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Frequency Tuning of Perfect Absorbing Metamaterial using a Thin Conformal Dielectric

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Abstract

Metamaterials, in the form of perfect absorbers, have received attention for sensing and light harvesting applications. Reciprocal plasmonic metasurfaces allow frequency tuning in simple post-fabrication processes. Here we demonstrate this tuning using thin conformal dielectric coatings deposited using atomic layer deposition.

Index Terms

metamaterial, absorption, infrared, atomic layer deposition, direct laser writing

I. Introduction

Optical metamaterials are a group of engineered materials that are composed of an arrangement of artificial structures, which result in properties that are not exhibited in naturally occurring compounds. These unique optical properties can be used to produce extraordinary optical effects including narrow band filtering [1], perfect lensing [2], and perfect absorption [3].

In order to achieve perfect absorption, metamaterial designs that rely on heterostructures have shown promising results [3], [4]. Heterostructured materials are composed of multiple, stratified constituents. We have developed a reciprocal plasmonic metasurface that is composed of two plasmonic metasurfaces with reciprocal surface geometries that are separated by a dielectric spacer. We have also explored the optical response of reciprocal metasurfaces when coated with a thin conformal dielectric. Our observations indicated that such dielectric coatings can induce a spectral red-shift of the main resonance of the reciprocal plasmonic metasurface allowing for the tuning of the resonant frequency.

II. Materials and Methods

A schematic of the unit cell of the investigated reciprocal plasmonic metasurface can be seen in Figure 1. The reciprocal plasmonic metasurface was composed of a rectangular Au bar array separated by a dielectric spacer from a rectangular hole array. A negative-tone photoresist polymer was used as a dielectric spacer. Fused silica glass was employed as a substrate. The infrared optical response of the reciprocal plasmonic metasurface was calculated using finite element modeling (FEM) simulations through COMSOL. Accurate dielectric function data for fused silica glass and IP-Dip were obtained using spectroscopic ellipsometry and were used for the FEM calculations [5], [6].

The effect of a conformal dielectric coating of amorphous Al_2O_3 on the spectral response of the reciprocal plasmonic metasurface was investigated for different coating thicknesses: 10 nm, 20 nm, 30 nm, and 40 nm. A simple harmonic oscillator approach consisting of six Gaussian oscillators was used to describe the optical properties of the amorphous Al_2O_3 grown using atomic layer deposition.

The reciprocal plasmonic metasurfaces investigated here were fabricated using a two-step process: two-photon polymerization (Photonic Professional GT, Nanoscribe GmbH) followed by Au metallization (Kurt J. Lesker PVD 75).

Linearly polarized reflectance spectra were captured using a Hyperion 3000 microscope (Bruker) in combination with a Vertex 70 FTIR spectrometer (Bruker).

In order to experimentally explore the effect of ultra-thin conformal dielectric coatings on the spectral location of the reciprocal plasmonic metasurface resonance, Al_2O_3 coatings were deposited using atomic layer deposition (Cross flow Savannah G2) in 10 nm thickness increments up to 40 nm. The depositions were carried out using trimethylaluminum as a precursor and H_2O as an oxidizer. Infrared reflectance measurements were conducted between each iteration to characterize the spectral response of the metasurface. COMSOL-based FEM model calculations were carried out for the corresponding conformal coating thicknesses for the comparison with the experimental infrared reflectance data.

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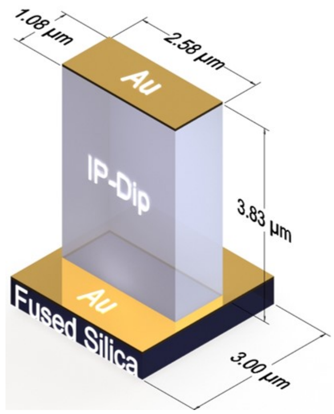

Fig. 1. Depiction of the square unit cell used in COMSOL modeling. The metasurface is composed of three layers: an IP-Dip polymer fin, a 50 nm Au dipole layer atop the fin, and a 50 nm layer surrounding the base of the fin. Fused silica is used as a substrate arranged into a 50 μm × 50 μm array.

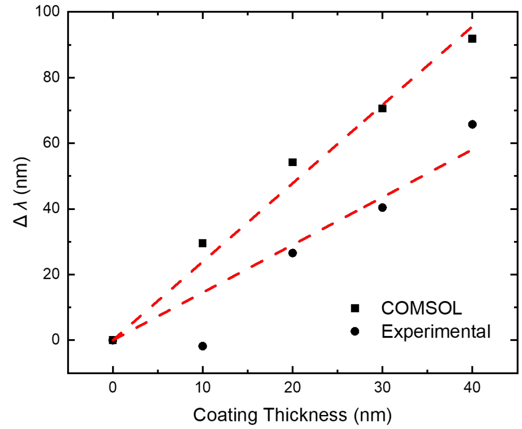

Fig. 2. Experimental and finite element modeling results delineating the effects of incremental conformal coatings of amorphous Al_2O_3 deposited on reciprocal plasmonic metasurfaces.

III. Results and Discussion

The incident radiation was polarized along the long axis of the rectangular dipoles forming the top metasurface, as shown in Figure 1. The reflectance spectra were dominated by a reflection minimum with a center wavelength of 4.8 μm. This reflectance minimum was due to a resonant absorption caused by the reciprocal plasmonic metasurface at that wavelength.

Figure 2 shows the experimental reflectance as a function of wavelength and coating thickness in the spectral vicinity of the reciprocal plasmonic metasurface resonance. Figure 2 shows that the reflectance minimum of the reciprocal plasmonic metasurface resonance followed a linear spectral shift from λ = 4.8 μm for the uncoated sample to λ = 4.9 μm for a coating thickness of 40 nm. We determined the slope of the experimental wavelength shift versus the coating thickness to be 1.5 versus 2.4 obtained from calculations.

The origin of the absorption in reciprocal plasmonic metasurfaces occurs from constructive interference within the dielectric spacer which is enhanced by the coupling between the top and bottom metasurfaces. Field enhancement between the dielectric spacer fins resulted in the extreme sensitivity of the optical response to minute and local ambient index changes [3].

IV. Conclusion

Reciprocal plasmonic metasurfaces were experimentally demonstrated and characterized. The samples were synthesized using a two-step fabrication process. This two-step fabrication technique is advantageous, as it ensures the alignment of the reciprocal surfaces by design. Experimental infrared reflection measurements revealed the expected reciprocal plasmonic metasurface resonance, which was observed for the investigated geometries at 4.8 μm. The location of this resonance was confirmed using finite element calculations. After incremental conformal coatings of the reciprocal plasmonic metasurface with Al_2O_3 using atomic layer deposition, a shifting of the resonance wavelength was observed. The reciprocal plasmonic metasurface geometry therefore offers the tunability of the absorption wavelength through a thin conformal coating of a dielectric.

To conclude, the simple configuration and sensitivity to thin conformal dielectric films demonstrated the reciprocal plasmonic metasurface as an adaptable platform for rapid prototyping perfectly absorbing metamaterials. In addition, the conformal dielectric coatings were shown to enable the adjustment of the metasurface resonances.

Acknowledgment

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