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Parameter Optimization of Foundry-Enabled Modified Bragg Grating Filters

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Abstract: The rapid commercialization of silicon photonics necessitates scalable narrow-band filtering elements with high extinction and free spectral range. We design such filters with Particle Swarm Optimization that meet lithography constraints of commercial silicon photonic foundries. © 2022 The Author(s)

1. Introduction

Silicon photonics technologies are becoming widely deployed with applications expanding beyond long-haul optical telecommunications, to intra- and inter- data centers communication, aerospace, automotive and fiber-to-home deployments. These are all enabled by commercial silicon photonics foundries with some offering monolithic electronic and photonic functionalities. Narrow band filters are a key element of many optical systems and are available in the form of microrings, MZIs and similar devices; although these suffer from both nonlinear optical, thermal, and low free spectral range (FSR) limitations [1]. It is desirable to have optical filters with narrow bandwidth, high extinction ratio, high FSR and the capacity to handle high optical powers, while meeting size considerations and compatibility with commercial foundry fabrication.

Integrated Bragg Grating Filters (IBGFs) are a viable design type to meet these goals and have been widely demonstrated using E-beam lithography, typically comprising of waveguide corrugation widths close to 10nm [2]. These small corrugation widths then result in filter bandwidths close to 1nm, which is desirable for Wavelength Division Multiplexing and other applications. Commercially however, a common silicon photonic (SiP) node using 193nm DUV lithography fabrication has limited ability to meet design requirements to fabricate corrugation widths smaller than 90-100 nm, and moreover, impose constraints such as minimum feature size, separation and area of islands and holes [3]. Here we demonstrate an efficient design method and describe an example IBGF optimized to meet the lithography constraints of commercial silicon photonic foundries. Despite the growing prevalence of inverse-design type optimization schemes [4], Particle Swarm and similar meta-heuristic optimizations [5] are better suited for photonic designs with non-differentiable objective functions. Thus we employ a robust and efficient PSO algorithm to optimize several geometrical parameters of a modified IBGF to obtain a narrow bandwidth and high extinction filter, while adhering to strict design rule checking (DRC) constraints of a commercial foundry.

2. Device Design and Optimization

The bandwidth of Bragg Grating style filters is typically proportional to the periodic refractive index perturbation Δn which is traditionally achieved by modulating the width of the waveguide resulting in a corrugated structure. The multiple repeated reflections then interfere constructively around the Bragg wavelength λ_B and result in a notch in transmission around λ_B. Fig. 1. depicts the evolution of the structure from a dielectric stack to integrated photonics in the form of corrugated waveguides and finally to the general design framework used in this work – that of an extended cladding-modulated Bragg grating filter. The design of our modified IBGFs achieves index modulation with the help of cladding separated rectangular "posts" and have been reliably fabricated in a commercial foundry [6], [7] previously. Similar cladding-modulated structures with cylindrical posts have been utilized for narrowband filtering, channel separation and dispersion engineering [8], [9] using E-beam lithography.

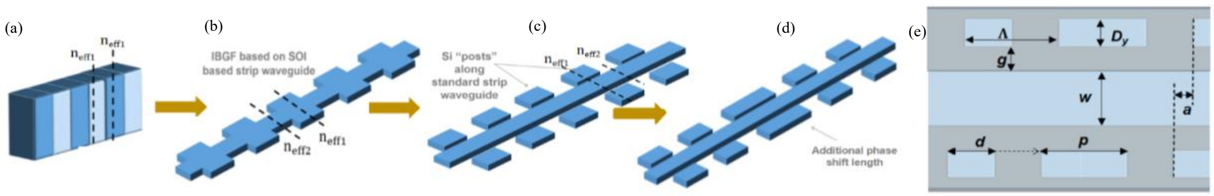

Fig. 1. (a) Integrated Bragg filters follow the basic principle of a dielectric stack with a periodic refractive index modulation, (b) a traditional integrated Bragg grating-based filter created with a periodic corrugation along a strip waveguide. (c) Extended cladding-modulated "posts" based design of this work provides greater tolerance to CMOS fabrication. (d) An additional phase-shift in the structure creates a narrow notch to the filter spectrum. (e) Parameters that define a separated post filter structure; from left clockwise - Bragg period, gap size, post width, asymmetry, phase-shift length, duty cycle and waveguide width.

These modified Bragg grating filters have several geometrical parameters as shown in Fig. 1(e), which affect the filter response in various ways and provide multiple design variables to tailor the filter response for different applications. Notably parameters like duty cycle, phase shift length addition and asymmetry introduce a narrow notch in the filter spectrum which can be exploited for narrow bandwidth applications. Lithography constraints are applied in the limits of the optimization for relevant parameters thereby guaranteeing strict compliance to foundry DRC. PSO is applied on Lumerical's varFDTD simulations - with a custom bandwidth computation algorithm - to a minimizing bandwidth and maximizing extinction Figure of Merit (FoM) function. Starting with a nominal device following the analytical method described in [6] resulting in a bandwidth of 14.43nm, we optimized for two design cases – (i) a filter with most of the parameters of Fig. 1 included (excluding a constant Bragg period and filter length) and (ii) a filter without a narrow notch in the spectrum, by excluding parameters like duty cycle and phase shift length.

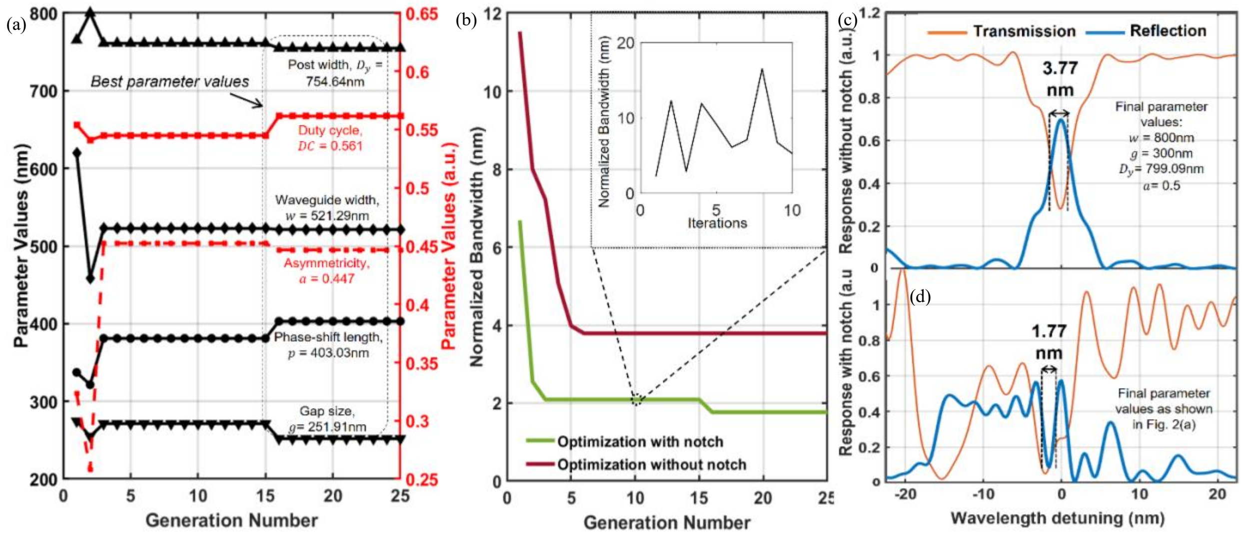

Fig. 2. (a) Demonstration of parameter values progression for a filter where 6 filter parameters are optimized using PSO and optimized parameters are noted, (b) comparison of the figure of merit progression over 25 generations for two cases. Inset shows the 10 iterations within one generation. The simulated transmitted and reflected power response with respect to wavelength detuning, as shown in (c) and (d) for both these cases result in a much-reduced bandwidth compared to a nominally designed filter with 14nm bandwidth

3. Results and Discussion

PSO achieved a stable result within just 8 generations (each comprising 10 iterations) for the first design case and 18 generations for the second (Fig. 2). The global best FoM at every generation was updated if the iteration yielded an improved FoM, Fig. 2(b) inset. The optimization converged within 8 hours when performed on a i7-6700 CPU @ 3.4 GHz with 16 GB RAM for the first case, demonstrating the efficiency of the method. The optimized parameters yield an extinction over 50% and bandwidths of 3.77nm and 1.77nm for the filters with and without a notch for case (i) and (ii) respectively (Fig. 2(c-d). As another variation, starting with the post-optimized response of case (i) (Fig. 2(c)), we added a phase-shift section in the center of the filter, that produced a notch in the spectrum with a bandwidth of 2.53nm. Other parameters like duty cycle and asymmetry can also be varied for a narrower bandwidth from the notch section. Applying trends of obtaining a smaller bandwidth post-fabrication ([2],[6] and [7]), we expect the bandwidth to be closer to our design target of 1nm, which is significantly lower than the 14.43 nm bandwidth of the initial filter design. We therefore obtain a compact ($55\mu m$ long and $3\mu m$ wide), narrow-bandwidth filter with reasonably high extinction that is strictly compatible with commercial foundry fabrication.

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