Visible to infrared polarizer based on one-dimensional aluminium gratings.

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Abstract

Spectral dependence of polarized optical transmission through a one-dimensional Al grating arrays has been investigated. Our simulations show that nearly 85 % of light gets transmitted through the Al grating arrays for TM polarization and less than 1 % for TE polarization. The enhanced transmission through these structures is due to the excitation of surface plasmon resonances. The effects of the structural parameters on the transmission spectra for both polarizations are studied. The polarization selective transmission through these structures has potential use as an efficient polarizer for the corresponding frequency band as well as design of polarization sensitive pixels for imaging devices.

1 Introduction

Large levels of light transmission through arrays of subwavelength holes or slits in metallic films, also popularly called extraordinary transmission (EOT) of light, are now well known [1, 2, 3, 4]. This effect, originally discovered by Ebbesen et al [5] depends significantly on the mediation by surface plasmon excitations at the different interfaces in the structured plasmonic films. The extraordinary transmission(EOT) through a periodic array of square/circular shaped holes in thin films of Ag/Au films was extensively studied in the previous work [6, 7]. Recently, a new counter intuitive phenomenon have been reported in ultra-thin structured plasmonic films, showing a resonant suppression in the transmission and increase in the absorption[8]. A thick single layer Ag grating of thickness nearly 668 nm shows absorption at visible frequencies with absorptivity of nearly 80 %. The absorption through these single layer grating structure due to the simultaneous excitation of the SPP modes and cavity mode resonances [9]. Different shapes and sizes of the nanostuctures have been proposed to give rise to either enhanced transmission or absorption properties by coupling of the electromagnetic wave to different modes of excitations in the structures.

In this study, we propose a simple design of a one dimensional aluminum grating arrays on glass substrate, which are shown to give rise enhanced optical properties with polarization dependent extra-ordinary transmittance. Concurrently, we have also investigated the influence of structural parameters on transmission characteristics in the wavelength of our interest.

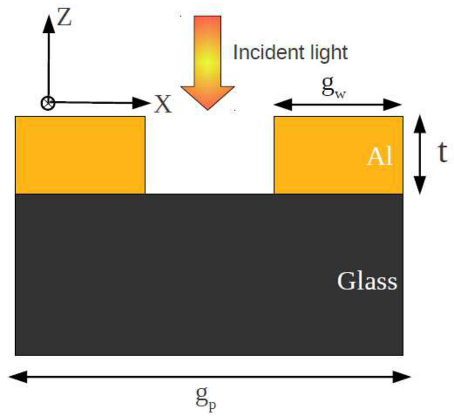

Figure 1. Schematic diagram of the unit cell of Al grating array on the glass substrate. The dimensional parameters are denoted as grating width 2 g_w, grating period p, thickness of the grating array as t.

2 Proposed model

The schematic diagram of the unit cell of the Al metallic grating on the glass substrate as well as the propagation configurations of the incident electromagnetic radiation are shown in Fig. 4.1. The thickness of the Al grating is denoted as t. The width of the Al lines and the period of the grating are denoted as 2 g_w and g_p respectively. The COMSOL multi-physics[10] (commercial software package) based on the finite element methods is used for investigating the remittances (R, T and A) of the proposed system. A plane electromagnetic wave is incident normally on the grating array with two possible orthogonal plane polarizations. When the wave is incident with the electric field is parallel to the lines of the grating denoted as TE polarization, and when it is perpendicular (or has a component that is perpendicular) to the grating lines it is denoted as TM polarization. Perfectly matched layers (PMLs) are used at the edges of the computational domain along the direction of propagation to avoid unwanted reflections. The unit cell was simulated using periodic boundary conditions along the $x-y$ directions to replicate the unit cell in the transverse direction so that the structure can be considered as an infinite two-dimensional array. The wavelength dependent reflec-

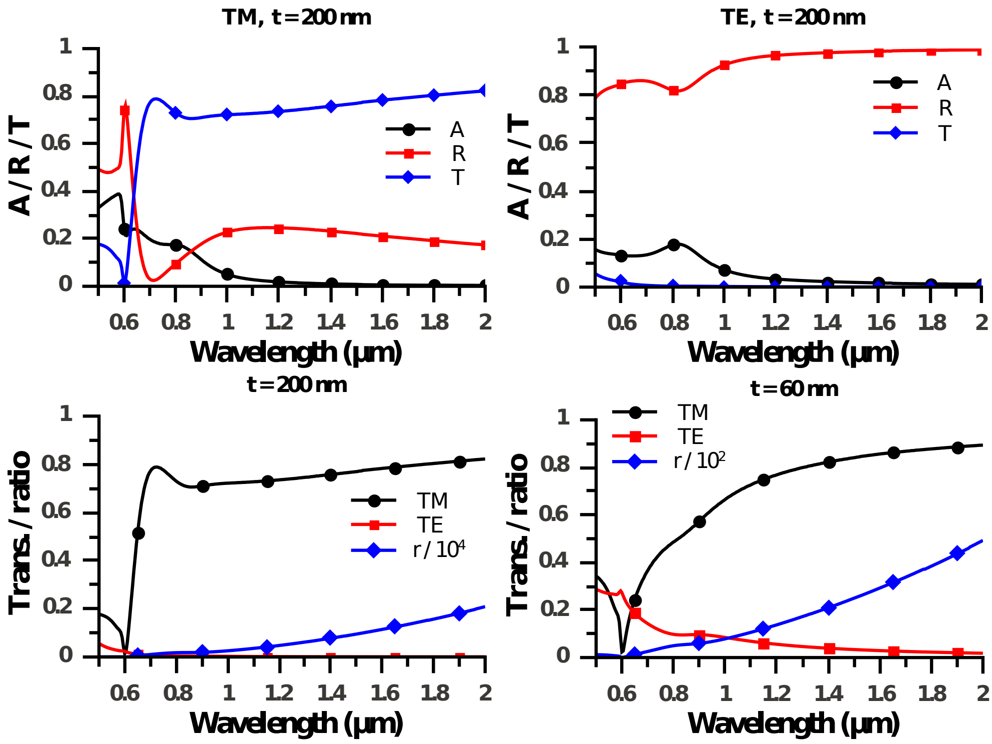

Figure 2. (a) - (b) The reflectance, absorbance and transmittance plot for the Al grating arrays of grating width (g_w) 0.2 μm and lattice period 0.4 μm for TM and TE polarization. (c) - (d) The transmittance and ratio of transmittance (r) for TM to TE polarization through Al lines of grating width 0.2 μm and lattice constant 0.4 μm and thickness of the grating lines are 200 nm and 60 nm respectively.

tion and transmission of the structure were calculated from the S-parameters. The dielectric function Al was described by using the Lorentz-Drude model in the wavelength range 0.5 μm - 2 μm.

3 Results and discussions

The simulated transmittance, absorbance and reflectance spectrum of the array of Al lines on the glass substrate for TM polarized light (when the incident electric field is applied perpendicular to the Al lines) and TE polarized light (when the incident electric field is applied parallel to the Al lines) at normal incident are plotted in Fig. 2 (a) - (b). In this case, we have taken the width of the grating and grating period as g_w = 0.1 μm and g_p = 0.4 μm. The thickness of Al grating lines is 200 nm. In case of TM polarization, we note a broadband transmittance spectrum above the wavelength of 0.65 μm. In addition to that, a sharp dip is observed at the wavelength of 0.6 μm. The reflectance and the transmittance curve seem to be complementary to each other in the wavelength band. At the wavelength of 0.52 μm, we note a absorption peak with absorptivity of 40 %. After that the absorption spectrum decreases monotonically with the wavelength of the incident radiation. In case of the TE polarization, we note a broadband reflectance spectra rather than the transmittance. Here also the reflectance and the absorbance are seen to complementary in nature. The transmittance is almost zero above the wavelength 0.6 μm. In comparison the transmittance of light through the proposed Al line arrays in both polarization, a high broadband transmittance is seen in case TM polarization, whereas zero transmittance in the TE polarization is seen across the NIR frequencies. The ratio (r) of the transmittance spectra for TM to TE polarization is plotted in Fig. 2 (c) and ranges from 10^2 to 10^4 in magnitude. As it is observed that r increases with the wavelength of incident radiation.

To know the effect of the grating thickness on the optical spectrum, we changed the thickness of the Al lines from 200 nm to 60 nm, while keeping all other parameters of the proposed model the same. The simulated transmittance spectra for both polarizations of light are plotted in Fig. 2 (d) for film thickness of 60 nm. In the case of TM polarization, we note that the transmittance spectra for 200 nm Al lines is slightly decreased as compared to the case of 60 nm film thickness, but the broadband nature of transmittance starts from the 0.65 μm pitch for 200 nm film thickness and 1.4 μm for 60 nm film thickness. By comparing the ratio of the transmittances (r) for TM to TE polarization, we notice that r for the 200 nm film thickness is nearly 100 times higher than the 60 nm film thickness of Al lines.

In order to understand underlying physics behind such broadband transmission effects for the TM polarization, we investigated the electromagnetic field distributions at different wavelengths which are plotted in Fig. 3 (a) - (d). Noting that the overall transmittance spectra for both polarizations and film thicknesses of 60 nm and 200 nm seem

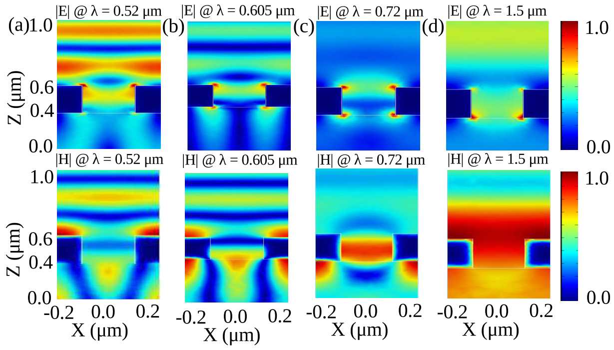

Figure 3. (a) - (d) Electro-magnetic field distribution at the wavelength 0.52 μm, 0.605 μm, 0.72 μm and 1.5 μm for aluminum grating array with grating width as grating width 2 (g_w) = 0.2 μm and grating period (g_p) = 0.4 μm for TM polarization of light. The thickness of the grating is t_1 = 200 nm.

to be similar, we have plotted the electric field distributions for the Al grating with film thickness of 200 nm, line width of 0.2 μm and grating pitch of 0.4 μm. In Fig. 3 (a) - (d), top panel shows the electric field distributions and bottom panel shows the magnetic field distributions at the wavelengths of 0.52 μm, 0.605 μm, 0.72 μm and 1.5 μm. Fig. 3 (a) (top panel) shows the electric field distributions at the wavelength 0.52 μm, where it is observed that the electric fields are more localized at the top edge of the Al gratings and in same time the magnetic fields are localized more at the Al lines (air-Al interface). At this wavelength, we have seen that the dip in reflectance and peak in both transmittance and the absorption are coincident as shown in Fig. 2 (a). At this wavelength the peak in the absorbance curve is attributed due the localized field at the top edge of the Al grating. Since high field localization at the top edge the grating, we have seen the low transmittance as compared to the reflectance spectra. At the wavelength of 0.605 μm, where we have very low transmittance and high reflectance, the electric fields in Fig. 3 (b), are more localized at the top and bottom edge of Al lines, and the magnetic fields are mostly intense near the Al line and also in the cavity region which is formed by two adjacent Al lines. The field localization at the air - Al interface appears to give rise to high reflectance rather than transmittance. Further, we notice a broad band of transmittance above the wavelength of 0.65 μm. The electric and magnetic field distribution at the wavelength 0.72 and 1.5 μm are plotted in Fig. 3 (c) - (d). At the wavelength 0.72 μm, the electric field and magnetic field are more localized at the top and bottom edges of the grating line and the magnetic fields are more localized in the cavity region and at the Al-glass interface. In addition we see that the fields are localized at the top and the bottom edge of the line and in the cavity regions, which appears to lead to high transmittance. At the wavelength of 1.5 μm, the electric fields are more localized at bottom edge of Al line at the Al - glass interface. The localized field at the Al-glass interface seems to lead to high transmittance at this wavelength.

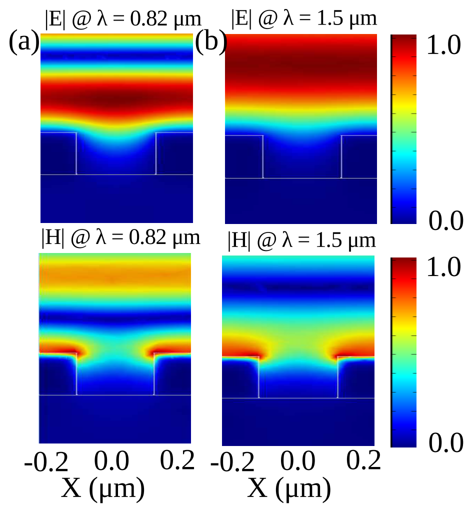

Figure 4. (a) - (b) Electro-magnetic field distribution at the wavelength 0.82 μm and 1.5 μm for aluminum grating array with grating width as (2 g_w) = 0.2 μm and period (g_p) = 0.4 μm for TE polarization of light.

To understand the spectral response for the TE polarization, we have plotted the electromagnetic field distributions at the wavelength of 0.82 μm and 1.5 μm in Fig. 4 (a) - (b). Fig. 4 (a) shows that the electric fields slightly penetrate into the air cavity regions at the wavelength 0.82 μm, which gives rise to a small absorption peak in the absorption spectrum. Further, we plotted the electric field distributions at the wavelength of 1.5 μm to understand the zero transmittance behavior in Fig. 4 (b). From the field distributions plot, we observe that the incoming energy gets completely reflected from the grating array. We consider the effective medium theory to explain the high reflection for the TE polarized light. The effective electric permittivity of the medium is expressed as $\varepsilon(\omega) = f\varepsilon_{Al} + (1-f)\varepsilon_{air}$, where f is the fill fraction given by the duty cycle of the grating. We substitute the respective value, the estimated new plasma frequency (ω^{eff}) close to 0.7 μm to 0.8 μm, hence we see a high reflectance above these wavelength.

4 Conclusion

We summarize this work as follows: a broadband Al grating based polarizer was designed and simulated. The polarizers have shown a high broadband transmittance (> 85 %) for TM polarization and low transmittance (< 1 %) for TE polarization over the wavelengths larger than 0.8 μm. The proposed design can be easily fabricated by cost effective methods like laser interference lithography. Here, we have focused on the optimized parameters for a NIR polarizer based on the Al grating, we expect that our finding could potentially help to develop an Al grating based polarizer in NIR wavelength applications.

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