Investigation of Propagation Loss of Passive Silicon Waveguides Using Two Different Etching Techniques

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Abstract:

This work characterizes the propagation losses of passive silicon waveguides of 1.0 μm and 1.5 μm width fabricated using two different processing techniques, known as Etch #1 and Etch #2. The Fabry-Perot method of loss measurement was used to determine the losses and the reflectivities of each waveguide, and using that information, the effective indexes were also then found. The final results compare the losses and the indexes vs. the wavelength of light being transmitted through each waveguide. It was found that for 1.0 μm widths, Etch #1 was less lossy, while for the 1.5 μm widths Etch #2 proved better.

Introduction:

For decades now, silicon (Si) has been the material of choice for the fabrication of semiconductor devices. While electronic devices are widely fabricated on the Si platform, Si photonics devices are still under exploration because of the lack of efficient light source, which is mainly limited by the intrinsic indirect bandgap in Si. Researchers at Intel and at the University of California, Santa Barbara, have already demonstrated a hybrid Si evanescent platform where III-V epitaxial structures are bonded to silicon-on-insulator (SOI) wafers so that the optical mode inside the III-V region can be manipulated by changing the Si waveguide dimensions. The confinement factor inside the III-V layers can thus be changed for different photonic devices such as lasers, amplifiers, modulators, and photodetectors. As the waveguide dimension shrinks, based on the requirement for larger confinement factor in III-V, the propagation loss in Si waveguides are more affected by the fabrication process errors such as waveguide shape and sidewall roughness. In order for transmission to be most effective, the losses throughout the waveguide need to be minimized. In this work, two etching techniques with different amount of chlorine (CL_2) and boron trichloride (BCL_3) flow have been used to fabricate the Si waveguides. The focus of this project is to determine what the propagation loss is for these two methods, thereby determining which etching technique produces the lower loss.

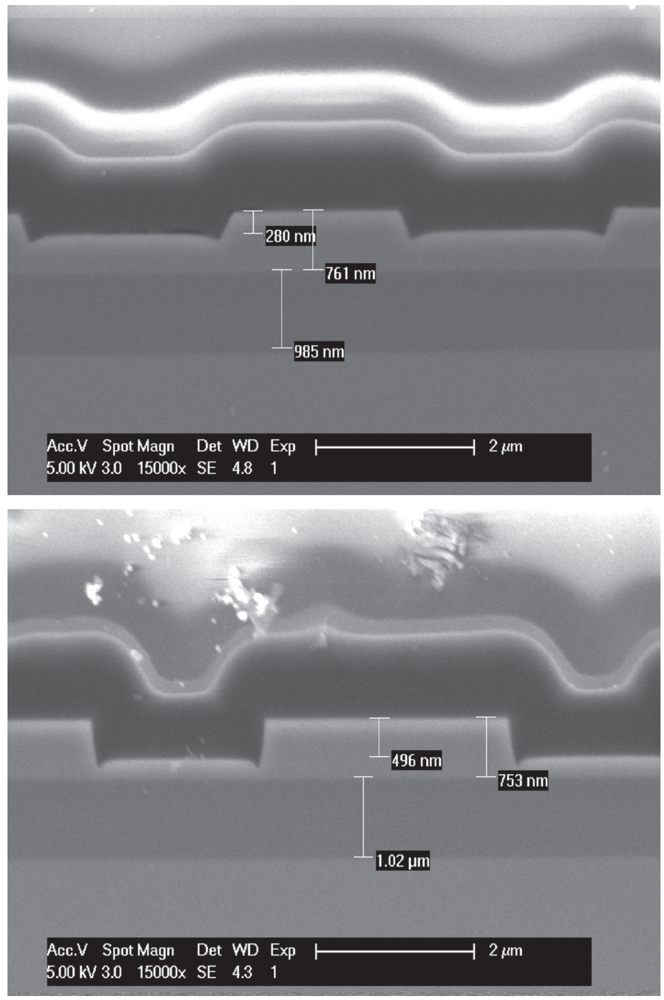

Figure 1: Etch #1 (top) and Etch #2 (bottom) waveguide dimensions.

Table for Figure 1

Technique	Gas (sccm)		Pressure (Pa)	Power (V)	
	Cl_2	BCl_3		FWD	SCR
#1	8	4	0.4	120	500
#2	0.8	0.6	0.24	40	400

Differences in gas, pressure, and power used for ICP etching.

Experimental Procedure:

Loss measurements were performed using the Fabry-Perot interferometer technique, which involved making the assumption that the highly polished waveguide end facets acted like partially transmissive mirrors, effectively creating a Fabry-Perot cavity between them. By coupling a tunable laser onto an end facet of the waveguide and performing a frequency sweep, the periodicity of the light exiting the waveguide can be viewed and used for data analysis. The light source was swept over a range of 100 nm, starting at 1525 nm and ending at 1625 nm, and the data was sampled every 25 nm over a range of 1 nm. The light exiting the waveguide was collimated with a 100x objective lens and sent through a dielectric beamsplitter, which separated the light into its transverse electric and transverse magnetic components, which were then each collected by a photodetector and sent on to an oscilloscope for viewing and data collection.

The waveguides were fabricated using different techniques, the biggest differences being a] the gasses present in the inductively coupled plasma (ICP) chamber, used for etching, and b] their relative pressures, a lower pressure resulting in smoother waveguide walls [1]. Two chips were fabricated using the two etching techniques. Each chip contained waveguides of differing widths, of which the 1.0 μm and 1.5 μm widths were examined in this experiment. In Figure 1, #1 lists the differences in the ICP processing, and #2 lists the differences in the resulting dimensions.

Results:

Upon obtaining the Fabry-Perot graphs of the light exiting the waveguides, the noise present in the figures was filtered out, and then calculations were made to determine the intensity ratio (min/max intensity). This ratio was the then used with Equation 1, relating the loss coefficient and the reflectivity to the intensity ratio. By plotting the intensity function versus the length of each waveguide, the loss and reflectivity can then be determined from the slope and y-intercept of the fitted line on the resulting graph.

This process was repeated for every data measurement made for all the 1.0 μm and 1.5 μm waveguides on the 1.5 mm, 2.5 mm, and 4 mm chips for both Etches 1 and 2. Table 1 clearly lists the results of this analysis.

The equation that relates the measured values to the loss and reflectivity is given as:

$$\alpha L - \ln(R) = \ln\left(\frac{1+\sqrt{\xi}}{1-\sqrt{\xi}}\right)$$

Equation 1: This equation relates the min/max intensity ratio to the reflectivity and the loss.

The waveguide losses followed a general trend of being the least lossy around 1550 nm, becoming more lossy the greater or smaller the wavelength becomes. Since 1550 nm is one of the two most common optical communication wavelengths, this result means that devices operating with either of these waveguides in place will have the greatest signal strength at that nominal wavelength.

Conclusions and Future Directions:

For now, it seems as though both fabrication techniques proved to yield rather similar results, although it would appear that waveguides fabricated using Etch #1 perform better than Etch #2 at a width of 1 μm, while the opposite seems to hold true for a width of 1.5 μm. However, it is unclear as to how much attenuation losses due to the roughness of the waveguides factored into the loss differences. To eliminate this, the fabricated waveguides should be examined after a baking process has performed during their fabrication, allowing for the photoresist to reflow (thereby smoothing out the sidewalls) before the fabrication process is fully complete.

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References:

[1] Matsutani, Akihiro, "Vertical and Smooth Etching of InP by Cl_2/Xe Inductively Coupled Plasma," Jpn. J.Appl.Phys, vol. 38, pp. 4260-4261, 1999.

1.0µm	Etch #1			Etch #2		
	Loss (db/cm)	Reflectivity	Index	Loss (db/cm)	Reflectivity	Index
1525nm	-8.975	0.340	3.793	-13.603	0.194	2.572
1550nm	-4.174	0.299	3.417	-6.843	0.305	3.464
1575nm	-9.533	0.338	3.778	-8.642	0.285	3.290
1.5µm	Etch #1			Etch #2		
	Loss (db/cm)	Reflectivity	Index	Loss (db/cm)	Reflectivity	Index
1525nm	-4.658	0.327	3.668	-11.708	0.301	3.435
1550nm	-6.514	0.306	3.476	-5.294	0.303	3.446
1575nm	-9.121	0.333	3.732	-6.884	0.296	3.389

Table 1: Differences in loss, reflectivity, and effective index for Etches 1 and 2 at different wavelengths and waveguide widths.