Fabrication of Silicon Nitride Waveguides

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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 generated 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:

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References:

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[2] Saleh, B.E.A and Teich, M.C. (2007) Fundamentals of Photonics, John Wiley & Sons, Inc. Hoboken, New Jersey, 8, pp.308-311.

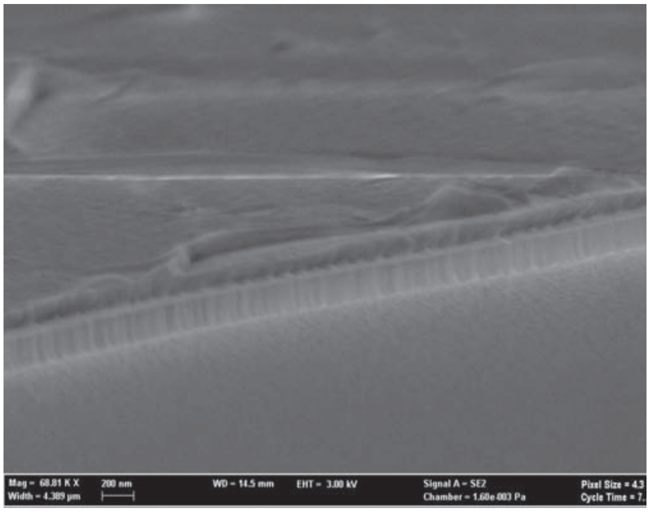

Figure 1: SEM image of Si_3N_4 sample from run 1 of trial II; etched 200 nm. Note: Photoresist not fully removed.

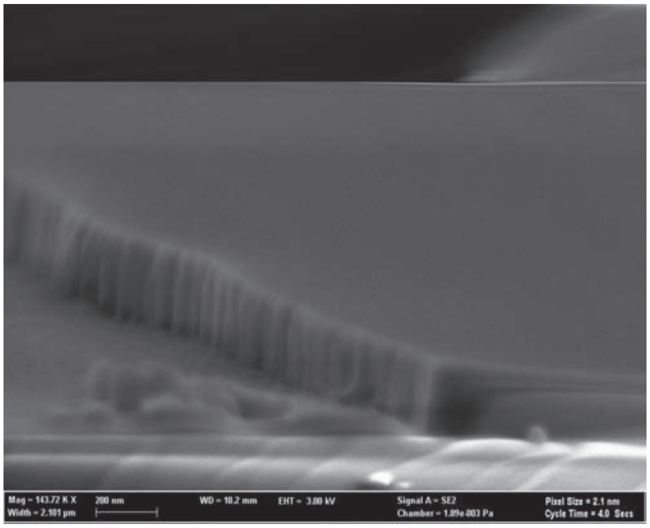

Figure 2: SEM image of Si_3N_4 sample from run 1 of trial III; etched 200 nm.

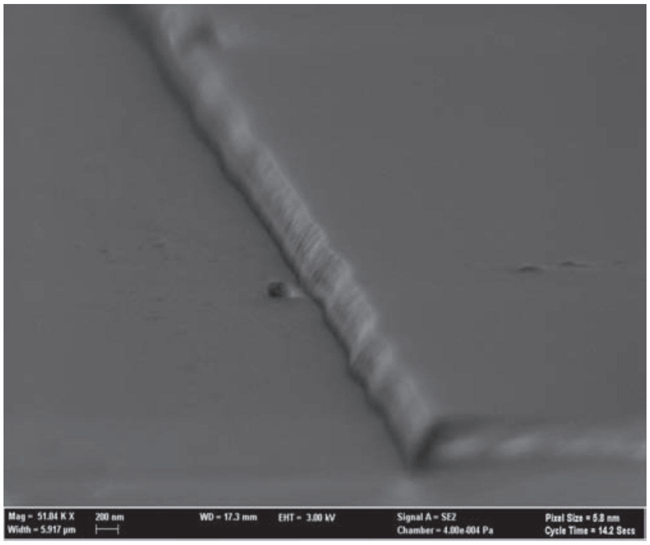

Figure 3: SEM image of Si_3N_4 sample from run 1 of trial IV; etched 450 nm.