Optics Communications 391 (2017) 48–56

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Theoretical investigations on a class of double-focus planar lens on the anisotropic material

Mahdieh Bozorgi, Zahra Atlasbaf*

Faculty of Electrical and Computer Engineering, Tarbiat Modares University, Tehran, Iran

ARTICLE INFO

Keywords:
Anisotropic thin film
Planar lens
Plasmonic nano-antenna
Green's function
Method of Moments (MoM)

ABSTRACT

We study a double-focus lens constituted of V-shaped plasmonic nano-antennas (VSPNAs) on the anisotropic TiO2 thin film. The phase and amplitude variations of cross-polarized scattered wave from a unit cell are computed by the developed fast Method of Moments (MoM) in which the dyadic Green's function is evaluated with the transmission line model in the spectral domain. Using the calculated phase and amplitude diagrams, a double-focus lens on the anisotropic thin film is designed in 2 µm. To validate the numerical results, the designed lens is analysed using a full-wave EM-solver. The obtained results show a tunable asymmetric behavior in the focusing intensity of the focal spots for different incident polarizations. It is shown that changing the thickness of anisotropic thin film leads to the changing in such an asymmetric behavior and also the intensity ratio of two focal spots. In addition, the lens performance is examined in the broadband wavelength range from 1.76 to 2.86 µm. It is achieved that the increasing the wavelength leads to decreasing the focal distances of the designed lens and increasing its numerical aperture (NA).

1. Introduction

Typical beam forming devices such as lenses are based on the design of the proper phase shifts along the different light paths. The common way to realize these shifts is using the transparent materials with appropriate optical characteristics and suitable geometries to provide the relevant propagation length. This length is at least comparable to the incident wavelength. This long propagation length is a disadvantage of such devices to use in integrated optics [1]. Furthermore, the transparent materials have some limitations in the mid- and near-infrared frequency regions [2]. Fresnel zone plates can be the alternative of traditional beam focusing devices. Light hitting these devices, which consist of a set of radially symmetric opaque and transparent rings, diffracts around the opaque zones and thereby make the desired focus. However, the large dimensions of Fresnel zone plates are not compatible with integrated optical systems [3]. Fresnel lenses with stepwise discontinuities on their surface have low absorption losses and high numerical aperture. However, the complicated manufacturing process makes it difficult to be used in the integrated optics [4]. To reduce the mentioned shortcomings, ultra-thin planar lenses have been introduced in [1,2] and [5–9] which are composed of sub-wavelength V-shaped plasmonic nano-antennas (VSPNAs) on the dielectric. By proper selection of the features of nano-antennas (e.g. their size, rotation angle, etc.), these elements are able to maintain a pre-described phase shift for the scattered wave and thus to generate a desired wave-front. Analysis and design of such lenses are based on the calculation of the phase response of their unit cells similar to reflect- [10], and transmit-[11] arrays. Obviously, this phase response is affected by the thickness and the properties of the supporting dielectric, as well as the element shape. However, it is desirable to have control over the dielectric anisotropy of the materials as well as the polarization angle of incident light. This can be achieved by mounting planar plasmonic nano-antennas on an anisotropic film in which the optic-axis has various angles with respect to the direction of the incident electric field.

In this paper, we design an ultra-thin double-focus lens using VSPNAs [12] on an anisotropic TiO_2 thin film to examine its tunable behavior. In the design of such structure, the phase variations of 2π are provided by impinging a plane wave to the unit cell and calculating the phase of the cross-polarized scattered wave in terms of physical parameters of the phasing element. To this end, we use an accurate and fast computational technique based on the derivation of the dyadic Green's function used in an integral equation for the induced current densities on VSPNAs. The resultant integral equation is then solved by the Method of Moments (MoM) with the entire-domain basis and Galerkin's test functions. This technique has been recently presented by the authors in [13]. Using the calculated phase and amplitude diagrams, the proper VSPNAs are selected to satisfy the phase profile

* Corresponding author.
E-mail addresses: mahdieh.bozorgi@modares.ac.ir (M. Bozorgi), atlasbaf@modares.ac.ir (Z. Atlasbaf).

http://dx.doi.org/10.1016/j.optcom.2017.01.006
Received 10 October 2016; Received in revised form 13 December 2016; Accepted 5 January 2017
0030-4018/ © 2017 Elsevier B.V. All rights reserved.

of the lens which is obtained with the help of equal optical length principle [7]. The planar lens is designed on the uniaxial anisotropic thin film in which the optic-axis is directed in x-axis. Such a structure is able to focus the reflected and transmitted waves in the back and front focal spots, respectively. To really assess the designed structure in its expected operation domain, the entire of the system is simulated by a full-wave EM-solver based on Finite-Element Method (FEM) for both isotropic and anisotropic materials. The obtained results indicate that unlike the isotropic materials, using anisotropic one leads to the focusing intensity of the focal spots to be different for the TE- and TM-polarized incident light. It is also shown that the lens responses are asymmetric in both the back and front focuses when the normally incident light has symmetric polarization angles with respect to the bisector of V-shaped elements. In other words, one can obtain a tunable optical lens by rotation of the polarization angle of the incident light. In addition, investigating the thickness effect of the anisotropic thin film shows that the changing this parameter leads to changing the mentioned asymmetric behavior and the intensity ratio of the focuses. The wavelength response of this structure is characterized in the broadband wavelength range from 1.76 to 2.86 µm (105–170 THz). It is determined that increasing the wavelength leads to decreasing the focal length and increasing the numerical aperture (NA). The design of an ultra-thin double-focus lens with a thickness of 30 nm, high NA (0.85–0.97), full width at half maximum (FWHMs) of $1 - 1.5\mu m$, and the depth of focuses (DOFs) of $2.4 - 3.4\mu m$, makes it useful for photonic integrated circuits. This structure may have many applications in the photonic devices in which the focusing components are used. Such a structure can be used as a beam steering component, tunable lens, and focusing reflector [14]. In addition, the implemented lens can be used in the laser marking technologies [15].

2. Model description

The quasi-periodic structure considered as a planar lens consists of a 2D lattice of VSPNAs mounted on the uniaxial anisotropic thin film. The unit cell configuration and its design parameters are depicted in Fig. 1. As shown in Fig. 1(a) and (b), when the polarization of the incident light is along the bisector direction of VSPNA, the current distribution of each arm is the same as L/2-length dipole nano-antennas (Symmetric mode). Such a distribution is the same as the one half of L-length ones when the vector of electrical incident field is perpendicular to the bisector axis of VSPNA (Asymmetric mode). In both mentioned modes, the polarization of the scattered field is the same as the incident light. When the VSPNA is illuminated by an incident light with arbitrary polarization, both of these modes are excited and thereby the polarization of the scattered wave is changed with respect to the incident light [12]. Moreover, the cross-polarized component of the scattered wave is significant when the polarization of the incident light has angle 45° with respect to the bisector direction of VSPNA. In this case, the cross-polarized scattered wave of a V-shaped element has π phase shift with respect to the mirror image of the same structure shown in Fig. 1(b) [12]. Such elements are used for the design

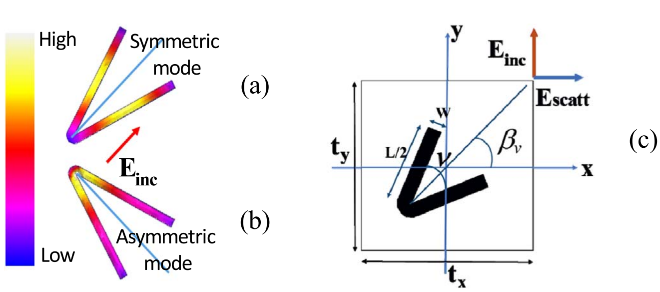

Fig. 1. (a) VSPNA, and (b) its mirror image, with the current distributions for the incident light polarization shown in the figures. (c) A sketch of the unit cell and its design parameters.

of tunable double-focus lens based on the phase response of cross-polarized component of the scattered wave in the following. It should be noted that, throughout this paper, the information of the cross-polarized component of the scattered wave is taken into account for the analysis and design of the lens structure.

The next section deals with the basic steps of the computational technique developed for the design of a planar lens on the anisotropic thin film.

2.1. Method of analysis

The simplified schematic of the unit cell is shown in Fig. 1(c). Such a unit cell is assumed on an anisotropic thin film. The anisotropic material has been studied in [13] to examine the scattering characteristics of the periodic plasmonic nano-antennas. In this work, by the anisotropic material we mean a thin film whose the optic axis is along the x-axis. So, the principal permittivities (ε_E, ε_O, ε_O) are assumed to describe the anisotropic material.

For the analysis, the scattered field is first related to the induced effective surface current density on VSPNA grating by using the procedure mentioned in [13]. Therefore, the following relation must be satisfied on the VSPNA surface:

$$\mathbf{E}_{\tan}^{scat} + \mathbf{E}_{\tan}^{exc} = Z_{eq}\mathbf{J}_{eff}, \tag{1}$$

where $\mathbf{E}^{exc}$ is the exciting electric field in the case of the metallic element is removed, and “tan” refers to tangential component. Note that plasmonic effects must be included in the analysis. To this end, an equivalent impedance matrix of the VSPNA ($Z_{\rm eq}$ in Eq. (1)) is added to the formulation. In reality, the loss of metallic grating due to plasmonic effects can be included in our analysis method by using $Z_{\rm eq}$, which is given by:

$$Z_{eq} = \left(\frac{\mu_0}{\varepsilon_0}\right)^{0.5} N^{-1} \tag{2}$$

in which, N is the complex refractive index of the metal [16]. It is worthwhile to point out here that $Z_{\rm eq}$ in the described formulation is obtained by using an approximation in the Maxwell's curl equations. In [13], it has been demonstrated this approximated value is valid for nano-antennas with the thickness of 25–40 nm in the wavelength range of 0.85–6 µm. These limitations have been taken into account for all of the reported results in this paper.

In the spectral domain, after relating the scattered field to the two components of the surface current density, one can use Eq. (1) to arrive at:

$$-\begin{bmatrix} E_x^{exc} \\ E_y^{exc} \end{bmatrix} = \sum_{m=-\infty}^{\infty}\sum_{n=-\infty}^{\infty} (\widetilde{\mathbf{G}} - Z_{eq}\mathbf{I}_{2\times2})\cdot\widetilde{\mathbf{J}}_{eff}\, e^{j(\alpha_n x+\beta_m y)} \tag{3}$$

where $\widetilde{\mathbf{G}}$ is the dyadic Green's function in the spectral domain and has four components $\widetilde{G}_{xx}$,$\widetilde{G}_{xy}$,$\widetilde{G}_{yx}$ and $\widetilde{G}_{yy}$, while $\widetilde{\mathbf{J}}_{eff} = [\widetilde{J}_x, \widetilde{J}_y]$ is the induced effective surface current density on VSPNAs in the spectral domain. (α_n,β_m) are defined as:

$$\alpha_n = 2n\pi/t_x + k_0 \sin\theta \cos\phi, \tag{4}$$

$$\beta_m = 2m\pi/t_y + k_0 \sin\theta \sin\phi \tag{5}$$

where t_x and t_y are the dimensions of the unit cell in the x-and y-direction, respectively, as shown in Fig. 1(c), k_0 is the free-space wavenumber, (θ, ϕ) are the spherical angles characterizing the direction of the incident plane wave. As far the material of thin film is homogenous and isotropic, the spectral dyadic Green's function appearing in Eq. (3) can be evaluated using the spectral-domain immitance approach described in [17]. Therefore, by means of the MoM, one can solve the above system of integral equation and calculate the induced effective surface current densities on the VSPNAs and thereby the scattered fields. However, for a planar lens on an anisotropic thin film,

Download English Version:

https://daneshyari.com/en/article/5449514

Download Persian Version:

https://daneshyari.com/article/5449514

Daneshyari.com