Interleaved Dielectric-Metal Plasmonic Grating Polarizer

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Abstract: We demonstrate novel metasurface optics leveraging the interaction of interleaved dielectric and metal plasmonic subwavelength gratings. A flat polarizer with high extinction ratio and high transmission for a wide angle of incidence is reported. © 2024 The Author(s)

1. Introduction

Controlling and detection of the polarization state of light is essential for many applications in photonics devices and systems. It is also one of the key features that differentiate the human vision system from many other biological species. Subwavelength gratings with a period smaller than the incident wavelength have been extensively studied and applied for polarization manipulation [1-3]. According to the grating theory, only the zeroth-order diffraction exists when light is normally incident on a subwavelength grating surface.

A dielectric high contrast grating (HCG) is a subwavelength grating with grating bars having a relatively high refractive index compared to that of the surrounding medium [4]. It can be designed to achieve a high reflectance or high transmittance with low loss. Compared with conventional gratings, HCG is more selective to the incident light polarization. However, a regular dielectric HCG polarizer cannot be designed to accept a wide angle of incidence.

With the development of plasmonic nanoscale structures fabrication and characterization, studies of the metallic plasmonic gratings (MPGs) have attracted much interest for their potential applications in optics and photonics [5-6]. Generally, MPGs prefer the transverse magnetic (TM) polarization (the electric field is perpendicular to the grating stripe), because only the TM-polarized incident light can excite surface plasmons at the metal-insulator interface. The excited surface plasmons are attributed for the anomalous optical characteristics of MPGs, such as the enhanced optical transmission (EOT). However, MPGs typically require much smaller dimensions than subwavelength due to the plasmonic effect causing difficulties in manufacturing.

In this paper, we present a novel interleaved grating structure based on dielectric HCG and metallic plasmonic grating. This structure combines the advantages of both HCG and MPGs, and exhibits a high extinction ratio, transmittance and a large acceptance angle. Comparing with other polarizers, this structure is very thin and has a relatively large period. According to the principles of metal acting on electromagnetic waves, electromagnetic waves can only interact with it on the surface of metal. For most metals, skin depth is about 10nm, but the thickness of the current metal grating is generally much larger than that. Thicker metal grating is just to support the specific structure of the grating, the metal inside does not have any photoelectric action. By using HCG to support thin metal structure, the thickness of metal can significant decrease. And different from conventional MPGs, our design can achieve the EOT of the transverse electric (TE) (the electric field is parallel to the grating stripe) polarization.

The Finite-Difference Time-Domain (FDTD) method is used to calculate the transmittance spectra and angle dependence. This method is also used to optimize the structure parameters to realize the high transmittance and the high extinction ratio in polarization.

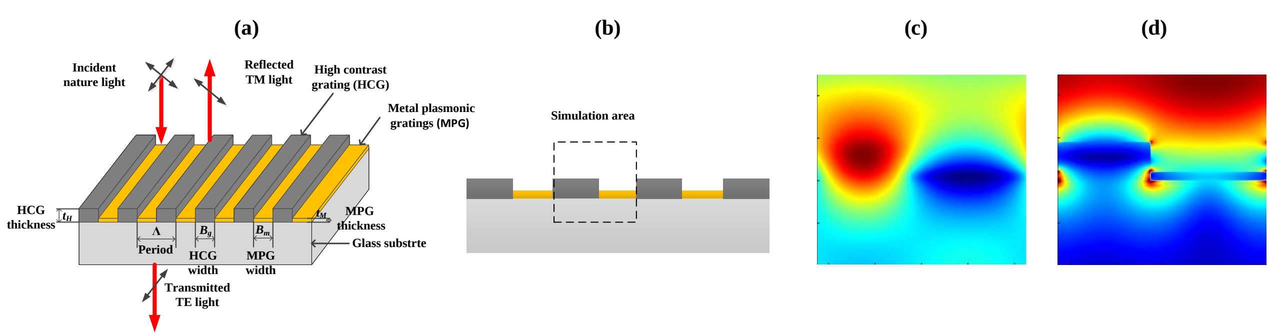

Fig. 1 a) The schematic diagram of the designed optical polarizer. b) The sideview schematic diagram of the designed optical polarizer. The propagation properties of the (c) TE and (d) TM plane waves incident on top of the proposed grating with 1 period.

2. Structures and simulation results

The schematic of the proposed polarizer is presented in Fig. 1(a) and (b). The main elements are HCG interleaved with metal plasmonic gratings. Where main parameters of our structure are the HCG width B_g, thickness t_g, plasmonic metal antenna gratings width B_m, thickness t_m, grating period Λ. Fig. 1(c) and (d) represent the field distributions obtained in continuous plane wave regime at λ = 0.94μm for the TE and TM waves, respectively. One can see that TE waves propagate along the bar of HCG basically unaffected, while TM waves are indeed strongly reflected back by the MPG.

Fig. 2(a) and (b) show the transmittance contours as functions of the normalized wavelength (λ/Λ) and the normalized HCG thickness (t_g/Λ), for the TE and TM cases, respectively. Fig. 2(c) show the ER contours as functions of the normalized wavelength (λ/Λ) and the normalized HCG thickness (t_g/Λ). The Duty cycle (B_g/Λ) is 50% and MPG thickness t_m is 25nm. The ER is defined as:

$$ER = 10log_{10}(\frac{T_{TE}}{T_{TM}}) \tag{1}$$

As shown in Fig. 2(a), the transmittance of TE isn't sensitive to the designs, for all the dimensions transmittance of TE is larger than 50%. The high transmittance of TE can be achieved at very small normalized HCG thickness t_g/Λ (typically from 0.1 to 0.3) and it is also wideband at normalized wavelength λ/Λ (from 1.5 to 3). As shown in Fig. 2(b), the transmittance of TM insensitive with t_g/Λ at special λ/Λ. We also calculate the ER contours as shown in Fig. 2(c), which indicate that when t_g/Λ equal to 0.2 and λ/Λ equal to 2.0, the polarizer design can get good performance and tolerance of fabrication.

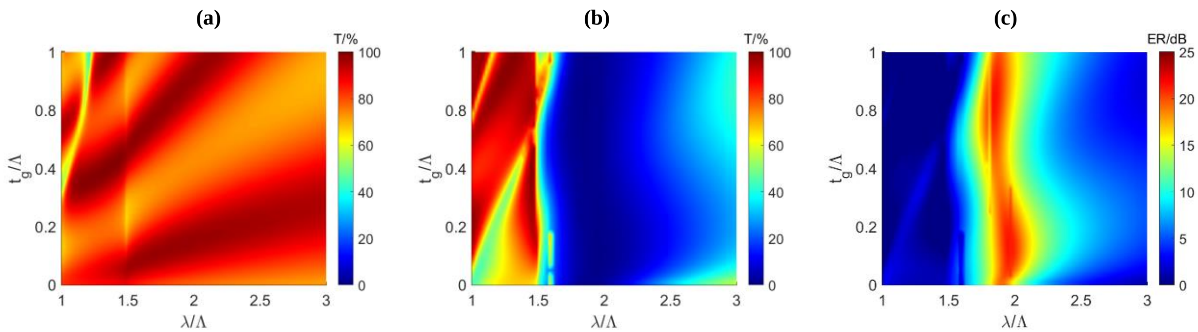

Fig. 2 the transmittance contours as functions of the normalized wavelength (λ/Λ) and the normalized HCG thickness (t_g/Λ), for the (a) TE and (b) TM cases. (c) ER contours as functions of the normalized wavelength (λ/Λ) and the normalized HCG thickness (t_g/Λ)

When the λ is 0.94μm, the transmittance/ER contours as functions of the HCG width B_g and MPG width B_m is present in figure 3. As shown in Fig. 3(a), there are one area get high TE transmittance (larger than 90%), which the B_g is from 250nm to 350nm and B_m is from 100nm to 300nm. As shown in Fig. 3(b), there are very large area get low TM transmittance (small than 5%), which the B_g is from 100nm to 350nm and B_m is from 200nm to 400nm. As shown in Fig. 3(c), there some design which get very high ER (large than 20dB).

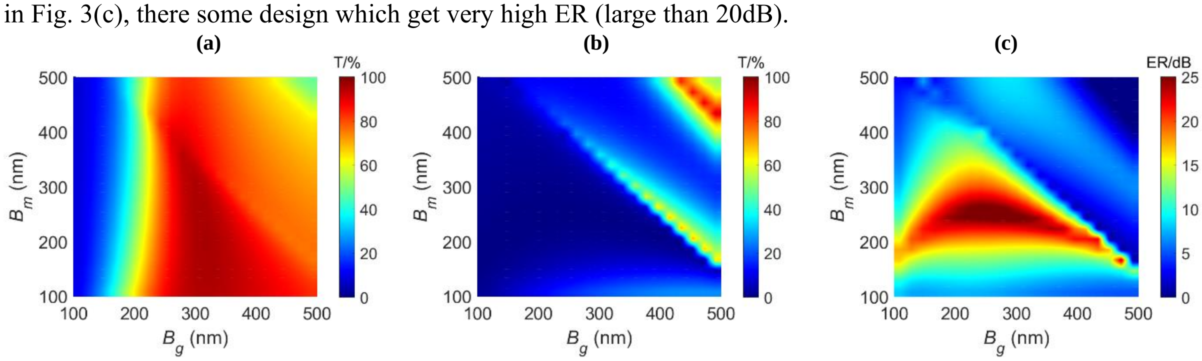

Fig. 3 The transmittance contours as functions of the HCG width B_g and MPG width B_m, for the (a) TE and (b) TM cases. (c) ER contours as functions of the HCG width B_g and MPG width B_m

3. Experiment setup and results

Based on our numerical simulation and technical possibilities, we use electron-beam lithography to fabricate the polarizers with the following parameters range: t_g is [70,110] nm, t_m is [10,30] nm, B_g is [150,300] nm and B_m is [150,300] nm. Finally, we pick up the polarizer with best performance in the transmittance capacity test. The transmittance capacity of 940nm IR laser source for our polarizers was experimentally examined in the setup presented in Fig. 4(a) and Fig. 4(b). The laser source is collimated by lens can then arrive the surface of polarizer, the polarizer can be rotated, so both TE and TM transmittance can be tested, and at last we use power meter to detect the transmittance different.

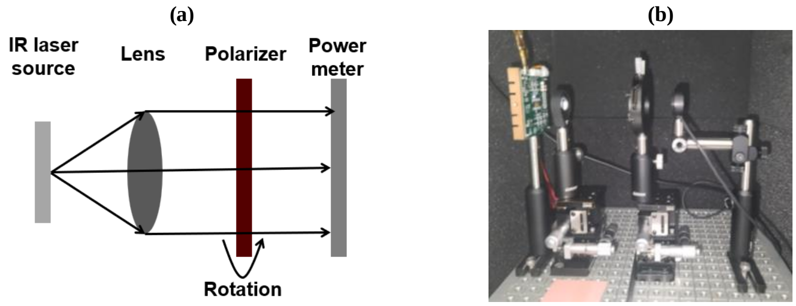

Fig. 4 a) The schematic diagram of the experiment setup. b) The pictures of the experiment setup.

Fig. 5(a) shows the picture of fabricated polarizers on 3-inch wafer. The experimental results are presented in Fig. 5(b), it shows the dependence of transmittance versus the incidence angle (following the longitudinal direction of the bar) of an input collimating Gaussian beam for the polarizer. It shows that as the incidence angle increases, both transmittance of TE wave (T_{TE}) and transmittance of TM wave (T_{TM}) decreases. However the amount of variation is very small, <10% from 0 to 50 degree incidence. Further, the experimental results agree well with theory.

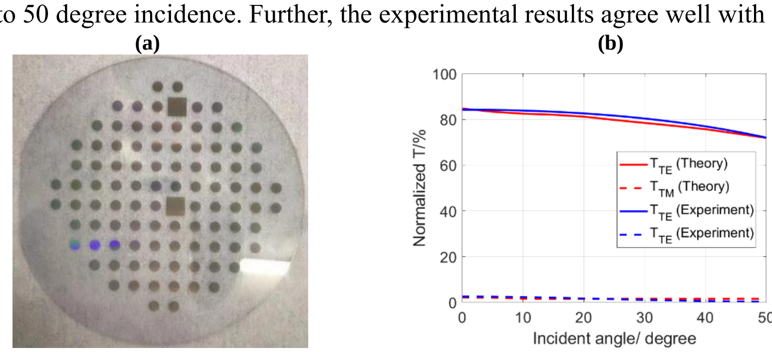

Fig. 5 a) The picture of real polarizers on 3-inch wafer. b) The dependence of transmittance versus the incidence angle.

4. Conclusions

We investigated a unique dielectric-metal plasmonic polarizer. Our experimental findings align well with our numerical simulations. The maximum TE transmittance achieved was 85%, and the Extinction Ratio (ER) reached up to 20dB. Furthermore, these performance properties remained stable despite wide variations in the incident angle of the light beam.

Acknowledgments

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