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Optimization for Arrayed Waveguide Grating having MMI Coupler for Flattened Transfer Function

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This paper describes an efficient optimal design method for an arrayed waveguide grating (AWG) having MMI coupler with flattened transfer function. The objective function is the norm of the difference between calculated and target spectra. To analyze the AWG transfer function, the Fresnel-Kirchhof diffraction formula was employed and the design variable was optical path difference of each array waveguide. The (1+1) Evolution Strategy was applied to an eight-channel coarse wavelength division multiplexing (CWDM) AWG as the optimization tool. For obtaining a broadened spectrum, we use a MMI coupler and the variation in optical path difference at each array waveguide changes the shape of the transfer function to obtain the optimal spectrum shape.

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I. INTRODUCTION

Integrated multiple wavelength filters are being developed for coarse wavelength-division multiplexing (CWDM) telecommunications and computer networks. In particular, arrayed-waveguide gratings (AWGs) have already proven to be critical components for many applications for passive and active routing of optical networks [1], [2]. In order to allow the concatenation of many such devices and to relax requirements on accurate wavelength control in a network, their spectral response must necessarily be accurately designed. Many techniques that have been introduced in order to design the spectral response of an AWG have been aimed at achieving a broadened or flattened transfer function by use of multimode output waveguides [3], two cascaded grating devices [4], multiple gratings [5], or a multimode interference coupler [6]. Some design methods using an analytic form of objective function have also been proposed [7], [8]. However, these techniques are sequential, that is, physical parameters are determined according to a fixed order one by one or assume a particular mode profile to simplify the problem. Thus, they might be applicable to designing desirable devices in a one-valued optimization method or to designing ones having a particular input or propagating mode profile. To overcome previous shortcomings, author proposed a systematic optimization method for Gaussian transfer function. Recently, on the other hand, to achieve a broadened transfer function, a multimode interference (MMI) coupler has been employed [10].

In this paper, an efficient optimal design method for an arrayed waveguide grating (AWG) with flattened transfer function is presented. The spectral response of AWG was computed by using the Fresnel-Kirchhof diffraction formula. For a broadened transfer function, we used an MMI coupler at the end of the input waveguide. The (1+1) Evolution Strategy was employed as the optimization tool. The optimization method presented here is applied to a design of 8-channel AWG for CWDM. The design results show that the optimization method presented here is very useful in designing the AWG spectrum and developing some new type of AWG. This algorithm can be extended to another objective function with other weighting factors and optical parameters.

II. SPECTRAL ANALYSIS OF AWG

The Fresnel-Kirchhoff diffraction theory was employed for the calculation of the spectrum of AWG in our work. The transfer function for an AWG device is calculated by the following equation:

$$H(\delta) =- C_0\int_{-\infty}^{\infty}\{a(x)e^{j\Phi(x)}\}e^{j\delta x}dx \tag{1}$$

C_0 is the normalization factor, $\Phi(x)$ is the grating phase, the detuning parameter $\delta = (\beta - \beta_B)\cos\Psi$, with propagation constant $\beta = 2\pi n/\lambda$, and β_B corresponding with the wavelength λ_B at the bandpass center of the AWG filter response. $a(x)$ is the variation of electric field amplitude across the waveguide array, and $\cos\Psi$ denotes the direction cosine of the propagation constant in the second slab waveguide.

The phase at the ith array waveguide $\Phi(x_i)$ can be expressed as follows:

$$\Phi(x_i) = \frac{2\pi}{\lambda} n(L_{\min} + \triangle L + \triangle L_i)$$

$L_{\min}$ is the shortest length of array waveguide, $\triangle L$ is the conventional optical path difference and $\triangle L_i$ is an additional optical path difference at the ith array waveguide. We chose (Li at each array waveguide as design variables like the previous one [9] (see Fig. 1). The variation in optical path difference at each array waveguide changes the shape of transfer function to obtain the optimal spectrum shape.

An AWG demultiplexer consists of a waveguide array, a set of input/output waveguides, and two free propagation regions (FPRs). To obtain broader spectral response, the input waveguide is followed by an MMI coupler that acts as a twofold image generator. According to the self-image theory, a twofold image can be formed in the MMI region and the separation between the two image peaks [10] as shown Fig. 2. The transfer function of AWG is similar to one at the end of MMI coupler and the broader spectrum can be obtained at the output waveguides.

III. OPTIMIZATION OF AWG USING (1+1) EVOLUTION STRATEGY

A. (1+1) Evolution Strategy

In this paper, (1+1) ES is employed as a main optimization tool. Among several stochastic methods, ES uses the principle of organic evolution for searching for the optimal values. The ES is widely used because it can find the global optimal solution, the algorithm is simple, and convergence speed is fast. The algorithm roughly consists of four parts: reproduction, mutation, competition, and selection [11], [12].

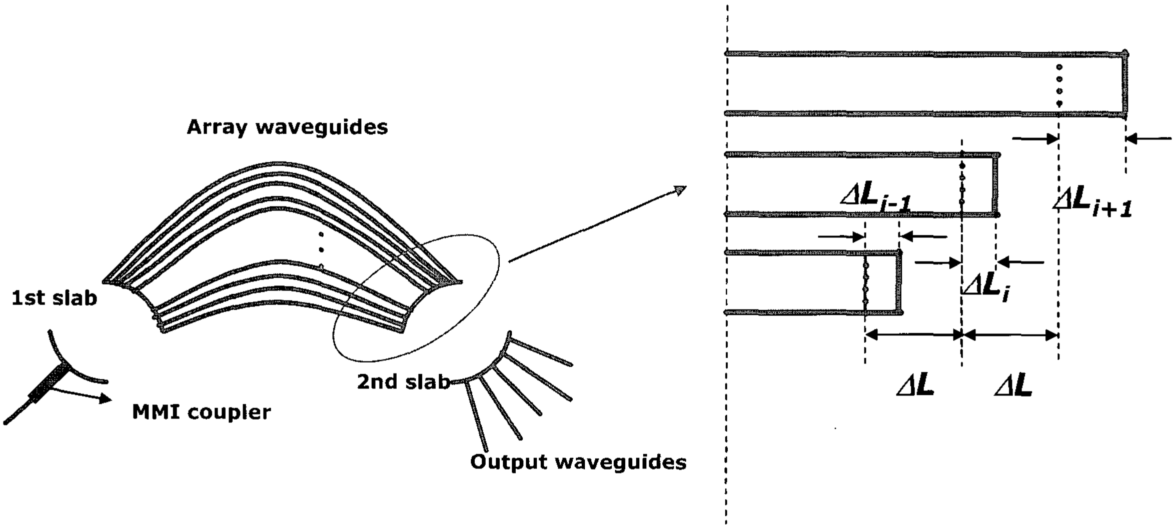

FIG. 1. Schematic configuration of AWG and design variables.

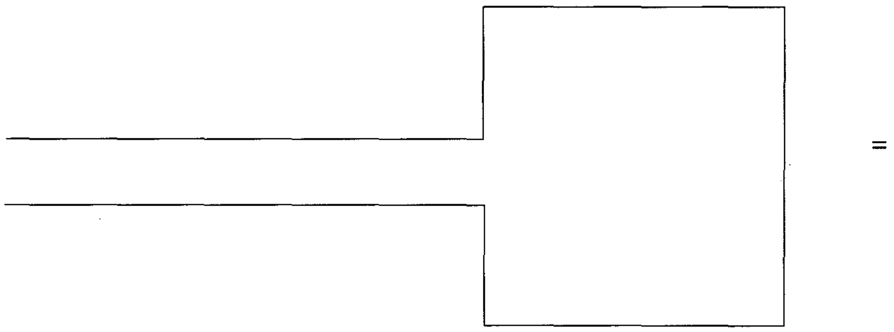

FIG. 2. Geometrical configuration of MMI coupler and Gaussian beam of two-fold images.

The (1+1) ES is a simple mutation-selection scheme called two membered ES. The "population" consists of one parent only, determined by a certain parameter configuration, creating one descendant by means of adding a normally distributed random vector (mutation) to the parameter values. The 'fitter' of both individuals, obtained by evaluating the objective function, serves as the ancestor of the following iteration (selection). The step width is adjusted periodically (e.g. after 10×*np* function calls, where *np* is the number of optimization parameters) in such a way that the ratio of successful mutations over all mutations becomes *p*. This strategy parameter is usually set to *p*=0.2. In this paper, an annealing factor is set to be 0.85 and a shaking process is also considered to prevent a solution from converging to a local minimum.

B. Objective Function

In this paper, the objective function of the optimal design of AWG was chosen the norm of difference between the calculated and target (rectangular shape) spectrum. The optimization problem and the objective function are defined as follows:

$$\text{Minimize Objective Function} = \sqrt{\sum_{i=1}^{N} a_i e_i^2} \qquad (2)$$

where e_i is the difference between calculated transmission and target value at the *i*th analysis point, as shown Fig. 3, N is the number of analysis points and a_i is a weighting factor with $\sum_{i=1}^{N} a_i^2 = 1$.

The optical spectra are calculated by the Fresnel-Kirchhoff diffraction theory [9]. Then, the objective function is computed by (2). If the objective function is smaller than the specified value, or the relative error between present and previous optimization step is smaller than the predefined tolerance, then the optimization process is terminated.

IV. OPTIMIZATION RESULTS

Table 1 shows our initial parameters. The optimization method presented here was applied to the design of a 8-channel AWG for CWDM. The waveguide was assumed a silica-based one.

Fig. 4 (a) shows the transmission spectra of Gaussian (without MMI coupler) [9], initial and final stage (with MMI coupler), respectively and Fig. 4 (b) is an enlarged one. This shows that the shape of transmission got broader than that of the initial stage but unavoidably the loss got larger than that of the Gaussian. We see that our optimization method is simple and efficient for designing AWG with the broadened

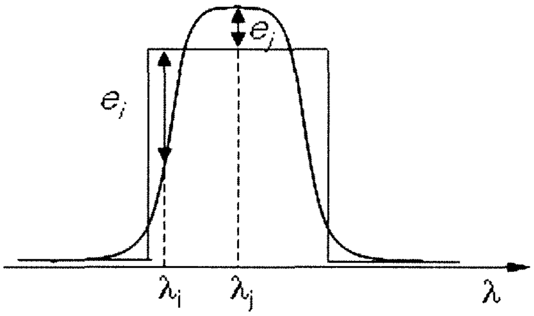

FIG. 3. Comparison between the calculated and target spectrum.

TABLE 1. Initial Parameter.

Parameter	Value	Parameter	Value
n_core	1.4566 @1.55 μm	Number of AW	151
n_clad	1.4457 @1.55 μm	ΔL	2.1222 μm
Width of IW	6 μm	Width of OW	6 μm
Width of AW	13 μm	Focal length	12926 μm
Width of MMI Coupler	13.55 μm	Length of MMI Coupler	134.9 μm

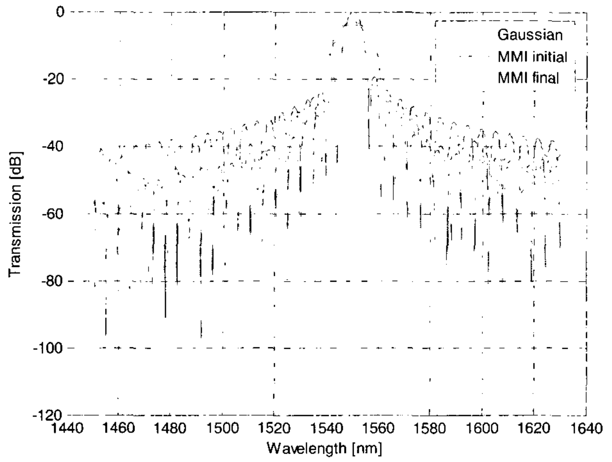

FIG. 4 (a). Transmission spectra of Gaussian (without MMI coupler) [9], initial and final stage (with MMI coupler)

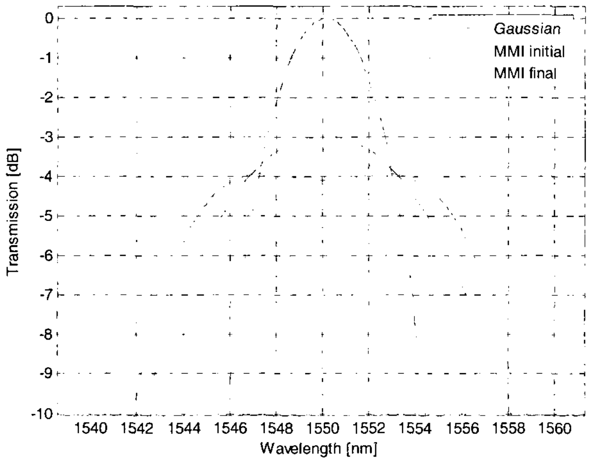

FIG. 4. (b) Transmission spectra of Gaussian (without MMI coupler) [9], initial and final stage (with MMI coupler) (Enlarged).

spectrum.

Fig. 5 shows the bandwidths of optical spectra at the initial and final state. The figures and table show that the several bandwidths get larger and the increments in the upper region of the transfer function are more than those in the lower and thus approach the target shape.

Table 2 summarizes the optimal results of arrayed waveguide lengths. In general, a fabrication resolution for width exceeds 1 μm in the case of 6 μm width but the one for length can be decreased to submicrometers. Therefore, these results can be applied to the practical devices.

By changing the weighting factors, 'the importance' of the physical parameters can be further emphasized. One may enhance 'the importance' of some physical parameters by increasing their weighting factors and hence, improving the nearness to the target value. Furthermore, there are no limitations or requirements in choice of design parameters and design variables.

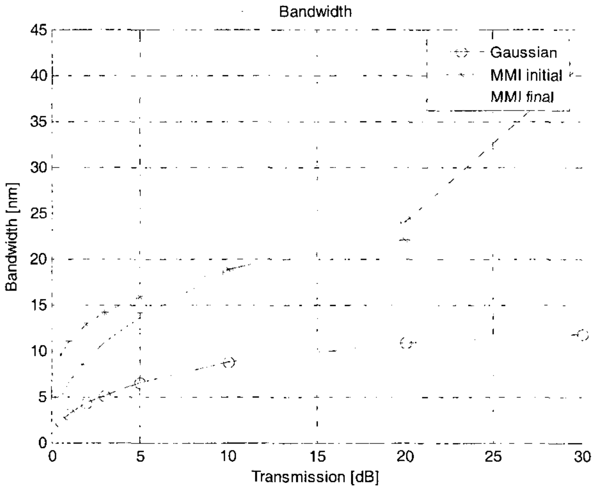

FIG. 5. Bandwidths. for initial and final stage (with MMI coupler).

V. CONCLUSIONS

This paper presents the systematic optimum design method of AWG having MMI coupler to obtain desired transmission spectra. The frequency response of AWG is calculated by the Fresnel-Kirchhoff diffraction theory and was obtained from their transmission. The (1+1) ES is employed as an optimization tool. MMI coupler acts as a key role for obtaining flattened spectra. The optimization method presented here is applied to the design of an 8-channel AWG with the rectangular target transfer function. The design results show that the optimization method presented here is very useful in designing AWG spectrum having MMI coupler and developing some new type of AWG. This algorithm can be extended to another objective function with other weighting factors and optical parameters.

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