Partially Self-Assembled Planar Photonic Structures

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Abstract:

Waveguides, which are planar photonic structures, use the principles of refractive index contrast to propagate light in a desired path. One of the major problems with current waveguides is optimizing the efficiency. Various sources for loss in waveguides exist, including sidewall roughness which results in scattering. The motivation behind this project is to improve the efficiency of waveguides by eliminating surface roughness, without implementing a complex process.

We fabricated new smooth waveguides by exploiting the surface tunability of a silicon wafer using patterned hydrophobic and hydrophilic regions. The hydrophilic region was a film of 5.6 μm of oxide, while the monolayer FOTS was used to make the hydrophobic area. Norland Optical Adhesive 71 (n = 1.56) was used as the waveguide material. The adhesive, when applied in a very thin, uniform layer, selectively forms on the hydrophilic lines and dewets from the hydrophobic surroundings. The waveguides were found to have a lens-shaped cross-section with a ratio of 10:1 width to height by SEM. Observations using SEM and AFM showed these waveguides were indeed smoother than current technology. They were also coupled with an optical fiber and successfully guided light with a measurable output. Waveguides of various lengths were measured to calculate the loss vs. length. Loss results are still in progress.

Introduction:

Nanophotonics research is becoming more significant in today's society of smaller and faster systems. Waveguides use index of refraction contrast to direct light down a desired path. Through direction of this light, information can also be transferred. These waveguides can be used in areas such as telecommunications, data transfer on silicon using chip-to-chip interconnects, and even in biology—using them to direct light on a micro-scale.

A problem with the current fabrication of these waveguides is scattering due to sidewall roughness. The current fabrication process involves lithography and etching, both of which add to sidewall roughness. In order to alleviate this problem, an entirely new process was developed and tested. Our process involved patterning hydrophilic and hydrophobic regions on silicon in order to self-assemble ultra smooth waveguides.

Experimental Procedure

Wafer Fabrication:

Oxide was deposited on a <100> N-type silicon wafer using plasma enhanced chemical vapor deposition (PECVD) at a rate of 457 nm/min for 15 minutes. Oxide was used because we required a material that was less hydrophobic than FOTS and had a lower index of refraction than our waveguide material. PECVD was chosen over thermal oxide because thermally growing over 5 μm of oxide would have taken more than 12 hours in the furnace. Using an optical measurement system, thickness measurements were found to be 6.5 μm $^+$/- 0.1 μm. Shipley Photoresist 220-3 was then spun at 4000 rpm, ramp 1800 rpm/s for 60 seconds. The wafer was baked for 90 seconds at 130°C. A 5 inch square photomask was used that produced 8.5 μm lines with 200 μm spaces in between when exposed using a 5X i-line autostepper. An exposure time of 0.4 seconds with a focus offset of -7 was used and a step size of 2 cm. The postexposure bake was for 3 minutes also at 130°C.

The wafer was developed in MIF300 developer 60 seconds using an automated wafer developing tool. After development the wafer consisted of oxide where the exposed resist was developed away and 8.5 μm unexposed photoresist lines. Using a molecular vapor deposition tool (1, 1, 2, 2-Perfluorooctyl) trichloro-silane, FOTS (a hydrophobic monolayer) was deposited on the entire wafer.

To lift off the resist, the wafer was placed in acetone for 1-2 minutes followed by IPA for another minute, and then water to rinse the wafer. Dissolving the resist in acetone also released the FOTS on top of the resist, and therefore the resulting wafer had hydrophilic oxide lines with hydrophobic FOTS monolayer surrounding them. The FOTS monolayer is not affected by the acetone, IPA, or water.

Waveguide Fabrication:

10 microliters of Norland Optical Adhesive 71 (NOA71) (n=1.56 cured) were dropped in the hydrophobic square surrounding the waveguides. The adhesive begins as a viscous liquid. This volume was then squished by a Teflon® piece to give an even, thin layer which allowed the adhesive to selectively stay on the hydrophilic waveguides and dewet from the hydrophilic surroundings back onto the larger hydrophilic region where it was dropped. This was repeated until it was verified under microscope that the lines were uniformly covered. The wafers were then cured for 10 minutes under UV lamp. After curing, the NOA 71 hardens into a solid.

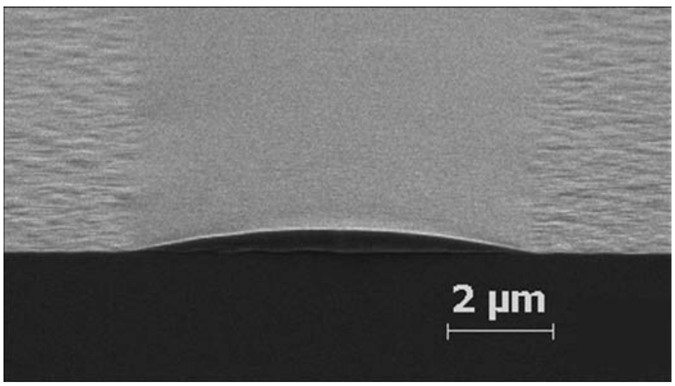

Figure 1: SEM image of profile 8.5 µm waveguide.

Results and Conclusions:

This new fabrication process did in fact produce ultra smooth waveguides using a self-assembled method. The waveguides produced displayed a 10:1 width to height ratio as shown by the scanning electron microscope in Figure 1. These waveguides were also smoother than current technology waveguides as shown by the AFM in Figure 2. Using the calculation software, the roughness of these structures was reported to be less than 1 nm, while current technology stands around 5-6 nm. Actual losses are being measured and we expect them to be less than current technology waveguide losses.

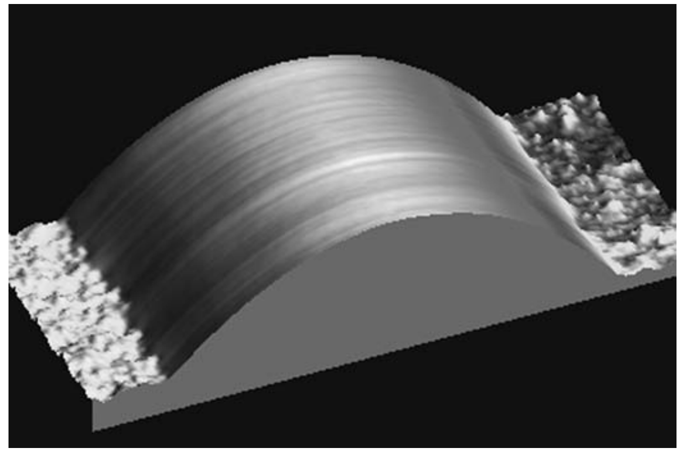

Figure 2: AFM image of smooth surface of 8.5 µm waveguide.

This project illustrated a way to decrease losses in waveguides using an entirely new approach to the problem. This new, simple fabrication process showed that there are other methods to making usable waveguides that could prove to be better than just optimizing the current fabrication method. Future work on this project will include applications to flexible substrates, greater control of the waveguide profile, and investigation of new materials.

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References:

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