Characterizing NL response of metal-dielectric metasurfaces

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Abstract: A method for retrieving effective n_2 and α from bianistropic parameters of non-linear metasurfaces is introduced. The effective nonlinear parameters of a metasurface covered by a NL layer are compared vs a bare NL layer.

OCIS codes: (160.3918) Metamaterials; (190.4400) Nonlinear optics, materials.

1. Introduction

Characterization of the non-linear optical response of thin dielectric films enhanced with plasmonic metasurfaces has been attracted substantial attention due to the reduced dimensionality of the metasurface nanoantenna arrays combined with their strong and tunable field enhancement. In a nutshell, the effective χ^3 of a metasurface covered by a thin NL material layer in the simplest case [1, 2] can be described as a product of two optically dispersive complex values – a field enhancement factor and the third order susceptibility of the NL layer. Henceforth, it is possible to engineer an effective nonlinear metasurface by matching the nanoantenna resonance with the dispersion of the NL susceptibility. Here we describe a method for retrieving effective n_2 and α from bianistropic parameters of non-linear metasurfaces. The effective nonlinear parameters of a metasurface combined with a NL layer are compared vs a bare NL layer. As an example, we describe the use of a gold nanoantenna array to enhance both the nonlinear refractive index (n_2) and 2PA of an organic dye with a relatively large 2PA - 4,4'-bis(diphenylamino)stilbene (BDPAS) [3]. Our simulation results show that the effective nonlinear refractive index, n_2, is enhanced by 2-3 orders of magnitude (along with least a 3-orders of magnitude enhancement for α) relative to a BDPAS layer of the same thickness.

2. Theory

The effective refractive index for a bi-anistropic reciprocal layer as a function of the material parameters is given by

$$n = k_0 \delta^{-1} \cos^{-1}\left[\tfrac{1}{2}\left(s + s^{-1}\right)\right], \qquad (1)$$

where δ is the thickness of the NL layer, k_0 is the vacuum wavenumber and s is a factor obtained from the reflection and transmission coefficients [4]. Then, from the effective refractive index, the nonlinear parameters are obtained from:

$$n_2 = \mathrm{Re}\left\{n - n_0\right\}/I, \quad \alpha = \mathrm{Im}\left(n - n_0\right)/I\left(2k_0\right), \qquad (2)$$

here n_2 and α are effective non-linear refractive index and absorbtion coefficient (both in general frequency and intensity-dependent), I is the illumination intensity, n_0 is the linear refractive index obtained by measuring the transmission and reflection coefficients at a low intensity, and k_0 is the vacuum wavenumber.

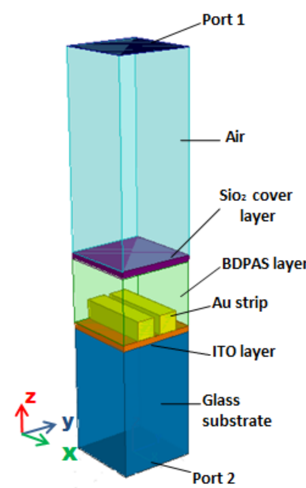

Fig. 1. Test geometry

3. Results and discussion

The test problem is calculated using a commercial full wave solver (Comsol Multiphysics) built on the finite element method (FEM). A FEM domain unit cell of the simulated geometry is shown in Fig.1. The metasurface nanostructure consists of three layers over a glass substrate. The NL material is a BDPAS dye layer that is sandwiched between two layers which are essential for fabrication, a silicon dioxide layer from the top and an ITO layer from the bottom.

First, the transmission matrix of the cover layer and the ITO layer are obtained using the simulated reflection and transmission coefficients for two sides illumination for each layer independently as in [4].

Second, the whole setup is simulated without gold at different thicknesses. By knowing the transmission and the reflection coefficients for two-side illumination, transmission matrixes of the cover layer and the ITO layer and then, the transmission matrix for the BDPAS layer can be obtained to get the nonlinear properties from (1) and (2).

Finally, once the gold strips are added, their effect on the effective NL parameters of the layer is investigated.

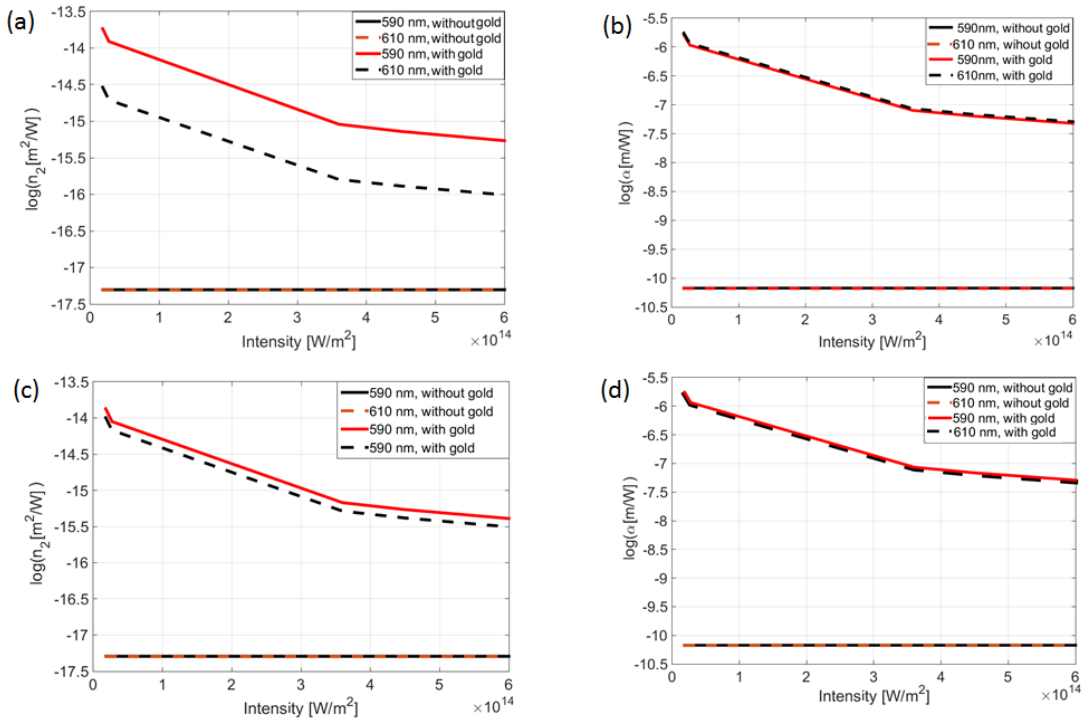

Fig. 2. (a),(b) the obtained n_2 and α for y-polarized incident illumination at wavelengths 590 nm and 610 nm for BDPAS layer thickness 140 nm, with and without gold strips (c),(d) at thickness 160 nm.

As shown in Fig.2, in case of BDPAS without gold strips, the proposed method is able to retrieve the NL properties of BDPAS layer at wavelengths 590 nm and 610 nm. As expected, the retrieved parameters are consistent with the input parameters of the simulated NL layer; they do not depend on neither the incident wavelength nor the thickness of the layer. In the case of BDPAS with embedded gold strips, the distribution of enhanced field in the gap between the gold strips mainly depends on the incident wavelength and the thickness of the layer. Unsurprisingly, the enhanced field increases the nonlinearity of the layer. This enhancement is manifested in the increase of the retrieved NL parameters values shown in Fig.2. Although Fig. 2 depicts the results only for y-polarized illumination, the proposed method is capable of taking into account the polarization-coupled parameters and can be used to obtain the NL parameters tensors [5].

In this paper, a method for retrieving effective n_2 and α using a bianistropic characterization technique for non-linear metasurfaces is introduced. The effective nonlinear parameters of a metasurface covered by an organic dye layer are compared vs the parameters of a bare dye layer without a metasurface. The simulation results shown in Fig. 2 indicate that the effective nonlinear refractive index, n_2, is enhanced by 2-3 orders of magnitude (along with least a 3-orders of magnitude enhancement for α) relative to a BDPAS layer of the same thickness.

4. References

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