Journal of Lasers, Optics & Photonics
ISSN: 2469-410X
Tang, J Laser Opt Photonics 2017, 4:1
DOI: 10.4172/2469-410X.1000151

Review Article Open Access

Application of Periodical Nanostructures in Thin Metal Film for Near Infrared Multispectral Filters

Tang Y*

Department of Mathematics and Physics, North Carolina Central University, Durham, NC 27707, USA

Abstract

Surface plasmonic nanostructures with cross-shaped-hole array in metal thin films are studied for multispectral filters, which cover visible to near-infrared wavelengths. Surface plasmons are induced from incident wave by the periodic arrays of nanostructures of the metal thin film, and then localized surface plasmon polaritons oscillate in the cavity, which is formed by two surfaces of metals through near-field excitation. The transmission spectra of light through these nanostructures are investigated with the finite-difference time-domain method; our simulations show that the features of the hole, and the periods of the array along with other parameters are critical to the optical spectral performance. The optical characterizations of our fabrications of these nanostructures milled by focused ion beam demonstrated very similar results of transmission spectra of simulation results. The simulations demonstrate he optical performance of the metal nanostructures, it is possible to obtain desired multispectral filters by programming parameters of those plasmonic nanostructures.

Keywords: Nanostructures; Multispectral filters; Metallic plasmonic nanostructures

Introduction

Near Infrared Multispectral filters split the spectrum into multiple bands so that the transmission or reflection spectra can identify the materials, samples, or other objects. Motorized filter wheels [1] or multiple cameras [2] are employed to obtain multispectral imaging. Filter arrays [3] are discussed as one approach for multispectral imaging, and metallic plasmonic nanostructures [4] have been studied for multispectral filters too. The plasmonic multispectral is based on the extraordinary light transmission (ELT) phenomenon in the metallic nanostructures. The fraction of light transmitted through a periodic array of sub-wavelength-hole [5] in a metallic film exceeds the open fraction occupied by the holes at certain wavelength is related to the periodicity of the hole array [6] and the transmission can be anomalously large as compared to well-established predictions for isolated holes [7]. The main mechanism of ELT is that the incident light couples to localized surface plasmon polaritons (SPPs) on the metal film.

Our previous investigations [8] show that the process of this ELT can be understood as: the light couples to SPPs by the sub-wavelength-holes of the thin metal film, then the localized SPPs propagate in the sub-wavelength-holes and after that the SPPs couple to light from the sub-wavelength hole on the other side of the metal film. The optical transmission spectrum is dependent on the periodicities of the sub-wavelength-hole array; and the aspects of the hole are very important to the transmission too. For rectangular hole array, the length (longer side of a rectangular hole) is decisive to the magnitude and band width of the transmission; and the width (shorter side) of the hole has little effect on the peak magnitude, but has effect on the location of the peak. Since the SPPs propagate through the hole from side of light incident to the other side of the metal and then couple to light, thus these sub-wavelength-holes in the metal film can be treated as a Fabry-Perot cavities. Therefore, the thickness of the metal film is viewed as the length of the cavity; multi-modes of light from these metallic structures can be obtained by increasing the metal film thickness. Two transmission peaks are observed from rectangular hole array in a thickness of 200 nm gold film. The investigation shows that thicker gold film produces band-pass type peaks for the studied nanostructures. The polarization of the incident plane wave is very crucial to obtain a high transmission peak for a rectangular hole array; high optical transmission is achieved when the polarization of the light is parallel to the short ridge of the rectangular hole array. Cross-shaped-hole arrays (CSHAs) are selected [4] to diminish the polarization-dependent transmission differences of incident plane waves. In this paper, we have the CSHAs on a thin gold film with thickness of 100 nm to produce a single transmission peak, and we vary the periodicities of the CSHAs while keep the width of the rectangular hole as 50 nm, and the length is proportional to the periodicities. The periodicities vary from 350 nm to 400 nm, and so on to 750 nm. We fabricated these nanostructures on the 100 nm thick gold film on quartz subtract; the optical characterization is carried out with the UV-Vis-NIR Microspectrophotometer. The experimental results matched well with the simulation transmission spectrum.

Simulations

The finite difference time domain (FDTD) method is a numerical analysis technique used for modelling computational electrodynamics, and it is used to find approximate solutions to the Maxwell's equations over time within some finite computational region, in which space is divided into a discrete grid and the fields are evolved in time using discrete time steps. MEEP [9] is software with the FDTD method, we used MEEP for simulating the electromagnetic wave in the MDM structures. In order to obtain accurate and high efficient simulation results, we set the grid to 10 nm, and applied the parallel computing, which is provided by the Texas Advanced Computer center (TACC) of the Extreme Science and Engineering Discovery Environment (XSEDE) [10]. In the simulations, the Lorentz-Drude model (equation

***Corresponding author:** Tang Y, Department of Mathematics and Physics, North Carolina Central University, Durham, NC 27707, USA, Tel: (919) 530-5106; E-mail: tangy@nccu.edu

Received March 20, 2017; **Accepted** March 26, 2017; **Published** March 31, 2017

Citation: Tang Y (2017) Application of Periodical Nanostructures in Thin Metal Film for Near Infrared Multispectral Filters. J Laser Opt Photonics 4: 151. doi: 10.4172/2469-410X.1000151

Citation: Tang Y (2017) Application of Periodical Nanostructures in Thin Metal Film for Near Infrared Multispectral Filters. J Laser Opt Photonics 4: 151. doi: 10.4172/2469-410X.1000151

1) is utilized to describe the dielectric function of the gold film:

$$\varepsilon = \varepsilon_{\infty} + \sum_{j=0}^{k} \frac{\sigma_j \omega_j^2}{\omega_j^2 - \omega^2 - i\omega\Gamma_j} \quad (1)$$

Where $\varepsilon_{\infty}=1$ is the infinite dielectric constant, ω is the frequency of the incident light, ω_j is the frequency of the critical points, $1/\Gamma_j$ is the constant for lifetime, and σ_j is the strength. We took the data of the critical points for the dielectric function from this reference [11]; and then we applied the unit in the MEEP and converted these parameters to the MEEP system shown in Table 1 below.

The sketch of the CSHAs nanostructure is shown in Figure 1a. It is a layer of gold film with the CSHAs. The cross hole of the CSHA is formed with two rectangle holes. The cross-section view of yz plane of the unit cell for the simulation is shown in Figure 1b, in order to obtain the hole array in the simulations, we set the boundaries in both x and y directions as Bloch-periodic boundaries, and at both ends of z axis there are a perfect match layer at the outmost to absorb reflections; A plane wave light source is placed next to the PML Layer inside the unit cell on the right end, so the light is traveling in z direction, the CSHA gold film is placed in the center of the unit cell, and the transmission spectrum is computed the flux of electromagnetic energy as a function of frequency, it is detected by an optical detector at the left end of the unit cell.

Omega (ω_j)	Gamma (Γ_j)	Sigma (σ_j)
1.000e-20	0.0427	4.015e+41
0.3340	0.1940	11.3629
0.6681	0.2777	1.1834
2.3898	0.7003	0.6568
3.4643	2.0075	2.6455
10.7214	1.7821	2.0148

Table 1: Dielectric function parameters of gold for MEEP simulations.

The transmission spectrum of CSHAs is shown in Figure 2, in this simulation, the length and width of the rectangular hole for the CSHA are set to 280 nm and 50 nm for period of 350 nm, respectively; and the thicknesses of the metal films are set to 100 nm. We varied the period from 350 nm to 750 nm by increasing 50 nm for each periodicity, and the length of CSHAs is 0.8 of the period, meantime, the width of the rectangular hole and the thickness of the gold film are kept as constant. The simulations show that the transmission peak is shifting gradually to longer wavelength as the periodicity increasing. We applied this property to create a multispectral filter by arranging these increase periodicities together; such an arrangement is shown in Figure 3. When a broad band electromagnetic wave incidents on this filter, each periodicity part of the CSHAs will transmit its own spectrum.

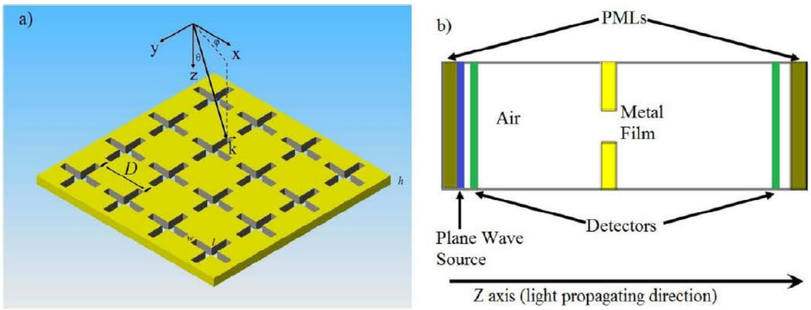

Figure 1: a) Sketch of the nanostructures on gold thin film, and b) cross-section view of the unit cell for simulations.

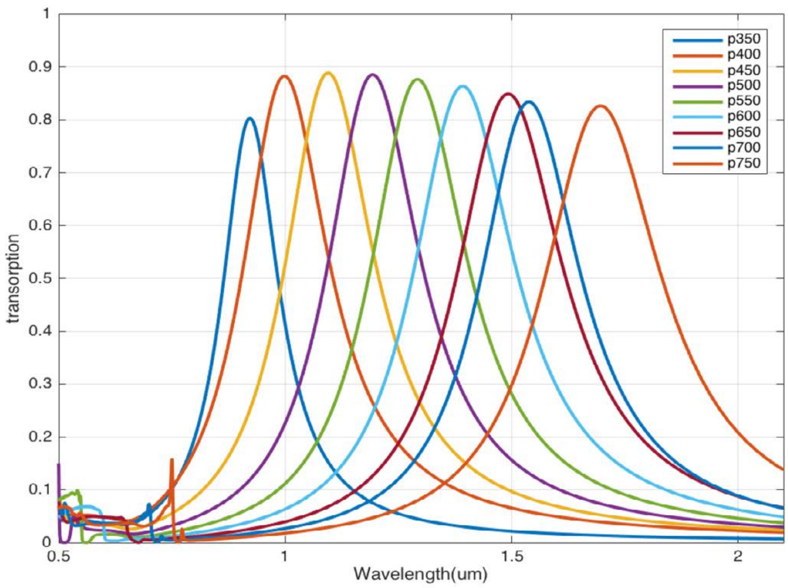

Figure 2: Simulation results of the transmission spectrum of the CSHA nanostructures from period of 350 nm to 750 nm.

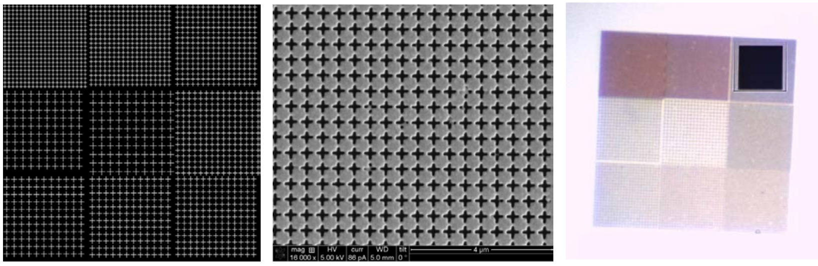

Figure 3: The patterns of the multispectral filters with 9 periodicities (left), the zoom in view of the pattern of periodicity of 450 nm (middle), the image under microscope (right).

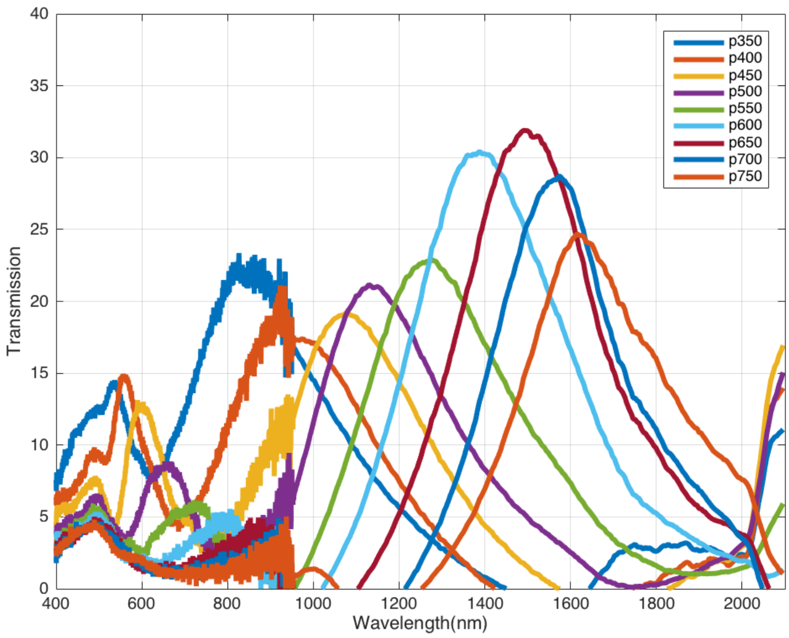

Figure 4: Measurements with the microscopic photospectropy results from grid 12_35-75(2016-1-27).

Fabrications and Characterization

The 100 nm thick gold film is deposited on a clean quartz 2" wafer in the CHA Industries Solution Electron Beam (E-Beam) Evaporator. The nanostructures patterns are writing in files of BMP format, and is same as features as the simulations with computer, and the focused ion beam (FIB) (FEI Helios 600 Nanolab Dual Beam System) is utilized for milling these nanostructures from the created patterns; the patterns are created with a current of 9.7 pA, depth of 50 nm (Si), dwell time of 3 µs, and scan direction of right to left. One sample of period of 450 nm is shown in Figure 3. This 45 µm by 45 µm CSHAs along with other periodicities sample are characterized with the UV-Vis-NIR microspectrophotometer (CRAIC), the transmission spectrum is shown in Figure 4. The multispectral filter image under the microscope is shown in Figure 3. The measurements show the transmission peaks shift to long wavelengths when the periodicity of the nanostructures increases; this matches well with the simulation conclusions.

Conclusions and Discussion

From our investigations the CSHAs in metal film by simulations and fabrications show that it is possible to utilize the surface Plasmon induced by the metallic nanostructures as multispectral filters, meanwhile, the simulations well predicted the outcome of the fabrication samples; therefore, we can program the nanostructures to obtain the desired transmission spectrum. There are discontinuities on the transmission spectrum for periods of 350 nm to 500 nm in Figure 4, this is because the calibrate problem from microspectrophotometer has two lamps for illuminating, xenon/mercury lamp and halogen lamp.

Acknowledgement

The Author wants to thank the strong support in creating the patterns with FIB from Mr. Amar S. Kumahar at CHANL UNC. This work was supported in part by NSF: HRD- 1345219, DMR- 1523617, NASA: NNX09AV07A, ARO: W911NF-13-1-0165, and XSEDE grant: TG-DMR130018.

References

1. Koenig F, Praefcke W (1998) Proc SPIE 3409: 34-41.
2. Everitt JH, Escobar DE, Cavazos I, Noriega JR, Davis MR (1995) A three camera multispectral digital video imaging system. Remote Sens. Environ 54: 333-337.
3. Lu YM, Fredembach C, Vetterli M, Susstrunk S (2009) Designing color filter arrays for the joint capture of visible and near-infrared images. IEEE Image Proc, pp: 3797-3800.
4. Tang Y, Vlahovic B, Brady DJ (2011) Metallic nano-structures for polarization-independent multi-spectral filters. Nanoscale Research Letters 6: 394.
5. Genet C, Ebbese TW (2007) Light in tiny holes. Nature 445: 39-46.

6. Ebbesen TW, Lezec HJ, Ghaemi HF, Thio T, Wolff PA (1998) Extraordinary optical transmission through sub-wavelength hole arrays. Nature 391: 667-669.
7. Bethe HA (1944) Theory of Diffraction by Small Holes Phys Rev 66: 163-182.
8. Tang Y, Vlahovic B, Brady DJ (2013) Metallic nano-particles for trapping light. NANO 8: 65.
9. http://ab-initio.mit.edu/wiki/index.php/Meep
10. https://www.xsede.org/
11. Rakic AD, Djurisic AB, Elazar JM, Majewski ML (1998) Optical properties of metallic films for vertical-cavity optoelectronic devices. Appl Optics 37: 22.