EPJ Web of Conferences **266**, 09006 (2022)
EOSAM 2022
https://doi.org/10.1051/epjconf/202226609006

Experiments and simulations of chiro-optical response in low-cost nanohole arrays in silver

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Abstract. 2D metasurfaces based on periodic nanoholes in metal have been proposed in various plasmonic platforms. Specifically, their resonant features have led to applications spanning in biosensing. Here we investigate additional degree of freedom in elliptical nanohole arrays with hexagonal geometry: chiro-optical effects. Namely, the in-plane asymmetry and a slightly elliptical shape of nanoholes were previously shown to differently extinct light of opposite handedness, even at normal incidence. We now fully characterize nanoholes in Ag, fabricated by low-cost nanosphere lithography. We first measure the dependence of the transmitted intensity for opposite handedness, in a broad spectral and angle of incidence range. We then resolve the circular polarization degree of the transmitted light when the nanohole array is excited with linear polarization. Finally, we numerically investigate the origin of the chiro-optical effect at the nanoscale. We believe that circular polarization resolving of the transmitted degree could be further adapted as a highly sensitive tool in chiral sensing.

1 Introduction

Plasmonic nanohole arrays have been popular for decades due to their ability to couple light into plasmon oscillations at the metal-dielectric interface, thus enabling resonant electromagnetic field confinement and enhancement at the nanoscale [1]. The nanohole shape asymmetry and/or the in-plane tilt allow for additional degrees of freedom. Specifically, properly designed nanoholes can differently interact with left and right circularly polarized light (LCP and RCP, respectively), thus exhibiting chiro-optical effects and circular dichroism (CD). We have previously proposed the in-plane and shape breaking of symmetry in elliptical nanohole arrays (ENHA), and showed that such simple geometries lead to interesting chiro-optical effects in the near-infrared range [2-4]. These samples can be fabricated by means of low-cost, nanosphere lithography [2,3,5,6] and further optimized to giant CD in absorption and transmission [4].

In this work, we perform a detailed chiro-optical characterization of Ag-based ENHA, by means of two types of experiments, and two corresponding set-ups of numerical simulation. We first use a broadly tuneable near-infrared laser to excite ENHA with LCP and RCP at various degrees of incidence. As expected, the array shows rather low extinction CD due to the low ellipticity of the nanoholes. Next, we excite the ENHA with linear polarization and measure the polarization state of the transmitted beam. This nanostructure shows peculiar same sign circular polarization degree in the output, and we believe that this is due to the intrinsic chirality, even though it is rather low. This is the reason why believe that one needs to perform a complete characterization of the input and output state of the light interacting with the ENHA, and choose the one which is more dependent on the asymmetric features. To corroborate our assumptions, we perform numerical simulations which finally show the origin of the existence of circular polarization degree in the output.

2 Experiments

Our sample is made of ENHA in 55 nm of Ag, with hexagonal periodicity of 518 nm. It was previously investigated in Ref. [3], where we obtained low extinction CD at normal incidence. Here we apply the incidence-angle dependent set-up such as in Ref. [5]. The sample shows characteristic features of both extrinsic and intrinsic chirality, reaching only 5% at larger angles.

Next, we turn to the set-up presented in Fig. 1(a), which measures the circular polarization degree of the field transmitted through the sample We make use of a near-infrared laser (Chameleon Ultra II by Coherent Inc.), and we monitor the wavelengths range between 700 nm

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to 1000 nm. We use laser light polarized in the x-direction, which impinges on a sample, and gets transmitted to the output rotating quarter-wave plate (QWP), then linear polarizer (LP). The measurements are done at different angle of incidence, by rotating the sample between -45° and 45°. To measure the circular polarization degree in the output, QWP can be rotated, too. Finally, a Si photodiode (PD) caught this transmission.

In Fig. 1(b) we show spectral results at normal incidence, when QWP is fully rotated from -90° to 90°, where -45° and +45° represent LCP and RCP in the output, respectively; results are normalized to the transmission with QWP at 0°. We note that across the whole spectrum, light is prevalently transmitted to RCP, suggesting intrinsic chirality. Remarkably, we do not see abrupt differences of this behaviour at oblique incidence.

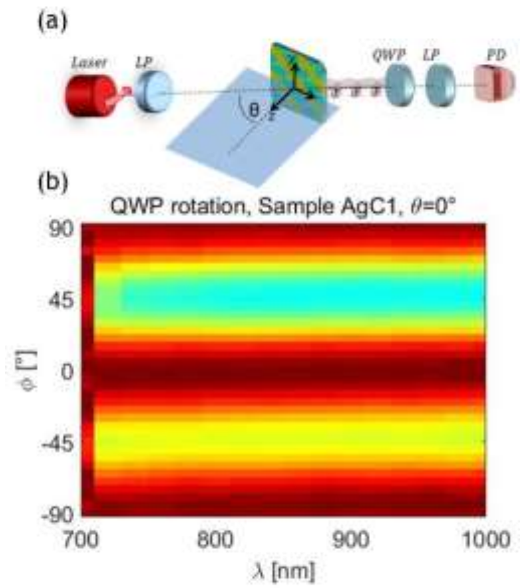

Fig. 1. (a) Set-up for the measurement of angle-dependent, spectrally tuneable circular polarization degree in the output. (b) Wavelength-QWP angle transmission map at normal incidence.

3 Simulations

Next, we numerically investigate the variation of polarization state of light passing through a plasmonic nanohole array with hexagonal unit cell, using the Lumerical (FDTD) software. The FDTD simulation region is defined as a rectangular unit cell (a and $a\sqrt{3}$, where $a = 518nm$) with periodic boundary conditions in xy plane. The light source is a linearly polarized plane-wave in x-direction, at 800 nm. The structure is a semi-infinite rectangle made of glass with a refractive index of 1,5, covered with 55 nm of Silver (Ag). Then an array of nanoholes is etched in the Ag layer. Finally, the detector is a polarztn_ellipse analysis group.

We analyze the polarization of linear incident light in output passed through normal and tilted elliptic nanohole array with diameters Dx=350nm, and Dy=400 nm. As expected, the tilting of the array changed the polarization from linear to elliptical. For the tilted array, we next simulate different nanoholes dimensions. Fig. 2 shows the evolution of the light in output for different diameters. As seen, at first the circular nanoholes do not change the incident polarization. Then by increasing D_y, the detected elliptical polarization keeps increasing.

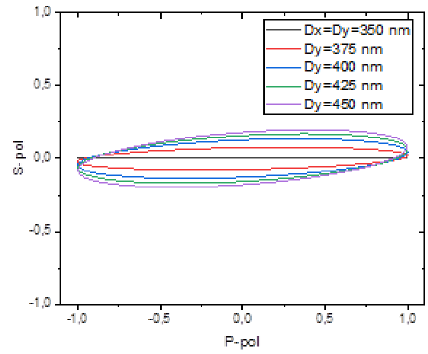

Fig. 2. (a) Set-up for the measurement of angle-dependent, spectrally tuneable circular polarization degree in the output. (b) Wavelength-QWP angle transmission map at normal incidence.

4 Conclusions

We investigate, experimentally and numerically, chiro-optical properties of hexagonal nanohole arrays in Ag. The slightly elliptical shape and the in-plane tilt leads to different circular polarization degree of the output beam. The samples are obtained by low-cost self-assembling approach. When excited by linear polarization, they give interesting circular polarization features in the transmitted beam. We believe such measurements are highly sensitive to asymmetric features of the nanostructured devices.

A. B. acknowledges LASAFEM Sapienza Università di Roma Infrastructure Project prot. n. MA31715C8215A268.

Z.E, B.B., C.S. and E. P. acknowledge Erasmus+ programme between Sapienza Università di Roma and Universities in Morocco.

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