

Low Loss Etchless Silicon Waveguides

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Abstract— Fabrication of silicon waveguides without performing any silicon etching is demonstrated. The silicon waveguides are defined by the concept of “selective oxidation”. The experiment demonstrates that the waveguides formed by selective oxidation produce ultra-smooth sidewalls since etching of silicon is avoided. The Si etching usually creates damage from ion bombardment and chemical reactions that occur during plasma etching. The final waveguide also demonstrates very low light loss based on optical testing which shows that no light scattering is observed. The final waveguide has a width of $1.5\ \mu\text{m}$ and a height of $\sim 80\ \text{nm}$. The GCA stepper is utilized to expose the SOI sample. In order to do this an alternative method of exposing a wafer piece is needed which excludes the use of a special wafer pedal. This method is also demonstrated in the paper.

Index Terms— Waveguides, light scattering, optical testing, optical fiber

I. INTRODUCTION

Electrical interconnects (i.e. copper wire) suffer from an interconnect bottleneck. With decreasing node size, high heat dissipation is an issue along with a speed limitation of the electrons in copper wire. Optical interconnects in silicon are a viable alternative. Silicon nanophotonics integrates light within circuitry on a chip in order to achieve high performance processing and manipulation of information at very high speed and bandwidth (THz). Since silicon has a very high refractive index, it can trap light in a submicron space by means of total internal reflection – this structure is called a waveguide. Making a silicon waveguide with minimum light loss is for the best way to efficiently transfer information on silicon.

II. THEORY

Since the refractive index of silicon (~ 3.5) is clearly higher than the refractive index of silicon oxide (~ 1.46), the total internal reflection (TIR) occurs at the boundary of Si and SiO_2 (Figure 1). TIR allows light travel through the silicon waveguide.

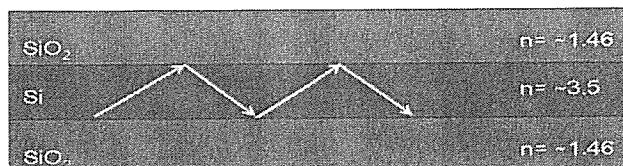


Figure 1: Total Internal Reflection, demonstrating the concept of a waveguide

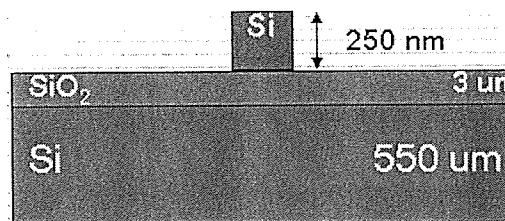


Figure 2: Cross section of a regular silicon waveguide

As Figure 2 depicts, the silicon etching is required in order to define a silicon waveguide. However, the damage which can be created on the silicon waveguide during the silicon etching step is one of the biggest problems that can cause the waveguides to have a significant light loss.

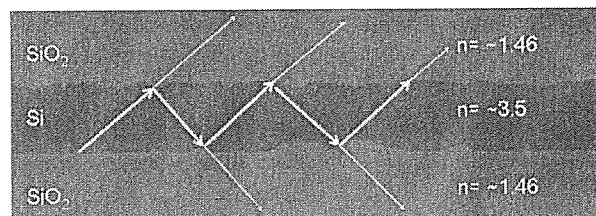


Figure 3: Damaged silicon waveguide, demonstrating the problem of silicon etching

When there are defects on the surface of the silicon, light scatters at the interface between Si and SiO_2 as figure 3 demonstrates. Defining the silicon waveguide utilizing the concept of the selective oxidation instead of silicon etching is the main focus of the project: Si is consumed under regions of thin oxide at a much faster rate than the Si under thick oxide regions.

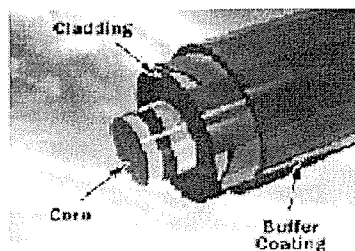


Figure 1: Optical fiber

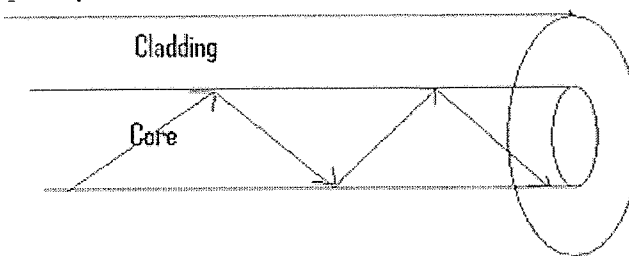


Figure 2: schematic of optical fiber

GCA stepper

placing a piece on the pedal

Also, 2 seconds of exposure time results in excellent exposure on silicon pieces. However, the same exposure time on SOI sample results in over exposure due to the reflection of the radiation from the $3\text{ }\mu\text{m}$ thick buried oxide. The figure 8 illustrates the pattern of the waveguides which are over exposed. Therefore, the exposure time has to be decreased to 1 second in order to have right exposure. Figure 9 shows the right pattern of waveguides after decreasing the exposure time. It indicates that the GCA stepper is capable of exposing SOI pieces. Exposure doses and the focus settings are optimized for the SOI sample

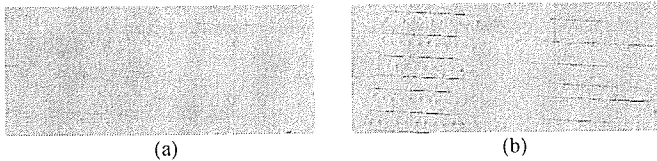


Figure 8: The pattern of waveguide that are over exposed

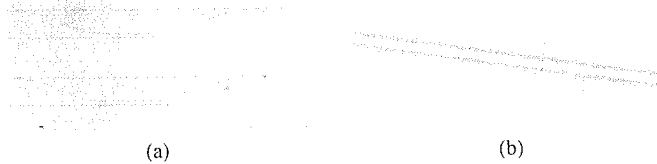


Figure 9: The pattern of waveguide after correcting the exposure time

C. Oxide Etch

The oxide etch requires good selectivity since the target oxide thickness that has to be etched away is 650 nm . Decreasing the O_2 flow in the chamber demonstrated the selective oxide etching. SEM images obtained after oxide etches affirm that the thickness of oxide and the roughness of oxide are at the desirable level. Figure 10 illustrates the SEM image of the sample after the oxide-etch. As the figure shows, the developed etch recipe selectively etches the oxide. No roughness is observed and the oxide thickness is measured to be 686.1 nm . The $\sim 700\text{ nm}$ of TEOS that is deposited using P5000 is well protected by photoresist masking layer. The width is measured to be $1.428\text{ }\mu\text{m}$ which is very close to the target width which is $1.5\text{ }\mu\text{m}$.

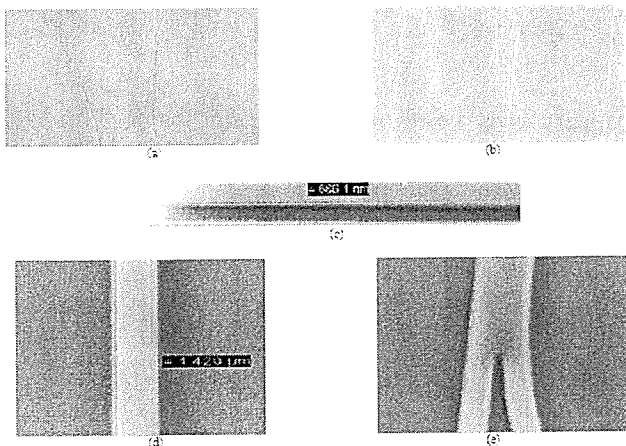


Figure 10: SEM images of the waveguide after oxide etch (c) shows the thickness of the oxide layer (d) shows the width of the waveguide

D. AFM Image

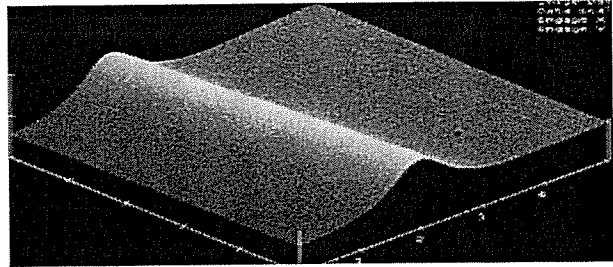


Figure 11: AFM image of silicon waveguide

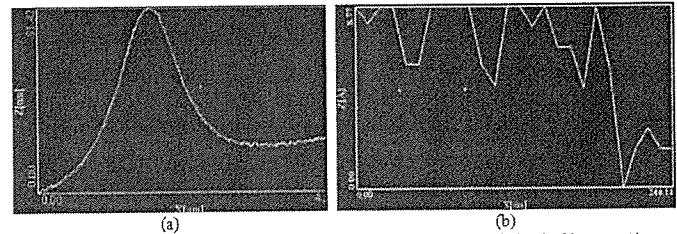


Figure 12: Roughness of silicon waveguide (a) across the width of the waveguide (b) across the length of the waveguide

Figure 11 illustrates the AFM image of the silicon waveguide and figure 12 (a) and (b) depict the roughness of the silicon waveguide. According to figure 12 (a), the height of the silicon waveguides are 81.42 nm which is very close to the target height of 80 nm . Also, the graph shows that there is no bumps across the curve which means that the side-wall of silicon waveguide is very smooth. Figure 12 (b) is the roughness graphs that is obtained across the length of the waveguide. As it can be seen from the graph, the roughness is less than $\sim 9\text{ \AA}$. Therefore, it can be concluded that the silicon waveguide has no roughness. One of the primary goals of the project was to create very smooth surfaces and sidewalls for silicon waveguides. The key to this technique is that the silicon layer has never been exposed to etching plasma since it is always covered by SiO_2 . Therefore the resulting silicon waveguide should be ultra smooth. The AFM image shows that this technique has been achieved by defining the waveguides using selective oxidation.

E. Optical Testing

Figure 13 illustrates the set-up of optical testing. The final device is placed in between optical fibers. The optical fiber on the right side couples with the input of the waveguide in order to transfer the light to the waveguide. The optical fiber on the left side collects the amount of light that comes out from the output of the waveguide.

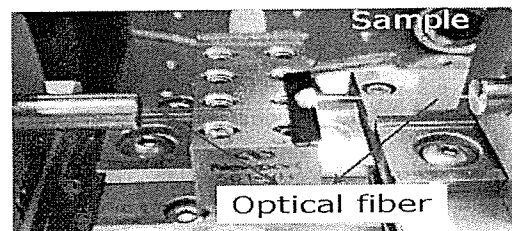


Figure 13: Optical testing set-up