The fundamentals of multi-splitting filtering technology

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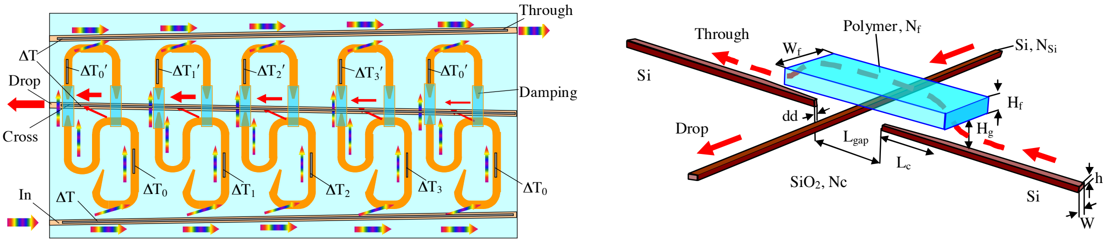
Abstract: We present the general description on novel optical filter/multiplexer constructed by multiply coupled waveguides. For the study, a modified effective index method (MEIM), has been used. It correctly describes, in the 2D case both the phase and the group indexes in a 3D silicon wire waveguide and makes it possible to simulate complicated SOI structures by 2D FDTD. The silicon wire crossings are realized by means of a vertical up and down coupling through the silica buffer of tapered Si wires with the upper thick polymer waveguide. FDTD modeling prove that a short 0.26 mm multiplexer with 32 couplers has FSR 35 nm, spectral resolutions 1.4 nm, internal loss -0.7 dB and sidelobes -20 dB.

Introduction

Silicon photonics [1] creates a great amount of optical devices intended for different applications from telecom to sensors. None of them are ideal but each has some advantages related to the others. A brief description of original results which make the building blocks of multi-splitting (MS) photonic structures on silicon-on-insulator (SOI), which can be used as tunable filter or reconfigurable optical add drop multiplexer (ROADM), are discussed and reviewed in the paper.

A design of multi-splitting multiplexer

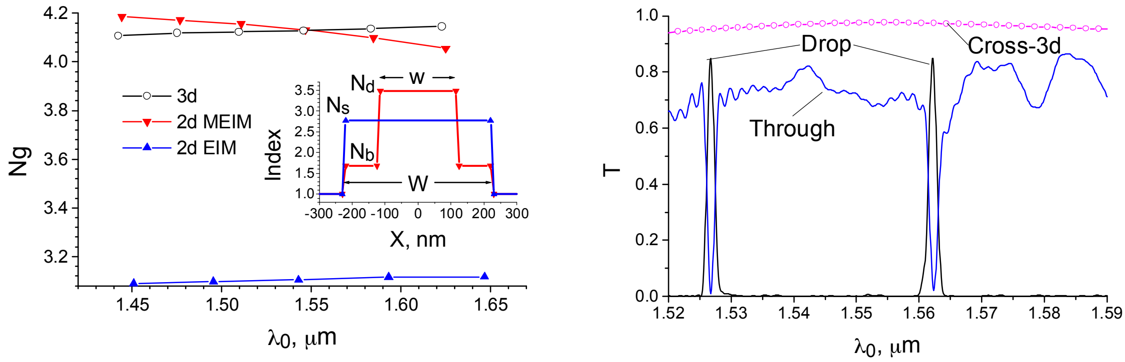
A general view of the novel multi-splitting multiplexer [2, 3] is shown in Fig. 1(a). It uses multilayer wire crossing [4, 5] (see Fig.1(b)). The input signal (In) is coming into the bottom Si wire waveguide and splits into sub-beams by multiple adiabatic directional couplers with the varying coupling ratio (different gap width) which is responsible for the filter apodization. Each of sub-beams goes further along the crossed waveguides (vertical in a structure design) and is combined in the output wire waveguide (Drop) by an appropriate set of similar couplers. The structure has a constant optical path difference of $\Delta S = L_a + L_b$. Thus, at drop optical wavelengths, all the sub-beams add in the phase along the Output wire waveguide (Drop) and produce efficient filtering. All other wavelengths pass further the coupler, cross the Drop waveguide and further combined in the output wire waveguide (Through) by an appropriate set of similar directional couplers. These couplers also have the varying coupling ratio (generally inversely respective to In and Drop bus waveguides) in order to increase the Through signal efficiency. Structure design provides the condition that the most of spitted sub-beams have the same pass difference on the way from input (In) to output (Through). Thus, all the optical wavelength which are not filtered by Drop channel will be transmitted to the Through output. As a results, the structure presented in Fig. 1(a) could be used as the optical multiplexer, as well as the optical filter.



a) *b)*

Fig. 1. The principle view of multi-splitting tunable multiplexer (a) and a basic scheme of multilayer effective crossing of two silicon wires by vertical coupling with a polymer waveguide (b).

Device examination is very complicated and the study has been divided into several interconnected parts, which are focused on one key point. The first part is devoted to the approach of multilayer waveguide crossing [4, 5] which is also suitable to construct a damper. Next part discuses the modified effective index method MEIM [6] which is optimal for direct 2D modeling of the device as it correctly (with about 1% error) describes in 2D case the phase and group index of 3D silicon wire waveguide (see Fig.2(a)). Optimum filter design [3] takes into account a constant pass-length difference and variation of coupling strength by controlling the gap between directional couplers used as power splitters. Spectrum properties of the MS filter (see Fig.2(b)) and it tuning by thermo-optic effect are examined by direct 2D modeling jointly by 2D FDTD and MEIM, and taking into account the presence of the wire crossings studied by 3D FDTD.



a) *b)*

Fig. 2. Numerical modeling of MS-multiplexer by FDTD and MEIM. Group indexes as a function of optical wavelength λ_0 for different simulation cases (a); wavelength dependence of transmitted power for Drop and Through channels of the optical multiplexer with 32 directional couplers (b). A curve Cross-3d presents waveguide crossing transmitting efficiency. In the insert are the refractive index profiles for EIM and MEIM.

Conclusion

We discuss optical properties of a new tunable optical multiplexer which utilized multiple coupled silicon wire waveguides in SOI structures. In order to provide a negligible scattering, the wire crossings are realized by means of a vertical up and down coupling through the silica buffer of tapered Si wires with the upper thick polymer waveguide. For the multiplexer study, a modified effective index method, which utilizes the combined index profile with two spatial parameters, has been used. It correctly describes, in the 2D case both the phase and the group indexes in a 3D silicon wire waveguide and makes it possible to simulate complicated SOI structures by 2D FDTD. Our FDTD modeling proves a general conception of the multiplexer on SOI and demonstrates that a short 0.26 mm structure with 32 couplers has spectral resolutions 1.4 nm, internal loss -0.7 dB and sidelobes -20 dB. It provides the wavelength tuning (without Vernier principle) within FSR 35 nm at optical wavelength 1550 nm by the four sets of thermo-optical phase shifters with ΔT<140 C°. A device of 0.7 cm in size will provide a 0.05 nm filter linewidth. It is CMOS compatible. Work is executed by a support of the grant No 12-07-00018a by the Russian Fund for Basic Research. The author acknowledges RSoft Design Group, Inc., for providing the user license for FDTD simulations [7].

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