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Enhanced optically induced magnetization due to inverse Faraday effect in plasmonic nanostructures

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ABSTRACT

Ultrafast all optical magnetic switching in plasmonic nanostructures based on the inverse Faraday effect recently has been proposed as a possible route towards magnetic data storage media with very fast writing speed. We have been examined inverse Faraday effect in three different kind of plasmonic nanostructures with Fourier modal method. Our modeling results predict significant enhancement of inverse Faraday effect around all major types of plasmonic nanostructures for a circularly polarized incident light due to surface plasmon polariton propagation near the interface of the metal–dielectric and nonzero value of inverse Faraday effect in this structures even with a linearly polarized excitation unlike the inverse Faraday effect in uniform bulk materials. Also the results show that the field distribution can be varied by changing light wavelength and angle of incidence which opens a possibility to locally control field distribution. Consequently, to affect locally the medium induced magnetization via the inverse Faraday effect and for practical applications in data storage and data processing and also sensing applications can be used widely.

1. Introduction

Plasmonic nanostructures provide abundant routes to control light matter interaction by nanostructures [1–4]. The interaction of light with magnetized nanostructures is manifested in various magneto-optical phenomena such as Faraday, Kerr and other ones [5,6]. These effects observed as a rotation of the polarization plane of light transmitted or reflected through a magnetized magnetic medium. Moreover, induce the magnetization by light which named as inverse Faraday effect (IFE) or inverse transverse magneto-optical Kerr effect has been the subject of intense in recent years [7–9]. This optically induced magnetization has been observed in a number of diamagnetic glasses, several organic and inorganic liquids and also different shape of plasmonic periodic nanostructures. It is necessary to emphasize that it is two dimensional periodic films that present practical interest due to electric field amplification inside the medium. Change in this amplification factor is the main aim of researchers during recent years, which can be attained by the aid of new plasmonic structures.

In this paper, we have been examined IFE in three kind of perforated plasmonic structure as perforated dielectric/metal/paramagnetic; perforated metal with coaxial holes/paramagnetic and perforated metal with square holes/paramagnetic structures.

2. Structure definitions

As our knowledge, the inverse Faraday effect (IFE), M, depends on the verdet constant of the medium, V, and also the electric field inside it as a difference between right and left circularly polarized light, $(I_R - I_L)$, as $M = (\lambda V/2\pi c)(I_R - I_L)$. For a paramagnetic medium, verdet constant is calculated by $V = 4\pi^2\chi/n\lambda$, where n is the refraction index, χ is the material constant describing conventional Faraday effect, $\chi = g4\pi H$, g is a medium gyrotropy, and H is the external magnetic field. Hence to get high value of the IFE one need either to find a material with large Verdet constant or to make the value of $m = |Im(E(\omega) \times E^*(\omega))|$ inside a material as large as possible. The quantity m is the induced dc magnetic field and thus the induced magnetization factor parameter. Here we will consider a plasmonic material, i.e. a medium which sustains propagation of the surface plasmon polaritons (SPP) to enhance electric field in the medium. Generation of SPPs yields to amplification of the intensity of the electromagnetic field which is necessary to enhance IFE in our plasmonic structure. SPPs can be excited only under certain conditions in particular in the presence of periodic structures on a surface. These structures can be

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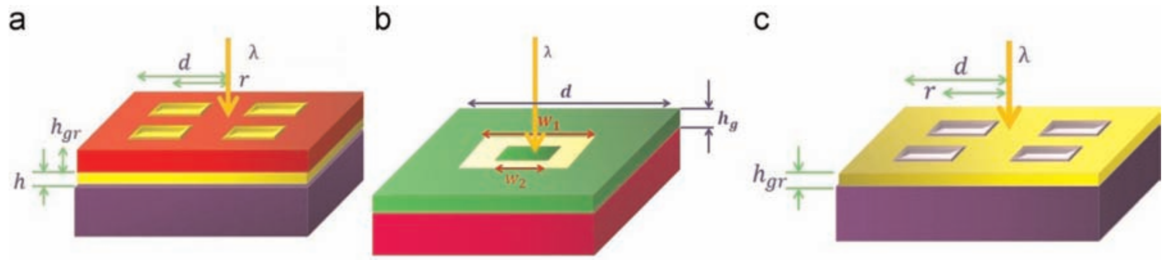

Fig. 1. Schematic of the plasmonic nanostructures: (a) perforated dielectric/metal/paramagnetic; (b) perforated metal with coaxial holes/paramagnetic. (c) Perforated metal with square holes/paramagnetic.

classified as perforated dielectric film on the surface of metal layer sputtered on the paramagnetic substrate (Fig. 1(a)), perforated metal layer with coaxial holes on paramagnetic layer (Fig. 1(b)) or perforated metal with square holes on paramagnetic layer (Fig. 1(c)).

In all structures, d, r, h_{gr} are grating period, holes size and grating thickness respectively and we assume that the thickness of the paramagnetic substrate is much larger than h_{gr} and h.

The first structure is a dielectric layer which is deposited onto metal ones and these two layers have been perforated and the paramagnetic layer is placed directly under our grating double layer structure. In the second ones, we removed the above dielectric layer and we have perforated metal layer with coaxial holes and the paramagnetic layer is placed directly under this kind of perforated metal layer. Difference between third structure with the second one is in the kind of holes in the metal layer which is squares holes that donot have coaxial positions. We know that, to achieve high IFE, we need to enhance electric field amplitude inside the paramagnetic layer. For this purpose, the SPP must be localized at the metal/paramagnetic interface. The conditions of the excitation of the horizontal, the travelling along the metal/dielectric interface, or the vertical, excited at the holes walls, SPPs depend on the geometrical parameters of the structure such as grating period, thickness and also holes size [10]. For this purpose, we change the structural parameters of structures to see how these parameters can be influenced on the IFE enhancement factor.

In all of structures, we assume circularly polarized light as incidence light. In this case, the wavelengths of light that can excite the surface plasmon resonance are given by [11]:

$$\lambda(m,n) = \frac{d}{\sqrt{i^2+j^2}}\sqrt{\frac{\varepsilon_d\varepsilon_m}{\varepsilon_d+\varepsilon_m}}, \tag{1}$$

where λ is the wavelength of light in vacuum, d is the hole array period, i and j are mode indices. The period of the resulting SP interference pattern can be formulated by [13,14]:

$$d_{ip} = d/2\sqrt{i^2+j^2}, \tag{2}$$

which is $2\sqrt{i^2+j^2}$ times smaller than that of the DG.

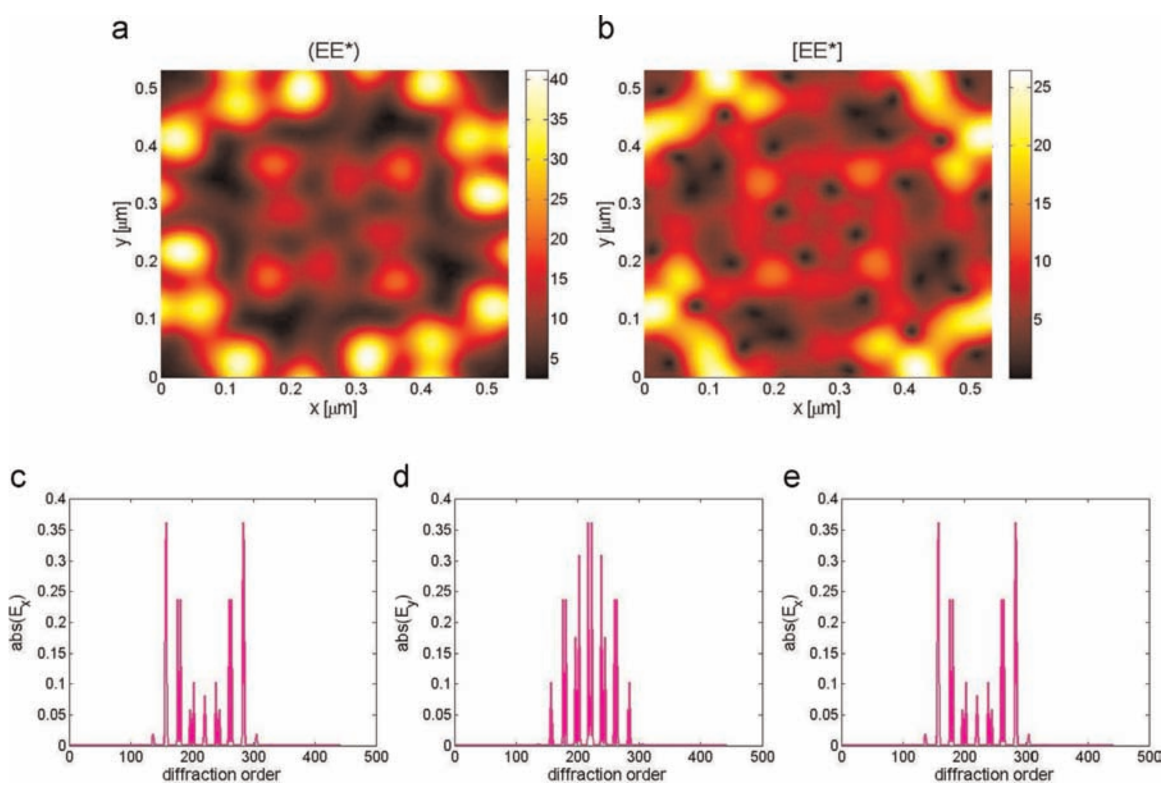

Fig. 2. Contour plots (a) for I and (b) for m at 10 nm depth inside the paramagnetic across a unit lattice. A grating is of the first type (Fig. 1(a)) and paramagnetic permittivity is 5.5, d = 533 nm, r = 272 nm, h_{gr} = 147 nm, h = 57 nm; λ is 550 nm corresponding to the excitation of SPP by the 3-rd transmitted diffraction order (the hole is in the center of the unit cell). (c)–(e) represent the absolute value of the Fourier coefficients of the components x, y and z of electric field of (m, n)-transmitted orders at 10 nm depth inside the paramagnetic.