Bismuth-based Metamaterials: Fundamentals and Applications

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Abstract

Bismuth shows outstanding optical properties, including a metal-like response in the ultraviolet-visible and a dielectric character with a giant refractive index in the infrared. Herein, we explain how this enables bismuth-based metamaterials to show a remarkable optical response over these spectral regions. Such response can be tuned in a static way by suitable metamaterial design and in a dynamic way by harnessing the solid-liquid transition of bismuth. We discuss the applications of such metamaterials to information technology, energy harvesting and sensing.

1. Introduction

The semi-metal bismuth (Bi) is a non-conventional material platform for applications in photonics, because its optical properties strongly contrast with those of usual metals and semiconductors. These optical properties are driven by giant interband electronic transitions, which endow Bi with a metal-like response in the ultraviolet-visible and a dielectric character with a giant refractive index (n~10) in the infrared [1,2]. Thanks to that, Bi nanostructures can be used both as plasmonic and high index building blocks of metamaterials in the corresponding spectral regions [3,4]. Herein, we show how to tailor and assemble such building blocks to achieve Bi-based metamaterials showing an optical response tuned by design in a selected spectral range from the ultraviolet to the infrared. Besides such static tuning, we show how to harness the solid-liquid transition of the Bi nanostructures for an active tuning of the metamaterials' optical response. Finally, we discuss the applications of such metamaterials to information technology, energy and sensing.

2. Results

The considered metamaterials are built from Bi nanostructures: nanoparticles, nanorods, nanofilms with a three-dimensional distribution within a transparent matrix. By suitably selecting the nanostructure morphology and organization, their plasmonic and high-index response can be tailored and hybridized with cavity modes to tune the spectral response of the metamaterial. Such tuning can be achieved both in the ultraviolet-visible and infrared, to achieve ultranarrow resonances or a broadband perfect absorption of light.

These spectral features can also be tuned dynamically by harnessing the solid-liquid transition of the Bi nanostructures. In particular, upon controlled heating, a fraction of the nanostructures within the metamaterial can be melted to tune its optical response in an analog manner [4].

These properties make suitably designed Bi-based metamaterials appealing for several photonic applications: (i) they enable the analog tuning of the amplitude and phase of light in the visible regime, as needed for high density information processing [4]; (ii) they enable an efficient trapping of ultraviolet-visible and/or infrared light in subwavelength dimensions, as needed for photodetection or solar energy harvesting [3,5]; (iii) they enable optically-monitored sensing with a high figure of merit as needed for ultrasensitive non-invasive sensing applications.

References

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