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Surface plasmon resonance sensor based at metallic subwavelength structures

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ABSTRACT

Simulated transmission spectrums and the change of the transmission peak position with the refractive index by the finite-difference time-domain method are present. The considered structure is the two-dimensional metallic square hole and trapezoid hole array, and the change of the transmission peak position with the refractive index can achieve about 1000 nm RIU^{-1}. In comparison, the sensor properties of the metallic trapezoid hole array is better than that of the metallic square hole array. Meanwhile, the field intensity enhancement and localization of the metallic trapezoid hole are better. Meanwhile, these array structures can extensively apply to biochemical sensor devices design and localized field enhancement device so on.

1. Introduction

Surface plasmon polariton is the collective oscillation of the free electrons at the metal film surface [1–6]. Many scientists studies the optical properties of metallic nanostructures and the SPPs' excitation at metal film surface, which have extensive application in the light beaming [7–9], localized field intensity enhancement [10,11], Raman scattering enhancement [12,13], biochemical sensor device [14,15] and photonics, nanophotonics circuit construction [16–19] and so on. Sensor based surface plasmon polaritons have been extensively studied experimentally [20–22] and theoretically [23–25] and the refractive index sensitivity is better. The refractive index sensitivity for the metal film is larger, which can achieve about 10E5 by measuring the reflectivity [22]. The sensor principle of the single nanoparticle and metallic nanoparticle array is based on the localized surface plasmon resonance [20–25]. For example, the lineshape of the extinction spectrum of the metallic nanoparticle array with the radius 50 nm is narrow and can achieve about some nanometers. The refractive index sensitivity of the metallic nanoparticle array is about 200 nm RIU^{-1} [25]. But the sensor based on the metallic hole array is exploited smaller, which is also based on the surface plasmon resonance at the metallic film surface.

The near field measurement technology, such as the near field scanning optical microscopy technology [26,27], can overcome the light diffraction limits and get the electric field intensity at the metal film surface. In this letter, we simulate the near field transmission spectrum and the near field intensity distribution of the periodic hole array by use of the finite-difference time-domain method (FDTD) [29,30]. In the simulation, we explore the material properties [28] from the Johnson and Christy referenced in Refs. [29,30]. Better refractive index sensitivity is achieved about 1000 nm RIU^{-1} for the metallic trapezoid hole array. The effects of the structure shape and other structure parameter on the refractive index sensitivity are considered. The refractive index sensitivity of trapezoid hole array is larger than that of the square hole array. Meanwhile, the geometries parameters have effects on the refractive index sensitivity, including the lattice constant, film thickness and so on.

2. Results and discussion

Fig. 1 shows the transmission spectrums simulated by FDTD in the near-infrared wavelength range with the refractive index changing from 1.0 to 1.5. The inset in Fig. 1 shows the considered square hole array, which is two-dimensional array with the hole size 0.1 μm and the lattice constant 400 nm. The structure is fabricated in the silver film with the film thickness 400 nm and the light is incident in *y*-axis with the electron field polarized in *x*-axis. There is transmission enhancement at the wavelength 1.18 μm for the metallic square hole array with the refractive index 1.0. The transmission intensity is larger and can achieve 0.5 and the spectrum width is about 400 nm. The transmission peak positions increase with the increment of the hole index. It is at the

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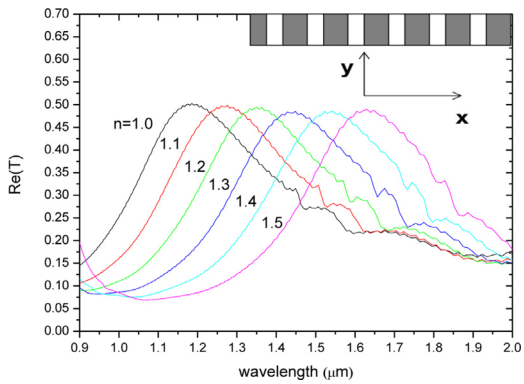

Fig. 1. Simulated the transmission spectrums for the metallic subwavelength structure. The size of the metallic square hole array is 100 nm and the depth is 400 nm with the lattice constant 400 nm. The index of the square hole is changed from 1.0 to 1.5.

wavelength 1.180 μm for the trapezoid hole index 1.0 and at the wavelength 1.629 μm for the trapezoid hole index 1.5. So the refractive index sensitivity is about 898 nm RIU^{-1} for the trapezoid hole array.

The transmission enhancements through the subwavlength hole array are associated with the excitation of the surface plasmon polaritons (SPPs). The SPPs' excitation must satisfy the energy conservation and the momentum conservation depicted as Eqs. (1) and (2):

$$\bar{k}_{sp} = \bar{k}_{0//} + i\vec{G}_x + j\vec{G}_y, \tag{1}$$

$$\bar{k}_{sp} = |\bar{k}_{sp}| = \mathrm{Re}\left(\frac{\omega}{c}\sqrt{\frac{\varepsilon_m(\omega)\varepsilon_d}{\varepsilon_m(\omega)+\varepsilon_d}}\right) \tag{2}$$

where the $\bar{k}_{sp}$ and $\bar{k}_{0//}$ are the wavevector of the surface plasmon wave and the element of the wavevector parallel the metal film surface. Meanwhile, $\vec{G}_x$ and $\vec{G}_y$ are the inverse wavevector of the periodic nanoparticle array in the x direction and y direction. Then transmission enhancement at wavelength 1.18 μm results from the excitation of the surface plasmon wave and corresponding to the SPPs air/silver (10) mode. The transmission peak position will increase with the increment of the lattice constant and the other geometric parameter, such as hole size and hole shape, also has some effect.

Fig. 2(a) shows the transmission spectrums for the metallic trapezoid nanohole array simulated by FDTD in the near infrared wavelength range. The considered structure is trapezoid with the bottom size 100 nm and the upper size 20 nm, which is fabricated in the film thickness 400 nm. The structure is two-dimensional with the lattice constant 400 nm. The light is incident in y-axis with the electron field polarized in x-axis shown in the inset in Fig. 2(a). There is transmission abnormalities in the near infrared wavelength range from 1.2 μm to 2.0 μm, and the transmission can achieve 0.3. The transmission abnormality origins from the excitation of the surface plasmon wave and is corresponding to the SPPs air/silver (10) mode at the metallic film surface. The transmission peak positions increase with the increment of the hole index. It is at the wavelength 1.303 μm for the trapezoid hole index 1.0 and at the wavelength 1.829 μm for the trapezoid hole index 1.5. So the refractive index sensitivity is about 1050 nm RIU^{-1} for the trapezoid hole array, which has the better sensitivity than that of the square hole array and can apply to biotical or chemical sensor extensively. We get the change of the transmission peak positions with the refractive index for the square and trapezoid hole array shown in Fig. 2(b). The transmission peak positions increase with the increment of the refractive index and are larger for the trapezoid hole array than that of the square hole array. The slope is about 800 nm RIU^{-1} for the square hole array and larger than 1000 nm RIU^{-1} for the trapezoid hole array. So the sensitivities are better for the trapezoid hole array than that of the square hole array. The hole shape has larger effect on the refractive index sensitivities. The trapezoid hole array can extensively apply for the biotical or chemical sensor.

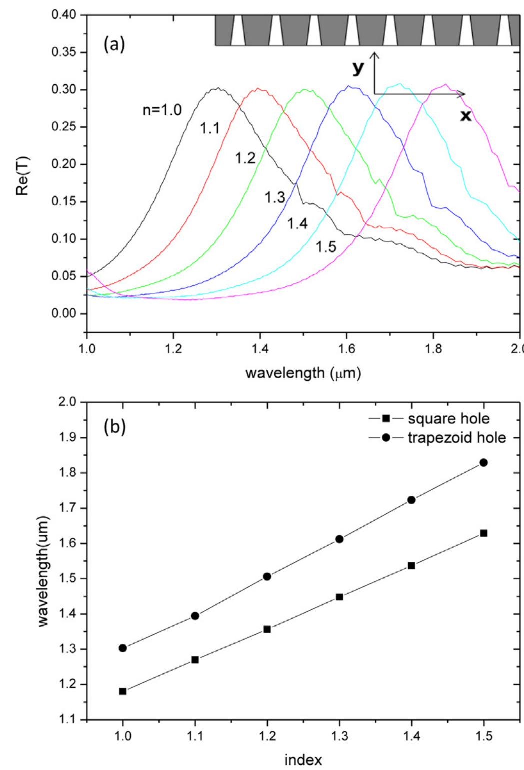

Fig. 2. (a) Simulated the transmission spectrums for the metallic subwavelength structure. The size of the metallic taper hole array is 100 nm and the depth is 400 nm with the lattice constant 400 nm. The index of the square hole is changed from 1.0 to 1.5. The inset is the structure and the light incidents in y-axis with the electric field polarized in x-axis. (b) The change of the transmission peak positions with the index of the square hole and the taper hole.

Fig. 3 shows the transmission spectrum for the square hole array simulated by FDTD in the near infrared wavelength range. The considered structure is square with the size 100 nm and the film depth 300 nm. The structure is two-dimensional with the lattice constant 400 nm and 600 nm respectively. There is transmission enhancement at the wavelength 0.518 μm and 0.947 μm shown in Fig. 3(a), which origin from the excitation of surface plasmon wave. The transmission enhancement at the wavelength 0.518 μm is corresponding to the SPPs air/silver (11) mode. Meanwhile, the transmission enhancement at the wavelength 0.947 μm is corresponding to the SPPs air/silver (10) mode. The transmission peak position is at the wavelength 1.248 μm for the square hole array with the hole index 1.5. The refractive index sensitivity is about 600 nm RIU^{-1}, which is smaller than that of the square hole array with the film thickness 400 nm. There is transmission enhancement at the wavelength 0.685 μm and 1.254 μm, which origin from the excitation of surface plasmon wave. The transmission enhancement at the wavelength 0.685 μm is corresponding to the SPPs air/silver (11) mode. Meanwhile, the transmission enhancement at the wavelength 1.254 μm is corresponding to the SPPs air/silver (10) mode. The transmission peak position is at the wavelength 1.675 μm for the square hole array with the hole index 1.5. The refractive index sensitivity is about 800 nm RIU^{-1}, which is slightly smaller than that of the square hole array with the lattice constant 400 nm. In comparison, the structure shape has larger effect on the