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Research Report

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Abstract

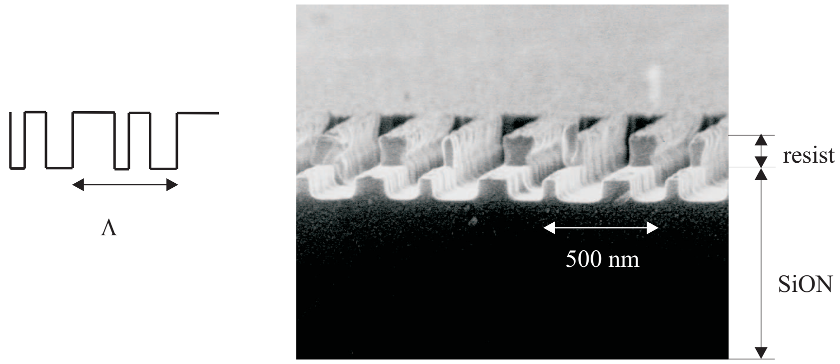
We present the apodization of the spectral response of surface-corrugated Bragg gratings by a concatenation of dual modulation gratings. The resulting response is optimized by an evolutionary algorithm within the experimentally determined parameter space.

1. Introduction

The use of wavelength division multiplexing (WDM) requires optical filters for adding and dropping single wavelength channels at certain network nodes. Bragg grating based filters[1] are an attractive choice when the requirements for intra-channel crosstalk are stringent. But uniform Bragg gratings suffer from large side lobes in their spectral response, which deteriorates the inter-channel crosstalk or causes poor bandwidth utilization. A side lobe reduction is possible by altering the coupling strength according to a bell-like function along the grating[2]. In the case of surface-corrugated gratings with constant etch depth this may be done by the concatenation of gratings with different duty cycles as has been suggested by Sakata[3] for codirectional couplers and Little[4] for contradirectional coupling. In this paper we describe a generalization of the duty cycle variation, namely the use of dual modulation grating patterns that consist of two grating ridges per grating period. We present the results of a feasibility study we have performed to determine possible patterns. The spectral response of concatenated gratings designed in this manner is simulated and optimized with an evolutionary algorithm that will briefly be described. The optimization leads to simulated gratings with a band width utilization of 50% at an intra-channel crosstalk of better than -30 dB and an inter-channel crosstalk of better than -20 dB. The corresponding taper function differs remarkably from the well-known classical taper functions.

2. Apodization scheme and feasibility study

The coupling coefficient between the forward and backward traveling modes in a Bragg grating is given by the overlap of the first Fourier coefficient of the periodic dielectric waveguide perturbation with the field amplitudes. Obviously the Fourier coefficient is smaller, the more the duty cycle of the grating deviates from 50%. The minimum coupling strength is therefore determined by the minimum ridge and groove sizes, respectively, that can be realized. Estimations using the minimum ridge width we have produced (50 nm) and a grating period of 520 nm yield a minimum coupling coefficient that is still around 40% of the maximum coupling coefficient. The achievable coupling strength variation is thus very limited. To overcome this problem and to synthesize weaker gratings we have extended the idea of varying duty cycles by using also grating patterns with two grating ridges and grooves per period as is schematically shown in Figure 1a.



(a) (b)

Fig. 1. (a) Schematic drawing of a grating pattern with two ridges and grooves within one period, (b) SEM image of such a grating pattern written by e-beam lithography and etched 100 nm deep into SiON.

To find the experimental constraints and the range of possible coupling coefficients we have written several of these grating patterns. SiON waveguides were grown by PECVD and annealed before undergoing electron-beam lithography. Details of the process technology can be found elsewhere[5]. We used an IBM Vector Scan e-beam lithography system to pattern the gratings in 300-nm-thick PMMA resist, and CHF_3/O_2 reactive ion etching to transfer them 100 nm deep into the core. Given that the grating feature widths are constrained to the e-beam system's discrete addressing grid, we were able to write 19 different grating patterns allowing a variation of the coupling coefficient from 1 to 10 cm^{-1}.

3. Simulation and optimization of the spectral response of the concatenated grating filter

To taper the grating strength according to a bell-like function we concatenate subgratings with different patterns in ascending grating strength order towards the middle of the grating. We compensate for the undesired impact of the different grating patterns on the average refractive index and hence on the resonance wavelength by changing the waveguide width accordingly. We simulated the spectral response of the grating with the transfer matrix method using effective refractive indices[6]. The spectral response of the apodized Bragg grating was optimized by a variation of the subgrating lengths, except for the length of the middle subgrating that was chosen to keep the total grating strength $\sum_{i=1}^{19} \kappa_i L_i$ constant. The objective is a grating with an intra-channel crosstalk of better than -30 dB within a bandwidth of 0.4 nm and an inter-channel crosstalk as small as possible outside a bandwidth of 0.8 nm.

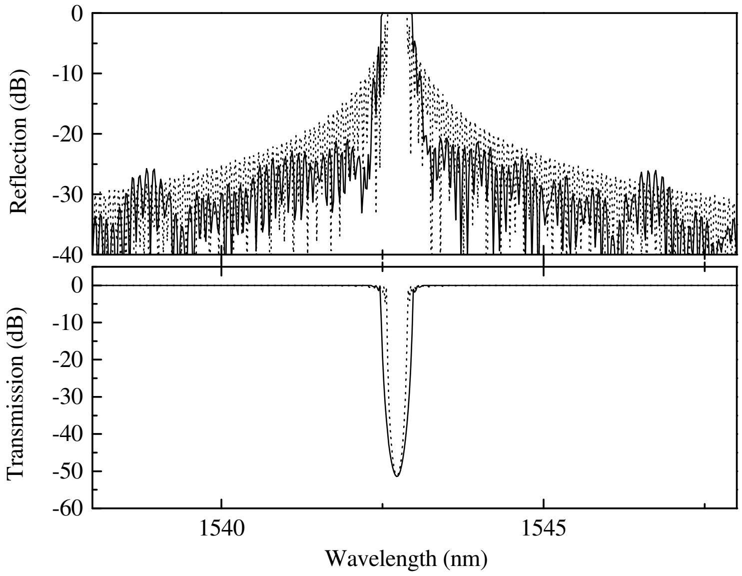


Fig. 2. Simulated spectral response of a concatenated grating (solid line) and of the equivalent uniform grating (dotted line). Both gratings are 11 mm long.

To define the quality of the grating we determine those points within the simulated wavelength grid for which the specifications are not fulfilled and take the sum of the overstepping. The fitness of an individual grating is then taken as the inverse of this sum. Because of its potential for finding global extrema of non-convex functions we have used a breeder genetic algorithm for the optimization[7]. This algorithm mimics the process of evolution by applying operators for reproduction, crossover and mutation to a set of different concatenated gratings called population. The individual subgrating lengths are represented as bit strings. Initially 50 concatenated gratings (individuals) are created randomly to form the starting population.

From this population two individuals are chosen with a probability that increases with increasing fitness of the individuals. Two offsprings are generated by a standard two-point crossover and "mutated" afterwards by reinitializing individual bits with a small probability. The new bit strings are then inserted into the population and the two worst individuals of this extended population are dropped. This algorithm has been successfully applied to the optimization of non-periodic optical structures[8,9]. We have also optimized grating responses with a conventional optimization scheme, namely the simplex-down-hill method using a discretization of a well-known taper function such as a raised sine as a starting guess. It turns out that the simplex-down-hill method does not lead to as good of gratings as the evolutionary algorithm due to the nonmonotonical fitness function. It is advantageous though to refine the solution found by the evolutionary algorithm by an appended conventional optimization. Figure 2 shows the simulated spectra of an optimized concatenated grating consisting of 19 different patterns (solid line). The dotted line corresponds to a uniform grating with the same average strength and the same length. The side lobes outside the 0.8 nm band are successfully reduced to less than -20 dB compared to -9 dB for the uniform grating. Figure 3 shows the coupling strength distribution of the optimized grating together with conventional continuous taper functions[10]. It is apparent that the optimized taper function differs significantly from a discretization of any of the other taper functions. Hence the use of a discretized conventional taper function is not sufficient even when optimized with a conventional optimization scheme.

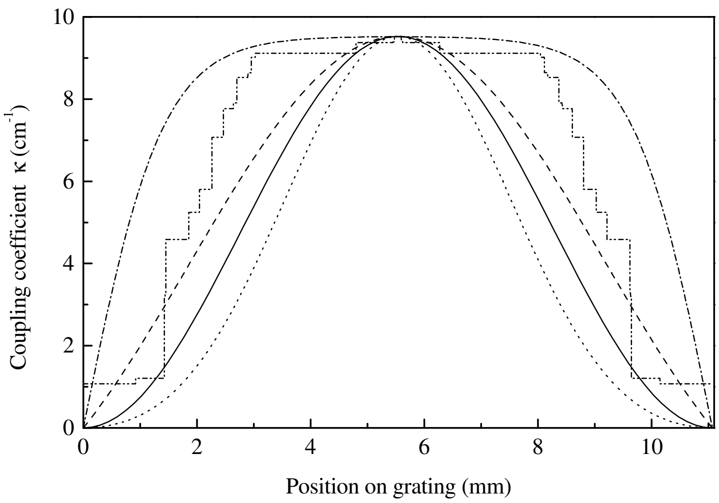


Fig. 3. Coupling strength distribution along the grating for the optimized concatenated grating (dash–double dotted line) and several conventional taper functions (Blackman function (dotted line), raised sine (solid line), sine (dashed line), positive hyperbolic-tangent profile (dash–dotted line)).

4. Conclusion

We have presented a method to synthesize apodized surface-corrugated gratings by the concatenation of dual modulation patterns. These concatenated gratings have been simulated and optimized towards a rectangular filter function by means of an evolutionary algorithm. The parameter space for the optimization has been determined with a feasibility study. The simulated spectral response of the optimized grating complies with an intra-channel crosstalk of -30 dB and an inter-channel crosstalk of better than -20 dB for a bandwidth utilization of 50%. A comparison with experimental results will be presented at the conference.

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