Broadband Enhancement of Faraday Effect Using Magnetoplasmonic Metasurfaces

Soheila Kharratian,¹ Hakan Urey,² and Mehmet C. Onbaşlı^{2,*}

¹ Department of Materials Science and Engineering, Koç University, Istanbul, Turkey

² Department of Electrical and Electronics Engineering, Koç University, Istanbul, Turkey

*monbasli@ku.edu.tr

Abstract: Magneto-optical Faraday effect enables ultrafast photonic devices based on nonreciprocal polarization rotation; however, the intrinsic weakness of Faraday effect prevents miniaturization and practical applications of nonreciprocal photonic devices. Magnetoplasmonics offers new mechanisms for enhancing magneto-optical effects using surface plasmon resonances, which generally have narrow bandwidths. Using finite-difference time-domain modelling, we demonstrate a magnetoplasmonic metasurface, which remarkably enhances the Faraday effect in a wide spectral range. While Faraday rotation in a bare bismuth-substituted yttrium iron garnet film is below 0.02° in the studied range of 600-1600 nm, the proposed metasurface yields few degrees of rotation in a broad band with a maximum exceeding 6.5°, which indicates about three orders of magnitude enhancement. We also show that by optimizing the configuration of the system including the geometry and excitation parameters, the metasurface response and operation band can be tuned further, and rotation values higher than 20° can be achieved. Finally, we present guidelines for designing magnetoplasmonic metasurfaces.

Keywords: Magneto-optics, Plasmonics, Faraday effect, Metasurfaces, Faraday effect

1. Introduction

Magneto-optical (MO) Faraday effect is the rotation of the polarization plane of light when it passes through a magnetized matter. The angle of rotation is directly proportional to the path length of the light in the magnetized medium, with a coefficient of proportionality named specific Faraday rotation:

$$\alpha_F = \frac{\chi}{n} \vec{M} \cdot \vec{k} \quad (1)$$

where α_F is the Faraday rotation per unit path length, χ is the magnetic susceptibility, n is the refractive index, $\vec{M}$ is the magnetization vector, and $\vec{k}$ is the wavevector [1, 2]. Faraday effect finds applications in various optical devices including isolators [3–5], circulators [6–8], and spatial light modulators [9–11], as well as data storage [12–14], sensing/imaging systems [15–17], and in the growing field of spintronics [18, 19]. Despite these applications, the small magnitude of the specific Faraday rotation in the majority of MO materials limits its applicability and prevents miniaturization of the MO devices [20]. Hence, enhancement of the Faraday effect has become an attractive research topic and different approaches such as using suspended plasmonic particles [21, 22], core-shell magnetoplasmonic nanoparticles [23, 24], magnetoplasmonic crystals [25–27], magnetophotonic crystals [28–30], and graphene infiltration [31] have been reported in this regard.

Plasmonic metasurfaces (PMs) present another method for enhancing MO effects, particularly in the visible and near-infrared range. PMs are two-dimensional arrays of metallic nanoantennas with subwavelength spacings that induce oscillations of the conduction electron density, called surface plasmons (SPs), during interaction with an electromagnetic (EM) wave [32–36]. When the EM wave is coupled to the SPs, coherent fields with mixed nature of EM waves and surface charges, named surface plasmons polaritons (SPPs), are formed in the metal-dielectric interface. SPPs propagate along the interface and decay evanescently in the perpendicular direction due to the damping by the Joule heating and radiative emission. Thus, SPPs confine the EM waves along the metal-dielectric interface, in length scales on the order of diffraction limit ($\sim \lambda_0/2n$). The integration of PMs into MO materials allows for localization of EM wave in the MO material, which increases light-matter interactions and leads to enhanced MO

effects. Despite the increased interaction, the resonant characteristic of this phenomenon causes the MO enhancement to be generally narrowband and limits the applications [37–42]. Recently, broadband optical modulation has been studied using different approaches such as metamaterials [43–45] or photonic crystals [46]. In the field of magnetooptics, Kalish et al. [47] have demonstrated multiband enhancement of transverse MO Kerr effect (TMOKE) using quasiperiodic plasmonic structures. Pappas et al. [48] have reported a relatively broadband enhancement of longitudinal MO Kerr effect (LMOKE) in the spectral range of 600–750 nm, by embedding gold nanoparticles into bismuth-substituted yttrium iron garnet (Bi:YIG) films. Nevertheless, an effective broadband enhancement of the Faraday effect has not previously been reported, whereas Faraday rotation is potentially the largest and most practical MO effect.

In this study, using finite-difference time-domain (FDTD) simulations, we demonstrate a magnetoplasmonic metasurface comprised of a 2D array of gold nanoantennas on a MO Bi:YIG film, which remarkably enhances the Faraday effect in a wide spectral range over the near-infrared band. The proposed structure entails different periodic distances, which lead to multiple resonances, and the overlap of these resonances enables a broadband response. First, we compare the transmission (T) and Faraday rotation (FR) spectra of the proposed metasurface with those of the bare Bi:YIG film and the Bi:YIG film covered by a uniform gold layer. Next, we study the mode profiles in the peaks and dips of the spectra and discuss the origin of the resonances and MO enhancement. We also investigate the effect of geometric and excitation factors, such as width and thickness of the plasmonic nanoantennas, periodic lattice parameters, and polarization of the incident light on the T and FR spectra. Finally, we discuss the feasibility of active tunability and present guidelines for designing magnetoplasmonic metasurfaces.

2. Structure, materials, and methods

The proposed magnetoplasmonic metasurface consists of a 2D array of ultrathin gold (Au) nanoantennas on a 10 nm thick Bi:YIG film deposited on a glass substrate, as shown in Fig. 1. Au is a noble metal with small Ohmic losses and low absorption, which offers highly functional plasmonic properties [49], and Bi:YIG is an MO material with large Verdet constant that yields large MO effects in relatively low magnetic fields [50]. The geometric parameters l , s , and d in Fig.1 have fixed values of 250, 80, and 50 nm, respectively. Width (w), thickness (t), the period of structure in x and y directions (p_x and p_y) were initially considered to be 50, 5, 250, and 400 nm, respectively, however, the effects of changing these structural parameters on the optical and magnetooptical response of the metasurface are studied in Section 4. The incident light was first assumed to be polarized in the x direction ($\theta = 0^\circ$), but the effect of the exciting polarization is also investigated as a tuning mechanism for the metasurface response.

Metasurfaces with extremely small thicknesses are crucial for the miniaturization of optoelectronic devices for compact applications, e.g. certain sensing, robotic, and space systems, or studying light-matter interactions at the nanoscale [51, 52]. Reduction of thickness in thin films leads to new dimensionality-related effects originating from strong confinement of electrons, and ultrathin films exhibit peculiar properties due to the quantum size effect. While plasma frequency (ω_p) in bulk materials and rather thicker films is only defined by the electronic band structure of the material, ω_p in ultrathin films shows a redshift with decreasing thickness. Such a tunability introduces a unique platform to design advanced multifunctional devices in a wide operational range. Furthermore, smaller thicknesses cause lower dissipative losses and retain low optical damping, which makes them favorable in terms of energy considerations and support of strong plasmons for a device design [51, 53]. In gold clusters with sizes > 3 nm, the optical properties can be described by a bulk dielectric function with relevant modifications corresponding to the electron scattering at the surface. Below this size, a gradual discretization occurs in the plasmonic resonances [54]. Although controlling the thickness in the nanometric scale is a challenging measure, ultrathin films with thicknesses smaller than 10 nm down to atomic layers have been studied for their strong and tunable plasmonic effects [55–59].

We use the finite-difference time-domain (FDTD) method and Lumerical software to calculate the field components and investigate the optical and MO response. The optical data for gold and glass (SiO_2) are taken from Johnson and Christy [60] and Palik [61], respectively. Considering the magnetization (M) direction perpendicular to the film plane (xy), i.e. M parallel to z direction, the MO film is defined by a permittivity tensor in the form of:

$$\varepsilon = \begin{bmatrix} \varepsilon_1 & +i\varepsilon_2 & 0 \\ -i\varepsilon_2 & \varepsilon_1 & 0 \\ 0 & 0 & \varepsilon_1 \end{bmatrix} \quad (2)$$

where the diagonal element ε_1 is related to the complex refractive index and the off-diagonal element ε_2 is responsible for the MO activity such as Faraday/Kerr rotation and ellipticity. Generally, ε_1 and ε_2 have complex values, which are dispersive with respect to wavelength. Here, we use the average values of $\varepsilon_1 = 5.5 + 0.0025i$ and $\varepsilon_2 = (1-0.15i) \times 10^{-2}$ for Bi:YIG [40, 41, 62–64].

Fig. 1. (a) Schematic layout of the proposed magnetoplasmonic metasurface. The thickness of the magneto-optical Bi:YIG film is 10 nm. (b) Top view of a unit cell, where the geometric parameters $l = 250$, $s = 80$, and $d = 50$ nm have fixed values throughout the study. The width (w), thickness (t), the period of the structure in x and y directions (p_x and p_y) were initially considered to be 50, 5, 250, and 400 nm, respectively, however, the effects of changing these variables on the response of the magnetoplasmonic metasurface are studied. The incident light was first assumed to be x-polarized ($\theta = 0^\circ$), but polarization variation is investigated as a mechanism for tuning the response of the metasurface.

FDTD simulations are performed in a unit cell with periodic boundary conditions in x and y directions and perfectly matched layer (PML) boundary conditions in the z direction. A planar light source with linear polarization and propagating perpendicular to the film plane, along -z axis, is used.

3. Theory

The photon momentum of a plasmon on a thin metal film is generally several hundred times larger than the momentum of a free space photon with the same energy [65]. Thus, for efficient coupling of light to SPs and exciting SPPs, a momentum matching technique such as using a prism, isolated holes, or gratings is required [42, 66]. When the plasmonic structure has a periodic configuration, based on the unit cell boundary conditions, different complicated phenomena can occur along with the excitation of SPPs. In structures that have continuous metal-dielectric interfaces in the unit cell boundaries, such as 1D and 2D plasmonic gratings, a collective radiative effect named SPP-Bloch wave (SPP-Bw) mode can be observed. According to the Bragg coupling condition, SPP-Bw mode is excited when:

$$\vec{k} = \vec{k}_{\parallel} + \vec{G} \quad (3)$$

where $\vec{k}_{\parallel}$ is the in-plane wavevector of the incident light, and $\vec{G}$ is the reciprocal lattice vector.

For a plasmonic metasurface consisted of a periodic array of discrete nanoantennas with large dielectric spacings, a collective lattice plasmon mode caused by scattering from the array of nanoantennas and mediated by the diffractive coupling between SPPs can be generated. In this case, the optical energy scattered by one antenna is more likely to be collected by the neighboring antennas, resulting in a collective lattice plasmon instead of decaying as free-space light. The lattice plasmon modes can be considered as a type of surface Bloch mode composed of many Bloch harmonics from the array. According to the Bloch's theorem, for a square 2D array, the in-plane wavevector for the diffraction order of $\{m,n\}$ is defined as:

$$\vec{k}_{m,n} = \vec{k}_0 \sin \phi + m \frac{2\pi}{p_1} \vec{u}_1 + n \frac{2\pi}{p_2} \vec{u}_2 \quad (4)$$

where $\vec{k}_0$ is the free space wavevector, ϕ is the incidence angle, p_1 and p_2 are the array pitches in the directions of unit vectors $\vec{u}_1$ and $\vec{u}_2$, respectively. When all the momentum of the scattered radiation is parallel to the plane of the array, i.e. $|\vec{k}_{m,n}| = \vec{k}_0$, and the normal wavevector vanishes, the effect is called Rayleigh's anomaly (RA). This phenomenon converts the scattered fields into grazing waves that can be hybridized with the SPPs and result in SPP-RA modes. RA is not a resonant effect, however, the SPP-RA coupling can lead to sharp resonant features in the spectra and offers a mechanism for enhancing SPP modes. These hybridized resonances are called surface lattice resonances (SLRs).

Another mechanism for enhancing SPP modes is the hybridization of plasmonic modes with guided modes when the plasmonic nanoantennas are in proximity to waveguiding structures. In such a configuration, the antenna array couple light from free space into the waveguide modes. Since such couplers can also decouple light from a waveguide mode into free space, these modes are leaky and known as quasi-guided modes. SLRs are favored for large plasmonic antennas in a surrounding medium with homogeneous dielectric properties, while the quasi-guided modes require a waveguiding component with a higher refractive index compared to the surrounding environment [37, 49, 67, 68].

In summary, the spectral and spatial overlap of plasmonic and photonic modes lead to superior hybridized modes combining deep subwavelength confinement and strong light-matter interaction characteristic with long-range guiding and modal volume extended over film plane. These plasmonic-photonic modes enable sharp optical resonances that can be tuned by geometric, lattice, and excitation parameters.

4. Results and discussion

In this section, the results on the broadband enhancement of Faraday rotation using the magnetoplasmonic metasurfaces are presented and the origin of the enhancement is systematically investigated. Fig. 2 compares the T and FR spectra of the proposed magnetoplasmonic metasurface (red lines) with those of a bare Bi:YIG film (black lines) and the Bi:YIG film covered by a plain gold layer with the same thickness as the nanoantennas' thickness (blue lines), all on glass substrates. The geometric variables are $w = 50$ nm, $t = 5$ nm, $p_x = 250$ nm, and $p_y = 400$ nm, and an x-polarized light source ($\theta = 0^\circ$) is used for the metasurface investigated in this figure. The T spectrum of Bi:YIG film does not change significantly within the studied range of 600-1600 nm. The plasmonic metasurface, however, shows resonant features, and the transmission of the Bi:YIG film with a plain gold layer diminishes almost linearly with increasing wavelength (Fig. 2a). Comparison of the FR spectra (Fig. 2b) shows negligible FR values for the bare Bi:YIG film in comparison to the proposed metasurface, and adding a plain gold layer on top of the Bi:YIG film improves the Faraday effect only slightly in the wavelengths shorter than 1400 nm, as magnified in Fig. 2c. While the FR values for the Bi:YIG film are below 0.02° in the studied spectral range, rotation values up to 6.5° are achievable using the proposed metasurface as shown in Fig. 2b.

Fig. 2. (a) Transmission and (b) Faraday rotation spectra for a 10 nm thick Bi:YIG film (black lines), the plasmonic metasurface comprised of 10 nm thick Bi:YIG film and 5 nm thick plasmonic structures with geometric parameters of $w = 50$, $p_x = 250$, and $p_y = 400$ (red lines), and a 10 nm thick Bi:YIG film covered by a 5 nm thick gold film on top (blue lines). (c) Magnification of part (b) for small rotation angles. The polarization of the light source is considered to be in the x direction ($\theta = 0^\circ$) for these calculations.

The structure of the proposed metasurface comprises different periodic distances as shown in Fig. S1 (Online Resource 1), which leads to multiple resonant peaks in the T and FR spectra. The x-polarized incident light experiences four different periodic configurations on the metasurface, each inducing a resonance in the metasurface response [69]. As a result, four major peaks are observed in the FR spectrum of the magnetoplasmonic metasurface (Fig. 2b). If one looks at the structure as a simplified 1D grating, one can see four different square wave patterns (1-4). This results in four different energy distributions among harmonics in k-space. As a result, one can expect four different resonant peaks. The overlap of these resonances leads to enhanced FR in a broad spectral range. The FR peaks around $\lambda = 800$, 1080, and 1355 nm are correlated with the respective dips in the T spectrum. For the FR peak around 1160 nm, the related transmission dip is indeed covered by the adjacent stronger dip at 1080 nm, as can be understood from the asymmetric shape of this resonant dip in the T spectrum (Fig. 2a). The proposed plasmonic metasurface makes it possible to achieve few degrees of rotation in a broad wavelength range and a maximum FR exceeding 6.5° , in a total thickness of 15 nm, which indicates about three orders of magnitude enhancement in Faraday effect at the respective wavelength.

To explain the resonant features of the magnetoplasmonic metasurface observed in Fig. 2, we investigate the mode profiles at the main peaks and dips of its spectra. Fig. 3 shows the distribution of the electric field normalized to the incident field, $|E/E_0|$, at the interface between the plasmonic structures and the MO film, for different wavelengths. At $\lambda = 680$ nm, a minor dip in the T spectrum is observed, accompanied by a minute peak in the FR spectrum. The mode profile of a unit cell at this wavelength shows modes propagating along the gold antennas, most pronouncedly in the shorter edges, and the enhancement factor ($|E/E_0|$) is mainly below 10 (Fig. 3a). At $\lambda = 800$ nm, SPPs are mostly propagating along the longer edges of the nanoantennas (Fig. 3b) with some localization under the gold structures. At $\lambda = 915$ nm, the propagating surface plasmon resonance (PSPR) mode intensity diminishes (Fig. 3c). Comparison of parts b and c of Fig. 3 shows similar values for the maximum field enhancement (about 28) at both wavelengths, however, distribution of the high field in a larger area at $\lambda = 800$ nm leads to a greater net enhancement at this wavelength and places it in a peak position in FR spectrum, while $\lambda = 915$ represents a dip. At $\lambda = 1080$ and 1255 nm, the surface plasmons are mostly localized in the corners of the nanoantennas (Fig. 3d,e). These strongly localized surface plasmon resonances (LSPRs) increase the light-matter interactions and result in remarkable enhancement of FR. Higher enhancement factors in Fig. 3d compared to Fig. 3e leads to an FR peak at 1080 nm and a relative decrease at 1255 nm, yet showing a significant rotation value. At $\lambda = 1355$ nm, both PSPR and LSPR modes coexist (Fig. 3f), leading to a maximum FR, although the maximum E-field enhancement is not observed at this wavelength.

Fig. 3. Distribution of the electric field normalized to the incident field, $|E/E_0|$ in the xy plane at the interface between the gold nanoantennas and the Bi:YIG film, for different wavelengths of (a) $\lambda = 680$ nm, (b) $\lambda = 800$ nm, (c) $\lambda = 915$ nm, (d) $\lambda = 1080$ nm, (e) $\lambda = 1255$ nm, and (f) $\lambda = 1355$ nm. Note the different maxima among the color bars.

The effect of geometric parameters on the spectral T and FR response of the plasmonic metasurface has been studied in Fig. 4. Increasing the width of gold nanostructures (w) reduces the transmission, improves the FR, and causes a redshift in the spectra, as shown in Fig. 4a,b. Giant rotation angles, higher than 20° , are achieved for $w = 70$ nm. As indicated in Fig. 4c,d, increasing the thickness of gold nanostructures (t), not only decreases the transmission and enhances the FR but also considerably blueshifts the spectra. For thicknesses smaller than 5 nm, no significant FR peaks are observed in the studied band. Increasing t sharpens the peaks and narrows down the spectral range of enhancement. While both w and t can be used as tools of tuning the operation wavelength, peak positions are more sensitive to the change of t . Knowing the effects of these geometric parameters, one can optimize the proposed magnetoplasmonic metasurface based on the application requirements and the limits for T and FR. According to the results depicted in Fig. 4, for the broadband applications, plasmonic structures with large widths and small thicknesses are recommended.

Fig. 4. Effect of (a,b) width and (c,d) thickness of the gold nanoantennas on the optical and magneto-optical responses of the magnetoplasmonic metasurface.

Considering the metasurface with $w = 70$ nm in Fig. 4a,b, three distinctive resonances are recognized. In contrast to the resonances around $\lambda = 900$ and 1200 nm that blueshift with decreasing the antenna sizes, the resonance around $\lambda = 1350$ nm shows no significant spectral shift with changes in the size of the plasmonic structures. Hence, the resonances around 900 and 1200 nm can be assigned to plasmonic modes and the resonance at 1350 nm can be related to photonic modes of the metasurface. In this case, where the thickness of the nanoantenna is considered to be 5 nm, a pronounced coupling is not observed between the modes. However, for higher thicknesses (purple and green lines in Fig. 4c,d), a strong coupling exists between the plasmonic and photonic modes, and in accordance with the previous reports [58], all the resonances considerably shift towards shorter wavelengths with increasing t . Such a strong coupling results in sharp resonances, enabling up to 18° FR for nanoantennas with 20 nm thickness.

In Fig. 5, we investigate the impact of periodicity on the performance of the proposed metasurface. Increasing the period of the plasmonic structures in the x direction (p_x), leads to higher transmission but lower FR (Fig. 5a,b). Increasing the period in the y direction (p_y), has a similar effect, however, in a less pronounced manner (Fig. 5c,d). In contrast to the geometric parameters that provide a means to control the spectral position of the resonant peaks in addition to the peak intensity, periodicity does not noticeably change the shape of spectra or position of the peaks. Thus, for enhancing the FR without changing the working wavelengths, reducing the period of the plasmonic array would be the best reconfiguration option.

Fig. 5. Effect of periodicity in (a,b) x direction and (c,d) y direction on the optical and magneto-optical responses of the magnetoplasmonic metasurface.

In addition to the structural parameters that need to be considered before design and fabrication, there are other parameters, which can dynamically tune the performance of a metasurface. A means for such a control is the polarization of the incident light. Fig. 6 indicates the effect of the polarization direction of light on the optical and magneto-optical responses of the magnetoplasmonic metasurface. According to Fig. 6a, by changing the polarization of the incident light from x towards y direction (increasing θ from 0° to 90°), a remarkable increase in transmission accompanied by changes in the shape of T spectra is observed. Fig. 6b indicates that the metasurface has a broadband enhancement effect only for right-angle polarizations ($\theta = 0^\circ$ and 90°) and oblique polarization angles exhibit strong and narrow resonances. It is notable that for oblique polarization, the sign of FR changes with asymmetric Fano-type line shapes. In such a configuration, the structural asymmetries allow for the coupling of discrete non-radiative (dark) modes that result from SLRs and have finite spectral linewidths, with the normal transmittance through the film (bright mode) that can be considered as a continuum. The interference between dark and bright modes results in Fano resonances that have narrow spectral width and enable more efficient confinement of light, leading to a large enhancement of optical field and FR [37, 41, 67, 68]. Fig. 6 shows that for incident light with $\theta = 30^\circ$, FR angles up to about 20° are achieved with reasonably high transmissions (over 40%). Comparing the spectra for $\theta = 0^\circ$ and 90° , one can observe that y-polarized light results in slightly smaller FR while its transmission is significantly higher than the light with x polarization. Therefore, for the applications that are more sensitive to transmission, using a y-polarized light source with the proposed metasurface is preferable.

Fig. 6. Effect of polarization of light on (a) transmission and (b) Faraday rotation of the magnetoplasmonic surface. θ is the angle between the polarization plane of the incident light and the x axis.

Another mechanism for tuning the performance of magnetoplasmonic metasurface is the use of a magnetic field as an external signal for dynamic control of the magneto-optical response. At a given configuration, altering the magnetization of the MO material would change the off-diagonal element of the permittivity tensor, ϵ_2 , which determines the magnitude of achieved FR [70]. Switching the magnetization direction would change the sign of FR, leading to the MO rotation in opposite angular orientation [71].

5. Magnetoplasmonic metasurface design guidelines

In this section, based on the results shown in Fig. 2-6, we present guidelines for designing magnetoplasmonic metasurfaces with any desired properties:

5.1 Operation wavelengths

The application requirements determine the operation wavelengths. The MO material must have nonzero and sufficiently large off-diagonal elements in the permittivity tensor, at the application wavelengths. The operation band of plasmons determines the plasma frequency and the corresponding plasmonic material, e.g. gold and doped graphene for THz regime [72, 73]. The size of plasmonic antennas has a prominent role in determining the resonance wavelengths. Increasing the width of antennas shifts the peaks towards higher wavelengths, while changing the thickness has an opposite effect. For obtaining multi- or broadband performance, the geometry of the plasmonic nanoantennas must include different periodic distances. The geometrical configuration, especially the thickness of the nanoantennas, determines the span of the operational band for the plasmonic metasurface.

5.2 Simultaneous maximization of the magneto-optical effect and transmission

An efficient plasmonic metasurface for nonreciprocal devices requires materials with large MO properties and low optical losses. Simultaneous enhancement of transmission and Faraday rotation is necessary for achieving an acceptable signal-to-noise ratio in applications such as telecommunications, sensing, and signal processing. Both localized and propagating surface plasmon modes, and also coupling between plasmonic and photonic modes could be exploited for maximizing the FR enhancement while controlling the losses. Multiple resonances in the transmission spectra lead to strong multi- or broadband enhancement of MO effects. The configurational parameters provide tuning means for the optimization of optical and MO responses of the magnetoplasmonic metasurface. The results presented in this study show that the thickness of nanoantennas (t) and the periodicity of structure in the direction of the incident light polarization (e.g. p_x in the case of x-polarized incident light) allow for significant enhancement of FR without a

remarkable drop in T. Moreover, for the proposed metasurface, y-polarized incident light yields transmission values considerably higher than the x-polarized light, while the resultant FR is only slightly lower.

5.3 Polarization dependence/independence

For polarization or angular orientation selectivity/insensitivity of the magnetoplasmonic metasurface, the geometry of nanoantennas must be designed without/with n-fold rotational and mirror symmetries. In other words, mirror plane and circular symmetries in the nanoantenna geometry could help achieve polarization independence, whereas the lack of symmetry in the antennas structure leads to different responses based on the polarization of the incident light. The latter enables a new class of optical devices that can be switched and controlled by the polarization of light [74].

6. Conclusion

A magnetoplasmonic metasurface was demonstrated using a two-dimensional array of gold nanoantennas on a magneto-optical Bi:YIG film, which remarkably enhances the Faraday effect in a wide near-infrared band. While Faraday rotation in the bare Bi:YIG film is below 0.02° within the studied wavelength range of 600-1600 nm, the proposed metasurface significantly improves the performance. The metasurface enables few degrees of rotation in the broad band of 1000-1400 nm with a maximum exceeding 6.5° . This indicates about three orders of magnitude enhancement for the Faraday effect, in a total thickness of 15 nm (comprised of 10-nm thick Bi:YIG film and 5-nm thick gold nanoantennas). The results were further improved by tailoring the geometric parameters and periodicity of the plasmonic structure, leading to rotation angles higher than 20° . Besides the structural parameters that determine the operation wavelengths, the polarization of the incident light and magnetization state of the magneto-optical material were suggested as tools for active tuning of the metasurface response. These tunable magnetoplasmonic metasurfaces could be used for wavelength-selective sensing surfaces, isolators, filters, and other free-space optical signal processing applications. Finally, guidelines based on the investigated results were presented for designing desired magnetoplasmonic metasurfaces and improving the efficiency.

Funding

This work was financially supported by the European Research Council Advanced Grant (ERC-AdG) Wear3D Project No: 340200, TUBITAK Grant No. 119S362, and TÜBA-GEBİP Award by Turkish Academy of Sciences.

Disclosures

The authors declare no conflicts of interest.

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