Design and Simulation of a Si_3N_4 Sub-GHz Resolution Integrated Micro-Spectrometer

Houman Ghorbani [a], Ramanand Tewari [a], Mohammad Rad [b], Eric Bernier [b], Trevor J. Hall [a]
(a) Faculty of Engineering, University of Ottawa, 25 Templeton St., Ottawa, ON, K1N6N5, Canada
(b) Huawei Technologies, Ltd, 303 Terry Fox Dr, Kanata, ON, K2K 3J1, Canada
Hghor044@uottawa.ca

***Abstract*- Silicon Nitride (Si_3N_4) based photonics circuits fabricated using TriPleX technology have proven to be low-loss while occupying relatively small footprint. We designed and simulated an Arrayed Waveguide Grating (AWG) with 50 GHz channel spacing over 5 nm wavelength range in the C-band together with a Micro Ring Resonator (MRR) with an FSR of 50 GHz as integrated building blocks of a micro-spectrometer using Si_3N_4 waveguides. Simulation results reveal 2 – 4 dB loss for AWG and sub-GHz resolution for MRR.**

I. INTRODUCTION

Photonics Integrated Circuits (PICs) have attracted a significant interest over the past years due to their high reliability, compact structure, light weight, and easy integration with electronic circuits. Moreover, as CMOS is the dominant technology in electronics, PIC material platforms that are compatible with CMOS are widely used such as Silica on Silicon (SOS), Silicon on Insulator (SOI), and Silicon Nitride (Si_3N_4). SOS has a number of advantages such as low cost, high efficiency in fiber coupling due to large waveguide dimensions, and low loss; however, the low index contrast difference between core and cladding makes it large in dimensions which requires quite a large footprint. SOI has the highest index contrast among CMOS compatible materials which guarantees a very small footprint; but because of higher wave confinement inside the waveguide, scattering loss due to sidewall roughness is increased. Si_3N_4 has a refractive index higher than SOS and lower than SOI while keeping a low-loss property which makes it suitable for low-loss and relatively low footprint designs [1].

Arrayed Waveguide Gratings (AWGs) implemented in SOS have shown exceptional performance but have footprints on a scale of centimeters. Very compact AWGs have been demonstrated in SOI but their performance is not robust to process variations. On the other hand, it is challenging to implement Micro Ring Resonators (MRRs) with a Free Spectral Range (FSR) large enough for Coarse Wavelength Division Multiplexing (CWDM) applications for example, because of the small perimeter and large bending radius required which favours SOI implementation but again performance is not robust to process variations. Trimming becomes mandatory for circuits combining AWG and MRR implemented in SOI but the small size of the MRRs leaves little room for the insertion of variable couplers and phase shift elements. An alternative approach is to use laser trimming but that is manual, time-consuming and expensive. We are exploring circuits combining AWG and MRRs. The FSR requirement on the MRR is thereby relaxed to the channel spacing of the AWG permitting larger rings more amenable to trimming. As a consequence, we are exploring Si_3N_4 as a low-loss and relatively compact integration platform intermediate between SOS and SOI suited to the implementation of both AWG and MRR.

Recently, Si_3N_4 platforms have been enhanced by the emergence of TriPleX technology [2] which lowers the loss by introducing high quality fabrication process. Different waveguide geometries have been taken into account in [3] such as single strip (SS), double strip (DS) which are birefringent, while boxed shaped (BS) waveguides are polarization insensitive. Their single mode operation region as well as the effective refractive index of the fundamental mode has been demonstrated. Thin core SS waveguides have been designed and their bend losses for different radii and thicknesses have been calculated in [4, 5]. A double strip (DS) waveguide design has been reported in [6] with a 170 nm core thickness which has achieved low bending loss at lower radii than previous works. In this paper, we design and simulate AWG and MRR devices applying waveguides with Si_3N_4 core and silica cladding as building blocks of a micro-spectrometer.

II. WAVEGUIDE DESIGN

In addition to material, waveguide geometry plays a key role in obtaining higher mode confinement which enables tight bends in the structures without significant bend loss. Fig. 1 (a) and (b) show the cross section of SS and DS waveguides, respectively. The goal of our design is to maximize the mode confinement which is crucial for sharp bends while keeping the waveguide operating in the single mode regime. We restricted our simulations to TE waves because of their electric field orientation which provides lower bend loss than TM. The Si_3N_4

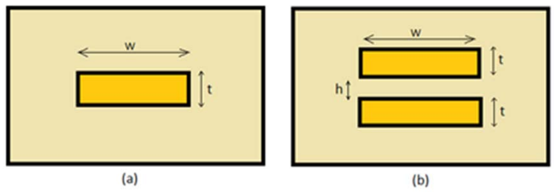


Fig. 1. Waveguide cross section of (a) SS, (b) DS configuration.

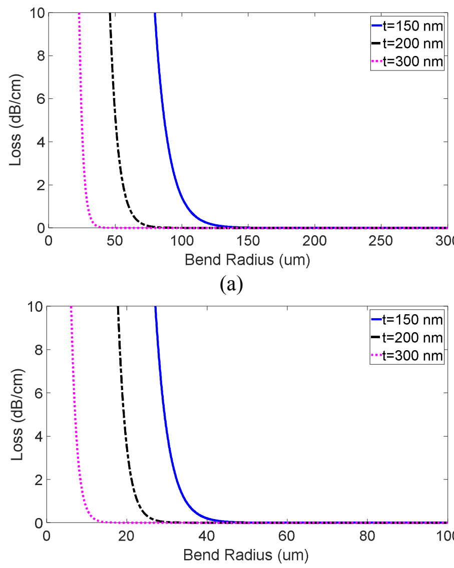
layer can be as thick as circa 300 nm without causing a crack in the structure due to internal stress. Refractive indices of Si_3N_4 and silica are circa 1.98 and 1.44, respectively over the communication window. The simulation has been carried out over the whole C-band to ensure single mode operation. Table I represents effective indices of the fundamental TE mode for different waveguide thicknesses and widths at 1550 nm which are conducted in Photon Design's Fimmwave environment. As seen, increasing the thickness will scale up the mode effective index which means more mode confinement in the core. An increase in thickness, however, would admit a higher order bound mode in the waveguide; hence, the width of the waveguide needs to be scaled down to guarantee a single mode regime. Bending loss versus different curve radii of the above-mentioned waveguides at 1550 nm are depicted in Fig. 2. It is clear that for a certain amount of loss, sharper bends could be achieved for a waveguide with higher effective index.

III. Arrayed Waveguide Grating Simulation

We made use of SS waveguide with 300 nm thickness and 1200 nm width (also shown in Table I) for the design of AWG and MRR. Fig. 3 demonstrates transmission spectrum of the designed AWG with dimensions of 7mm x 4mm which has 12

TABLE I
Effective Refractive Indices For Different Cross Sections

Type	t (nm)	h (nm)	w (nm)	TE00 index
SS	150	-	2000	1.5
SS	200	-	1500	1.53
SS	300	-	1200	1.59
DS	150	50	1200	1.57
DS	200	50	1100	1.62
DS	300	50	900	1.67



(a)

(b)

Fig. 2. Bend loss versus bend radius at 1550 nm for (a) SS, (b) DS waveguides with h= 50 nm

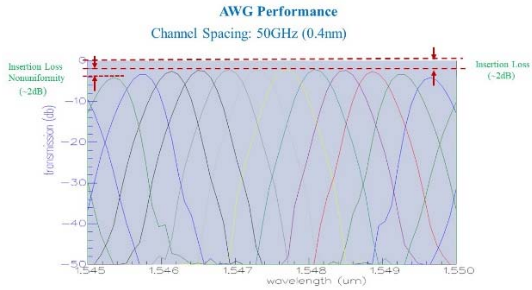


Fig. 3. Transmission spectrum of AWG.

output channels with 0.4 nm (50 GHz) spacing between adjacent channels over 5 nm wavelength range in the C-band. The insertion loss varies between 2 – 4 dB over the entire C-band.

IV. Ring Resonator Simulation

We designed a ring resonator according to the transmission spectrum of the AWG so that the MRR should have an FSR equal to channel spacing of AWG which is 0.4 nm. Fig. 4 represents power transmission spectrum of the drop port of MRR around the first resonance in the C-band with ring radius of 650 um, a power self-coupling ratio of 0.988 in each coupling region, and waveguide loss of 0.5 dB/cm in the ring section. A sub-GHz resolution of 6 pm has been achieved for 0.4 nm (50 GHz) FSR and a Q-factor of more than 200,000.

In summary, we designed and simulated an AWG as well as an MRR compatible with the AWG as two integrated building blocks of a micro-spectrometer using low-loss Si_3N_4 waveguides.

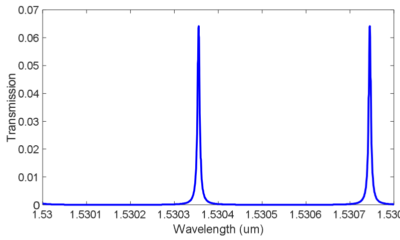


Fig. 4. Power transmission of add-drop single ring filter of 650 um radius

References

[1] A. Melloni, R. Costa, G. Cusmai, and F. Morichetti, "The role of index contrast in dielectric optical waveguides," *Int. J. Materials and Product Technology,* Vol. 34, No. 4, pp. 421–437, 2009.

[2] K. Wörhoff, R. G. Heideman, A. Leinse and M. Hoekman, "TriPleX: a versatile dielectric photonic platform," *Adv. Opt. Techn.* 4(2): pp. 189–207, 2015.

[3] F. Morichetti, et al. "Box-Shaped Dielectric Waveguides: A New Concept in Integrated Optics?," *J. Lightw. Technol.*, vol. 25, no. 9, pp. 2579–2589, Sep. 2007.

[4] J. F. Bauters, et al. "Ultra-low-loss high-aspect-ratio Si_3N_4 waveguides," *Opt. Express*, vol. 19, no. 4, pp. 3163-3174, Feb. 2011.

[5] M. C. Tien, et al. "Ultra-high quality factor planar Si_3N_4 ring resonators on Si substrates," *Opt. Express*, vol. 19, no. 14, pp. 13551-13556, Jul. 2011.

[6] L. Zhuang, et al. "Low-loss, high-index-contrast Si_3N_4/SiO_2 optical waveguides for optical delay lines in microwave photonics signal processing," *Opt. Express*, vol. 19, no. 23, pp. 23162-23170, Nov. 2011.