Influence of a Polyimide Coating Layer on Losses of Fabricated SOI Slot Waveguides

Maithem Salih*[1] and Alan Mickelson[2]

[1]*Department of Electronics and Communication Engineering, University of Kufa, Najaf, Iraq*
[2] *Department of Electrical, Computer and Energy Engineering, University of Colorado Boulder, CO 80309, USA*

Received January 2, 2023; accepted July 1, 2023; published July 2, 2023

Abstract—We demonstrate experimentally and simultaneously the impact of the Polyimide (PI) coating layer on the coupling and propagation losses of the fabricated SOI slot waveguides at 1550 nm operation wavelength and TE polarization.

Many attempts have been made to shrink photonic building blocks to realize massive integration as in electronics. The first and most important attempt that will pave the way toward the photonic integrated circuit (PIC) is through sub-wavelength light confinement [1]. A novel waveguide structure, which has been demonstrated in [2–3] and is termed a slot waveguide, has recently been considered a promising solution for all optical systems in which processing (logic) functions work in tandem with interconnections to carry out processing without electrical conversion [4]. The slot waveguides property of high confinement of light in the nanoscale region with a low refractive index makes it as a primary building block for systems such as all-optical signal processing [5–6]. Furthermore, a slot waveguide could be proposed as an interconnection element with ultra-low propagation loss [7]. For all of these applications, the investigation of the total losses which are expected to be expressed by a slot mode device is vita.

An array of 200 Silicon-on-Insulator (SOI) slot waveguide devices of varying slot widths, ribs widths, taper lengths, and slot lengths were created in each cell of a wafer fabricated at a commercial foundry. The cells were cleaved into individual chips after fabrication. Some chips were coated with thin films of polymers that fully infiltrated the slots. Measurements of spectral loss were made on the grating coupler waveguide devices of both coated and uncoated chips. Individual devices exhibited insertion losses varying from several dB up to values so great that the response was below the noise floor of the optical spectrum analyzer employed as a receiver. The chips that failed the transmission test were primarily uncoated ones.

* E-mail: maythem.shukur@uokufa.edu.iq

Figure 1 shows a general layout for the grating coupler waveguide devices which were used in order to test SOI slot devices in this work.

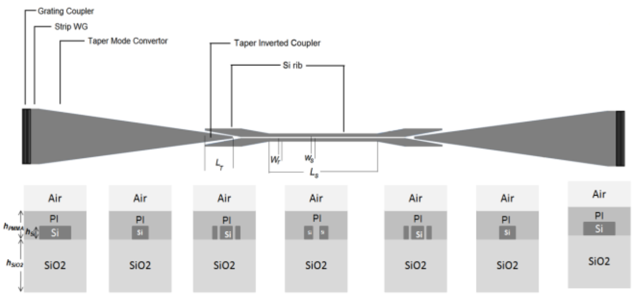

Fig. 1. The layout of an SOI slot device.

Scanning electron microscopic (SEM) images of sections of fabricated devices are shown in Fig. 2. As can be seen in this Figure, a little roughness appears on the sidewall of each Si rib regardless of the width. Their sizes are estimated of about 5 nm. The size magnitude of this roughness is small compared to the slot dimensions, but the effects on guiding properties and propagation loss may still be significant.

As mentioned before, some chips were coated by a thin polymer layer with about 500 nm thickness while other chips were kept without coating. The transmission of each device has been experimentally measured as a grating coupler waveguide, as shown in Fig. 1. Each device has been tested over a spectral width between 1500 and 1600 nm. Figure 4 shows the measured transmissions of coated and uncoated identical slot waveguides.

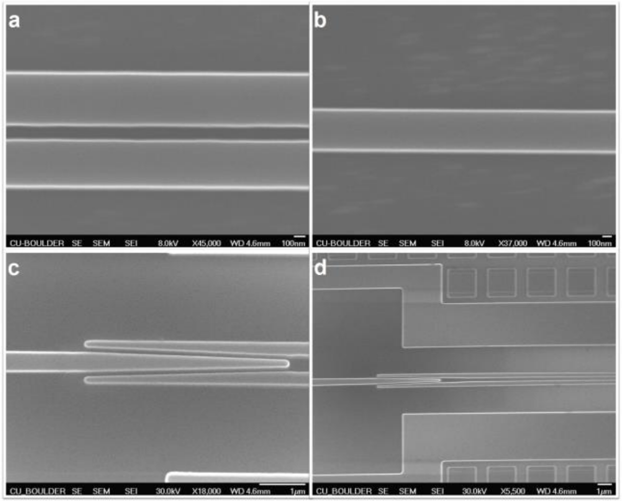

Fig. 2. SEM images for (a) a strip-slot taper coupling region (b) a tip of taper in face of a slot waveguide. (c) a slot waveguide (d) a ridge waveguide.

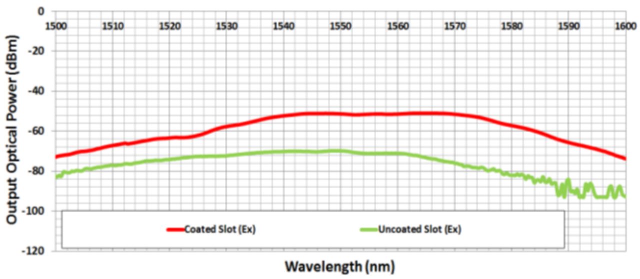

Fig. 3. The measured output optical power over 100 nm spectral width of coated (red), and uncoated (green), slot devices with 100 um slot length, 0.12 μm slot width, and 0.12 μm of each Si rib width.

Comparison of the measurements of the devices with each other shows that the coating layer enhanced the transmission by about 20 dB at 1550 nm wavelength.

The simulation and calculations have shown that the polymer coating layer enhanced the transmission of the tested slot devices mainly by decreasing the coupling loss and allowing observation of this change in the propagation losses, as shown in Fig. 4.

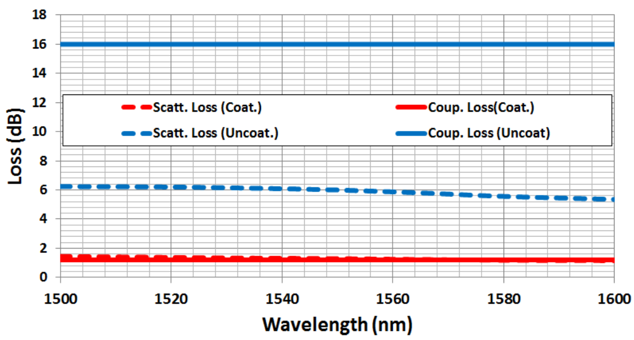

Fig. 4. The simulated scattering losses (dash), and coupling losses (Solid), for coated (red) and uncoated (blue) slot devices over 100 nm spectral width, 100um slot length, 0.12μm slot width, and 0.12μm of each Si rib width.

Accordingly, the coupled mode from the strip to the slot tends to oscillate in all regions of the waveguide structure in what is called a substrate radiation mode [8]. The resultant effective index is between the air and substrate refractive indices, so non-small fractions of the quasi-TE mode dissipate in the substrate and air. Figure 5 shows the coupling process of the optical power intensity of the quasi-TE mode via strip-slot taper coupler for both coated and uncoated cases, at 1550 nm wavelength.

From all measurements and analysis which have been performed, the main conclusion is the coupling efficiency of the strip-slot taper coupler is highly dependent on the refractive index of the coating layer of the coupling region and slot waveguide where it can be enhanced by about 15 dB according to coating layer and operation wavelength.

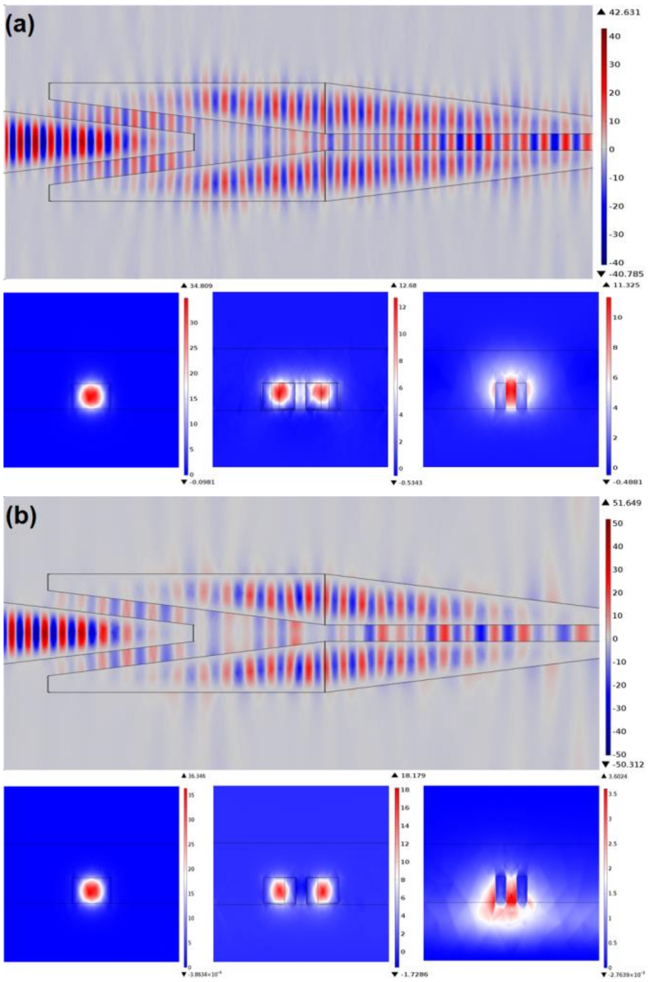

Fig. 5. The optical power intensity (W/μm^2) of quasi-TE mode, at 1550 nm wavelength, through a strip-slot taper coupler between a strip waveguide, 0.45×0.22 μm^2, and a slot waveguide, 0.22×(0.12 + 0.12+ 0.12) μm^2, in both (a) coated, and (b) uncoated cases.

References

[1] P. Dong, Y.K. Chen, G.H. Duan, D.T. Neilson, Silicon photonic devices and integrated circuits, Nanophotonics **3**(4–5), 215 (2014).

[2] Q. Xu, V.R. Almeida, R.R. Panepucci, M. Lipson, Experimental demonstration of guiding and confining light in nanometer-size low-refractive-index material, Opt. Lett. **29**(14), 1626 (2004).

[3] V.R. Almeida, Q. Xu, C.A. Barrios, M. Lipson, Guiding and confining light in void nanostructure, Opt. Lett. **29**(11), 1209 (2004).

[4] A. Mickelson, Silicon photonic slot guides for nonlinear optics, 2013 Int. Conf. Microw. Photonics, ICMAP 2013 (2013).

[5] A. Martínez *et al*., Ultrafast all-optical switching in a silicon-nanocrystal-based silicon slot waveguide at telecom wavelengths, Nano Lett. **10**(4), 1506 (2010).

[6] C. Koos *et al*., All-optical high-speed signal processing with silicon-organic hybrid slot waveguides, Nat. Photonics **3**(4), 216 (2009).

[7] Y. Li, K. Cui, X. Feng, Y. Huang, F. Liu, W. Zhang, Ultralow propagation loss slot-waveguide in high absorption active material, IEEE Photonics J. **6**(3), 2200606 (2014).

[8] Z. Wang, N. Zhu, Y. Tang, L. Wosinski, D. Dai, S. He, Ultracompact low-loss coupler between strip and slot waveguides, Opt. Lett. **34**(10), 1498, (2009).

