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Efficient design of spatially symmetric Bragg gratings for add/drop multiplexers

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Abstract

A simple and fast numerical procedure is presented for designing spatially symmetric Bragg gratings with no need for iteratively solving the coupled mode equations. Using a unique relation between the phase and the amplitude of the reflection spectra valid for spatially symmetric gratings, the grating spectra are suitably optimized to fit given specifications. At the end of the design process an inverse-scattering algorithm determines the spatial structure of the corresponding Bragg grating. This method is particularly useful for the design of add/drop multiplexers, where symmetry can be a crucial prerequisite.

Keywords: Bragg gratings; Inverse scattering

1. Introduction

The discovery of the photosensitivity of germanium-doped silica by Hill et al. in 1978 [1] was the starting point for the research on fiber Bragg gratings (FBGs). These first gratings only had a limited area of applications at that time, because the grating period was determined by the writing wavelength. In addition the refractive index modulation was constant over the grating length. These drawbacks were avoided by the external writing method proposed by Meltz et al. in 1989 [2]. With this technique the Bragg wavelength is nearly independent from the writing wavelength and the local grating period and strength can be customized along the grating length.

Based on this full freedom for the realization of the spatial grating structure, Bragg gratings are now used for variety of different applications both in fibers and planar waveguides [3]. Their wavelength selective transmission and/or reflection properties are used for instance in wavelength division multiplexers/demultiplexers [4], in fiber lasers and amplifiers [5], in photonic signal processors [6], as sensor elements [7] and as compensation elements for chromatic [8] and polarization mode dispersion [9].

In all of these applications the Bragg gratings have to fulfill certain spectral requirements. For the use in lasers the power reflection/transmission spectra are the most interesting properties. For Bragg gratings in add/drop-multiplexers, however, the phase characteristics are also of importance, as they determine the dispersion properties of the final device. When designing Bragg gratings one has to to find a spatial grating structure which fulfills these given spectral requirements. The relations between the spatial grating structure and the grating response are sketched in Fig. 1.

The coupled mode equations governing the properties of waveguide Bragg gratings have been established many years ago [10]. In these equations the properties of the quasi-periodic grating structure are specified by a spatially varying complex coupling coefficient $\kappa(z)$, the absolute value of which describes the local grating strength while its phase is associated with the local grating period [10]. Solving these

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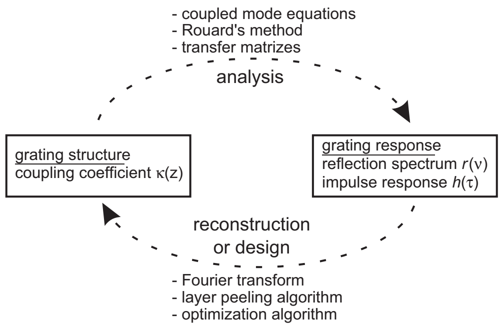

Fig. 1. Relations between spatial grating structure and grating response.

equations yields the transmission and reflection properties for the grating under consideration. The spectra of Bragg gratings with arbitrary local grating strength and period can be determined by dividing the grating into sections with constant grating strength and period. Each of these sections is described by a transfer matrix of a uniform grating and the transfer matrix of the full structure is the product of all individual matrices [11]. From this matrix the transmission, reflection, group delay and chromatic dispersion in transmission and from both reflection sides can be calculated.

It is also well-known how to tackle the inverse problem of finding the necessary $\kappa(z)$ for a prescribed complex reflection factor $r(\lambda)$: it is solved by using inverse-scattering algorithms. A review of existing methods is given in [12]. The layer-peeling algorithm is one of the best-suited methods and a brief introduction will be presented in Section 3.

2. Bragg gratings for add/drop multiplexer

One important application area for Bragg gratings are add/drop-multiplexers. In contrast to demultiplexers, like, for instance, arrayed waveguide gratings [13], one or several wavelength channels are dropped from the transmission link. In addition, the same wavelength channels can also be added to the data stream, see Fig. 2(a). This functionality makes an add/drop-multiplexer perfectly suited for its use in modern telecommunication networks. Such a device was already proposed in the introductory paper of integrated optics in 1969 [14].

One realization of an add/drop-multiplexer is shown in Fig. 2(b) [4]. It consists of a Mach–Zehnder interferometer with two identical Bragg gratings written into the two interferometer arms. The four ports are usually labeled as follows; port ①: input, port ②: drop, port ③: add, port ④: output. For all wavelengths outside the reflection bandwidth of the gratings this device acts as a Mach–Zehnder interferometer. If the interferometer arms are properly balanced all the power of these wavelengths is transmitted to the output port and no light will emerge at the add port. For the wave-

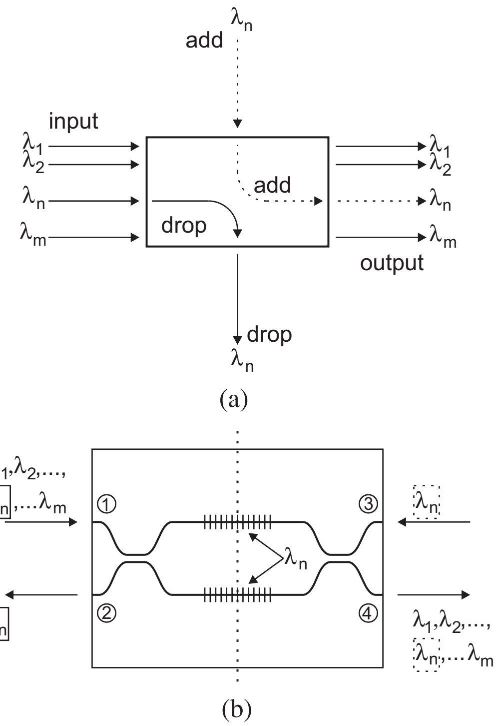

Fig. 2. Network function of an add/drop-multiplexer and schematic realization based on a Mach–Zehnder interferometer. The device is symmetric with respect to the dashed line.

lengths inside the reflection bandwidth of the gratings this device resembles a Michelson interferometer. If the phase difference between the reflected waves at the first coupler is properly adjusted, all the reflected power from the gratings emerges at the drop port. The device is symmetric with respect to the dashed line, so the same functionality is required to be provided from the add to the output port and enables an adding of wavelength channels to an existing data stream.

The systems specifications for a Mach–Zehnder interferometer-based add/drop-multiplexer, suitable for a 10 Gbit/s WDM system with a 100 GHz channel spacing, were given by ALCATEL [15]. The parts related to the used Bragg gratings are shown in Fig. 3.

Three different spectral regions with respect to the Bragg wavelength are defined in the specifications. In the range of ± 10 GHz$=\pm 0.16$ nm centered around the Bragg wavelength at 1550 nm the following specifications are valid:

- Transmission below -40 dB,
- Reflection higher than -0.5 dB,
- Chromatic dispersion in reflection lower than ± 15 ps/nm.

In the ranges more than ± 75 GHz $= \pm 0.6$ nm off the Bragg wavelength the following specifications are valid:

- Transmission higher than -0.5 dB,
- Reflection below -25 dB,
- Chromatic dispersion in transmission lower than ± 15 ps/nm.