Polarization characteristics of low-loss nano-core buried optical waveguides and directional couplers

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Abstract *The characteristics of a low loss buried optical waveguide with a nano-core-layer of SiN is analyzed. With such a low-loss optical waveguide, directional couplers are also designed, fabricated and characterized.*

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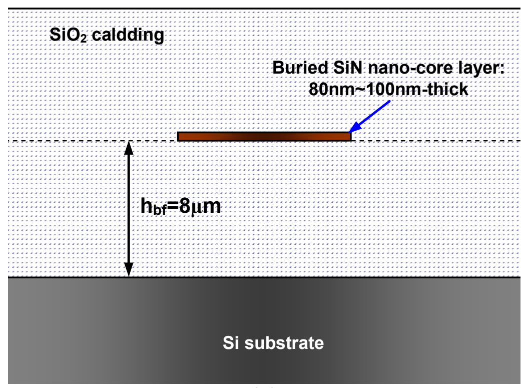
Introduction

Photonic integrated devices based on planar lightwave circuit (PLC) technology have made great advances in the past few decades. In order to realize various passive and active components, several material-systems, e.g., III-V [1], SiO_2-on-Si [2], silicon-on-insulator (SOI) [3], and polymer [4], have been developed. When choosing a material system for an optical waveguide, one of the most important things is to have low loss in the desired wavelength range. All of these materials mentioned above could have low absorption loss in the near-infrared range (1200~1600nm) for optical fiber communications. However, for optical waveguides, the scattering loss due to the roughness at the surfaces is one of the dominant sources for loss. In order to reduce the loss, one should reduce the refractive index contrast Δ, the roughness, and the overlap of the modal-field with the surfaces. However, the confinement becomes weaker when index contrast Δ is reduced. In order to achieve a high-density photonic integration, a medium index contrast Δ is usually needed. Since the top and bottom surfaces for a planar optical waveguide are much smoother than the sidewalls, the scattering loss is usually dominated by the sidewall roughness. It is expected to have a reduced scattering loss if a nano-scale core layer is used. In Ref. [5], we reported a low loss of 0.03dB/cm at 1550nm for 2-mm bend radius by using a buried SiN optical waveguide which has a wide but ultra-thin core (2μmx80nm). This provides a promising way to realize large-scale photonic integration circuits with relatively high integration density.

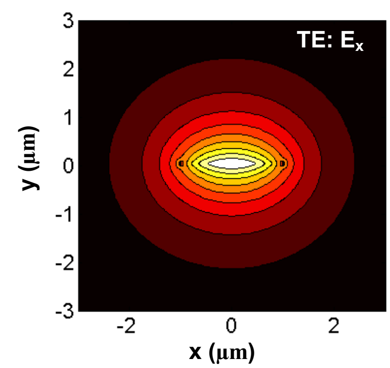
The polarization dependence of an optical waveguide is usually very important for most photonic integrated devices. In this paper, we give an analysis for the polarization dependence of such buried SiN optical waveguides and characterize the performance of small directional couplers.

The waveguide structure and the properties

Fig. 1(a) shows the cross section of the present buried SiN optical waveguides, which have a wide and ultrathin core region of SiN. The SiN core layer usually has a thickness of 80nm~100nm. The SiO_2 under-cladding has a thickness of 8μm to avoid any leakage loss to the substrate. The SiO_2 up-cladding is also 8μm -thick to make the waveguide symmetrical. The refractive indices for the SiN core and SiO_2 cladding are about 1.99 and 1.45, respectively. In this structure, the sidewall area is very small and consequently the overlap of the optical field with the side is minimized, which is helpful to reduce the scattering loss from the roughness of the sidewall.



(a)



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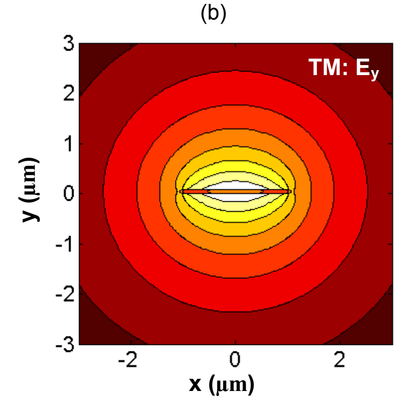


(c)

Fig. 1. (a). The cross section of the present low-loss buried optical waveguide with a nano-core-layer of SiN; (b) the mode profile of the TE-polarized fundamental mode; (c) the mode profile of the TM-polarized fundamental mode.

Fig. 1(b) and (c) show the profiles for TE- and TM- polarized fundamental mode fields, which are from the full-vectorial finite-difference mode solver. Due to the large index contrast and nano-dimension in the vertical direction, there is a strong electric field discontinuity for TM-polarization mode and the peak of the field in core region is much lower than that in the cladding region. The TM polarized mode has a much larger mode size than the TE polarized mode.

Fig. 2 shows the birefringence (i.e., the difference between the effective indices of TE- and TM-polarization fundamental modes) as the core width varies. Here the core thickness is fixed to be h_{co}=100nm. It can be seen that the birefringence increases as the core width increases and becomes very large (>0.01) when the core width is larger than 2μm. This is helpful to have a good polarization maintaining performance.

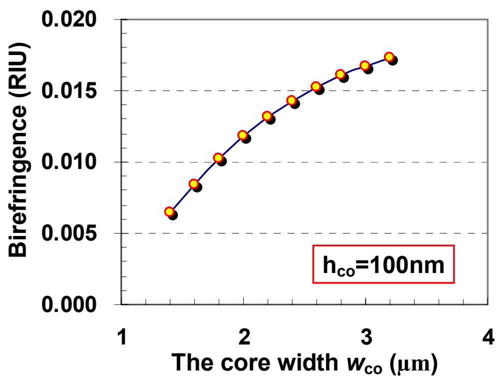


Fig. 2. The birefringence of the present low-loss buried optical waveguide with a 100nm-thick SiN core-layer.

Curved waveguides are of the most important basic elements for photonic integrated circuits. Fig. 3(a) and (b) shows the pure bending losses for the TE- and TM- polarized fundamental modes. In our calculation, the core width varies from 1.2 to 3.2μm. It can be seen that the core width plays a very important role when a low bending loss is desired. When the core width increases from 1.2 to 3.2μm, the pure bending loss decreases dramatically. Since the mode confinement is very polarization-dependent, one can see that the bending loss is also very different for TE- and TM- polarizations, as shown in Fig. 3(c). It can be seen that the bending radius could be as small as sub-millimeter while still having very low bending loss. In contrast, a much larger bending radius is required for TM polarization. Such a huge difference between the two polarizations makes it possible to have a simple high extinction ratio polarizer. For the applications requiring two polarizations, one has to choose a larger core area (increasing the core width or the core height).

Finally we fabricated directional couplers based on the present waveguide to verify the evanescent coupling between two waveguides. We use the standard structure for directional couplers, as shown in Fig. 4(a). In our design, we choose the core width w_{co}=1.6μm and the gap width w_g=1.0μm in order to guarantee an easy reproducible fabrication. The offset and length of the S-bend are around 50μm and 650μm in the x- and z- directions, respectively. The corresponding bending radius is about 2000μm.

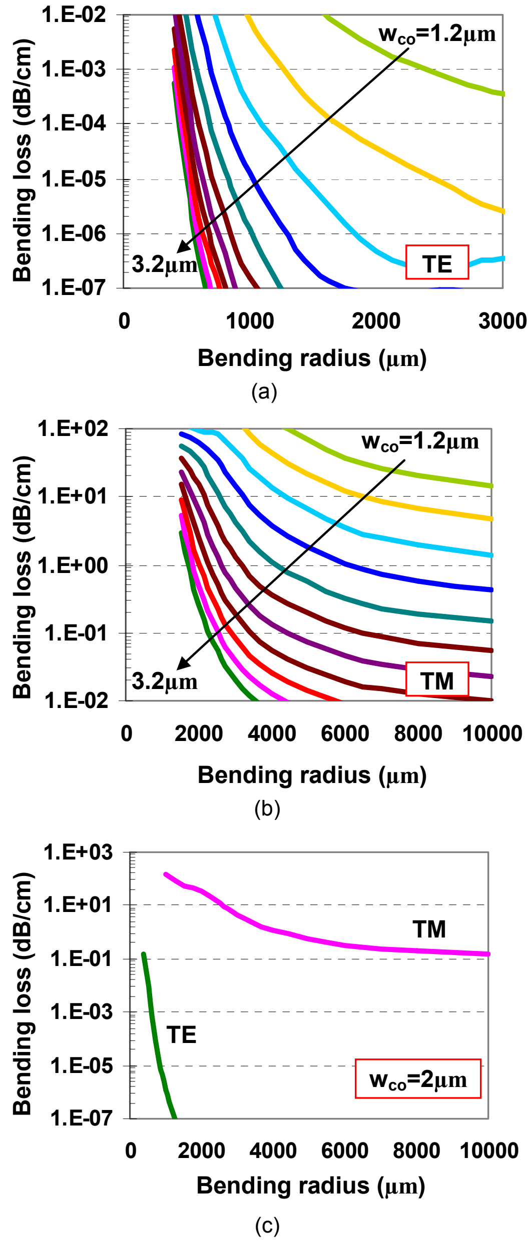
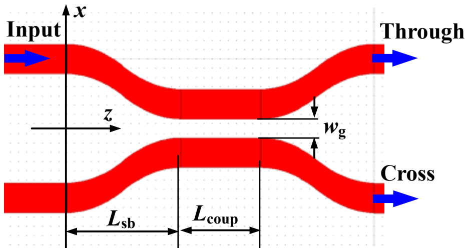


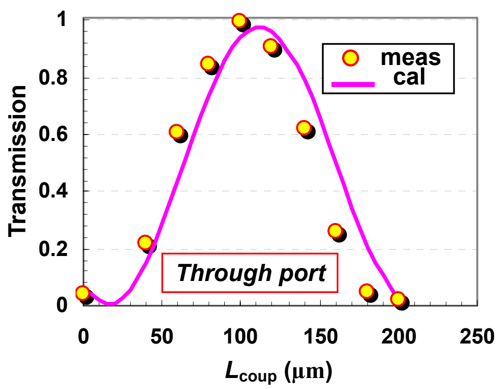
Fig. 3. The calculated pure bending loss of the fundamental mode as the core width varies from 1.2μm to 3.2μm with a step of 0.2μm (h_{co}=100nm) for (a) the TE polarization; (b) the TM polarization; (c) the comparison of bending loss for TE- and TM-polarization fundamental modes (w_{co}=2μm).

Fig. 4(b) and 4(c) shows the measurement results for the transmissions from the through port and the cross ports, respectively (see the circles). The solid curves in these figures show the calculation results by using beam propagation method. It can be seen that the agreement is reasonably good. We note that the transmission is close to 100% even when

L_{coup}=0 (see (c)). This is because of the evanescent coupling in the two S-bend regions. This strong coupling between two adjacent waveguides is useful to realize very compact couplers for power splitting.



(a)



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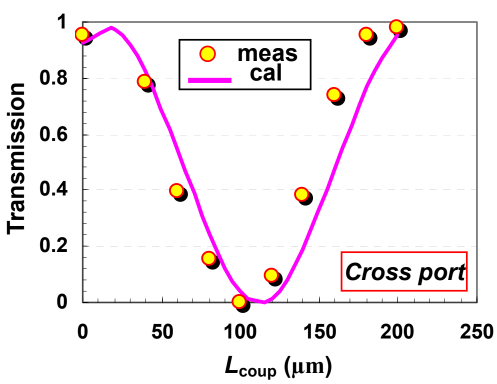

(c)

Fig. 4. The measured transmission for TE-polarization of the fabricated directional couplers as the length of the coupling region increases. (a) the through port; (b) the cross port.

Conclusion

In this paper, we have presented a low loss buried optical waveguide with a nano-core layer of SiN and given an analysis for the polarization dependence of this type optical waveguide. Due to the huge asymmetry in the horizontal and vertical directions, the present optical waveguide has very different properties for TE and TM polarizations. The TM polarization shows much higher bending loss than the TE polarization and this structure is useful as a polarizer. Finally we have also demonstrated the measured and calculated results for directional couplers based on the present low-loss SiN optical waveguide. Good performance was measured, in agreement with theory.

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