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Anomalous extinction independence on the polarization of one dimension metallic ellipsoid nanoparticle chains

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ABSTRACT

A series of silver ellipsoid nanoparticles are arranged in a line to investigate the anomalous extinction with the incident polarizations both perpendicular and parallel to the chains. Due to the partial interaction among the units, the anomalous extinction –like effect appears for the polarization along the chain with the long axis of the ellipsoid perpendicular to the chain. If the polarization changes from 0 to 2π, the extinction cross sections changed with the polarization angle are different in the structure of the long axis of the ellipsoid perpendicular to the chain with a certain lattice constant, which the phase difference is $\pi/2$. Our structure has potential applications in the optical key distributions.

1. Introduction

Localized surface plasmons (LSPs) are excited in metallic nanoparticles or nanostructures, which have been widely applied in the surface enhanced Raman scatterings (SERS) [1–5], the solar cell [6–10], and so on. The responses in the visible optics wavelength regime of the metallic nanoparticles or nanostructures are usually described by the absorption/extinction spectra [11–15].

A series of metallic nanoparticles are usually arranged in a line to investigate the dispersion relations or propagation properties of LSPs [16–20]. The mechanism of the anomalous absorption is also discussed, which reflects the strong resonance of the nanoparticle chains [21,22]. The anomalous absorption usually appears in the structure with the polarization perpendicular to the chain. If the polarization is along the chain, the anomalous absorption would disappear.

In this Letter, we investigate a series of the metallic ellipsoid nanoparticles arranged in a line to achieve the anomalous extinction independent on the polarization. The unit is a silver ellipsoid nanoparticle, and the long axis of the unit would be considered as the directions both perpendicular and parallel to the chains, respectively. The discrete dipole approximation (DDA) method is employed to simulate the proposed structures [23–26]. Due to anomalous extinction spectra independent on the polarizations, our structures have potential applications in the optical polarization detector, the key distribution and so on.

2. Models and calculation results

Our structure is shown in Fig. 1. The three axes of Ag ellipsoid nanoparticle are r_1, r_2 and r_2, respectively. The lattice constant l is no less than $3r_1$(or $3r_2$) in order to meet the need of the coupled-dipole approximate [16,17]. θ and ϕ are the

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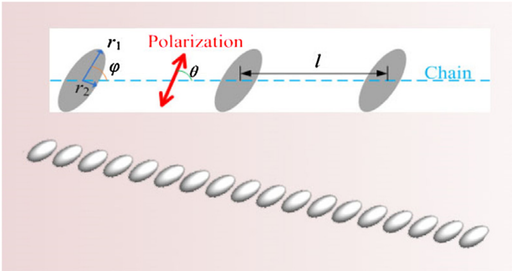

Fig. 1. The sketch of our structure.

angle between the directions of the polarization and the chain and the angle between the directions of the long axis (r_1) of the ellipsoid and the chain. The long and short axes are r_1 = 60 nm and r_2 = 40 nm. The dielectric constant of Ag is obtained from the Ref. [27].

First, we consider the normal conditions of the anomalous extinction, θ=ϕ=90°. The lattice constant l are adopted as l = 450 nm, 490 nm and 530 nm. And the extinction cross sections are obtained by DDA as shown in Fig. 2.

As Fig. 2 shown, the amplitude of the extinction peak changes non-monotonically with the lattice constant l increasing from 450 nm to 530 nm. This shows the normal condition of the anomalous extinction. This effect could be well described by the dipole approximation. The plasmonic property of a single ellipsoid nanoparticle can be described by the polarizability $_{\alpha i}$ and the expression for along the principal axes (i = 1,2,3) as [28]:

$$\alpha_i = \frac{V}{\left(L_i + \frac{\varepsilon_d}{\varepsilon(\omega) - \varepsilon_d}\right) + A\varepsilon_d x_i^2 + B\varepsilon_d^2 x_i^4 - i\frac{4\pi^2\varepsilon_d^{3/2}}{3}\frac{V}{\lambda_0^3}} \tag{1}$$

where $\varepsilon_d$and $\varepsilon(\omega)$ are the dielectric constant of the air and the silver, respectively. V is the volume of the ellipsoid, λ_0 is the wavelength in the vacuum and $x_i = \pi r_i/\lambda_0$. L_i is a geometrical factor given by [28]:

$$L_i = \frac{r_1 r_2 r_2}{2}\int_0^\infty \frac{dq}{\left(r_i^2 + q\right) f(q)} \tag{2}$$

where $f(q) = [(q + r_1{}^2)(q + r_2{}^2)(q + r_3{}^2)]^{1/2}$. A and B are the function of L_i as [28]:

$$A(L_i) = -0.4865L_i - 1.046L_i{}^2 + 0.848L_i{}^3 \text{and} B(L_i) = 0.01909L_i + 0.1999L_i{}^2 + 0.6077L_i{}^3 \tag{3}$$

The collective behavior is due to the coupling between the NPs at different lattice positions. In this letter, we focus on the cases of $l >> r_1$ (or r_2). Then the interaction between the nanoparticle at position nl and the other one at different lattice position ml can be described as dipole coupling and can be written as [21]:

$$S(k) = \sum_{m \neq n}\left[\frac{(1 - ikr_{mn})\left(3\cos^2\theta - 1\right)e^{ikr_{mn}}}{r_{mn}^3} + \frac{k^2\sin^2\theta e^{ikr_{mn}}}{r_{mn}}\right] \tag{4}$$

where k is the wave-vector in the vacuum. The polarizability of the system could be written as:

$$\alpha = \frac{1}{1/\alpha_i - S(k)} \tag{5}$$

and the extinction cross section is calculated as $C_{ext} \propto k\text{Im}(\alpha)$.

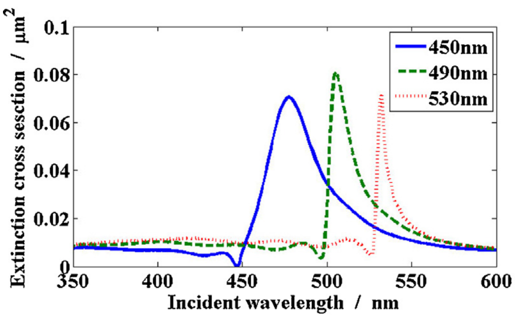

Fig. 2. The extinction cross sections with l = 450 nm, 490 nm and 530 nm with $\theta = \phi = 90°$.