Reflectance controlling based on surface plasmon polaritons stimulated over the surface of metallic nanostructures

Chang Liu[a,b,d], Sishun Wang[a,b,d], Dong Wei[a,b,d], Zhaowei Xin[a,b,d], Mingce Chen[a,b,d], Xinyu Zhang[a,b,c], Haiwei Wang[d], Changsheng Xie[d]
[a]National Key Laboratory of Science & Technology on Multispectral Information Processing, Huazhong University of Science & Technology, Wuhan 430074, China
[b]School of Automation, Huazhong University of Science & Technology, Wuhan 430074, China
[c]Innovation Institute, Huazhong University of Science & Technology, Wuhan 430074, China
[d]Wuhan National Laboratory for Optoelectronics, Huazhong University of Science & Technology, Wuhan 430074, China

ABSTRACT

The surface plasmon polaritons (SPPs) is an electromagnetic wave that can be stimulated and then propagates over the surface of the preshaped metallic nanostructures or the interface between the surface of the metallic nanostructures and the substrate media due to a strong coupling of incident light and the surface free-electrons moving on the metallic nanostructure surface with a featured micrometer scale. As shown, through SPPs, incident light energy can be localized effectively in a sub-wavelength region or space, and thus so-called light diffraction limit can be break through easily. Therefore, it has demonstrated a good prospects for developing advanced functioned materials or devices such as light absorbing materials, optical antennas, and optical information storage modules. In this paper, we propose a special metallic nanostructures, which can be used to absorb a certain band of incident light by converting them into a kind of local free-electron oscillation, which means that SPPs can be generated and processed efficiently. As shown, the metallic nanostructures will present a lower reflectivity in the wavelength range, and through adjusting several key parameters such as the period of the metallic nanostructures, we can achieve an effective control of reflectivity because a valley of the reflectivity curve can be formed, which means a low reflectance at a specific wavelength band has been obtained.

Keywords: surface plasmon polaritons, metallic nanostructures, low reflectance

1. INTRODUCTION

The surface plasmon polaritons (SPPs), which collectively resonate as dielectrics and metallic nanostructures surface electrons, couple with electromagnetic waves to form a polarized wave that is spread locally in the metallic nanostructures and medium interfaces, and its intensity decays exponentially with distance from the interface[1].And the development of plasmonics and metamaterials[2-4] in recent years has driven the birth of a series of new functional devices such as subwavelength waveguides[4,5], optical nano-antennas[6,7], hyper-lenses[8], hyperbolic lenses[9], optical concentrators[10], etc., have wide application prospects in many fields such as communication technology, biochemical detection, medical imaging, military stealthy design, nano-lasers, and solar cells.

2. METALLIC NANOSTRUCTURES DESIGN

The required metallic nanostructure shown in Figure 1 has been designed by us: the star-shaped.

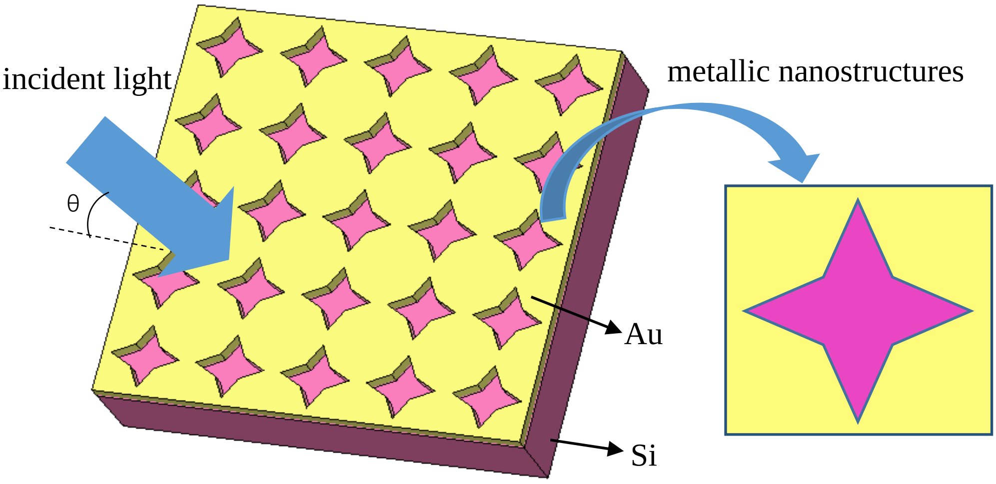
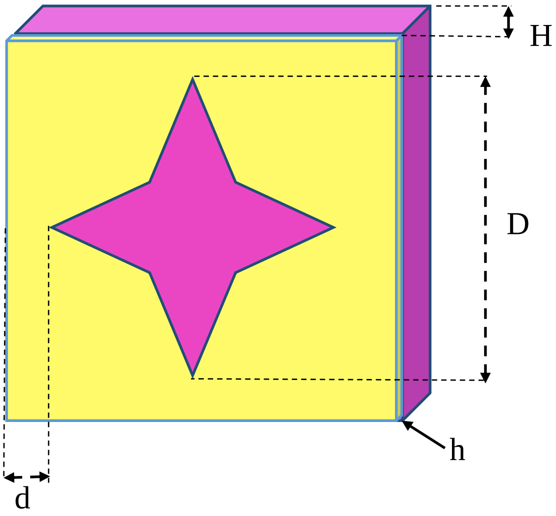


Figure 1. Periodic metal pattern

3. SIMULATION AND ANALYSIS

Our selected electromagnetic simulation software CST Microwave Studio (MWS). Simulation design of the metal micro-nano structure parameters shown in Figure 2.



Metallic materials: aurum (Au)

Base materials: silicon (Si)

Pattern length D: 400 nm

Margins d:10-50 nm

Angle of incidence θ: 35-55 °

Frequency: 0.1-100 THz

Metal film thickness h: 60-100 nm

Base thickness H: 500 nm

Figure 2. Metallic nanostructures parameters

When we fix D=400 nm, d=50 nm, and incident light angle θ=45°, When the metal film thickness h changes, the reflectance of the metal micro-nano structure changes as shown in Figure 3.

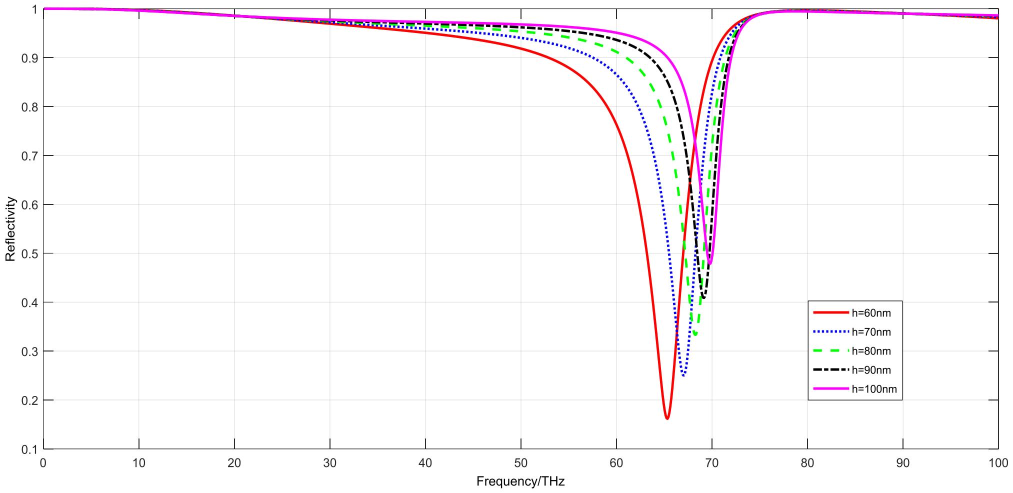


Figure 3. Reflectance curve at different metal film thickness

From the simulation results, it can be seen that when the thickness of the metal film is continuously reduced, the frequency corresponding to the reflectance trough has a red-shift, and the corresponding reflectance of the trough also decreases continuously. Decrease from the corresponding 0.478 at 100 nm to the corresponding 0.162 at 60 nm

From the simulation results above, we can see that when the thickness h is 60 nm, the result is better, so the thickness of the fixed metal film h is 60 nm. When we change ‘d’, the reflectance of the metal micro-nano structure changes as shown in Figure 4.

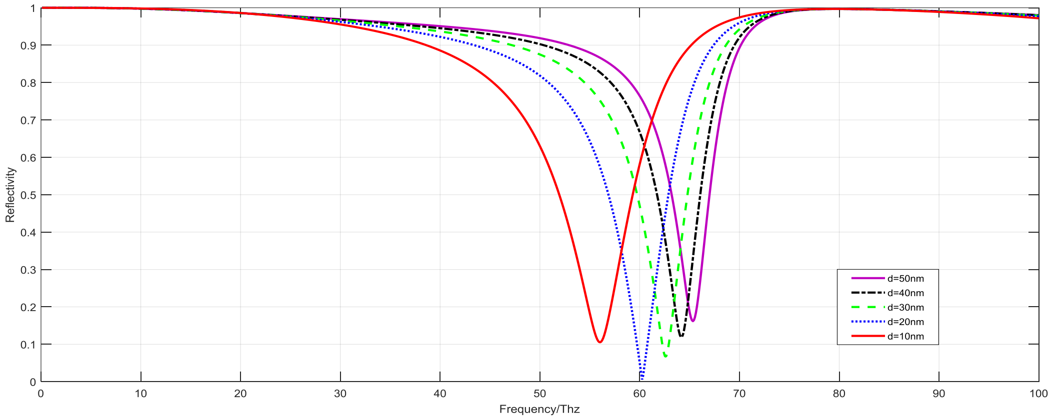


Figure 4. Reflectance curve at different margin conditions

From the above figure, we can see that when the margin is continuously decreasing, the frequency corresponding to the reflectance trough is red-shifted, but the minimum reflectivity decreases first and then increases. Decrease from 0.105 at 10 nm to 0.006 at 20 nm, then to 0.162 at 50 nm. This parameter may be related to the duty cycle of the graph.

From the above simulation results, it can be seen that when d=20 nm, the result is better, so the fixed d=20 nm. When the angle of incident light is changed, the reflectance curve of the metal micro-nano structure changes as shown in the figure 5.

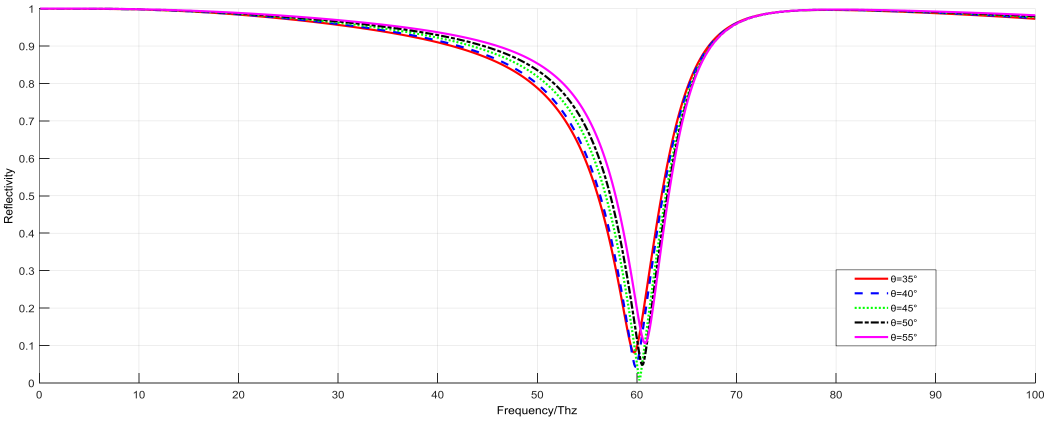


Figure 5. Reflectance curves at different incident angles

From the simulation results, it can be seen that when the incident angle decreases, the effect of changing the margin is the same, the frequency corresponding to the reflectance trough has a red shift, but the minimum reflectivity decreases first and then increases. Decrease from 0.106 at 55 degrees to 0.006 at 45 degrees and 0.08 at 35 degrees. It can be seen that changes in the incident angle range have little effect on reflectivity.

REFERENCES

[1] Barnes, W. L., Dereux, A. and Ebbesen, T. W., "Surface plasmon subwavelength optics," Nature, 424(6950), 824-830 (2010).

[2] Otomori, M., Yamada, T., Izui, K., et al. “Topology optimization of hyperbolic metamaterials for an optical hyperlens,” Structural & Multidisciplinary Optimization, 55(3), 913-923 (2017).

[3] Pryce, I. M., Aydin, K., Kelaita, Y. A., et al. “Highly Strained Compliant Optical Metamaterials with Large Frequency Tunability,” Nano Letters, 10(10), 4222-4227 (2017).

[4] Kim, N. C., Ko, M. C., Choe, S. I., et al. “Transport properties of a single plasmon interacting with a hybrid exciton of a metal nanoparticle-semiconductor quantum dot system coupled to a plasmonic waveguide,” Nanotechnology, 27(46), 465703 (2016).

[5] Tsang, H. K., Kang, J., Goda, K., et al. “Focusing subwavelength grating coupler for mid-infrared suspended membrane germanium waveguides,” Optics Letters, 42(11), 2094-2097 (2017).

[6] Regmi, R., Winkler, P. M., Flauraud, V., et al. “Planar Optical Nano-Antennas Resolve Cholesterol-Dependent Nanoscale Heterogeneities in the Plasma Membrane of Living Cells,” Nano Letters, 17(10), 6295 (2017).

[7] Yifat, Y., Ackerman, M., Guyotsionnest, P., “Mid-IR colloidal quantum dot detectors enhanced by optical nano-antennas,” Applied Physics Letters, 110(4), 041106 (2017).

[8] Chen, Y. A., Chang, I. L., Chen, L. W., “Spiral hyperlens with enhancements of image resolution and magnification,” Journal of Modern Optics, 63(11), 1-6 (2016).

[9] Oh, J. H., Min Seung, H., Young Kim, Y., “A truly hyperbolic elastic metamaterial lens,” Applied Physics Letters, 104(7), 8247 (2014).

[10] Benyakhlef, S., Mers, A. A., Merroun, O., et al. “Impact of heliostat curvature on optical performance of Linear Fresnel solar concentrators,” Renewable Energy, 89, 463-474 (2016).