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Metal nanostructured ferromagnetic as a possible source of optical magnetism

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Abstract
It is shown analytically that plasmon-mediated magnetic response can be realized at optical frequencies in nanostructured magnetized metallic ferromagnetics under certain restrictions on their electronic subsystem. According to the results of our calculations, the occurrence of magnetic resonance in the visible spectral region is expected in the vicinity of the electron plasma frequency. The effect of a ferromagnetic film with intrinsic optical magnetism on the properties of an optical system assembled from titania nanotubes metallized with Ni is analyzed.

Keywords: dielectric and magnetic response functions, plasmons, refractive index, complex dielectric constant, magneto-optical effects

(Some figures may appear in colour only in the online journal)

1. Introduction

Novel properties of nanomaterials which are controlled by their morphology and characteristic sizes have been a subject of intensive research and application in various fields. The reduction of the characteristic size to the nanoscale leads to the emergence of a number of new and rather interesting material properties which are not characteristic to their bulk form. These new material properties are not necessarily associated with quantum confinement effects. For instance, introduction of porosity in GaP at the nanoscale leads to a strongly enhanced quantum efficiency of the photoresponse [1] and cathodoluminescence [2]. Porosity-induced modification of the phonon spectrum was observed in GaP, GaAs, and InP [3, 4]. A more than hundred-fold increase in the optical second harmonic generation, as well as enhancement of THz emission was realized in porous GaP and InP membranes [5–8]. The downscaling to nanosizes is also a way to produce metamaterials exhibiting optical magnetism which is one of most the interesting problems of nanotechnology [9].

The bulk materials have a magnetic permeability μ very close to unity at optical frequencies, which leads to the absence of optical magnetism. This behavior can be explained by taking into account the fact that the magnetic susceptibility related to a spin flip in a magnetic field is on the order of $(\mathbf{v}/c)^2 \ll 1$, where $\mathbf{v}$ is the speed of the electronic subsystem and c is the speed of light in vacuum [10]. The high value of the bulk ferromagnetic permeability usually is related to the presence of nonelectromagnetic origin forces with a slow response time, which excludes the possibility of using these materials in the optical range [11].

The traditional approach in nanotechnologies for the production of optical magnetism relies on the use of nonmagnetic materials (so-called metamaterials). These are macroscopic structures with a strict underlying pattern that allows them to imitate a different-from-unity effective magnetic permeability [12–18]. However, there are some possibilities for realizing optical magnetism based on the bulk magnetism of materials. Two types of thin films with thickness around 10 nm and similar in origin, structure, and electric properties were used for these purposes [19, 20]. One of them has only ferromagnetic properties. The dielectric functions of films should be identical when the electric properties are identical. The observed optical properties of thin films can be explained by assuming the existence of optical magnetism in

