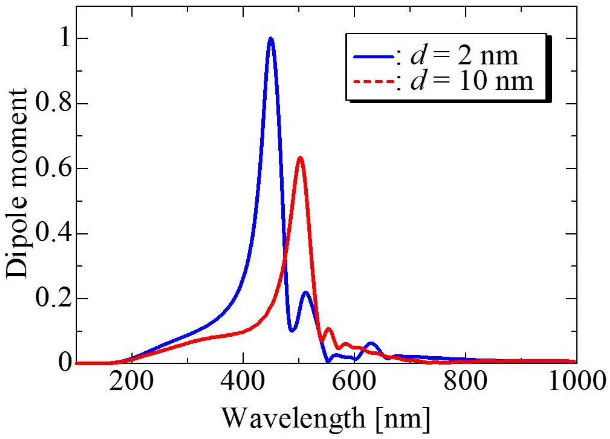

Fig. 2. Wavelength responses of the dipole moment in C5. The exciting direction is vertical to the chain axis.

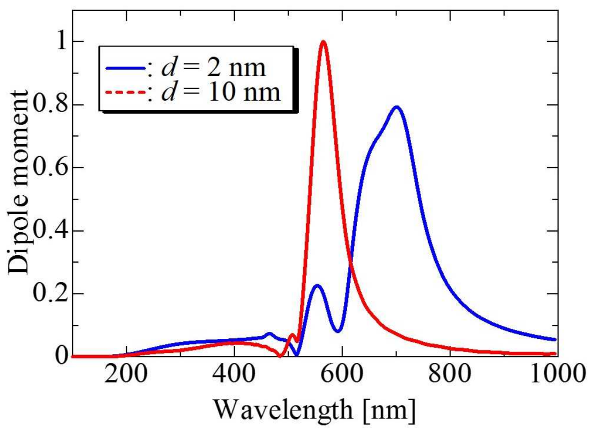

Fig. 3. Wavelength responses of the dipole moment in C5. The exciting direction is parallel to the chain axis.

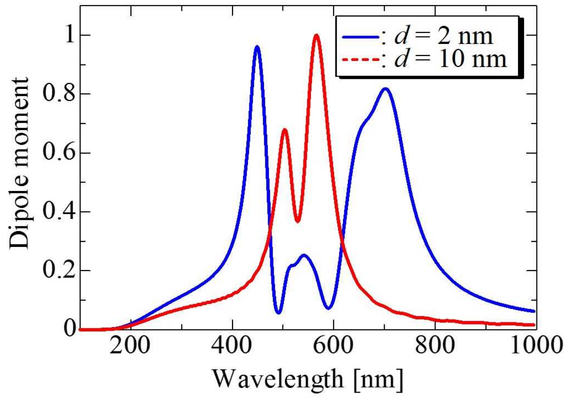

Fig. 4. Wavelength responses of the dipole moment in C5.The exciting direction is 45 degree inclined to the chain axis.

IV. CONCLUSIONS

In this paper, the wavelength response in a gold nano-cylinder chain has been investigated. In the case of the vertical exciting direction, the plasmonic resonant peak is blue-shifted as the distance becomes shorter. By contrast, the plasmonic resonant peak is red-shifted when the vibration direction is parallel.

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