

# Fabrication of Silicon Nitride Waveguides

Takia Wheat

Chemistry, Jackson State University

**NNIN REU Site: Center for Nanoscale Systems, Harvard University, Cambridge, MA**

*NNIN REU Principal Investigator(s): Marko Lončar, School of Engineering and Applied Sciences, Harvard University*

*NNIN REU Mentor(s): Parag B. Deotare, School of Engineering and Applied Sciences, Harvard University*

*Contact: takia.m.wheat@jsums.edu, loncar@seas.harvard.edu*

## **Abstract:**

Over the years there has been an ongoing demand for faster, better, and less expensive computer systems. Microelectronics have so far offered quality solutions, but have now reached their limitations. Nanophotonics is one alternative to microelectronics. Owing to its much larger bandwidth, it has high potential for providing solutions to faster computer systems through the manipulation of light, which is channeled using a waveguide. These waveguides, based on total internal reflection, are able to transport light from one area to another. Once light is between two mediums of lower refractive indices, it is reflected back and trapped, and can then be used in integrated optics to link together various optical devices and components. In this work, we report the fabrication of silicon nitride waveguides which can operate at standard telecom wavelengths. The fabrication of this waveguide mainly involved nanofabrication processes like e-beam lithography, which was used for defining the waveguides, followed by reactive ion etching (RIE) to transfer the pattern onto the silicon nitride surface. Optimization of the RIE etch chemistry was carried out to generate straight and smooth walled waveguides.

## **Introduction:**

In the technology of integrated circuits, it is advantageous to transport photons rather than electrons. Photons generate less heat, are less costly and travel faster. The technology has many applications ranging from: transporting light over long distances, and connecting components of miniaturized optical and optoelectronic devices and systems. The theory of waveguides operates on a principle of reflection which is achieved through a medium of refractive index  $n_1$  embedded in a medium of a lower index of refraction  $n_2$ . Therefore  $n_2 < n_1$ . The medium of lower index of refraction traps the light within, confining multiple total internal reflections [1]. Through this concept, it is possible to transport light from one area to another. Optical waveguides are used in the technology of integrated optics for generating, focusing, coupling and detecting light [2]. The light in the waveguides can be guided in different modes depending on the geometry.

The experimental waveguides were designed to be single-mode with step refractive index distribution, composed of silicon nitride. The wafer had three different layers; silicon (base), silicon oxide (insulating layer), and silicon nitride (waveguide layer).

## **Experimental Methods:**

The reactive ion etch (RIE) profile optimization was done with basic photolithography due to the time consuming fabrication of electron-beam written waveguides. During the basic photolithography, the wafer was properly prepared

and cleaned, increasing the photoresist's ability to adhere to the surface of the wafer. Photoresist 1813 was spun on the surface of the wafer, followed by baking at 115°C for 90 seconds. The sample was exposed for five seconds and developed in MF-319 for 45 seconds. Silicon nitride was etched using a  $H_2$ ,  $C_4F_8$  and  $SF_6$  chemistry. The gas ratios along with platen and coil power were optimized to generate straight walled etch profiles.

First, the sample was subjected to four runs, which started with varying  $H_2$  and pressure while maintaining  $C_4F_8$  (60 standard cubic centimeters per minute, sccm),  $SF_6$  (35 sccm), and coil (ICP)-1000 W, at constant values. After studying the sample, a second set of four runs were done on the sample without using  $H_2$  while keeping  $C_4F_8$  (130 sccm), coil (ICP)-1000 W, and pressure-10 mTorr, constant. A third set of four runs were done with further increasing of the  $SF_6$  while keeping the same parameters constant. Then a fourth trial of three runs was done with increasing platen and coil, while holding  $C_4F_8$  and  $SF_6$  constant.

## **Results and Discussion:**

The recipe with  $H_2$  etched faster into the  $SiO_2$  layer. It was found from the second run that the etch rate of silicon nitride was much slower without  $H_2$ . Due to the fact that the  $Si_3N_4$  was only 200 nm thick and the etching with the  $H_2$  recipe was quite fast, we discarded the use of  $H_2$  in further recipes. Further optimization of the recipe was done by varying

the other parameters. During trial II, the etching produced ranged from approximately 200-350 nm in five minutes. Runs two through four were excluded since run one (Figure 1) portrayed straighter walls than all the runs in trial I.

Trial III optimization followed that of trial II with variation of  $SF_6$  and platen since in trial II it was discovered that decreasing the  $SF_6$  and increasing the platen was not successful. We decided to increase  $SF_6$ , because in trial II decreasing the parameter did not straighten the walls, but achieved a reasonable etch rate. Run two of the recipe— $SF_6$  (100 sccm) and Platen (12 W)—portrayed the straightest walls and most proper etch depth over the other three runs. Figure 2 shows the etching done in run 1 (runs 3 and 4 show similar characteristics) and the walls are not straighter than the walls of the image in Figure 1, which led to run 1 having a better etch profile for trial III.

After finding an approximate value for parameter  $C_4F_8$  and  $SF_6$ , we wanted to see the affect platen and coil had on the etching of  $Si_3N_4$ . We discovered that increasing the platen and coil, which are the power, created a deeper etch in the  $Si_3N_4$  surface, see Figure 3. The image shows a darker line that separates the  $Si_3N_4$  and  $SiO_2$  layer.

After manipulating the recipe, it was found to produce a good anisotropic etch profile with  $C_4F_8$  (130 sccm),  $SF_6$  (100 sccm), platen (1000 W), coil (12 W), and chamber pressure (10 mTorr).

### Conclusions:

$H_2$  bonds with the fluorine in  $C_4F_8$  producing hydrofluoric acid (HF), which is known to etch  $Si_3N_4$ . It is suspected that this reaction is what caused the deep etching in the  $Si_3N_4$  layer and into the  $SiO_2$  layer. The RF power platen and coil are the powers which generate the plasma. As they were increased, it also caused an increase in etching, because it increased the acceleration of ions as they were accelerated upon the surface of the  $Si_3N_4$ . With a straight wall etch recipe for  $Si_3N_4$ , the etch rate was determined to be 50 nm/sec. This etch rate will be used in future research to etch e-beam written samples to fabricate the actual waveguides.

### Acknowledgements:

National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program.

### References:

- [1] Madou, Marc J., (1997), Fundamentals of Microfabrication, Ron Powers, Boca Raton, Florida, 1, pp.14.
- [2] Saleh, B.E.A and Teich, M.C. (2007) Fundamentals of Photonics, John Wiley & Sons, Inc. Hoboken, New Jersey, 8, pp.308-311.

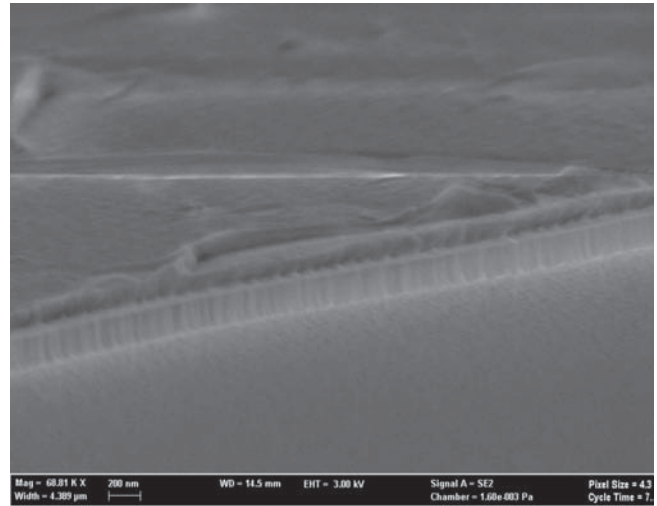


Figure 1: SEM image of  $Si_3N_4$  sample from run 1 of trial II; etched 200 nm. Note: Photoresist not fully removed.

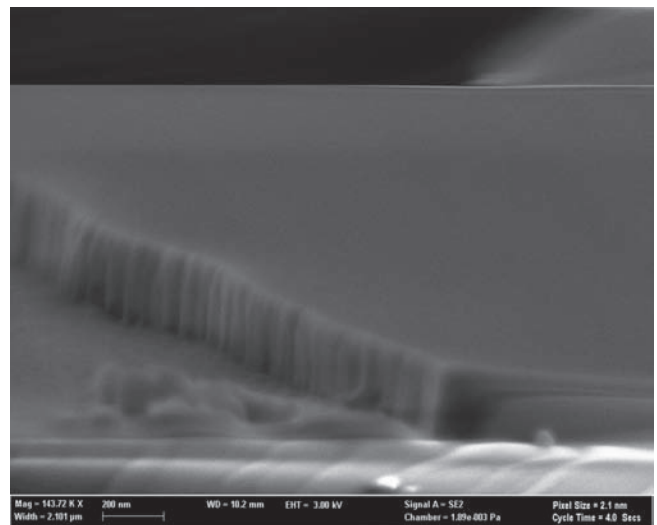


Figure 2: SEM image of  $Si_3N_4$  sample from run 1 of trial III; etched 200 nm.

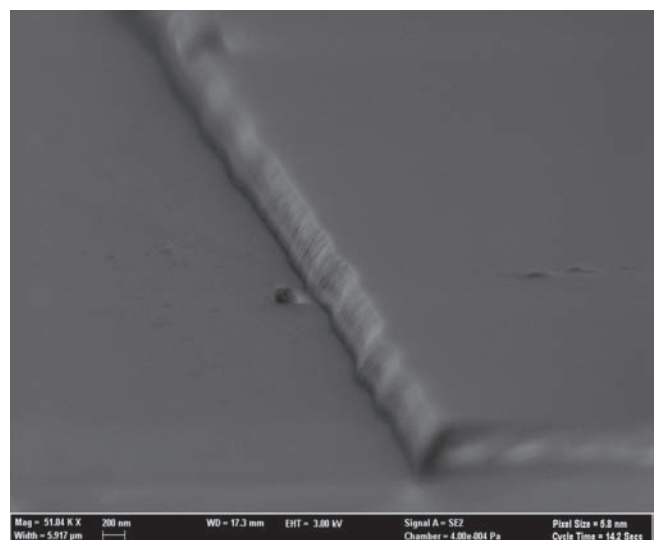


Figure 3: SEM image of  $Si_3N_4$  sample from run 1 of trial IV; etched 450 nm.