Analysis of Propagation Loss in Silicon-on-Insulator based Photonic Rib Waveguide with Small Cross Section

Veer Chandra, Rakesh Ranjan
OFC and Photonics lab, Department of ECE, National Institute of Technology Patna, India
veer.ecpg16@nitp.ac.in, rr@nitp.ac.in

Abstract: Silicon-on-Insulator based Rib waveguides are very popular for optical communication in recent years. Effective refractive index, propagation loss and propagation length have been analyzed at different widths and heights of waveguide. Compared to reported works, significantly lesser propagation loss, up to 0.1 dB/cm, has been achieved with light confinement of ~72%.

1. Introduction

In the silicon-on-insulator (SOI) based optical waveguides, the optical signal propagation with low propagation loss is highly relying on its cross sectional dimension. The main sources of propagation loss in an optical waveguide are absorption within the materials, scattering loss from the sidewalls, etc. [1]. SOI based single-mode photonic wires with significantly low propagation loss, as 0.4 dB/cm, has been reported in [3]. The authors have fabricated the silicon wire waveguides by the high-resolution lithography technology using argon fluoride (ArF) immersion lithography process to achieve the remarkably low propagation loss. For the development of silicon photonic devices, the study of propagation loss in single-mode SOI based waveguides and fabrication of Rib waveguide have been explored in [4]. The developed process used in this article is based on 300 mm SOI wafer technology and patterning using state-of-art 193 nm immersion lithography and dry etch process. The authors have reported the propagation loss up to 0.7 dB/cm. The superior process platform technology for silicon photonics has been presented using the 40 nm technology node CMOS line in [5]. The obtained the propagation loss is less than 0.5 dB/cm for the waveguide fabricated with process optimization. In this paper, to reduce the propagation loss to a significantly low level as compared with the reported propagation losses in literature, the geometry of the Rib waveguide has been optimized by considering different heights and widths of the optical Rib waveguide. Other waveguide related parameters, such as, effective refractive index (ERI), and propagation length have been analyzed to validate the optimized dimensions of the Rib waveguide. The propagation loss can be calculated from the Eq. (1) [2].

$$\text{Loss (dB)} = 10\log_{10}(\text{e}) \times \frac{4\pi . Im(n_{eff})}{\lambda} \tag{1}$$

where, $\text{Im}(\text{n}_{\text{eff}})$ is the imaginary part of effective refractive index.

2. Design and simulation of Rib waveguide

The basic structure of Rib waveguide is shown in Fig. 1 (a), where *w* is the width of the top layer of the Rib waveguide, *H* is the total height of the core (Si) layer, and *h* is the height of Rib (Si) layer. The material used for core is silicon and for the lower clad region is silica (SiO_2), having the refractive indices of 3.45 and 1.44 respectively at the operating wavelength of 1550 nm. Fig. 1 (b), shows the simulated mode field distribution of the Rib waveguide.

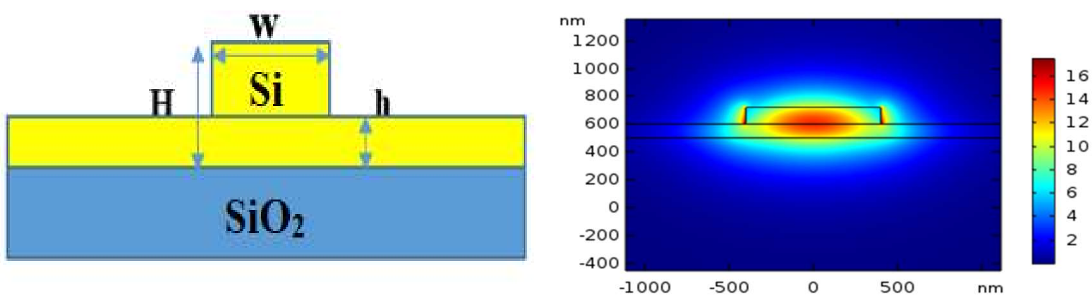


Fig. 1 (a) Basic structure and (b) Mode field distribution of Rib waveguide for Rib height (*h*) at H = 220 nm.

The propagation losses and propagation lengths have been estimated by varying the dimensions of the Rib waveguide. Mainly four different heights for the Rib layer (*h = 25 nm, 50 nm, 75 nm, and 100 nm*) have been considered for the analysis. For each value of *h*, the total height of the core layer (*H*) has been fixed at *220 nm* and the width (*w*) is varied from *500 nm* to *1000 nm*. All the simulations have been performed using finite element method (FEM) based COMSOL simulation software.

3. Results and Discussion

Fig. 2 shows the relationship between the real part of the ERI ($Re(n_{eff})$) and the width (*w*). The figure clearly depicts that for the smaller values of widths, such as *w = 500 nm,* the value of $Re(n_{eff})$ increases with the increasing Rib heights (*h*), while, for the larger value of *w* (such as, *1000 nm)*, the variation in $Re(n_{eff})$ is not significant. This is mainly because of the reason that for the larger widths (*w*), the increase in the heights of the Rib layer (*h*) does not have a significant impact to further increase the confinement of light in the core region. The variations of propagation loss and propagation length with respect to the width of the top layer and the height of rib layer of the waveguide have been demonstrated in Fig. 3 (a), and (b) respectively. It is clear from the figures that with the increasing widths, the propagation loss decreases and hence the propagation length increases. The similar relationship has also been observed with the varying heights of the Rib layer (*h*). The increase in Rib height can accommodate more light confinement and hence the propagation loss decreases significantly with corresponding increase in propagation lengths for the smaller widths, whereas, for larger width values, the impact of the Rib heights are marginal due to the same reason mentioned above.

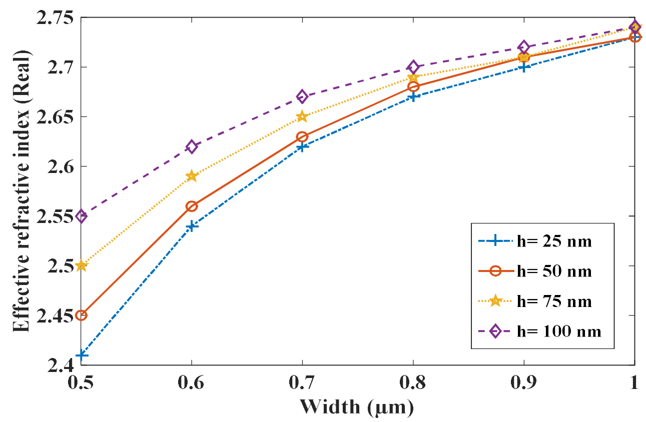
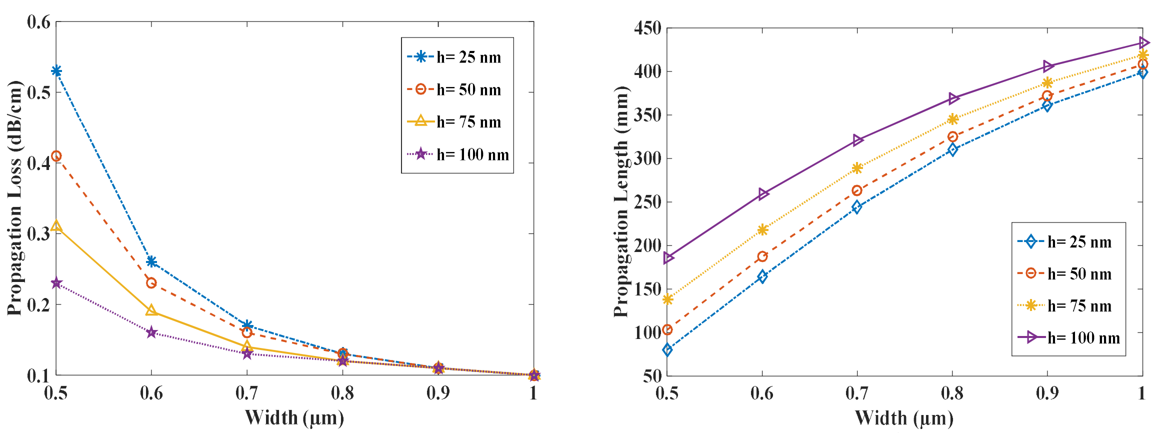


Fig. 2 Real part of effective refractive index for different width (*w*) and different Rib height (*h*) at H = 220 nm.



(a) (b)

Fig. 3. Propagation loss (a) and propagation length (b) for different width (*w*) and different Rib height (*h*) at H = 220 nm.

Table I demonstrate that with the increase in height (h), the corresponding propagation loss decreases and real part of the effective refractive index increases, while confinement factor will remain almost constant due to the fact that there is no significant change in the mode confinement area . In addition, the obtained results have also been compared with the results reported in [3-5], in terms of the propagation loss. Significantly smaller propagation loss up to 0.23 dB/cm and 0.1 dB/cm respectively for w = 500 nm and 1000 nm, have been obtained in the current work as compared to that stated in [3-5].

Table I. Different parameters value at H = 220 nm and w = 500 nm

Height (h)	ERI (Real part)	Propagation loss (dB/cm)	Confinement factor
h = 25 nm	2.41	0.53	0.69
h = 50 nm	2.45	0.41	0.69
h = 75 nm	2.50	0.31	0.70
h = 100 nm	2.55	0.23	0.72
h = 0 nm, w = 500 nm [3]	-	0.4	-
H = 220 nm, w = 457 nm [4]	-	0.7	-
H = 220 nm, w = 440 nm [5]	-	0.5	-

4. Conclusion

Rib waveguide is the most popular structure for the design of the photonic waveguides and sensors. One of the major problem associated with the Rib waveguide is its propagation loss. In the present work, it has been demonstrated that the propagation loss in the Rib waveguides can be reduced to a significant low value by the optimization of the waveguide geometry. In the current work, the minimum propagation loss of 0.23 dB/cm and 0.1 dB/cm have been obtained, respectively for w = 500 nm and 1000 nm, at λ = 1.55 µm. To validate the obtained results, the analysis have been extended with some other parameters, such as propagation length, effective refractive index (real) and confinement factor. Depending on the application of the Rib waveguide, one can further optimize the propagation loss/length.

5. Acknowledgements

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6. References

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