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2015

Bingi, J., & Matham, M. V. (2015). Plasmonic 2D nanopillar arrays in high index and gradient index medium for subtractive optical filtering. 2015 IEEE Photonics Conference (IPC), 156-157.

<https://hdl.handle.net/10356/83646>

<https://doi.org/10.1109/IPCon.2015.7323569>

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Plasmonic 2D nanopillar arrays in high index and gradient index medium for subtractive optical filtering

Jayachandra Bingi*, Murukeshan Vadakke Matham

Center for Optical and Laser Engineering, School of Mechanical and Aerospace Engineering,
Nanyang technological University, SINGAPORE, 639798.
E-mail: jbingi@ntu.edu.sg

Abstract: 2D metal nanopillar arrays in media of constant and gradient refractive indices are simulated and their subtractive colour filtering features are demonstrated. These results are expected to contribute to the next generation display technologies.

Spectral filter is a device that allows the selective (wavelength) band transmission. It is an important component for display and image sensing technologies. The size of the filtering component decides the pixel size where micro and nano patterned components are advantageous. For this purpose, the phenomena called additive colour filtering (ACF) is studied extensively by various strategies such as metal-Insulator-metal, metal-dielectric resonators and the metallic submicron hole-arrays which reduced the pixels to submicron sizes [1,2]. Most of the plasmonic ACFs are 1D submicron patterns. On the other hand, subtractive colour filtering (SCF) is an alternative scheme of ACFs in image sensing. Recently an ultrathin subtractive colour filter based on metallic subwavelength grating is reported. This works on the principle of extraordinary low transmission (ELT) which can yield subwavelength pixel sizes [3]. Taking the advantage from higher dimensional plasmonic nano patterns, there is a definite scope to fabricate devices with ultra-small pixel sizes, better photon throughput and polarization independent phenomena.

In this work, we simulate the 2D silver nanopillar array and analyze their optical properties in surrounding media of differing refractive indices (R.I). The nanopillar array (Figure 1a), with 30nm X 30 nm size by height and period 55nm respectively, is simulated in FDTD *Lumerical solutions*. The broad band light (0.25-1 μm) of amplitude one is applied on the structure and the transmission properties are studied. Figure 1b shows the transmission curves of the nanopillar array at different background R.I value 1, 1.5, and 2 (black, red and blue curves respectively). This structure is working as a subtractive filter with good absolute transmittance around 60%. The subtractive spectral band found to be shifted and broadened with increasing background R.I. The effect of background medium evident in the simulation data of the Ag nanopillar array within the SiN medium (Figure 1c), which has shown the subtractive colour band in the visible region with 60% absolute transmittance. Generally nano pillars are structures with two possible resonance modes (Transverse and longitudinal). Here, in free space conditions (R.I=1) both modes are overlapped and the transmission band is narrow. When the surrounding medium R.I is increased more than one there is a shift in longitudinal mode and hence the transverse mode become obvious. It is clear from the transmission spectra that in the high index surrounding medium there exists multiple plasmon resonance modes. This could be due to damped surface plasmon oscillations on nanopillar surface due to surrounding environment. Transmission properties of the Ag nanopillar array in the presence of gradient index are studied by placing the layers of 10 nm each of R.I (1-1.5-2) and (1.5-2-2.5). The transmission spectra of these samples are shown in figure 1d.

The transmission curve got smoothened in gradient index medium compared to that of constant index medium. The subtractive band is red shifted and broadened with increase in effective refractive index of surrounding media. Figure 1e shows the plasmon propagation scenario inside the medium where the plasmon is excited by the incident light and travel along the length and decay by reaching the other end. Hence most of the light is trapped between the nanopillars.

Figure1: a) The Ag nanopillar array design, b) plot of absolute transmission of Ag array in R.I 1(Black), 1.5 (red), 2 (blue) environments, c) Plot of absolute transmission in SiN medium, d) plot of transmission in gradient index media, e) The field distribution inside the structure at the beginning (left), middle (center), end (right).

In conclusion, utilizing the longitudinal resonance modes of nanopillar and their propagation dynamics in different dielectric environments can enable fabrication of ultrathin subtractive filters. Due to the nano size and separations in these SCFs, the pixel size can be reduced to nano regime which is very useful for transparent display technologies.

Acknowledgements: The authors acknowledge the financial support received through MOE (RG 98/14).

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