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Analysis of Designing Multichannel Fiber Bragg Gratings with Different Inverse Design Algorithms

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We have analyzed different inverse design algorithms for the synthesis problems of fiber gratings. An example of dense wavelength-division-multiplexing (DWDM) multichannel fiber Bragg grating (MCFBG) for optical fiber communication was synthesized and simulation results were analyzed and compared with use of the discrete layer-peeling (DLP) inverse scattering algorithm and Lagrange-multiplier constrained optimization (LMCO) algorithm. Simulation results show the LMCO method was more flexible than the DLP method.

Keywords: multi-channel fiber Bragg grating (MCFBG), discrete layer-peeling (DLP) algorithm, Lagrange-multiplier constrained optimization (LMCO) algorithm

1. Introduction

Due to the increasing demand for transmission capacity, the channel spacing of two adjacent dense wavelength-division-multiplexing (DWDM) channels has been as small as 50/25 GHz because of limited by the bit rate. For such small channel spacing, it is not easy to build narrow-bandwidth OADM/MUX/DEMUX filters that can separate different channels with small cross-talks and large usable bandwidth ratios. The fiber Bragg grating (FBG) based device technology is one of the available technologies that can meet the required performance. Among these filters, superstructure or sampled FBGs are especially attractive for DWDM applications in the existing long-haul fiber network due to their comb and multichannel spectrum responses.[1,2] However, in comparison to a single channel grating, manufacture of an N-channel FBG device requires greater variation of the photo-induced refractive index change. In fact, it has been shown that the total index change is directly proportional to the number of constituent gratings to be written, N times higher than a single channel grating.[2] Since the maximum index change in a silica glass by UV irradiation is on the order of 0.001, there is an upper bound in the practical fabrication on the number of gratings that can be written by the superposition method. By employing the powerful inverse design methodology, it is possible to design multichannel FBG (MCFBG) filters with large channel numbers. The designed MCFBG filters that can achieve the best performance are typically multi-phase-shifted FBGs with complicated profiles of coupling coefficients and long lengths. Special UV exposure setups are thus required to fabricate these complicated devices with the targeted performance. In 2003, Li and Sheng presented the inverse scattering discrete layer-peeling (DLP) algorithm for the direct design of multichannel fiber gratings with an additional simulated annealing optimization process for different channel phases.[3] Recently, the Lagrange-multiplier constrained optimization (LMCO) algorithm has been utilized to design MCFBGs for DWDM technology.[4] The proposed LMCO method constrains various parameters of the designed devices for practical application demands through a user-defined functional cost. The user-defined cost function in the proposed method can be able to define to meet demands of the designed devices for practical fabrication, for example, shorter grating length, lower index modulation of the grating. Although the complicated fiber grating based filters; especially MCFBGs, can be inversely designed using the above methods, however, the compared simulation results and theoretical discussions of the problems of such inverse design for complicated fiber gratings have not appeared in published papers so far. Therefore, in this paper, a comparative analysis of designed MCFBGs with the DLP and LMCO inverse design algorithms is presented. Our simulation results for the synthesis of the designed filters found that, when compared to the DLP algorithm, the LMCO method can easily embed various constraints in the cost functional of the algorithm for more flexible on the designed characteristics. Moreover, by varying the weighting parameters in the user-defined cost functional, the index modulation requirements can be controlled to meet practical fabrication conditions using the commercially available photosensitive fibers.

2. Discussion of Design Methods for MCFBGs and Results

Simulation results of the synthesis of MCFBG filters with the LMCO algorithm and the DLP algorithm, which have been successfully used in designing various fiber grating filters,[3,4] were compared and analyzed. Several MCFBGs with the two methods and having different grating length, channel number and bandwidth were synthesized; their target spectrum of the reflectivity can be easily set as follows

$$r = \sum_{m=-N/2}^{N/2-1} r_0 \cdot \exp\left(-\left\{ \frac{\lambda - \left[\lambda_c + \left(\frac{2m+1}{2} \right) \cdot \Delta_{CS} \right]}{\Delta\lambda} \right\}^{20} \right) \tag{1}$$

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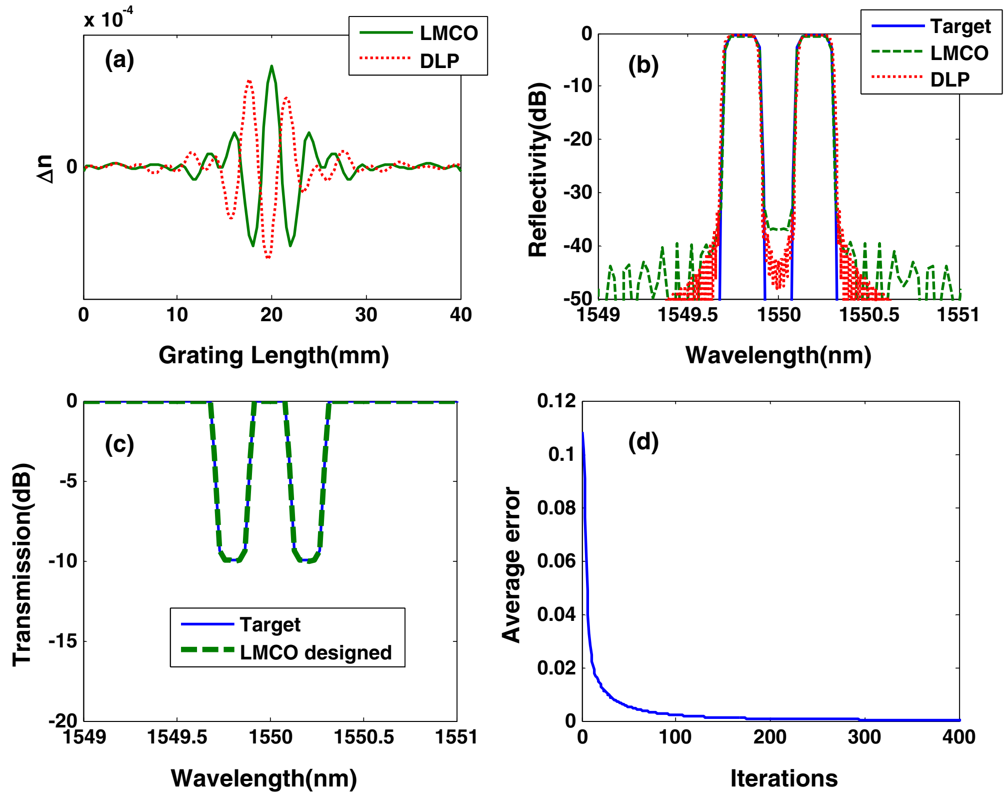

Fig. 1. (Color online) (a) Apodization profile of the index modulation for two-channel MCFBG by using DLP and LMCO methods, (b) reflection spectra, (c) transmission and target spectra, and (d) average error for the designed MCFBGs by the LMCO method.

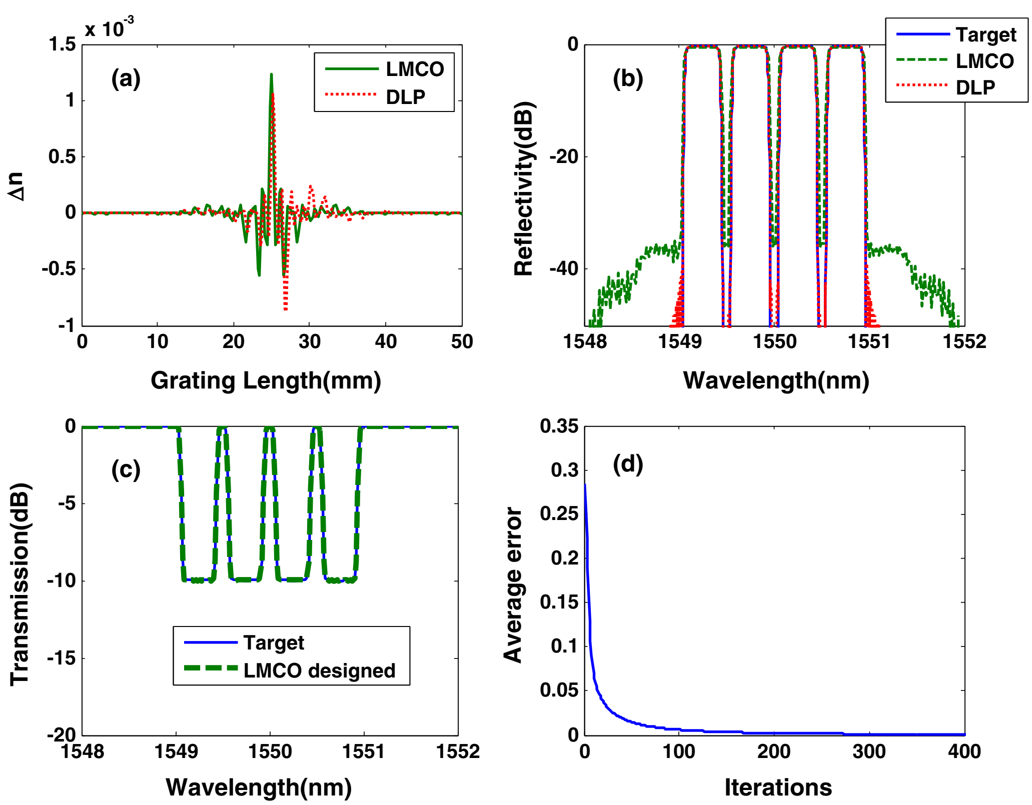

Fig. 2. (Color online) (a) Apodization profile of the index modulation for four-channel MCFBG by using DLP and LMCO methods, (b) reflection spectra, (c) transmission and target spectra, and (d) average error for the designed MCFBGs by the LMCO method.

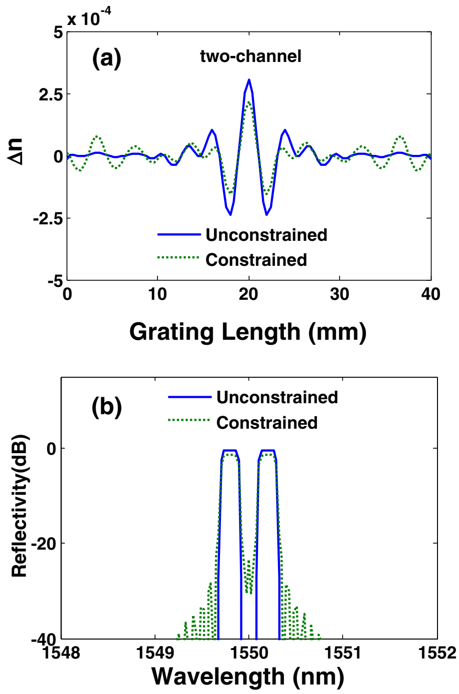

Fig. 3. (Color online) (a) Designed index modulation profiles for unconstrained and constrained conditions and (b) the corresponding reflectivity spectra for the two-channel MCFBGs with LMCO method.

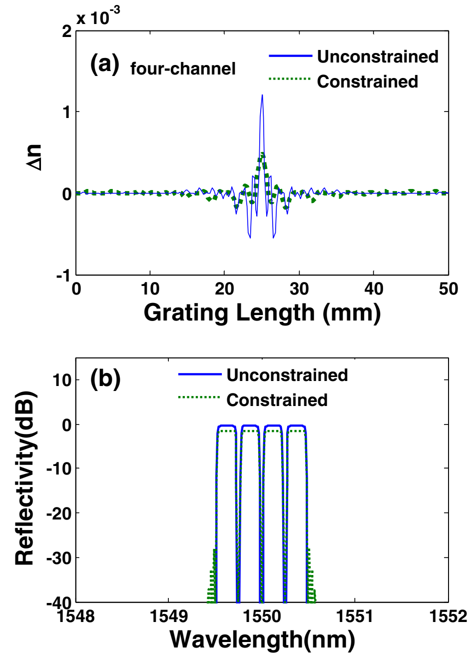

Fig. 4. (Color online) (a) The designed index modulation profiles for unconstrained and constrained conditions and (b) the corresponding reflectivity spectra for the four-channel MCFBGs with LMCO method.

where N is the total number of channels, r_0 is the maximum reflectivity, λ_c is the central wavelength, Δ_{CS} is channel spacing, and $\Delta\lambda$ is the bandwidth for each channel. The central wavelength is set to be 1.55×10^{-3} mm (1550 nm). The units of λ and L are mm, and $\kappa(z)$ is mm^{-1}. In the LMCO algorithm for synthesizing MCFBGs, α is an *ad hoc* constant and β is a weighting parameter which is zero for unconstrained conditions and nonzero for the constrained coupling coefficient design. The constraint on the value of the coupling constant can be more further with the sacrifice of the reflectivity spectrum quality by increasing the values of the weighting parameter β.

Figure 1 shows the simulation results of two-channel MCFBG where $N = 2$ with Δ_{CS} is 0.4 nm and $\Delta\lambda$ is 0.2 nm in -3 dB, designed using the DLP and LMCO methods. The results show the apodization profile (Δn) of the LMCO method as being more symmetrical and less complicated than that with the DLP method. In the following design example, a four-channel MCFBG, $N = 4$, with grating length 50 mm, Δ_{CS} 0.5 nm and $\Delta\lambda$ 0.4 nm in -3 dB, is synthesized. The simulation results appear in Fig. 2. Again, the designed reflection spectrum very well agrees with the target spectrum with either LMCO or DLP method.

It is worth noticing, in the above MCFBGs synthesis with the LMCO method, the weighting parameter β is zero for the unconstrained design. To further decrease the maximum value of the index modulation, $\beta = 1 \times 10^{-7}$ is used to control the maximum index modulation in the apodization profile. In Figs. 3 and 4, it can be seen that the maximum index modulation of the designed MCFBG could be significantly decreased by slightly sacrificing the channel reflectivity.

3. Conclusions

In conclusion, we have analyzed the simulation results of synthesis of DWDM MCFBGs filters with DLP and LMCO methods. When compared to the existing results from the powerful DLP method, except for the slightly longer computation time, a number of advantages in using the LMCO approach to solve the inverse design problems of MCFBGs have been identified. These advantages include the possibility of constraining the patterns of the coupling coefficient profiles, constraining the fiber grating length, and obtaining better solutions by skillfully arranging the weighting parameters regarding cost. These flexible features certainly have great merit in the design of practical fiber grating devices with special requirements.

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