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Asymmetric Transmission in Diffractive Chiral Metasurfaces Consisting of Nanoantennas

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ABSTRACT We have studied the asymmetric transmission in diffractive chiral metasurfaces consisting of nanoantennas. The study was made of lattice plasmon modes on the phenomenon of asymmetric transmission in chiral two dimensional arrays of plasmonic nanoparticles. It was demonstrated that asymmetric transmission resulted from contribution of higher order diffracted waves. It was shown that the isolated nanostructures has a fourfold rotational symmetry, the diffractive metasurfaces exhibited asymmetric transmission for normal incidence light within spectral range for which lattice plasmon modes were supported. It was found that lattice plasmon modes played role in enabling symmetric transmission in diffractive chiral metasurfaces. The symmetric transmission mechanism is due to different lattice plasmon mode excitation efficiencies of left circularly polarized and right circularly polarized and right circularly polarized light. The excitation efficiencies are controlled by tailoring the nano particles in plan distribution of scattered light for circularly polarized excitation and its alignment with the inplane diffraction orders of the metasurfaces. The phenomenon for a metasurface composed of an array of a chiral nanoparticles consisting of four nanoantennas. It was shown that the Rayleigh anomaly condition where the asymmetric transmission effect was strongest and metasurfaces supported lattice plasmon modes. It was found that the difference in the inplane scattered intensity varied as a function of the inplane angle around the nanostructure, rotating the nanostructure in the plane of the metasurface. The obtained results found in good agreement with previously obtained results.

KEYWORDS Asymmetric, Transmission, Chiral, Nanoantennas, Metasurface, Lattice Plasmon, Arrays, Nanoparticles, Excitation, Scattering.

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INTRODUCTION

Berova et al [1] studied that three dimensional chiral systems yielded a different optical response when interacting with either handedness of circularly polarized light and optical activity. Both phenomena were widely used for characterization of the optical response of the system. The chirality is also for two dimensional structures. Papakostas et al [2] studied that chirality is due to inability of two dimensional structures and its mirror image to be brought into congruence unless lifted from its plane. Plum et al [3] and De Leon et al [4] showed that the systems composed of chiral structures are known to exhibit chiral effects as well provided that surface normal and the electric field vector from chiral triad. This phenomenon is called extrinsic chrirality [5] and has been presented as variety of systems including single nanoparticle]6-7]. Fedotov et al [8] Fedotov et al [9], Schwanecke et al [10] and Aba et al [11] presented that for a given circular polarization state, the optical transmittance depended on the side of the sample that was illuminated. Khanikaev etal[12] studied the asymmetric transmission in planar arrays of chiral elements lacking fourfold rotational symmetry have attributed the phenomenon to the simulations presence of anisotropy and losses. When excited at normal incidence fourfold symmetric chiral hole appeared not to exhibit only asymmetric transmission [13-15]. Prosvirnin et al [16] showed that for a periodic arrangement of chiral nanostructures the possibility of loss channels associated with higher order diffraction. Meinzer et al [17], Hopins et al [18], Banzer et al [19] and Wozniak et al [20] studied that chiroptical phenomena have been explored in plasmonic systems such as individual nanostructures array of plasmonic nanostructures of metasurfaces [21-24] and plasmonic structures in suspended metafluid [25]. Kravets et al [26] and Bin-Alam et al [27] showed that these structures supported lattice plasmon mode enabled by diffractive coupling of localized plasmons.

METHOD

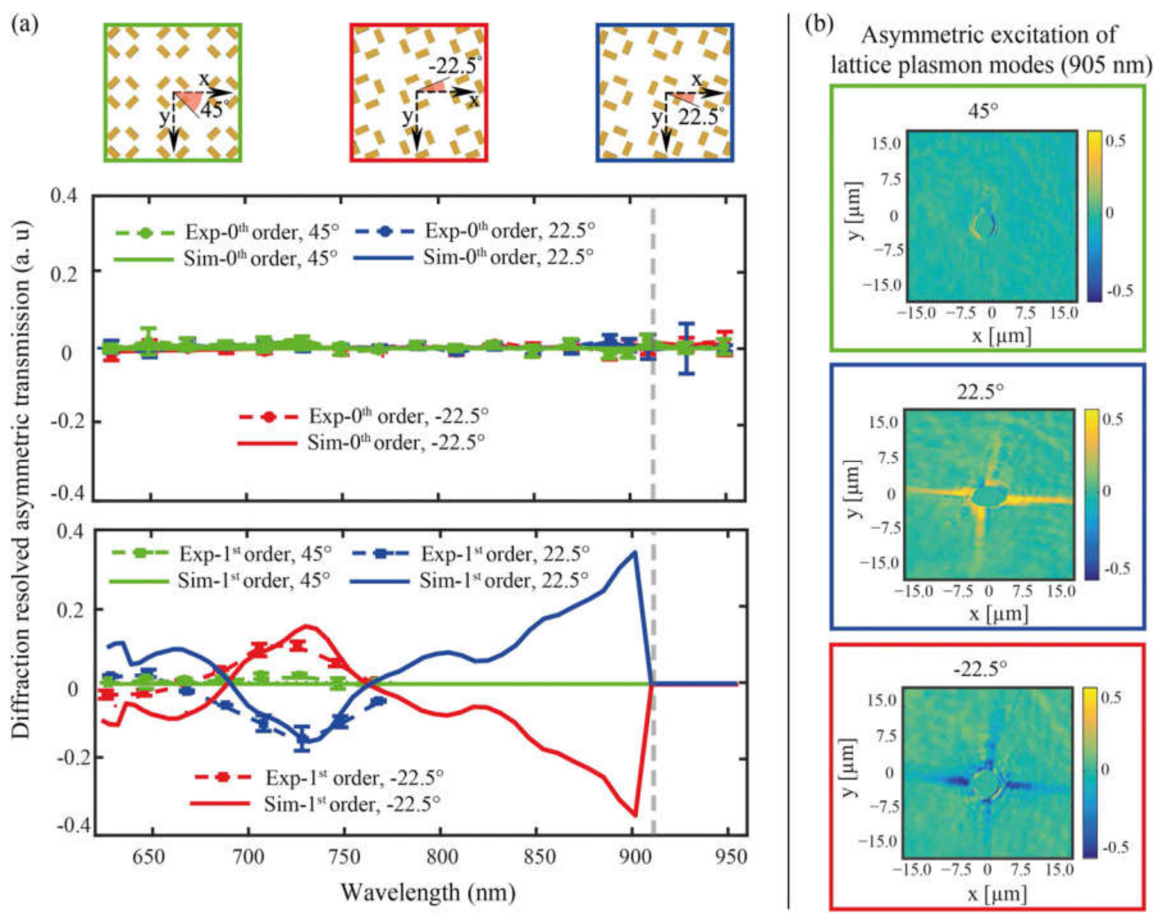
We have taken metasurface consisting of a planar array of nanostructures. The array lies on the (x,y) plane having a lattice spacing A=600 nanometer. The metasurface was illuminated by a circularly polarized plane wave propagating in the positive z-direction and impinging at normal incidence onto the surface. The individual nanostructures were chiral and created two dimensional chiral metasurface by rotating the nanostructure quadrumer at each lattice point around its corner. The metasurface supported lattice plasmon modes on the order of the optical wavelength. These modes resulted from the coupling of light scattered from neighboring particles through grazing diffraction orders. The individual quadrumer exhibited a non zero differential in plane scattering in a spectral range overlapping with the Rayleigh anomalies of the array. The intensity (ΔI) varied along the inplane angle, the differential excitation of lattice plasmon modes by right circularly polarized and left circularly polarized light also varied with the relative angle between ΔI and the lattice plasmon mode propagation direction. When $\Delta I_{\max}$ or $\Delta I_{\min}$ was along the propagation direction of a lattice plasmon mode then the difference in efficiency of excitation of that lattice plasmon mode was maximized or minimized. The transmittance of the metasurface as a function of quadrumer's rotation angles was computed. The asymmetric transmission was calculated by the relation

$$AT = \frac{T^R - T^L}{T^R + T^L}$$

Where T^R and T^L are he transmittance for right circularly polarized and left circularly polarized excitation.

RESULTS AND DISCUSSION

Graph (1) (a) shows the case of metasurface with quadrumers rotated by 45° in plane. This metasurface resulted in vanishing asymmetric transmission orders which is confirmed by simulation results and obtained experimental results. Graph (1) (b) shows the differential leakage radiation microscopy image obtained for this metasurface and also confirmed vanishing asymmetric propagation mode. Graph (1) (a) also shows the metasurface constituted by quadrumers with in plane rotation of 225° and -22.5°. This was confirmed by spectral plot in graph (1) (a). The differential leakage radiation microscopy image obtained for the chiral arrangements depicted asymmetrically excite of lattice plasmon modes with opposing sign as shown in graph (1) (b). Validating the sole contribution of the first diffraction orders to the obtained asymmetric transmission. It was also shown that the corresponding simulation for the zeroth diffraction order not featuring any significant spectral dependence of all studied metasurfaces as shown in graph (1) (a). The absence of asymmetric transmission of three quadrumer metasurfaces for the zeroth order. The obtained results were compared with previously obtained results and were found in god agreement.



Graph 1: Simulated diffraction-resolved asymmetric transmission results for achiral (45° rotation) and chiral (22.5°–22.5° rotations) metasurfaces.

CONCLUSION

We have studied the transmission for chiral metasurfaces in asymmetric case consisting of nanoantennas. The asymmetric transmission has been obtained through an unbalanced excitation for lattice modes by circularly polarized light of opposite handedness. It was found that the excitation efficiencies of the lattice modes and strength of asymmetric transmission were controlled by in plane scattering of the individual plasmonic nanoparticles such that the maximum scattering imbalance occurred along one of the in plane diffraction orders of the metasurface. The difference in the in plane scattered intensity varied as a function of the in plane angle around the nano structure rotating the nanostructure in the plane of the metasurface. It was found that when the asymmetric transmission effect was the strongest, the metasurface supported lattice plasmon modes that responded selectivity to the polarization handedness and confirmed asymmetric transmission mechanism enabled by the lattice plasmon modes. The results found were in good agreement with previously obtained results of theoretical and experimental works.

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