Four Color Filters in One using Large Area Plasmonic Substrates

L. Duempelmann, B. Gallinet, A. Luu-Dinh, M. Schnieper

Nanostructured silver nanowires can lead to polarization-dependent color effects in transmission. This effect is based on the collective and resonant oscillation of electrons in the metal, referred to the field of plasmonics. Overall this can lead to four distinct transmitted colors and their intermediate gradations. The proposed active tunable color filters are nearly incidence angle-independent and have great potential for several applications including optical security or tunable filters. They can be fabricated by roll-to-roll processes, potentially enabling cost-effective manufacturing [1].

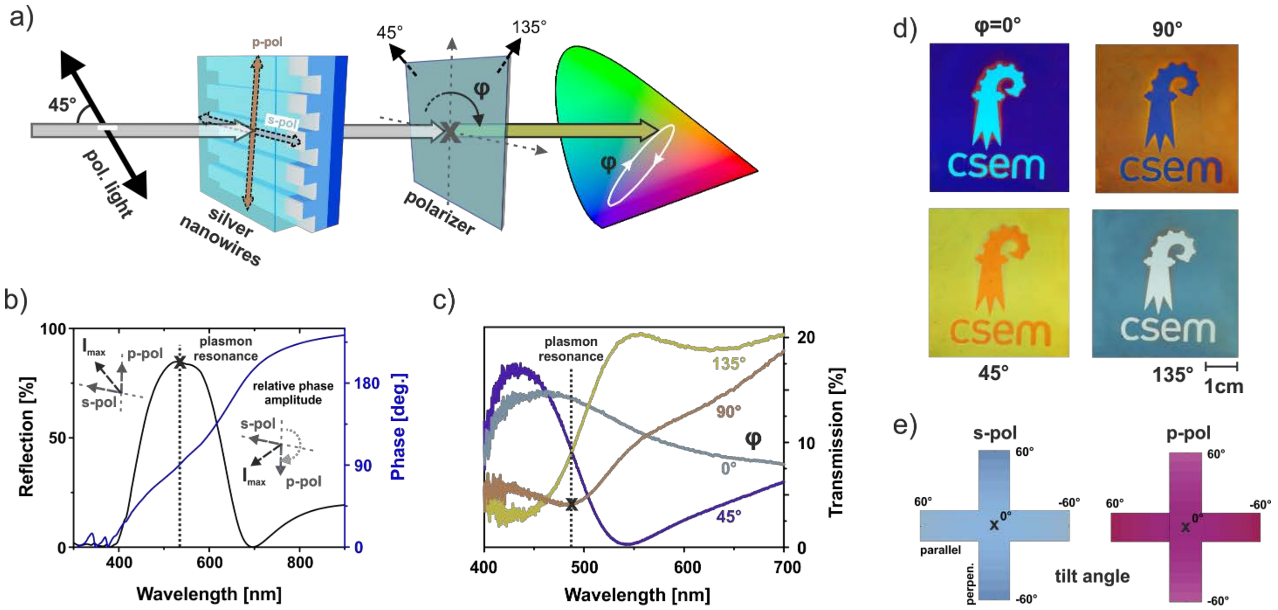

Figure 1: (a) Diagonal polarized light passes the plasmonic structure as s- and p-polarized light and is analyzed by rotation of a subsequent polarizer (angles in bold). (b) Graph of the reflection and phase shift present at the plasmonic resonance; inset displays the relative phase amplitude of the polarized states (before and after the resonance). (c) Measurement of the four main transmission spectra showing a cross-over of the two diagonal states (45° and 135°) at the plasmon resonance (lines are colored as measured) (d) Photos of a sample made at different rotation angles of the polarizer (bold). The sample (4.7 × 4.7 cm) was fabricated with 20 nm (logo) and 30 nm (background) silver thickness. (e) Simulated colors of the s- and p-pol of the filter upon different tilt angles (parallel and perpendicular to the nanowires).

Active tunability of filters can be essential for applications where varying spectral filtering properties are required, e.g. for visual effects or display applications. Compared to conventional color filters based on chemical dyes, the color filters based on plasmonics allow such active color tunability. Plasmonic resonances, responsible for the filtering property, are sensitive to the polarization and the tilt angle of the incident light.

Here we present a plasmonic filter based on periodic silver nanowires. It is designed to vary actively the color filtering properties via change of the polarization. The filter is also designed such that the optical properties are preserved at different tilt angles, which is essential for applications where a high field-of-view is required. The thickness of the proposed filter can be within few micrometers, making it highly attractive for miniaturized systems. Fabrication is done by replication of periodic nanostructures, evaporation of a thin layer of silver and embedding of the full structure. This protects it against oxidation, scratches, etc. and enables use in ambient condition.

The scheme of the plasmonic filter is shown in Figure 1a. Polarized light at 45° incidence excites the two polarization axes (arrows) of the periodic nanostructure. The polarization perpendicular to the nanowires (p-pol) excites a plasmon resonance, causing a wavelength-dependent phase shift of this polarization state around the resonance. The simulated reflection, phase shift, and the relative phase amplitude wavelength-dependent) of this state is shown in Figure 1b. Rotation of an analyzing polarizer with angle φ leads to a four fold transmission, as a crossing of two states is observed at the plasmon resonance (see Figure 1c), which specifically creates high contrast filters. Using the polarizer at smaller angular steps increases the number of filters far beyond the four basic ones.

Figure 1d shows photos of a sample taken at different polarization angles, leading to a completely different optical appearance. By changing the thickness of the silver nanostructures the plasmon resonance and therefore the color appearance can be altered. For many applications it is essential that these filtering properties are stable upon different tilt angles. The proposed plasmonic filter is designed to be stable in both tilt directions (perpendicular and parallel to the nanowires). Figure 1e shows such simulated colors (top-bottom and left-right respectively) for s-pol and p-pol of the filter.

The proposed active tunable plasmonic filters are compatible with large-scale fabrication processes, can be tuned spectrally via the geometry and are protected for ambient use.

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[1] L. Duempelmann, A. Luu-Dinh, B. Gallinet and L. Novotny, ACS Photonics 3 (2) (2016) 190-196.