Design of Polarization-Selective DOEs by RCWA method

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In recent decades, with the development of computer modeling techniques and fabrication technologies, especially micro-lithography, it is possible to analyze, design, and fabricate the DOEs in resonance domain where the transverse features are comparable to the operating wavelength. A number of rigorous diffraction theories are introduced such as rigorous coupled wave analysis (RCWA) method, modal method, boundary element method (BEM), finite element method (FEM), finite-difference time-domain (FDTD) method, and so on. In this paper, the analysis and design of polarization-selective DOEs with RCWA method are proposed.

In the RCWA method, a surface-relief grating is divided into a large number of thin layers (typically 50-100) parallel to the surface.[1] Each thin grating is then analyzed by using the state-variables method of solution of the rigorous coupled-wave equations for that grating.[2] Then boundary conditions (continuity of tangential **E** and tangential **H**) are applied to determine the general solution. Both TE and TM polarizations must be considered when one analyzed the polarization properties of that surface-relief grating.

Let us consider a typical retarder that introduces a phase shift between TE and TM components. We can write the Jones matrix associated with the following expression.[3]

$$\hat{W} = \begin{bmatrix} 1 & 0 \\ 0 & \exp(i\delta) \end{bmatrix}.$$

To study the effects of the retarder on which a generically polarized plane wave impinges orthogonally, we consider an incident linearly polarized plane wave whose electric field is at an angle of $\pi/4$ with respect to the x axis. The corresponding Jones vector is as follows

$$\overrightarrow{E_i} = E\begin{pmatrix} 1 \\ 1 \end{pmatrix},$$

where E is a constant amplitude factor. The field emerging from the retarder turns out to be

$$\overrightarrow{E_t} = \hat{W}.\overrightarrow{E_i} = E\begin{pmatrix} 1 \\ \exp(i\delta) \end{pmatrix}.$$

Now, if we set $\delta = \beta x$, with β is a positive constant, $\overrightarrow{E_t}$ can be seen as the superposition of two linearly polarized plane waves with orthogonal polarization states that have different propagation directions lying across the xy plane and an angular separation of $\vartheta = \arcsin(\beta / k)$, where k is the wave number. This element behaves like a polarizing beam-splitter (PBS).

In principle, a polarizing device could be realized by a blazed grating made with a uniaxial birefringent material as in Fig. 2. Moreover, to obtain phase variations that are multiples of 2π for both the TE and the TM polarizations in a period, we have to set

$$k_0(n_{TE}-1)a_0 = 2\pi l,$$
$$k_0(n_{TM}-1)a_0 = 2\pi l',$$

where l and l' are integers, a_0 is the grating thickness, and n_{TE} and n_{TM} are the ordinary and the extraordinary refractive indices of the birefringent material, respectively. From a theoretical point of view, by one's suitably choosing l and l', it is possible to satisfy these conditions for any pair of refractive indices. However, from a practical point of view, l and l' should be small enough that severe restrictions over the possible values of refractive indices are imposed.

It is difficult to find a material that has the exact refractive indices as mentioned above. A possible solution consists of using diffractive microstructures with subwavelength feature sizes, which behave like artificial dielectrics. Instead of changing the grating thickness as for the blazed grating, we keep the thickness fixed, while linearly changing the refractive indices as shown in Fig. 2. It seems to be possible to realize complex optical functions with a DOE when a more complicated grating profile is used.

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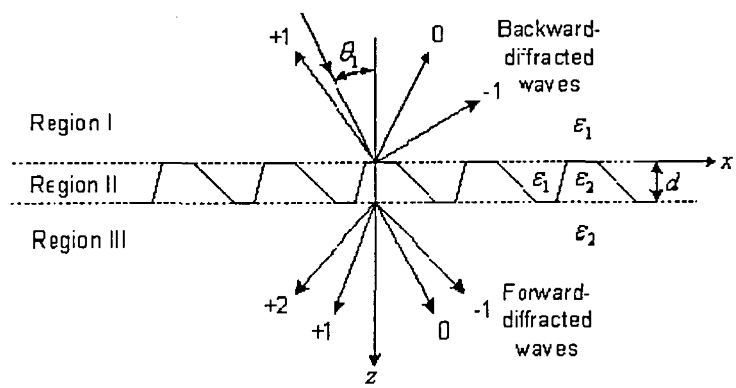

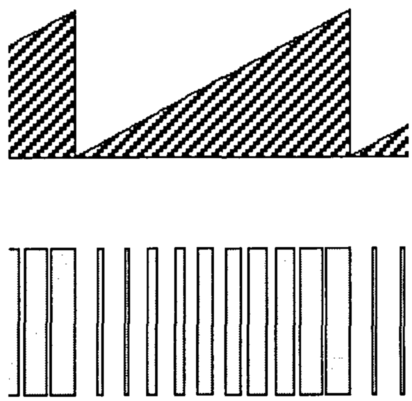

Fig. 1 Geometry of dielectric surface-relief grating

Fig. 2. From the birefringent blazed grating to the equivalent subwavelength binary grating

[1] M. G. Moharam, "Diffraction analysis of dielectric surface-relief gratings," *J. Opt. Soc. Am.*, vol. 72, no. 10, pp. 1385-1392, 1982.

[2] M. G. Moharam, "Rigorous coupled-wave analysis of planar-grating diffraction," *J. Opt. Soc. Am. A*, vol. 71, no. 7, pp. 811-818, 1981.

[3] Bahaa E. A. Saleh, Fundamentals of photonics (Wiley, New York, 1991).