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Transmission properties of periodically patterned triangular prisms

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Abstract

Transmission properties of plasmonic structure arrays are simulated by finite element method. The array unit is composed of two combined triangular prisms. Results reveal that several resonant modes are found in the transmission spectra, which are due to the resonance of the surface plasmon polariton in the metal slit or to the localized surface plasmon resonance of the combined prisms. The resonant wavelengths can be tuned by changing the structural parameters of the combined prisms. In addition, the resonant modes are sensitive to small refractive index changes of the surrounding media, revealing potential detection applications in nanophotonic systems.

Keywords: Plasmonics; Surface plasmon polariton (SPP); Localized surface plasmon (LSP)

1. Introduction

Surface plasmons (SPs) are surface electromagnetic waves coupled with collective oscillation of electrons at metal/dielectric interfaces [1–3,12]. Two kinds of SPs are mainly found, namely localized surface plasmon (LSP) and surface plasmon polariton (SPP).

LSPs are charge density oscillations confined to the metallic nanostructures [4]. LSP resonant wavelength and electric field distribution are strongly dependent on the shape, size, and elements of the metal structures [5], making tuning the resonant wavelength and varying the electric field distribution possible by altering the metal structure. In addition, the resonant wavelength depends on the environment of the surrounding media [5], which has drawn much attention in sensor applications using nanostructures with different topologies or different arrangement, such as nanospheres [6–9], nanodisks with missing wedge-shaped slices [10], dolmen nanostructures [11], and array of gold nanorods [12]. According to other research reports, the figure of merit (FoM) [13] ($\mathrm{FoM} = (1/fwhm) \times (\Delta w/\Delta n)$, where $fwhm$ is the full width at half maximum, $\Delta\omega$ and Δn represent the variation of frequency and refractive index, respectively) of a single silver nanocube on dielectric substrate can reach 5.4 [13]. At optimized conditions, which formed a Fano resonance in the nanocube, it can produce a higher FoM ranging from 12 to 20 [14].

SPPs are generated by the resonant interaction between surface charge oscillation and the electromagnetic field of light, which decays exponentially in the perpendicular direction [15,16]. SPPs are tightly bound to the vicinity of the surface beyond the diffractive limit, implying the possibility of guiding light on the sub-micron scale [17], which raises tremendous interest in waveguide applications. The propagation properties of

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SPPs have close connection with the structure parameters and the surrounding environment, which can also be used for sensor applications [18–25]. For a previous study, individual plasmonic structures are used to detect the refractive index changes in the resonator [20]. The FoM of SPP based sensor at metal/nematic liquid–crystal interface can reach 35 [26], and on the gold films, it can reach 54 [27], which exhibits a higher FoM than LSP sensor. However, the SPP intensity transmitted through the resonator is relatively weak. By contrast, the energy is strongly dependent on the excitation wave polarization in the SPP sensor application. All the above mentioned defects limit SPP sensors usage.

In the present paper, we propose a plasmonic sensor based on SPPs: it is composed of a periodic array of two combined triangular prisms. The triangular prisms are open to the outside media at two ends. In our calculations, the transmission characteristics of the structure are investigated through finite element method (FEM). Results show that several electron oscillation modes are found in the transmission spectra. These modes are caused by the resonance of the SPP propagation in the metal slit and the LSP of the combined prisms. In addition, the effects of structural parameters and dielectric media of the surrounding environment on their transmission properties are also studied. The results show very promising prospects of periodic triangular prism array for dielectric media sensor applications.

2. Structure and computational methods

Fig. 1 shows the plasmonic structure array and the unit of the periodic structure which is composed of two combined square triangular prisms placed in parallel. The prism has a height of H and a side length of L. The separation between two prisms is d. The periods in the x-direction and y-direction are both 200 nm. The incident light propagates along the z-direction with a polarization in the x-direction to excite the SPs around the prisms.

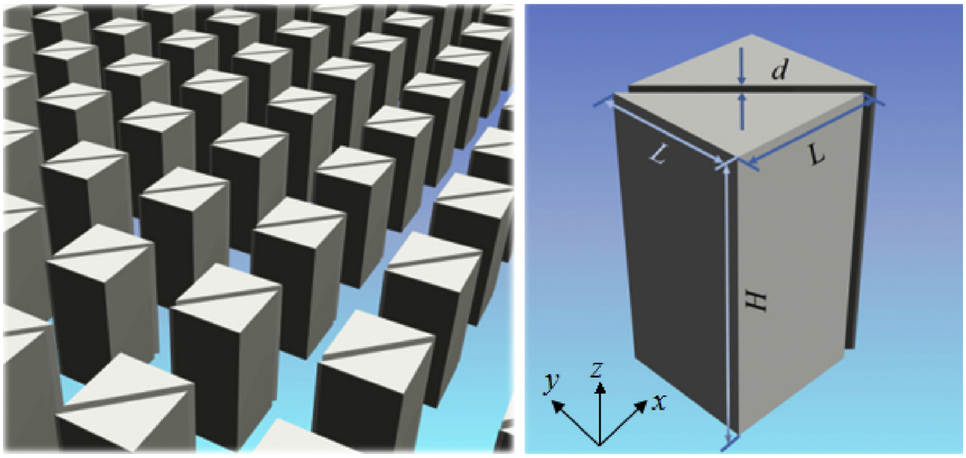

Fig. 1. Schematic diagram for the plasmonic structure composed of two triangular prisms with slit width of d, triangular side length of L, and height of H.

The transmission properties of the plasmonic structure arrays are investigated using a three-dimensional commercial FEM software (COMSOL Multiphysics). The frequency-dependent complex relative permittivity ε of silver has been presented by a previous paper in 1972 [28].

For metal–insulator–metal slit, the dispersion equation is characterized by [29,30]:

$$\tanh(\kappa d) = \frac{-2\kappa p\alpha}{\kappa^2 + p^2\alpha^2} \tag{1}$$

where κ and d are the perpendicular core wave vector and width of the insulator in the metal slit, respectively. The symbols in Eq. (1) are defined as $p = \varepsilon_{in}/\varepsilon_m$ and $\alpha_c = [k_0{}^2(\varepsilon_{in} - \varepsilon_m) + \kappa^2]^{1/2}$. ε_{in} and ε_m are the dielectric constants of the insulator and the metal, respectively. $k_0 = 2\pi/\lambda_0$ is the free space wave vector. κ can be solved from Eq. (1) by using the iterative method [20]. Thus, the effective index n_{eff} of the metal slit can be solved from $n_{eff} = [\varepsilon_m + (\kappa/k_0)^2]^{1/2}$. And the wavelength of SPPs can be expressed as $\lambda_{spp} = \lambda_0/Re(n_{eff})$, where $Re(n_{eff})$ is the real part of n_{eff}.

3. Results and discussion

Fig. 2 shows the transmission spectra of the combined triangular prism array and the cubic array. The slit width, side length, and vertical height of the prism are 10 nm, 100 nm, and 200 nm, respectively. As shown in Fig. 2,