Optical Spectroscopy of Hyperbolic Plasmonic Metamaterials

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***Abstract*—Linear and nonlinear optical spectroscopy of an array of Au nanorods, embedded in a dielectric matrix, is studied in the spectral range corresponding to specific dispersion points of such a structure. Experimental data is in a good agreement with the results of numerical modelling based on the effective medium model, as well as on linear and nonlinear FDTD simulations.**

Keywords—Optical harmonic generation, optical spectroscopy, nanorods, hyperbolic metamaterials.

I. Introduction

Hyperbolic metamaterials are characterized by special dispersion law that is determined by different signs of the diagonal components of the dielectric and magnetic permeability tensor due to a high structural anisotropy of these materials. One of the simplest realizations of a hyperbolic medium is an array of metallic nanorods in a dielectric matrix. It has been shown in a number of papers that such structures reveal new resonant features that are rather promising for applications in sensorics, lasing, enhancement of the nonlinear interaction, etc. [1,2]. Here we study the anomalous optical properties of arrays of metallic nanorods in a dielectric matrix by using the linear- and nonlinear optical spectroscopy.

II. Experimental details and results

The studied structures are arrays of gold nanorods made by electrochemical precipitation of Au in a porous Al_2O_3 matrix that served as a template. For such structures, the spectra of the components of the dielectric permittivity parallel ($\varepsilon_{||}$) and perpendicular ($\varepsilon_{\perp}$) to the rods' axis are calculated in the effective medium model for different filling factors of the metal. Near the resonant points, so-called epsilon-near-zero (ENZ) and epsilon-near-pole (ENP), distinct minima in the wavelength-angular transmission spectra are observed as stems from Figure 1. Namely, the long-wavelength resonance at 720 nm that becomes more pronounced as the angle of incidence is increasing, is attributed to the ENZ for the $\varepsilon_{||}$ component. At the same time, a constant in amplitude minimum in the wavelength region of 520 nm corresponds to the excitation of the resonance in the transverse direction, i.e. for $\varepsilon_{\perp}$ component.

Optical second harmonic generation (SHG) spectroscopy was studied when using the radiation of a femtosecond Ti-sapphire laser as a fundamental source. The laser tuning range is 740 - 870 nm allows to study the spectral edge of the long-wavelength resonance. As second harmonic generation is sensitive to the local electromagnetic field, so the SHG studies were performed in order to visualize the resonant effects associated with the ENZ point. A strong decrease of the SHG intensity with increasing wavelength observed in the experiment corresponds to tuning from the ENZ peculiarity. This is consistent with the results of the model calculations performed by using (i) the effective medium model and (ii) nonlinear FDTD method, the latter are shown in Fig. 2.

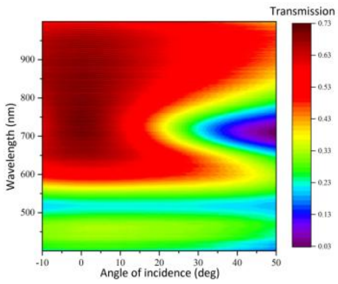

Fig. 1. Wavelength-angular transmission spectrum of Au nanorods in the Al_2O_3 matrix with the metal filling fraction of 16% for p-polarization.

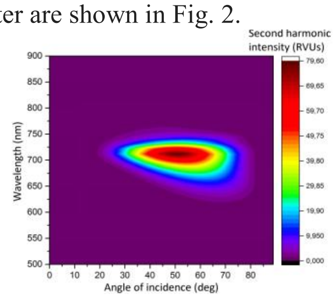

Fig. 2. Frequency-angular reflectivity spectrum of the second harmonic generation calculated in the effective medium model.

The distribution of the electromagnetic field strength was modelled by the FDTD method, which showed a strong absorption in the metal and localization of the electromagnetic field near the side walls of the rods in the resonant spectral range. Thus the appearance of the hyperbolic dispersion in an array of Au nanorods by the nonlinear-optical probe is demonstrated.

References

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