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Tuning of plasmon resonance through gold slit arrays with Y-shaped channels

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Abstract. We propose gold slit arrays with Y-shaped channels and investigate their transmission properties numacially. Results indicate that the surface plasmon resonance peak value keeps unchanged and the localized waveguide resonance peak red-shifts and falls obviously when the entrance slit width narrows. However when the entrance slit becomes extremely small the surface plasmon resonance peak red-shifts and falls sharply. Furthermore as the slit length increases, firstly the surface plasmon resonance peak splits into two peaks, the right peak value rise and they slowly converged into one single peak. To understand its physical origin, surface plasmon resonance and Fabry-Perot cavity resonance theories are suggested. We simulate their electric field distributions and find the electric fields become stronger as the slit become narrower or the dielectric constant become smaller. The results may be useful for the design of frequency-selective sensor and optical devices in the future.

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Key words: Y-shape channel slit array, optical transmission, surface plasmon resonance, localized waveguide resonance

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1 Introduction

Extraordinary optical transmission(EOT) through sub-wavelength hole array perforated on metal film has inspired great interest since it was first reported by Ebbesen etc[1]. Besides of sub-wavelength hole arrays [2,3], slit and slit array[4-7] are topics of considerable fascination to achieve extraordinary high transmission in several applications [8-10],

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including super-lenses, optical filters and microscopy. The initial work owes EOT to surface plasmon, but surface plasmon is not the sole factor contributing to EOT, it even has a negative influence in some case, like one-dimension metallic gratings [6]. Attention of EOT is mostly focused on the study of the influence of the shape, size, and periodicity of the metallic hole or slit array with straight channels [11,12]. Recently, notice has been taken of a hole or slit with a shaped channel, including a hole array with converging-diverging shaped channels [13-15], and a single slit with a stepped channel [16]. A slit or hole with a bent channel has also been researched [17,18]. Investigations of the bent channel metallic structure are mostly concentrated on the transmission of the structure as a single waveguide. Transmission properties of the periodic slit or hole arrays with bent channels [19] have been scarcely studied up to now. So this paper designs gold slit arrays with Y-shaped channels and investigate its transmission properties numacially.

In this paper, we investigate the transmission properties of the gold slit array with Y-shaped channel by employing the two-dimensional (2D) finite-difference time-domain (FDTD) method. The influence of the bent slit geometry parameters on the transmission spectrum has been discussed in detail. The results obtained here are helpful to design new sub-wavelength optical devices.

2 Model and simulation method

The analyzed structure is presented in Fig. 1. In our 2D FDTD calculations [20], perfectly matched layer boundary conditions [21] are used 2250 nm away from the interfaces of the gold film in the z and -z directions. And periodic boundary conditions are used above and below the slit due to the periodicity of the structure. We simulate the structure with a computational window of $L_y \times L_z = 750$ nm $\times$ 5250 nm, where the structure in the x direction is uniform and infinite. The structure is periodic in the y direction, and the period is $p = 750$ nm. The spatial and temporal steps are set as $\Delta y = \Delta z = 3.5$ nm and (c is the velocity of light in vacuum), and we send a Gaussian single pulse of light with a wide frequency profile. The probe location is set at away from the rear surface of the gold film, and the transmission spectrum is normalized by the calculation without a metallic structure.

The incident light impinges on the structure in the z direction with a polarization along the y direction. A schematic view in the y-z cross section of a lattice of the bent slit array in a freestanding gold film is shown in Fig. 1. The frequency-dependent permittivity of the metal is described by the Drude model:

$$\varepsilon = 1 - \frac{\omega_p^2}{\omega^2 + \gamma^2} + i\frac{\omega_p^2 \gamma}{\omega(\gamma^2 + \omega^2)} \tag{1}$$

where ω_p is the plasma frequency, γ is the collision frequency related to energy loss, and ω stands for the frequency. The parameters used in the Drude model for Au are $\omega_p = 1.374 \times 10^{16}\mathrm{s}^{-1}$ and $\gamma = 4.08 \times 10^{13}\mathrm{s}^{-1}$.