Research & Reviews: Journal of Pure and Applied Physics

e-ISSN:2320-2459
p-ISSN:2347-2316

Bending of Light to Enhance Wavelength Conversion

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Perspective

Received date: 24/07/2021

Accepted date: 28/07/2021

Published date: 31/07/2021

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PERSPECTIVE

Metasurfaces are artificial two-dimensional (2D) planar surfaces that contain sub wavelength 'meta-atoms' (i.e. metallic or dielectric nanostructures). They are known for his or her capability to realize better and more efficient light control as compared to their traditional optical counterparts. Abrupt and sharp changes within the electromagnetic properties are often induced by the metasurfaces instead of the traditional gradual accumulation that needs greater propagation distances. Supported this feature, planar optical components like mirrors, lenses, waveplates, isolators and even holograms with ultra-small thicknesses are developed. Most of the present metasurface studies have focused on tailoring the linear optical effects for applications like cloaking, lens imaging and 3D holography. Recently, the utilization of metasurfaces to reinforce nonlinear optical effects has attracted significant attention from the research community. Taking advantage of the resulting efficient nonlinear optical processes, the fabrication of integrated all optical nano-devices with peculiar functionalities including broadband frequency conversions and ultrafast optical switching will become achievable. Plasmonic excitation is one among the foremost effective approaches to extend nonlinear optical responses thanks to its induced strong local electromagnetic field enhancement. As an example, continuous phase control on the effective nonlinear polarizability of plasmonic metasurfaces has been demonstrated through spin-rotation light coupling. The phase of the nonlinear polarization are often continuously tuned by spatially changing the meta-atoms' orientations during second and third harmonic generation processes, while the nonlinear metasurfaces also exhibit homogeneous linear properties. Additionally, an ultrahigh second-order nonlinear susceptibility of up to 104 pm V^{-1} has recently been reported by coupling the plasmonic modes of patterned metallic arrays with inter-sub-band transition of multi-quantum-well layered substrate. So as to develop ultra-planar nonlinear plasmonic metasurfaces, 2D materials like graphene and Transition Metal Dichalcogenides (TMDCs) are extensively studied supported their unique nonlinear optical properties. The third-order nonlinear coefficient of graphene is five times that of gold substrate, while TMDC materials also exhibit a robust second-order magnetic susceptibility.

Many applications of metasurfaces have also focused on their ability to control light fields. The resonant behaviour, which produces these manipulations, is related to strongly enhanced near fields. These near fields are often exploited for the enhancement of non-linear processes in secondary materials, which find themselves within the near fields of the metasurface. This concept has been utilized in the detection of mid-infrared spectral fingerprints for the composition analysis of surface-bound analytes, also as for enhanced second-harmonic generation.

One area during which metasurface induced near-field enhancement has found particular success is photon up-conversion. Photon up-conversion materials, like lanthanide-doped particles, exploit a spread of energy-transfer mechanisms to convert multiple low-energy photo-excited states into one higher energy level, which may re-emit the pooled energy as a shorter wavelength photon, producing the photon up-conversion effect. The efficiency of this up-conversion process is often greatly enhanced by increasing the photo-excitation rate of the system, i.e., the sunshine intensity. So as to get high up-conversion efficiency at low incident intensity, near fields can locally increase the incident power for lanthanide-doped nanoparticles on the brink of a metasurface. This has been accomplished using metasurfaces consisting of 2D anodic alumina photonic crystals, SiO_2 opal photonic crystals, plasmonic particles and nanopillar based photonic crystals.

An alternative to metasurface based enhancement of the up-conversion process is superlensing via micro particles. The downside to super lensing is that the requirement of careful alignment of the up-conversion material with the focus of the lens.

e-ISSN:2320-2459
p-ISSN:2347-2316

However, counting on the appliance, this might not pose a big drawback.

Most of the results for the enhancement of the up-conversion process ask an excitation wavelength of 980 nm. This wavelength is often used for the efficient generation of visible photons, which makes it attractive for several applications, like the detection of biological agents by the attention. Up-conversion using lanthanide-based nanoparticles also can support transitions excited at a wavelength of 1550 nm, leading to emission, primarily, at 980 nm. This will be used for increasing the efficiency of photovoltaic devices, by converting below bandgap photons to a wavelength which will be absorbed by silicon. There has already been a report of up-conversion enhancement at 1550 nm using metallic nanostructures. The effect of stacking metasurfaces on their ability to supply enhanced near fields has, to the simplest of our knowledge, not been investigated thus far.

The metasurface is analysed with reference to near-field enhancement effects. Transmission measurements are wont to identify the spectral positions of resonances, with simulations confirming that the resonances are related to enhance near fields. So as to know the provenance of the resonant modes, each layer of the metasurface is simulated separately and their contribution to the entire metasurface is discussed. As a symbol of concept, the double-layer metasurfaces is roofed with lanthanide-doped up-conversion particles and their interaction with resonances of the metasurface is analysed by measuring up-conversion fluorescence upon excitation at 1550 nm. This leads to increased up-conversion efficiency, which we ascribe to a mixture of enhanced near fields of the metasurface and lightweight trapping effects thanks to high angle scattering. Finally, we present a four-layer stacked metasurface and discuss its potential for photon up-conversion applications upon low-intensity and broadband excitation.

The enhancement might be further improved by decreasing the extent of the up-conversion nanoparticles in order that their volume overlaps with the mode volume of the leaky resonance modes of the metasurface. The improved up-conversion of infrared shown here will enable new possibilities for the spectral manipulation of sunshine, including expanding the exploitable range of wavelengths for photovoltaic cell applications.