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Tunable plasmon resonance of a touching gold cylinder arrays

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Abstract. We investigate the plasmon resonance of a touching gold cylinder arrays surrounded with air or dielectric. We show that the plasmon resonance is tunable by modulating the cylinder radius, the cylinder layer and refractive index of the dielectric. It is found resonance peak blue-shifts and splits as the gold cylinder radius reduces, width of the resonance peak gets much smaller as layer increases, and resonant peak red-shifts noticeably as dielectric refractive index increases. Based on electric field distributions at the resonance wavelengths we reveal the mechanism of the transmission enhancement. These phenomena are helpful for the design of potential optics devices.

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Key words: touching gold cylinders, surface plasmon, electric field distributions

1 Introduction

Metallic nano-structures have attracted a great attention as they can provide many intriguing properties for application in fields like near-field microscopy and spectroscopy, nanoscale photonic devices [1], biological applications, and biosensors [2]. Controllable and tunable surface plasmon resonance of metallic nanopaticales [3], nanoshells [4], nanorods [5], and nanocylinders [6] are investigated recently. It is found that the electromagnetic field can be enhanced in the vicinity of the nanostructures [7,8]. Parameters such as size [9], shape [10], and the surrounding dielectric [11,12] of the structure are investigated in order to clarify the optical properties. It is reported there is an extraordinary optical transmission for a metallic slab perforated with hole arrays [13], even for a continuous metallic

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structure with periodically nanostructured on the surface [14]. If a series of nanocylinders are arranged parallelly touching each other periodically, forming a continuous structure, high enhancement transmission is expected.

In this paper, we investigate plasmon resonance of a touching gold cylinder arrays surrounded with air or dielectric. We show that the plasmon resonance is tunable by modulating the cylinder radius, the cylinder layer and refractive index of the dielectric. It is found that resonance peak blue-shifts and splits as the gold cylinder radius reduces, width of the resonance peak gets much smaller as layer increases, and resonant peak red shifts noticeably as dielectric refractive index increases. By analyzing electric field distributions at the resonance wavelengths, we reveal the mechanism of the transmission enhancement. These properties are helpful for the design of potential optics devices.

2 Model and theory

We apply a periodic array of gold cylinders as shown in Fig. 1, in order to demonstrate the optical property. Transmission spectra and electric fields are simulated by using the finite-difference time-domain (FDTD) method [15, 16]. In the entire work, we investigate a lattice of the periodic cylinder structure with 600 nm length in x-direction and 800 nm length in y-direction; cylinder radius is noted as r, and the thickness of the dielectric is noted as h, and the spatial and temporal steps are set at $\Delta x = \Delta y = \ln m$ and $\Delta t = \Delta x/2c$ (c is the velocity of light in vacuum), and we send a Gaussian single pulse of light with a wide frequency profile. Periodic boundary conditions are imposed on the left and right surfaces, and the perfectly matched layers (PML) are used on the top and bottom of the lattice [17]. Since there are no gaps between cylinders in the structure, all effects related to mechanism of light transmission directly through the slits are absent, and the resonant tunneling through a metal film is the only mechanism responsible for the enhanced transmission. In all calculations below, light illuminates on top of the structure at a normal incidence polarizing along x-direction.

When a plane wave is incident normally on the interface between a metal and a dielectric, in order to excite surface plasmon waves, the phase-matching condition as follows should be obeyed by the incident wave vector [13, 18]

$$\vec{k}_{sp} = \vec{k}_0 \sin\theta + i\vec{G}_x, \tag{1}$$

where k_0 is the wave vector of incident light and θ is the incident angle. $\vec{G}_x$ is the Bragg vector and $|\vec{G}_x| = 2\pi/p$, i is an integer, which is the mode indices. $\vec{k}_{sp}$ is the surface plasmon wave vector whose length is

$$|\vec{k}_{sp}| = |\vec{k}_0| \sqrt{\frac{\varepsilon_d \varepsilon_m}{\varepsilon_d + \varepsilon_m}} \tag{2}$$

ε_d and ε_m are permittivities of the dielectric and the metal, respectively.