Dielectric Metalens and Its Application in Near-Infrared Single Photon Detection

Guanhai Li
National Laboratory for Infrared Physics Shanghai Institute of Technical Physics, Chinese Academy of Sciences,
Shanghai, China
ghli0120@mail.sitp.ac.cn

Hui Yang
National Laboratory for Infrared Physics Shanghai Institute of Technical Physics, Chinese Academy of Sciences,
Shanghai, China
yhui1027@mail.sitp.ac.cn

Xiaofang Su
National Laboratory for Infrared Physics Shanghai Institute of Technical Physics, Chinese Academy of Sciences,
Shanghai, China
xiaofang@mail.sitp.ac.cn

Xiaoshuang Chen
National Laboratory for Infrared Physics Shanghai Institute of Technical Physics, Chinese Academy of Sciences,
Shanghai, China
xschen@mail.sitp.ac.cn

Wei Lu*
National Laboratory for Infrared Physics Shanghai Institute of Technical Physics, Chinese Academy of Sciences,
Shanghai, China
luwei@mail.sitp.ac.cn

Abstract*—Metasurfaces, the two dimensional form of metamaterials, have the outstanding properties in the manipulation of electromagnetic waves, the integration with the existing devices and one-step fabrication. In this talk, we will present theoretically and experimentally the conceptuly new metasurface to control light propagation, confinement and enhancement with anomalous functionalities. The interaction of light with traditional semiconductor materials and the related photon-electron energy transition are also taken into consideration. The experiment result matches our expectations. Finally, we will talk about the work we have done in metasurface integration with infrared single photon detectors.

***Keywords*—component, formatting, style, styling, insert (key words)**

I. Introduction

Recently, based on metasurfaces, tremendous advances have been achieved, verifying their potential possibility to be excellent candidates for replacing the conventional devices. Metasurfaces, planar thin structures that consist of subwavelength elements, possess the ability to provide unprecedented superiority for wavefront steering via introducing abrupt phase shifts. In virtue of their effectiveness in wavefront steering, various optical devices constructed of metasurfaces have been theoretically and experimentally demonstrated such as optical metalenses, wave-plates, holograms, and vortex beam generators. Besides, ultra-thin polarization resolving devices based on metasurface have also been demonstrated, making them excellent candidates for integration compact platforms. The chirality of the circular polarized (CP) light can be resolved by using an on-chip silicon microdisk or chirality-coded meta-apertures. However, resolving the polarization states of the polarized lights (circular, linear, and elliptical) in a compact way is in great request and has barely been investigated.

II. Our Results on Metasurface Focusing

We work on the light focusing with metasurface and have realized several anomalous functionalities at 1.55 μm.

A. Reflective metalens

We propose an ultra-thin planar reflective metalens with sub-diffraction-limited and multifunctional focusing. Based on the equal optical path principle, the specific phase distributions for multifunction focusing are derived. Following the formulas, on-center focusing with the characteristics of sub-diffraction-limited, high focusing efficiency (85%) and broadband focusing is investigated in detail. To demonstrate the flexibility of the reflective metalens, off-center and dual spots focusing (at the horizontal and longitudinal directions) are demonstrated.

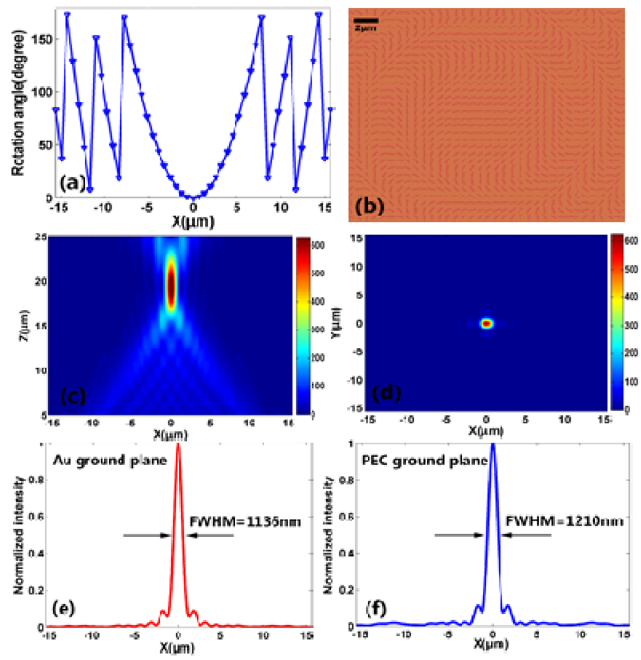

Figure 1: Rotation angle of the nanoblocks along x axis for on-center focusing. (b) Top view of the center of the reflective metalens. The required phase is imparted by rotating the nanoblock with different angle θ(x,y). (c) and (d) Simulated intensity (|E|2) profile of the reflected light in x-z plane at y=0 and in x-y plane at z=20μm with RCP incident light. (e) and (f) Vertical cuts of focal spot for the metalens with Au ground plane and PEC ground plane.

B. Polairzation Resolved Metalens

We demonstrate a novel polarization-resolved device (PRD) with the ability to accurately resolve the polarization states via simple measurement process. The PRD is composed of two elaborately designed metalenses, which are capable of focusing the two circularly polarized (CP) lights. Therefore, for an arbitrary polarized light (treated as a combination of the two CP lights), a discrepancy is exhibited on focusing efficiency, which inversely gives a way to calculate the ellipticity. With such a strategy, the generalized form for polarization resolving is derived, with which the ellipticity of the incident polarized light can be calculated (through just measuring the efficiencies of the two spots).

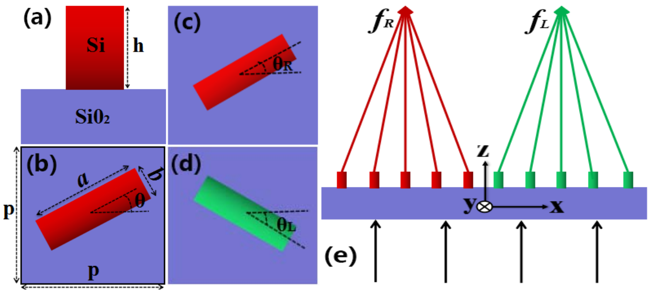

Figure 2: (a) Side view of the unit cell which composed of a silicon nanoblock placed on a half infinite silica substrate. (b) Top view of the unit cell. (c) and (d) The red and green nanoblocks with rotation angles θR and θL endow the required phase shift for focusing RCP and LCP lights, respectively. (e) Schematic of the metalens with RCP and LCP lights are focused into two focal spots.

TABLE I. CALCULATING THE ELLIPTICITY BY THE MEASURED EFFICIENCY

TL(%)	TR(%)	Ellipticity(X)	Incident ellipticity (X0)	Polarization state	Error*
32.42	0.67	1	1	RCP	0
0.67	32.42	-1	-1	LCP	0
15.95	15.95	0	0	LP	0
12.07	21.02	-0.281	-0.259	EP	0.022
8.28	24.81	-0.521	-0.5	EP	0.021
5.06	28.03	-0.723	-0.707	EP	0.016
2.61	30.48	-0.878	-0.866	EP	0.012
30.48	2.61	0.878	0.866	EP	0.012
28.03	5.06	0.723	0.707	EP	0.016
24.81	8.28	0.521	0.5	EP	0.021
21.02	12.07	0.281	0.259	EP	0.022

a. *Error=abs(X-X0)

III. CONCULSIONS

Besides the two results, we have some numerical results on holographic imaging and experimental results on the metasurface integrated with InGaAs materials. We will talk about on site.

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REFERENCES

[1] Hui Yang, Guanhai Li*, Guangtao Cao, Zengyue Zhao, Jin Chen, Kai Ou, Xiaoshuang Chen, Wei Lu Broadband polarization resolving based on dielectric metalenses in the near-infrared Optics Express 26(5): 5632, 2018.

[2] Guanhai Li, Brendan P. Clarke, Jin-Kyu So, Kevin F. MacDonald, Nikolay I. Zheludev, Holographic free-electron light source Nature Communications, 7, 13705, 2016

[3] Hui Yang, Guanhai Li*, Xiaofang Su, Guangtao Cao, Zengyue Zhao, Feilong Yu, Xiaoshuang Chen, Wei Lu, Annihilating optical angular momentum and realizing a meta-waveplate with anomalous functionalities Optics Express 25: 16907, 2017

[4] Xiaofang Su , Guanhai Li*, Hui Yang, Zengyue Zhao, Feilong Yu, Xiaoshuang Chen, Wei Lu, A visible high efficiency and polarization-insensitive 34-level dielectric metasurface hologram RSC Advances 7(42): 26371, 2017

[5] Hui Yang, Guanhai Li*, Guangtao Cao, Zengyue Zhao, Feilong Yu, Xiaoshuang Chen, Wei Lu, Polarization-independent metalens constructed of antennas without rotational invariance Optics Letters 42(19): 3996-3999, 2017.

[6] Hui Yang, Guanhai Li*, Xiaofang Su, Guangtao Cao, Zengyue Zhao, Xiaoshuang Chen, Wei Lu Reflective metalens with sub-diffraction-limited and multifunctional focusing Scientific Reports 7: 12632, 2017.

[7] Guanhai Li , Shaowei Wang, Xiaoshuang Chen, Wei Lu High efficiency and rapid response superconducting NbN nanowire single photon detector based on asymmetric split ring metamaterial Appl. Phys. Lett. 104: 231104, 2014.