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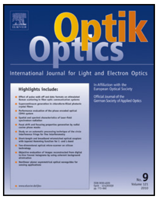

Design of sub-wavelength grating structure for filter regardless of polarization

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ABSTRACT

For isotropic dielectric thin films, polarization effect is an inherent character. As it will make the performance of optical-electric system go to bad, such polarization-dependent properties are often intolerable and should eliminate its effect in many applications. So the design of polarization insensitive filter is an indispensability work. In this paper, based on a four-part period grating, a filter regardless of polarization is gained by combing rigorous wave theory and multiobjective immune optimization algorithm. Its working wavelength is 1315 nm which is often used in laser system. The results of our design shows that TE and TM polarized wave have a reflection 0.482 and 0.485, respectively, at designed wavelength 1315 nm. And it denotes that two values all approach to the design objective good, and the polarization deviation is very little for their difference is 0.003. Therefore, the effect of polarization deviation at 1315 nm wavelength can be eliminated very well by the designed filter.

1. Introduction

When used at oblique angles of incidence, the reflectance and transmittance about S and P light is different [1]. This strong polarization effects is inevitably, and it is desirable property to design polarizer. However, it is undesirable and should be reduced to more applications. Many methods have been used to solve this difficult problem. Most theoretical design procedures are valid for a limited wavelength and/or angular range. And their structure is usually very complicated for too many lay number and kinds of coating materials [2,3]. The design and fabrication of non-polarizing beam splitters is still a challenging topic.

On the other hands, periodic layers and lattices exhibit many particular characters with the development of micro- & nano-technology. Essentially, sub-wavelength grating can be regarded as an equivalent thin film as its period is much smaller than the incident wavelength. Based on this character, sub-wavelength grating have been expected to realize special functions by combining its actual structure with the theory of optical thin film. In this case, some design work based on sub-wavelength grating structure has been greatly simplified. For example, the design process about shallow grating filter [4], resonance Brewster filter [5], transmission or reflection guided-mode resonance filter [6], broadband high reflection mirror [7], antireflection mirror [8,9], etc. The result of these research works are usually operating under normal incidence, and their filtering properties should depend on the polarization of the incident beam.

As the situation about design work to control polarization state based on micro- & nano-grating structure, many papers report the design of polarization beam splitter by using different kinds of sub-wavelength grating [10,11]. But for the design of non-polarization filter, the relevant report is relatively little. Only several design result based on guide-mode resonance effect is report, and which is usually valid under normal incidence [12,13]. In this paper, based on guide-mode resonance effect, combining with rigorous coupled-wave analysis and multi-objective optimization algorithm, a polarization insensitive filter operating at 1315 nm and under 45° oblique incidence is gained.

2. Device structure

Usually, a rectangular groove grating structure is composed of two materials of refractive indices n_H and n_L with duty cycle F. Other features of this kinds of two-part grating are groove depth d and period Λ. A plane wave is normally or obliquely incident at an angle of θ upon the binary dialectic grating. Then the grating is bound by incident media n_0 and substrate material n_S.

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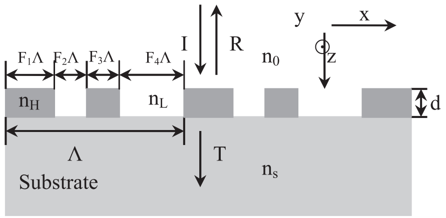

Fig. 1. Scheme of the four-part period waveguide gratings structure.

In this letter, we resort to a different guide-mode resonance configuration, in which each period is composed of two grating ridges with identical width, as shown in Fig. 1. In essence, this four-part period grating enables a rich set of Fourier harmonics with concomitant emergence of additional spectral features not available for the classic two-part period grating.

3. Analysis and design methods

For the proposed structure in Fig. 1, F_1, F_2, F_3, F_4 are the fill factors of different part, respectively. And they satisfy the equation

$$\Lambda = F_1\Lambda + F_2\Lambda + F_3\Lambda + F_4\Lambda \quad (F_1 + F_2 + F_3 + F_4 = 1) \tag{1}$$

Then the spatially modulated permittivity in the grating region can be expanded into Fourier series as

$$\varepsilon(x) = \sum_n \varepsilon_n \exp\left(i\frac{2n\pi x}{\Lambda}\right) \tag{2}$$

where the grating Fourier harmonics ε_n are given by

$$\varepsilon_0 = (1 - F_2 - F_4)\,n_H^2 + (F_2 + F_4)\,n_L^2 \tag{3}$$

$$\varepsilon_n = \left(n_H^2 - n_L^2\right)\frac{\sin[n\pi(1-F_4)] - \sin(n\pi F_2)}{n\pi} \quad (n = \pm 1, \pm 2, \ldots, \pm N) \tag{4}$$

According to the rigorous coupled-wave theory, coupled wave equation can be deduced from Maxwell equations by Fourier expansion of the relative dielectric constant and electromagnetic field in grating region [14,15]. Combining it with boundary condition on both side of the grating, we can work out the eigenvalue and eigenfunction. Then diffraction efficiency and amplitude of different levels diffraction wave in transmission or reflection region can be gained.

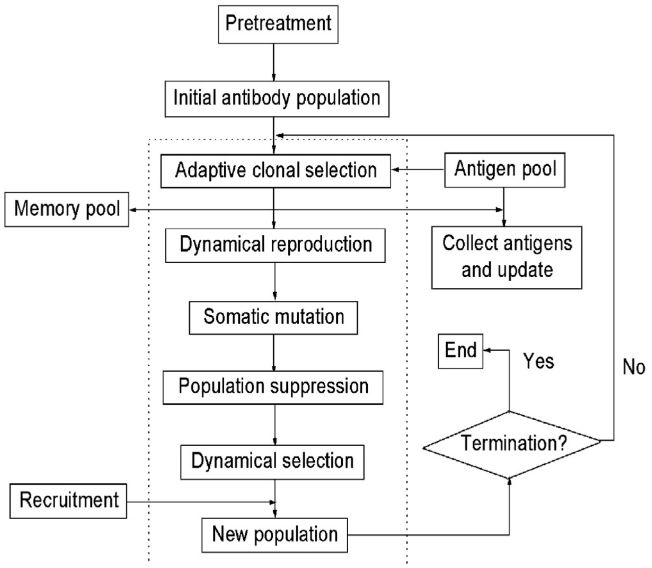

Fig. 2. Flowchart of multi-objective immune optimization algorithm.

ideas of T cell regulation [16]. It includes several vital schemes: constrain handling scheme associated with uniform design reported, specialized antibody affinity design, adaptive antibody evolution mechanism, immune selection, memory pool, antigen pool, and dynamically variable sizes of evolving populations as well. The flowchart of this optimization algorithm is simply drawn in Fig. 2.

High degree of distribution and parallel processing are the features of this type of optimization algorithm, which make it particularly apply to the design problem that the function formula between parameters and objective response is not obvious [17].

4. Design and results

We want to design polarization insensitive filter using multi-objective immune optimization algorithm for 50/50 beam division at the 1315 nm wavelength. Considering some factors in actual application will lead to wavelength drift, we expand the work wavelength region from single wavelength 1315 nm to waveband 1315 ± 20 nm. So we must consider the difference of reflection with different polarization part (TM and TE) in this spectral region. Its mathematical model can be concretely shown as

$$\mathrm{Min\,MF} = \min(\mathrm{MF_{TE}},\quad \mathrm{MF_{TM}})$$

$$\begin{cases} \mathrm{MF_{TE}} = \omega_1\left(\sum_{\lambda=1295}^{\lambda=1335}\left(R^D\left(X^D;\lambda,\theta;\mathrm{TE}\right) - M_{\mathrm{TE}}\right)^2\right)^{1/2} + \omega_2\left(\sum_{\lambda=1295}^{\lambda=1335}\left(R^D\left(X^D;\lambda,\theta;\quad\mathrm{TE}\right) - R^M\left(X^M;\lambda,\theta;\quad\mathrm{TE}\right)\right)^2\right)^{1/2} \\ \mathrm{MF_{TM}} = \omega_1\left(\sum_{\lambda=1295}^{\lambda=1335}\left(R^D\left(X^D;\lambda,\theta;\quad\mathrm{TM}\right) - M_{\mathrm{TM}}\right)^2\right)^{1/2} + \omega_2\left(\sum_{\lambda=1295}^{\lambda=1335}\left(R^D\left(X^D;\lambda,\theta;\quad\mathrm{TM}\right) - R^M\left(X^M;\lambda,\theta;\quad\mathrm{TM}\right)\right)^2\right)^{1/2} \end{cases} \tag{5}$$

If we resort to design polarization insensitive filter based on this four-part period grating, we could make its spectral response meet the requirement of design objective by adjusting its structural parameters (F_1, F_2, F_3, F_4; Λ, d). To find optimal filter parameters, we engage analysis/simulation and design/optimization methods. Thus, we numerically solve fundamental electromagnetic equations with pertinent boundary conditions using the rigorous coupled-wave analysis method first. This method provides the computational kernels in the design process that is rooted in optimization algorithm. In this paper, we adopt a nonlinear multi-objective immune optimization algorithm in the design process. That is proposed based on humoral immune response principle and

where $\mathrm{MF_{TE}}$, $\mathrm{MF_{TM}}$ are sub-objects of the design objective MF, and they corresponding to TE and TM polarization part, respectively. That is really the composes of some objective function formulations have be used in other research fields to handle different optimizations [18,19]. Then ω_1, ω_2 are weight factors. $R^D\left(X^D;\lambda,\theta;\quad\mathrm{TE}\right)$, $R^D\left(X^D;\lambda,\theta;\quad\mathrm{TM}\right)$ are actual calculated reflection value with TE and TM polarized part, respectively. And $R^M\left(X^M;\lambda,\theta;\quad\mathrm{TE}\right)$ $R^M\left(X^M;\lambda,\theta;\quad\mathrm{TM}\right)$ are design target value of reflection with TE and TM polarized part, respectively. In which, λ is the design wavelength and θ is the incident angle. X^D denotes a series of structural parameters (F_1, F_2, F_3, F_4; Λ, d) during design process. It should automatically change according our optimization algorithm