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A Single Grating-lens Focusing Two Orthogonally Polarized Beams in Opposite Direction

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Abstract. This paper proposes a novel high-contrast grating (HCG) element that simultaneously has two distinct functions; focusing and polarizing. The phase front distribution of a diffracted wave is fitted to that of an ideal conventional lens through properly controlling only the thicknesses of each grating bar. Finally, it is confirmed that the properly designed HCG can be a polarizer as well as a lens in the same time, and the two polarized diffracted waves are focused in the opposite directions

Keywords: Guided-mode resonance, high-contrast grating, optical grating-lens, optical polarizer, polarized diffractive wave

1 Introduction

Resonance-type anomalies in dielectric gratings was first identified and investigated in the early 1990s as a new potential optical element such as laser cavity mirror filter and electro-optic switch [1]. This resonance effect typically occurs in subwavelength regime, where there is only zero-order diffraction and all higher diffracted orders are evanescent wave. The resonances of the evanescent orders can couple to guided waves in dielectric layer. This coupling effect induces the rapid variation of the external fields, and this effect is called guided mode resonance (GMR) effect [2]. Especially, the subwavelength gratings having relatively high refractive index contrasts are called the high-contrast grating (HCG) [3].

The HCG can support merged leaky modes, and leads to form broad resonance regions. In addition, the localized resonances in the HCG create the pronounced modulations for both the transmission and reflection fields. With the development of the nanofabrication technologies, the HCGs have been exploited to design and build various optical elements such as broadband mirrors, tunable HCG-VCSELs and low loss hollow-core waveguides [4]. It has been recently proven that the phase front control can be achieved using non-periodic HCGs. Controlling the local phase responses of a HCG has been applied to many kinds of optical components; blazed grating [5], beam steering [6], polarizers [7] and planar focusing reflectors [8,9].

We proposed here a novel polarizable HCG lens which has a dual function as focusing and polarizing has been designed with considering the thickness controlled HCG structure using the rigorous coupled wave analysis (RCWA) [10] and the finite-

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element method (FEM). On the other hand, it is also possible to obtain proper phase fronts of both the TE and TM polarized lights for the simultaneously focusing operation using the locally controlled grating thickness of HCGs. Its characteristics including the properties for the simultaneously focused two orthogonal polarization states would like to be discussed in this paper. Especially, the suggested HCG element simultaneously focuses both the TE and TM polarized states in the transmitting direction and the reflecting direction, respectively.

2 Theoretical Backgrounds and Structure Design

The polarizable HCG lens suggested in this paper is designed based on the GMR phenomenon. The GMR phenomenon is occurred by coupling between the evanescent diffracted wave and the leaky modes supported by the waveguide grating. According to the GMR theory, the eigenvalues of the waveguide mode resonances for the TE and TM polarized lights are different. So, the GMR-based devices generally have different characteristics between the orthogonally polarized incident lights [1]. Also, the HCG has a relatively wide range of the resonance spectrum, and this spectral range also experiences a relatively large amount of the phase shift [8,11]. From the reason, it could be possible to control the phase front of a diffracted wave using the HCG. Moreover, if a phase front distribution of a diffracted wave is fitted to the one of an ideal conventional lens through properly controlling the grating parameters; the period or thickness of a grating structure, then a focusable HCG can be designed. So, this paper would like to prove that a grating structure having a uniform period and a designed thickness envelope could provide relatively large phase shifts to the two orthogonally polarized lights. As a result, it could be possible that a properly designed HCG can simultaneously have two distinct functions of a polarizer and a lens. Especially, the two polarized diffracted waves are focused in the opposite directions.

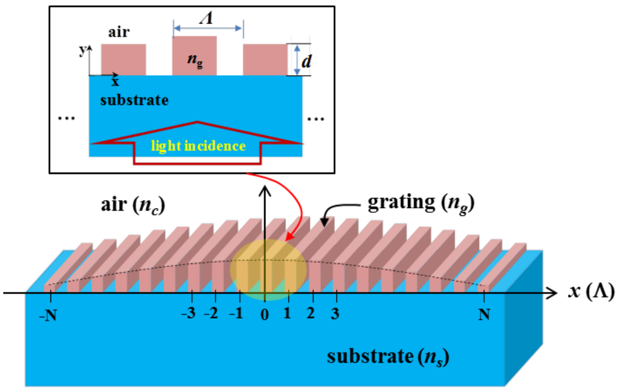

Fig. 1. Schematic structure of the novel polarizable HCG lens which is consisted with a single grating layer having a uniform period and locally varied thicknesses.

Through the ideas explained above, the suggested polarizable HCG lens can be schematically shown in Fig. 1. The HCG structure is formed using silicon material whose refractive index (n_g) is 3.48, and the structure is on the SiO_2 substrate which has a refractive index (n_s) of 1.81. Especially, the HCG structure has a uniform grating period of 676 nm and a uniform fill factor of 68 %. On the other hand, the thicknesses of the grating bars are central symmetrically varied along the x-axis, and each grating bar is indexed as 0, ±1, ±2, … ±*N*, where the index number of 0 is for the central grating bar as shown in Fig. 1.

3 Polarizable HCG Lens

Because the phase response associated with the resonantly scattered light can be used to control the phase front of the reflected or transmitted lights, it is necessary to locally control the grating parameters such as fill factor (*f*), grating period (Λ) and thickness (*d*). In addition, the HCG leads to strongly localized resonance in the grating region and provides a relatively large reflectance bandwidth [3].

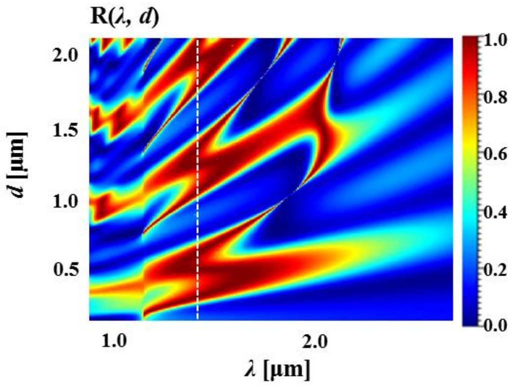

Fig. 2. Calculated Contour plot of reflectance is plotted as a function of wavelength and thickness for a fixed period of 676 nm and a fill factor of 68%.

To obtain a high reflectance (or transmittance) and large phase shift, the spectral characteristics of the suggested structure shown in Fig. 1 is analyzed using the RCWA. Here, a TM polarized plane wave is normally incident to the HCG structure. Figure 2 displays a reflectance map ($R(\lambda,d)$) as a function of wavelength (λ) and d. According to the simulation result, the lowest S-shaped area is a relatively wide area having high reflectance characteristics. In addition, this merged multiple resonance region is expected to obtain large phase shift of almost 2π at a fixed wavelength by tuning local grating thickness, while remaining high reflectance.

The numerical simulation results of the polarizable HCG lens are shown in Fig.3. Simulation results of the polarizable HCG lens with an aperture of 12.627 μm are presented to show its focusing function in the opposite direction for the two orthogonally polarized lights. The two polarized lights having a beam waist of 5.4 μm at the wavelength of 1550 nm are normally incident at the polarizable HCG lens. As results, the TE polarized light is focused on the transmission direction, and the TM polarized light is focused on the reflection direction. The focal lengths which are marked with the white dashed lines are calculated as 16.764 μm and 15.812 μm for the TE and TM polarized incident lights, respectively.

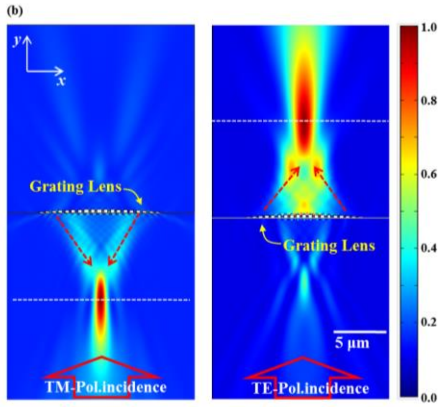

Fig. 3. Numerical simulation results of the polarizable HCG lens.

4 Conclusions

This paper proposes a novel HCG element that simultaneously has two distinct functions such as focusing and polarizing, and its design rules and its performances have been explained using both the RCWA and the FEM. The phase front distribution of the TM polarized diffracted wave is fitted to that of an ideal conventional lens through properly controlling only the thicknesses of each grating bar. The HCG structure having a uniform period and a designed thickness envelope can provide relatively large phase shifts for the two orthogonally polarized lights. Here, the phase variations of both the transmitted light for TE polarized light and the reflected light for TM polarization case are over 2π and over 4π, respectively.

This paper shows the possibility of the polarizable HCG lens using only controlled thickness profile with considering the fabrication convenience and the reliability. The suggested HCG element would be applied to various micro-structural applications such as polarization filters with better coupling efficiencies, optical image processors (CCDs, microscopes, and telescopes) with controlled polarization states, and other diffractive optical applications.

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