Optimizing Hard Mask Etching for Quartz NanoDevices

Rachel Miller

NanoEngineering, University of California, San Diego

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

NNIN REU Principal Investigator: Professor Marko Lončar, John A. Paulson School of Engineering and Applied Science, Harvard

NNIN REU Mentor: YoungIk Sohn, John A. Paulson School of Engineering and Applied Science, Harvard University

Contact: ram006@ucsd.edu, loncar@seas.harvard.edu, sohn@seas.harvard.edu

Abstract:

Quartz is well recognized for its superior mechanical properties in piezoelectric devices and has recently shown potential for use in tunable optical filters. However, due to the lack of thin film technology for quartz, its use has been limited to microscale devices. An angled etching fabrication technique has been adopted to realize nanoscale quartz devices. To employ this technique, an evaporated or sputtered aluminum or titanium mask must be used. In order to achieve high quality for nanomechanical or optical devices, surface smoothness is of utmost importance. To achieve this, we optimized hard mask dry etching to transfer a smooth sidewall to the final device. We tested various etch recipes, tracking the effect of temperature, gas flow, and DC bias on anisotropy and selectivity. Our most successful recipes with both aluminum and titanium etching resulted from increasing temperature and optimizing DC bias. Aluminum yielded an acceptable quality etch product. Titanium had issues with selectivity and stress.

Introduction:

The Lončar group has published work on angle-etching diamond for use in "A variety of nanoscale photonic, mechanical, electronic, and optoelectronic devices" [1]. We desired to apply this technique to quartz, a well studied and commonly used material in electrical and computer engineering. To do so, we required a reliable quartz etch procedure that preserved high selectivity and high aspect ratio [2]. In previous experimentation, photoresist and oxides had not been sufficient and instead aluminum and titanium were the most promising candidate mask materials.

Once these methods are employed, as depicted in Figure 1, the group can create and test quartz nanodevices for advanced scanning microscopy or optoelectromechanical devices such as optical tuners.

Experimental Procedure:

One centimeter by one centimeter samples were cut from a standard thickness quartz wafer. When ready to be used, 4-6 samples were then put into a 1:3 ratio H_2SO_4:H_2O_2 solution followed by sonication in acetone, then methanol, then isopropyl alcohol to remove impurities.

Hard Mask Fabrication, Patterning, and Etching. One micrometer of aluminum or titanium was electron beam vapor deposited. Pressure would rise as the deposition rate increased as a result of increased chamber temperature and increased particle count. Samples were then spincoated with photoresist and electron beam patterned. We then etched individual samples in the Plasma Therm Unaxis Shuttline reactive ion inductively coupled plasma etcher. As we observed changes in etch quality, we changed pressure, gas flow, and heat exchanger temperature.

Aluminum. In aluminum (Al), the variables commonly changed were pressure and temperature. Al was etched with various recipes, the most successful, as displayed in Figure 2B was with twelve standard cubic centimeters per minute (sccm) of BCL_3, 25 sccm of Cl_2, and 6 sccm of CH_4 flowing at a pressure of 8 milliTorr, which yielded a DC bias of 380.7 volts.

Titanium. With titanium, the etch recipe variables most commonly changed were time interval and temperature. We experimented with using multiple shorter time intervals (one to two minutes) to achieve more control over etch progression and avoid over or under etching.

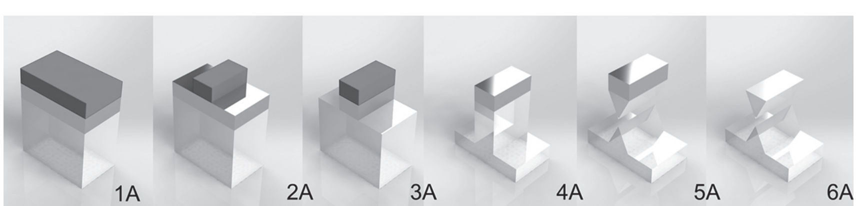

Figure 1: Top layer represents resist. Middle layer represents aluminum or titanium thin film. Bottom transparent layer represents quartz.

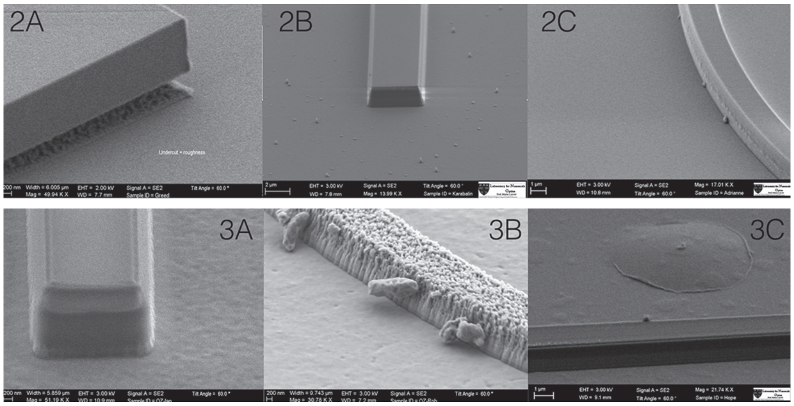

Figure 2, top left: *(2A) 300 nm aluminum film undercut and rough due to film being too thin and lack of polymer sidewall coating. (2B) One micron, more anisotropic, but residue remained. (2C) Almost all residue gone, anisotropic, clean sidewalls.*

Figure 3, bottom left: *Titanium film under etching, over etching, and film breakage.*

Imaging and Evaluation. These samples were imaged with the Zeiss Supra scanning electron microscope at a sixty degree tilt to observe changes in etch quality between recipes.

Results and Conclusions:

Aluminum Hard Mask Etch. Etch quality of aluminum was improved to be applied in full device fabrication. Figures 2A and 2B are from the first and last etch recipes, respectively. They demonstrate how introducing methane gas and increasing temperature yielded a more anisotropic etch with cleaner sidewalls. They also show that a thicker thin film of aluminum was needed to combat over etching and improve selectivity.

Methane was introduced to create polymers that would form protective layers on sidewalls, preventing undercutting and roughness during etching. However, once these polymers are introduced they can settle along with aluminum chloride, leading to over etching and/or disruption of structures. To reduce residue, we increased heat exchanger temperature to increase chamber volatility and easily reacting combined polymers or aluminum chloride out of the solid phase.

As seen in Figure 2B, we were successful in creating an anisotropic and clean etched product suitable for fabricating an angle-etched quartz nanodevice.

Titanium Hard Mask Etch. Titanium was not as successful because of its tendency to under etch (Figure 3A), over etch (Figure 3B), or structurally fail due to stress (Figure 3C).

Future Work:

Aluminum Mask Improvements. We were able to create a more anisotropic and clean etch with aluminum. Depositing aluminum at a lower pressure should eliminate minor film inconsistencies. Full cleaning of the etching tool should eliminate significant substrate residue.

Titanium Mask Improvements. In addition to over and under etching, film stress occurred in titanium. We hypothesized based on literature [2] that sputtering at a high temperature will alleviate stress. To simulate this change in the process we sputtered titanium onto a full wafer and measured bowing stress versus temperature. These preliminary tests supported that sputtering and increasing temperature could relieve stress, as seen in Figure 4.

Acknowledgments:

A special thanks to my Principal Investigator Professor Marko Lončar, my mentor YoungIk Sohn, and the whole Lončar group, in addition to Harvard University's Center for Nanoscale Systems, and the NNIN REU Program and NSF under Grant No. ECCS-0335765.

References:

[1] Burek, M.; et al., Free Standing Mechanical and Photonic Nanostructures in Single Crystal Diamond. Nano Letters 2012, 12, 6084-6089.

[2] Plummer, J.; Deal, M.; Griffin, P. Silicon VLSI Technology ; Prentice Hall: Upper Saddle River, NJ, 2000.

[3] Chang, R.; et al., Residual Stresses of Sputtering Titanium Thin Films at Various Substrate Temperatures. Journal of Nanoscience and Nanotechnology 2010, 10, 4562-4567.

[4] Kovacs, G. Micromachined Transducers Sourcebook.

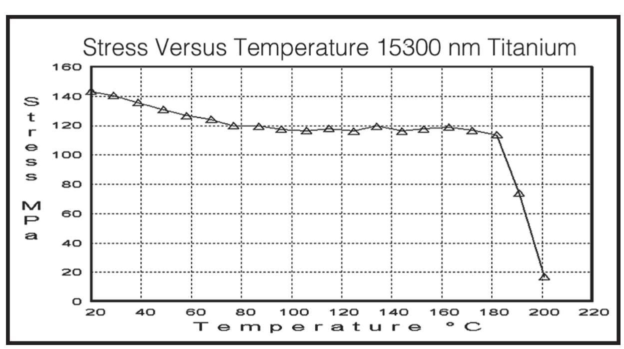

Figure 4: Stress vs. Temperature 15300 nm titanium.