Group-index and resonant field enhancement in a symmetric double-sided grated waveguide

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A numerical study has been carried out by means of the Green’s function method to explore possible performance improvements of a simple grated waveguide (GWg) by the variations of its grated structure. It is shown that a GWg featuring symmetric two-sided grated structure of 16 teeth with a 60 nm groove depth and having a symmetric refractive index profile with a relatively large contrast between the grated and ungrated layers is capable of delivering largely improved device performance compared to that achieved previously with a one-sided grating of 40 nm groove depth and asymmetric index profile. The improvement is characterized by a remarkable 8-fold and 15-fold increase in the group index and the maximum field intensity, respectively, at the first resonance wavelength above the upper band edge (shorter wavelength), while relatively less improvement is found at the first resonance wavelength below the lower band edge (longer wavelength). It is shown that more than 20% further improvement can be obtained by an appropriate shifting of the two innermost adjacent grating teeth in the case of the 40 nm groove depth. Apart from that, the result also reveals an interesting and remarkable correlation between the variations of the group index and the confined energy. © 2011 Optical Society of America

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1. INTRODUCTION

In the studies of photonic devices in the last decade, we have witnessed rapidly growing interest in the development of slow light devices mainly for two major purposes. One is the enhancement of light-matter interaction for increased sensitivity in optical sensing. The other one is the extension of the range of group velocity variation for the operations and controls of variable optical delay lines and other photonic devices used in optical information and communication technology [1,2]. There are two main directions of development pursued by researchers for the realization of integrated optical devices for those applications. One approach adopts the basic concept of coupled resonator optical waveguides (CROWs) [3], while the other has opted for the use of photonic crystal waveguides (PhCWs) [4]. A comprehensive and direct comparison between performances of the two types of devices for communication applications has recently been reported using the same silicon-on-insulator (SOI) technological platform [5]. It was shown that both structures can be used to synchronize the orthogonally polarized data streams of a 100 Gbyte/s polarization-division multiplexing differential quadrature phase-shift keying (PolDM-DQPSK) system without corrupting the phase information. Further comparison showed that the CROW devices are preferable for operational regime of upper data rate requiring longer delays and lower loss. On the other hand, for the terabit regime, the PhCWs may offer a more favorable prospect.

The study of grated waveguides (GWgs) with quasi-two-dimensional structures has recently gained a growing interest particularly for optical sensing applications, largely due to their potential excellent performance in terms of a large group index and strongly localized field [6–14]. The planar structures considered in most of those studies also offer the benefit of greater amenability of their on-chip fabrication by the existing technology compared to the much more demanding technology for the fabrication of fully three-dimensional devices [15]. However, for a waveguide with a uniform grated section as often found in earlier studies, one has to deal with the problem of out-of-plane scattering loss arising from the mode-mismatch between the modal fields of the grated and ungrated sections. In our recent study, this issue was addressed by considering a simple model of the waveguide having a one-sided grating structure with modified edge sections using the Green’s function method in the Dyson formulation [16]. It was demonstrated that an appropriately chosen symmetric tapering of the two end sections has resulted in a remarkable 85% loss reduction and 15% transmittance enhancement at the first lower (longer wavelength) band-edge resonance, with a less remarkable result found at the first upper (shorter wavelength) band-edge resonance. The enhancement of the resonance field and group index by increasing the number of grating cells as confirmed in the study, is apparently not the favorable choice as it implies an undesirable increase of the device size. Further, the same structural modifications responsible for the favorable loss reduction appeared to induce the undesirable opposite effects on the group index and field confinement. Therefore, for applications in optical sensing and time delay control (wave slowing), it is desirable