Spectral Bragg Filter with a Synthesized Transfer Function

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We suggest the technique of phase-shift keying to synthesize the spectral transfer function of an optical filter. The phase-shift keying consists in the formation of a reflection grating with several grating cells of equivalent period and amplitude, but different phases. Using a dynamic holographic grating as a filter, we demonstrate various transfer functions.

1 Introduction

Narrow band spectral filters are required for wavelength division multiplexing (WDM) in optical telecommunications. Spectral Bragg Filters with only one tunable maximum of the transfer function have been realized already by various methods based on the change of the grating period by the angles of the recording geometry [1], or the change of the mean refractive index by mechanical stress [2] and electric field [3]. The new method of phase-shift keying of Bragg gratings changes neither the grating period nor the mean refractive index, but consists of phase shifting several sections (cells) of the grating. This Bragg filter is not restricted to a transfer function with one maximum, but it allows to synthesize the transfer function, i. e. by the choice of the phases the shape of the transfer function can be fitted to a desired transfer function. Using this technique we present transfer functions having two maxima of different separation or a variable number of maxima. Fig. 1 illustrates a phase-shift keyed reflection Bragg grating consisting of N sections (cells) having same grating period and grating amplitude, but different phases. The Bragg grating is used as a spectral filter by illuminating the grating perpendicular to the grating planes. It is useful to define the transfer function of the Bragg grating as $\xi(\lambda)=A_{refl}(\lambda)/A_{in}$, where A_{in} and A_{refl} is the complex amplitude of the incident light and the reflected light, respectively, as a function of the wavelength λ. The experimentally observed quantity is the diffraction efficiency $\eta(\lambda)=|\xi(\lambda)|^2$.

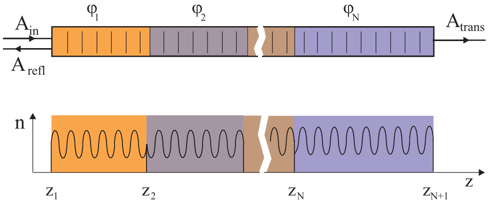

Fig. 1 *Read out geometry and principle of a phase-shift keyed Bragg grating. A_{in}, A_{refl} and A_{trans} are the complex amplitudes of the incident, reflected and transmitted beam, respectively. z_m and z_{m+1} for m=1, ..., N are the boundaries of the m-th grating cell having a phase shift of φ_m. n is the refractive index.*

2 Experimental Setup

Fig. 2 shows the experimental set-up to realize phase-shift keyed Bragg gratings. The grating is generated by the illumination of a photorefractive $BaTiO_3$ crystal (9) by the interference pattern of two coherent laser beams of a Nd:YAG laser (1) of 532 nm wavelength. The Bragg wavelength of the grating is adjusted by the angle 2θ between the recording beams. The phase-shift keying is realized by a liquid crystal cell (11) with 8 electrodes of 270 µm width and 30 µm spacing. By the AC voltage at the electrodes the phase shift of 8 grating cells of same length can be controlled. The diffraction efficiency as a function of the wavelength is measured by a tunable IR laser (5) and a IR photo diode (10). This setup allows to reconfigure the spectral Bragg filter within 3s and to observe the reconfiguration of the transfer function online.

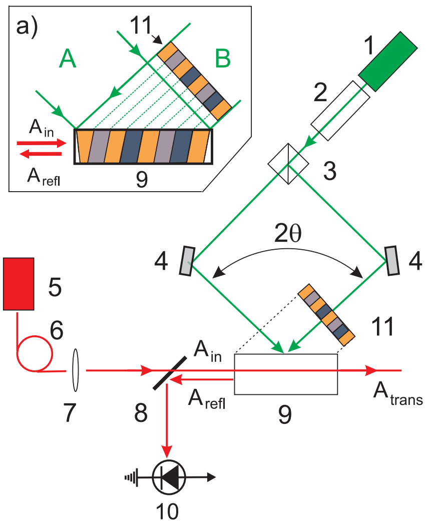

Fig. 2 *Experimental set-up: 1, Nd-YAG laser; 2, beam forming system; 3, beam splitter; 4, mirrors; 5, tunable readout laser; 6, single-mode optical fiber; 7, collimating lens; 8, IR beamsplitter; 9, $BaTiO_3$:Co crystal; 10, IR photo detector; 11, liquid crystal phase modulator. a) The phase modulator (11) with 8 cells and the crystal; A, B are the recording beams.*

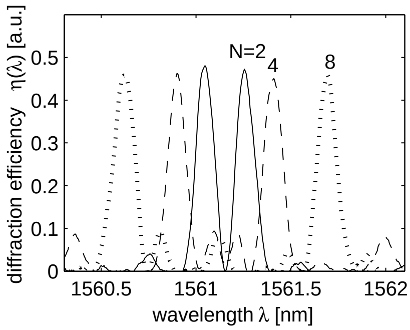

Fig. 3 *Separation of two maxima of the transfer function. Experimental dependence of the diffraction efficiency $\eta(\Delta\lambda)$ for the phase-shift keying with N cells of equal length and phases (0°, 180°, 0°, 180°, ...). The grating length is unchanged.*

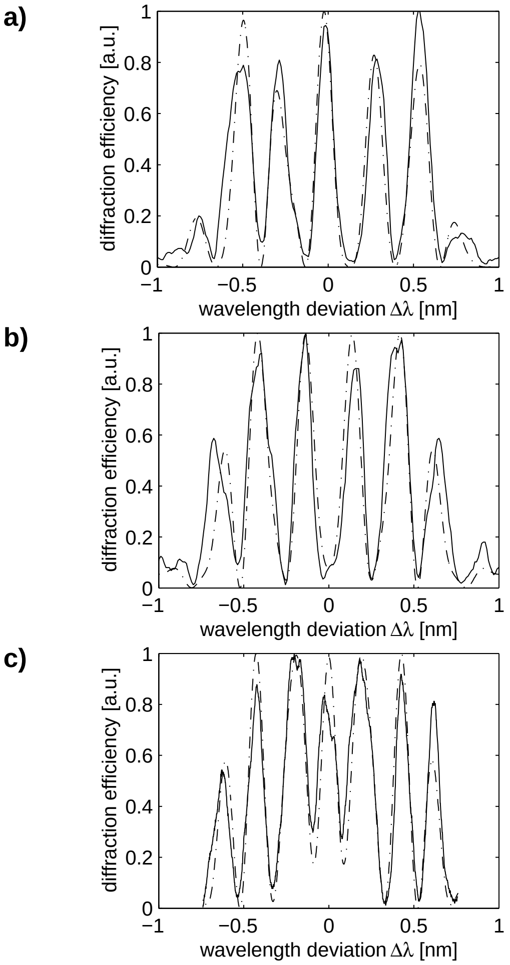

Fig. 4 *Experimental dependence of the diffraction efficiency $\eta(\Delta\lambda)$ on the wavelength deviation $\Delta\lambda=\lambda-\lambda_0$ from the Bragg wavelength with 5, 6 and 7 peaks (solid line). For the theoretical $\eta(\Delta\lambda)$ (dashed line) the grating length T=4 mm and the Bragg wavelength a) λ_0=1560.69 nm, b) λ_0=1560.70 nm, c) 1560.64 nm have been fitted to the experimental data. The phase-shift keying with 8 cells of equal length and the following phases have been used: a) (318°, 18°, 185°, 35°, 318°, 18°, 185°, 35°), b) (278°, 37°, 184°, 106°, 106°, 184°, 37°, 278°), c) (278°, 394°, 274°, 193°, 193°, 274°, 394°, 278°). Each curve has been normalized to its maximum.*

3 Results

Fig. 3 shows the diffraction efficiency η as a function of the wavelength λ for the phase-shift keying with N=2, 4 and 8 cells of same length, which have phases alternating between 0° and 180° from cell to cell. Keeping the grating length unchanged the separation of the two maxima can be controlled by the number N of phase-shifted cells. The separation of the maxima is 0.21 nm, 0.51 nm and 1.07 nm, respectively. This spectral Bragg filter can be applied to select two channels of a WDM system.

A multi-passband filter with a variable number of passbands can be accomplished by phase-shift keying with 8 cells of equal length and numerically calculated phases. The dependence of the diffraction efficiency on the wavelength with 5, 6 and 7 maxima is shown in Fig. 4a), b) and c). The used Bragg gratings differ only in the phases of the phase-shift keying. The experimental results (solid line) are in good agreement with theory (dashed line). Theoretical calculations show that more advanced transfer functions are possible with higher number of cells [4].

4 Conclusion

By the new method of phase-shift keying, which allows to synthesize the transfer function of a spectral Bragg filter, various transfer functions have been demonstrated experimentally. Due to the use of $BaTiO_3$ as recording material and a liquid crystal cell as phase modulator the transfer function is reconfigurable within 3s.

References

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