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Plasmonic metasurface filter with full color sensitivity and narrow band-pass in visible region

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Recently, metasurfaces have attracted extensive interests in imaging with desirable wavelength, realizing full or multicolor holograms [1, 2], printing [3], and image sensor [4] applications. Among these applications, discrete wavelength selection from white light plays a key role in optical information recording and imaging processes. Plasmonic metasurface filters provide rich platforms for readily realizing desirable wavelength selection due to color tunability, reliability, and multifunctionality. The advantages of metasurface filters beyond traditional filters are ascribed to three aspects. First, plasmonic color filters are based on the resonant interaction between incident electromagnetic field and the micro/nanoscale structures, which selects required wavelength via optimal design of optical elements including size, shape, thickness, chosen materials, and periodicity of unit cell arrays. Second, plasmonic metasurface filters are stable and insensitive to the ambient environment including humidity, high temperature, and even ultraviolet (UV) radiation, which is superior to some organic filters. Third, plasmonic metasurfaces can be employed as on-chip filter to directly integrate with a complementary metal oxide semiconductor (CMOS) image sensor [4, 5], promoting the development of advanced image sensor technology.

Currently, plasmonic-metasurface-based filtering ranging from UV to terahertz region have been investigated with proper design of unit cells and their arrangements. However, for most-investigated visible color filters, filtering with only primary color, weak transmission, and unsatisfied band width remains a bottleneck, which may limit the performance of complex full-color imaging. How to realize full-color filter with high-quality is a main issue for the investigation of plasmonic filters.

In this work, we design and demonstrate a metasurface filter as shown in Fig. 1a, where the metasurface consists of a metal layer and a SiO_2 substrate layer with thicknesses of $t_m = 10$ nm and $t_s = 100$ nm, respectively. Inspired by the typical SRR structure, the metal layer is designed as complementary SRR dimer arrays, which are etched on the aluminum layer. Compared with gold and silver, aluminum is low cost and abundant, which is a kind of high-quality plasmonic material with plasmon tunability ranging from UV to visible light [6].

Since the resonant wavelengths of metasurfaces depend on the design of unit cell, we select the resonant wavelengths of the metasurfaces by scaling the periodic parameters, SRR length and the gap distance. Polarization properties of micro/nanostructured metasurfaces are important for practical photonic devices [7]. Herein, for the visible light with linearly polarized along x-axis ($E_{\mathrm{in},\,x}$), transmission peaks of the metasurface filter present at 543, 595, 646, 694, 741, and 787 nm with increasing the geometric parameters, realizing visible color filters ranging from green light to red light, as shown in Fig. 1b. The transmission maxima of the metasurface filter are constant as $\sim 47\,\%$ and the linewidths (full width at half maximum) are ~ 32 nm for these specifications. As for the visible light with linearly polarized along y-axis ($E_{\mathrm{in},y}$) transmission peaks of the metasurface filter present at 417, 458, 494, and 527 nm with increasing the geometric parameters, realizing visible color filters ranging from violet light to green light, as shown in Fig. 1b. The transmission maxima of the metasurface filter are constant as $\sim 41\,\%$ and the linewidths are ultranarrow as 16 nm for these specifications.

Transmission spectra are closely related to the plasmonic resonances. Based on the plasmonic mode analysis of $E_{\mathrm{in},x}$ and $E_{\mathrm{in},y}$, plane waves, we can make some conclusions as follows: (1) basic magnetic dipoles are induced in the metasurface filter when transmit $E_{\mathrm{in},x}$

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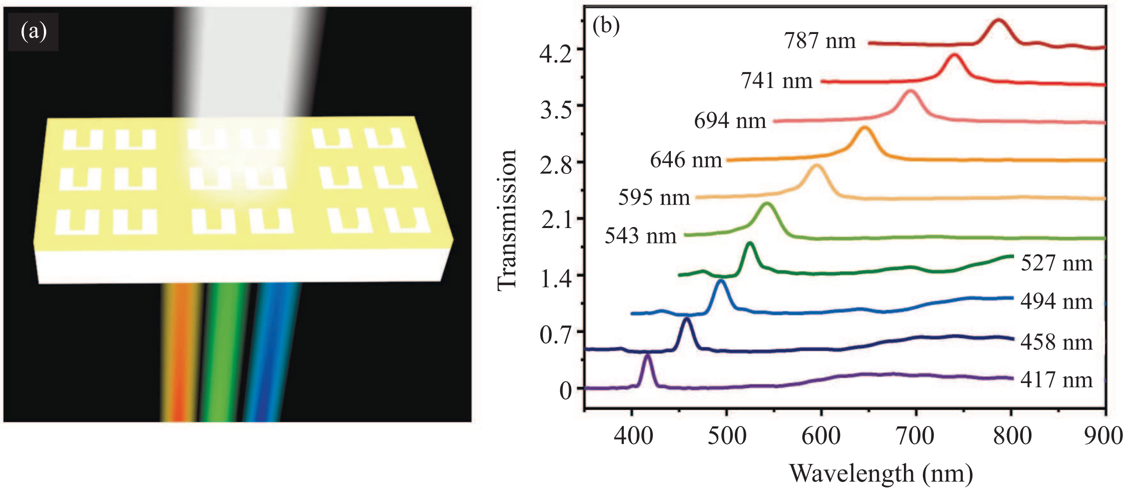

Fig. 1. (Color online) (a) – Schematic illustration of the metasurface filter under linearly polarized white light illumination. (b) – Transmission spectra of the plasmonic metasurface filters with different periodic parameters for linearly polarized visible light along x-axis ($543 \sim 787$ m) and y-axis ($417 \sim 527$ nm)

plane wave, while electric dipoles are generated for $E_{\text{in},y}$ plane wave; (2) plasmonic modes are basically identical as increasing periodic parameters at their resonant wavelengths for both $E_{\text{in},x}$ and E_{in}, y plane waves; (3) magnetic or electric field can be generated in the gap region with proper gap distance between SRRs, which originates from mutual interaction between the SRRs. Based on these conclusions, the polarization dependent filtering property of the metasurface can also be expanded to the dual imaging application.

In order to further examine the filtering performance of the metasurfaces, we explore the transmission spectra with respect to the SRR arm width as this parameter is related to the SRR resonance. The transmission resonant wavelength is tunable under x-polarized white light, while the transmission amplitude is controlled under y-polarized white light with maximum modulation depth of $\sim 92\,\%$. Furthermore, as for different incidences, the performance of this metasurface filter is guaranteed ranging from $0°$ to $40°$ for x-polarized illumination and $0° \sim 30°$ for y-polarized illumination. These results raise prospect of the plasmonic metasurface for tunable, compact, and on-chip filtering elements, promoting its potential in security, data storage, and optical information processing applications.

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