Grating profile optimization for reflection 1st order Littrow mounting

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Summary. One-dimensional multilayer reflection gratings with different groove shapes are considered and optimized for maximum diffraction efficiency in the first order in Littrow conditions. A rigorous formulation for the design optimization problem based on merit function minimization is presented. Nelder-Mead (simplex) method is applied for minimizing the merit function. At each step the direct problem is solved by means of a combination of the incomplete Galerkin's method and matrix techniques.

1 Introduction

Due to its selective special properties and capability of spacial decomposition of waves with different frequencies as well as spacial redistribution of the wave energy, diffraction gratings are extensively applied in modern optical devices, especially in laser systems [1]. Diffraction gratings are widely applied in semiconductor diode lasers for wavelength stabilization as mirrors in external resonators [2] as well as for laser tuning [3]. Another application of diffraction gratings in laser physics is connected with pulse compression in ultrashort high-power lasers that are based on chirped pulse amplifications [4]. In all cases it is crucial to use gratings which are capable of reflecting the incident light at a desired frequency (or wavelength) into one diffraction order with an efficiency as close to 100% as possible and special grating configurations are used, such as Littrow configuration (i.e. the geometry in which the light of a specific wavelength diffracted from a grating into a given diffraction order travels back along the direction of the incident light [1]). In such systems the gratings are traditionally covered with metallic films, or purely metallic gratings are implemented. Being fragile the gratings can be easily damaged, especially by high-intensity laser pulses [5]. To minimize the damage and to ensure reflection into one diffraction order it is desirable to implement entirely dielectric diffraction gratings [6, 7]. This gives rise to a specific problem of grating design and optimization. This problem, with respect to the applications described above has been widely discussed in the literature. However in many cases no optimization problem is solved but only some heuristic considerations are presented. Only several papers (for example [6]) contain rigorous formulation of the design problem in terms of a merit function which is minimized for obtaining the optimized structure. Thus it is very important to provide a rigorous formulation for the grating design problem and apply rigorous non-heuristic methods for obtaining the solution.

2 Problem statement

Within this paper we consider entirely dielectric one-dimensional multilayer reflection gratings with different groove shapes such as binary (Fig.1) and triangular (Fig.2) gratings. As the dielectric grating itself provides only good redistribution of incident wave energy between several diffraction orders, a multilayer dielectric mirror should be used for ensuring good reflectance (schematically presented as green and light green layers in Figs.1,2). The grating is placed on the top of the multilayer dielectric mirror deposited on a substrate (represented as a light brown area in Figs.1,2). The wave is considered to be incident (direction $< i >$) at a grating at some given angle θ. Our goal is to optimize the grating parameters via maximizing the diffraction into the first order for a given wavelength in case of first order Littrow conditions, i.e for the case when the $< i >$ and $< 1 >$ directions in Figs.1,2 are coincident.

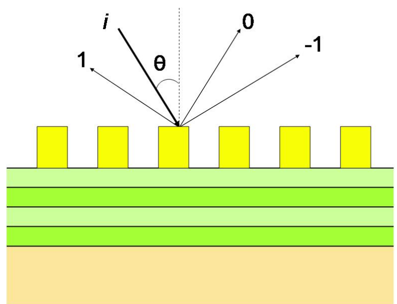

Fig. 1. Binary multilayer grating

3 Optimization algorithm

In each case (binary and triangular gratings) the multilayer grating structure is parametrized. A binary grating is determined by its period, groove depth and

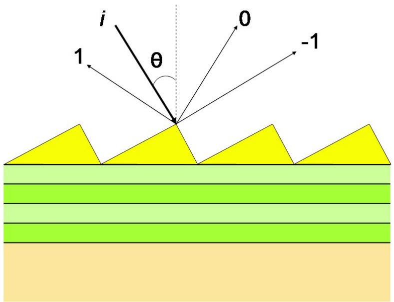

Fig. 2. Multilayer grating with triangular grooves

groove width, a triangular grating is determined by its period and blaze angle. There can be some restrictions on these parameters, apart from trivial physical ones (non-negative values of the parameters), resulting from the following requirements:

- only two diffraction orders (0, 1) should be propagating in both the incident medium and the substrate, all higher orders being evanescent;
- there should be no waveguide modes in the multilayer stack at a a given wavelength and at a given angle of incidence [6].

We provide a grating optimization algorithm based on a merit function minimization (or maximization) in terms of the variable grating parameters given above under the described constraints. The merit function represents the first order diffraction efficiency and should be maximized. Another formulation is also used, such as minimizing of the zero-order diffraction efficiency in case of only two propagating orders (0, 1). The multilayer mirror parameters are optimized independently, providing almost 100% reflectance for a given wavelength and for a given angle of incidence and as a starting point a quarter-wave stack is taken. The merit function minimization algorithm is based on the Nelder-Mead (simplex) optimization [8]. At each step the merit function is evaluated by obtaining the solution of a full-vectorial diffraction problem for Maxwell equations, which is obtained by means of a combination of the incomplete Galerkin's method [9, 10] and matrix techniques such as transfer matrix and scattering matrix methods [11]. These methods provide efficient solution of the problem of wave diffraction on a multilayer grating.

Within this paper we provide multilayer diffraction grating optimization for maximizing first-order reflection in Littrow conditions. Different polarization states (TE and TM polarizations) are considered. The results for gratings with different groove shapes, such as binary and triangular gratings, are obtained and compared with each other.

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