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# Sensitivity of Triangular Hybrid Au–Ag Nanostructure Array

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The sensitivity is one of the most important parameters in the sensing field. Silver triangular nanostructure array is the traditional substrate for detecting the targets. In this paper, we proposed triangular hybrid Au–Ag nanostructure array to be optimized substrate for nanobiosensor. Effort was made to study sensitivity of triangular hybrid Au–Ag nanostructure array through finite-difference time-domain (FDTD) algorithm-based computational numerical calculation method. The extinction efficiency was obtained by theoretical numerical calculation. It is found that the triangular hybrid Au–Ag nanostructure array possess the refractive index sensitivity of 273 nm/RIU when thickness of silver is 40 nm and the gold is 10 nm, and refractive index of the medium is around 1.33. It is higher than the pure silver nanostructure array (242 nm/RIU).



**Keywords:** Sensitivity, Triangular, Spectroscopy, Finite-Difference, Time-Domain.

## 1. INTRODUCTION

Recently, metallic nanostructures have attracted a dramatic increase in attention because of their plasmonic properties, which allows for many applications that rely on light absorption of metal, including surface plasmon resonance (SPR),[1,2] surface-enhanced Raman scattering (SERS),[3,4] sensing,[5–8] and imaging.[9] One of the most interesting application areas is label-free molecular bio-chemosensing based on the dependence of the scattering/absorption properties of the metal nanostructures on their local dielectric environment.[10–12] Triangular silver nanostructure array was proposed as the sensing substrate in the LSPR nanobiosensor application field. The refractive index sensitivity of the silver triangular nanobiosensor proposed by the other research group is about 200 nm/RIU.[13] However, how to avoid oxidation of the silver and to improve the refractive index sensitivity is still an open question. In the pervious work by Zhu et al.,[14] it is proposed that triangular hybrid Au–Ag nanostructure array may be used to avoid oxidation of the silver and to improve the refractive index sensitivity. By using the triangular hybrid nanostructure array, we have detected the staphylococcus aureus enterotoxin B (SEB) successfully. In this paper we focus on the refractive index sensitivity of the triangular hybrid Au–Ag nanostructure array. The finite-difference time-domain (FDTD) method was used to calculate the refractive index sensitivity when the thickness of the gold on the top of the triangular silver nanostructure array is 0 nm and 10 nm, respectively. The calculated results show that the triangular hybrid Au–Ag nanostructure array has higher refractive index sensitivity than the pure silver nanostructure array.

## 2. COMPUTATIONAL SETUP

The hybrid Au–Ag triangular nanostructure array was proposed as an optimized substrate for nanobiosensor. FDTD algorithm was used to calculate the refractive index sensitivity of the triangular hybrid nanostructure array. The FDTD method treats Maxwell equations as s set of finite difference equations in both time and space. The model space considered includes both the probe and the sample surface and consists of an aggregation of cubic cells with each cell having its own complex dielectric constant. The finite difference equations can be written as:[15]

$$\frac{H_{z(t;x,y+\Delta y,z)}-H_{z(t;x,y-\Delta y,z)}}{2\Delta y}-\frac{H_{y(t;x,y,z+\Delta z)}-H_{y(t;x,y,z-\Delta z)}}{2\Delta z}$$
$$=\tilde{\varepsilon}_{(x,y,z)}\frac{E_{x(t+\Delta t;x,y,z)}-E_{x(t-\Delta t;x,y,z)}}{\Delta t}$$

$$\frac{H_{x(t;x,y,z+\Delta z)}-H_{x(t;x,y,z-\Delta z)}}{2\Delta z}-\frac{H_{z((t;x+\Delta x,y,z)}-H_{z(t;x-\Delta x,y,z)}}{2\Delta x}$$
$$=\tilde{\varepsilon}_{(x,y,z)}\frac{E_{y(t+\Delta t;x,y,z)}-E_{y(t-\Delta t;x,y,z)}}{\Delta t}$$

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$$\frac{H_{y(t;x+\Delta x,y,z)} - H_{y(t;x-\Delta x,y,z)}}{2\Delta x} - \frac{H_{x(t;x,y+\Delta y,z)} - H_{x(t;x,y-\Delta y,z)}}{2\Delta y} = \tilde{\varepsilon}_{(x,y,z)} \frac{E_{z(t\_\Delta t;x,y,z)} - E_{z(t-\Delta t;x,y,z)}}{\Delta t} \quad (1)$$

where $E = E(E_x, E_y, E_z)$ and $H = H(H_x, H_y, H_z)$ are the electric field and the magnetic induction vectors, respectively, and $2\Delta x$, $2\Delta y$, $2\Delta z$ are increments along the three coordinate directions respectively, $\Delta t$ is the unit time increment, and $\tilde{\varepsilon}_{(x,y,z)}$ is the complex dielectric constant of the medium at that point. Equation (1) is simultaneously solved to determine the component values at the time $t + \Delta t$. Commercial professional software was adopted here for the computational calculation and numerical analysis.[16] Broad band of the incident light is ranging from 400 nm to 750 nm with plane wave in normal incidence angle $\theta = 0°$. Meshing size in $x$ and $y$ (two-dimensional simulation) is $\Delta x = 2$ nm and $\Delta y = 2$ nm, respectively. Simulation time $t$ (theoretically, $t = \Delta x/2c$, $c$ is the velocity of light) is set to be 125 fs. The output result is the relationship between the reflectivity and transmission index and the incident wavelength.



Using FDTD algorithm, we designed and calculated the extinction efficiency of the hybrid nanostructure array. Corresponding geometrical model of the triangular hybrid Au–Ag nanostructure array is shown in Figure 1. The triangular hybrid Au–Ag nanostructures are arranged on the glass substrate in the symmetry two-dimensional infinite arrays. They are equal in-plane width and the angle between the arris and underside of the triangular Au–Ag structure is uniform (see Fig. 1). This triangular array lies in $x$–$y$ plane and the incident light polarized of $x$-axis propagates along $z$ axis. The out-of plane heights of the Ag nanostructures is 40 nm and the gold is 10 nm. The in plane widths of each nanostructures is 100 nm. The period of the nanostructure array is 400 nm and the refractive index around the hybrid nanostructure is 1.0 (in air) and 1.33 (in water). For the glass substrate, the refractive index is about 1.52. For the gold and silver material, we used Drude model to calculate the reflectivity and transmission index of the triangular hybrid nanostructure array. From the calculated results, we can obtain the refractive index sensitivity of the pure silver and the hybrid Au–Ag nanostructure array.

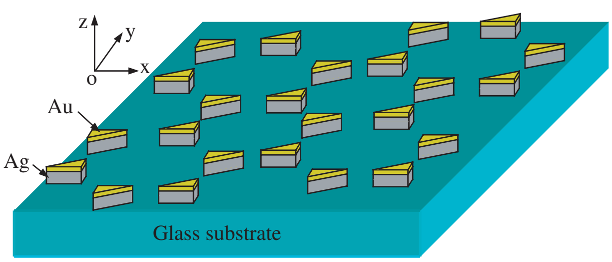


**Fig. 1.** The symmetry two-dimensional infinite model of triangular hybrid Au–Ag nanostructure array.

## 3. RESULTS AND DISCUSSION

In order to obtain the refractive index sensitivity of the nanostructure array, we calculated the extinction spectra of the refractive index of the mediums surrounding the nanostructure array. The refractive index sensitivity is defined as $m = \Delta\lambda/\Delta n$, where $\Delta\lambda$ and $\Delta n$ denote the peak of the wavelength change and the refractive index change, respectively.

Using FDTD method, the reflectivity and transmission index of the triangular pure silver and hybrid Au–Ag nanostructure array are calculated with in the visible light domain. The results are shown in Figure 2. The relationship between the transmission ($T$) and the extinction efficiency ($E$) can be expressed as: $E = -\log T$. Figure 2 shows that the resonant peak position at point A is at $\lambda = 525$ nm when the refractive index of the medium is 1.0. The out-of-plane height of silver is 40 nm.

The FDTD calculated results of relationship between the reflectivity and transmission index of the pure silver triangular nanostructure array and the incident wavelength are shown in Figure 3 when the refractive index of the medium around the nanostructure array change from 1.0 (in air) to 1.33 (in water). Figure 3 shows that the resonant peak position at point B is at $\lambda = 605$ nm when the refractive index of the medium is 1.33. The out-of-plane height of silver is 40 nm.

The FDTD calculated results of Figures 2 and 3 show that the refractive index sensitivities of the pure silver triangular nanostructure array is $m = \Delta\lambda/\Delta n = (605\ \text{nm} - 525\ \text{nm})/(1.33 - 1.0) = 242$ nm/RIU.

The refractive index sensitivity of triangular hybrid Au–Ag nanostructure array is calculated when 10 nm gold coating is on the top of the silver nanostructure array. The

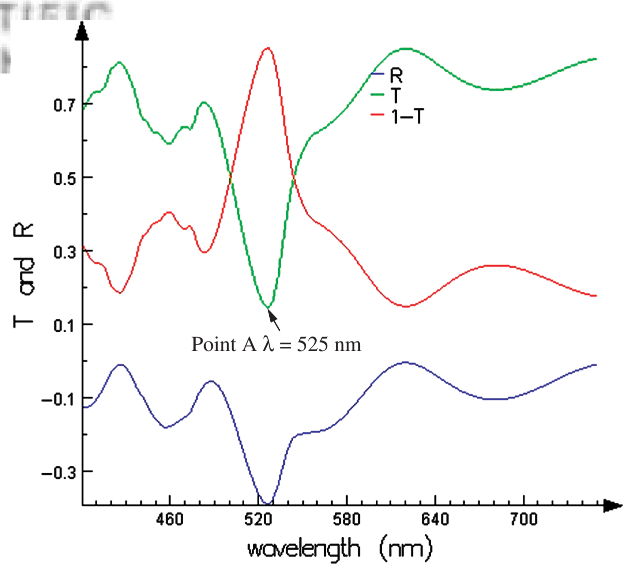


**Fig. 2.** The reflectivity and transmission index of the pure silver triangular nanostructure array calculated by FDTD when the refractive index of the medium is 1.0. The out-of-plane height of silver is 40 nm.

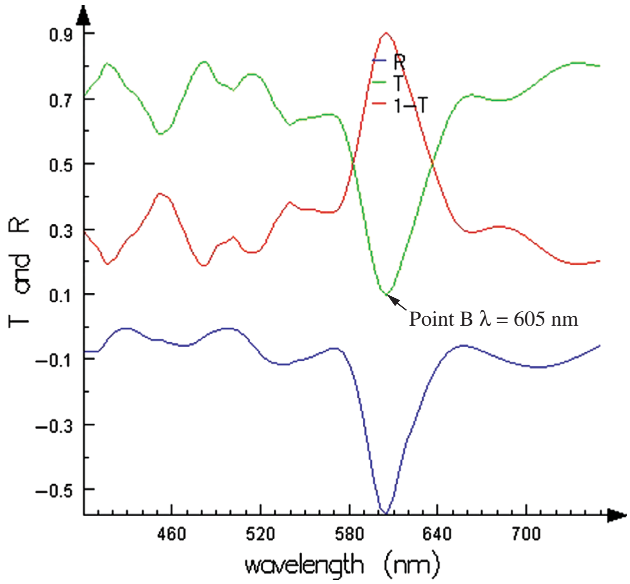


**Fig. 3.** The reflectivity and transmission index of the pure silver triangular nanostructure array calculated by FDTD when the refractive index of the medium is 1.33. The out-of-plane height of silver is 40 nm.

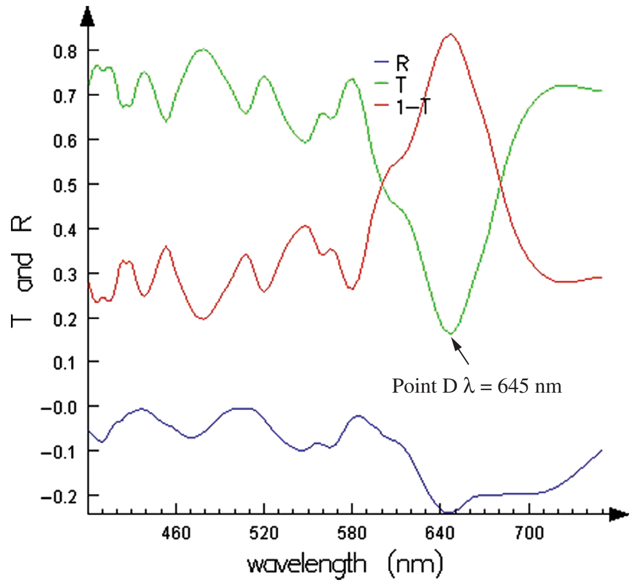


**Fig. 5.** The reflectivity and transmission index of the hybrid Au–Ag triangular nanostructure array calculated by FDTD when the refractive index of the medium is 1.33. The out-of-plane height is 40 nm for silver and 10 nm for gold.



reflectivity and transmission index of the hybrid Au–Ag nanostructure array are shown in Figures 4 and 5. Figure 4 shows that the resonant peak position at point C is at $\lambda = 555$ nm when the refractive index of the medium is 1.0. The out-of-plane height of silver is 40 nm and the gold is 10 nm. Figure 5 shows that the resonant peak position at point D is at $\lambda = 645$ nm when the refractive index of the medium is 1.33. The refractive index sensitivities of the triangular hybrid nanostructure array is $m = \Delta\lambda/\Delta n = (645\text{ nm} - 555\text{ nm})/(1.33 - 1.0) = 273$ nm/RIU.

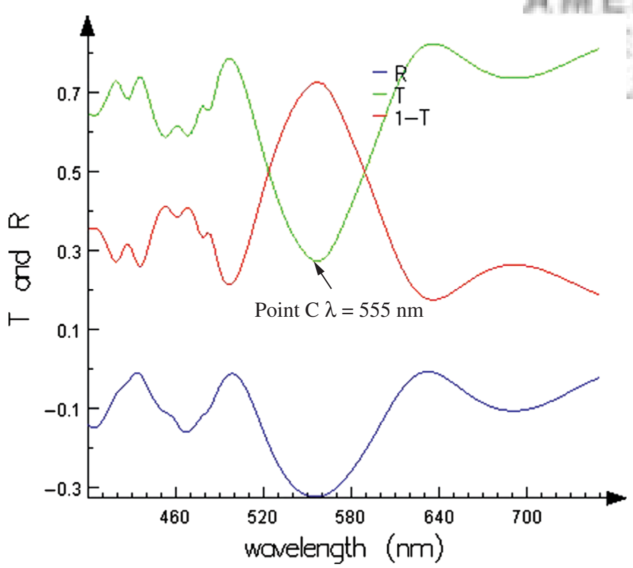


**Fig. 4.** The reflectivity and transmission index of the hybrid Au–Ag triangular nanostructure array calculated by FDTD when the refractive index of the medium is 1.0. The out-of-plane height is 40 nm for silver and 10 nm for gold.

## 4. CONCLUSION

The hybrid nanostructure array is an important new geometry for plasmonic nanoparticles combining the highly attractive nanoscale optical properties. The refractive index sensitivity of the hybrid Au–Ag triangular nanostructure array is calculated by FDTD method. The calculated result is 273 nm/RIU when thickness is 40 nm for silver, 10 nm for gold, and refractive index of the medium is changed from 1.33 to 1.0. It is higher than the pure silver triangular nanostructure array (242 nm/RIU) when the thickness of silver is 40 nm. So the triangular hybrid Au–Ag nanostructure array can be used as the optimized substrate for nanobiosensor. Such hybrid metallic nanostructures are suitable for industrial application and fundamental research.

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