Fabrication of Nanometer-Scale Gaps on Thin Nitride Membranes using Electron Beam Lithography

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Abstract:

Electron beam lithography, with its incredible accuracy and patterning precision, is on the forefront of nanotechnology and nano-gap fabrication. Nano-gaps hold promise for a variety of reasons. In molecular detection, smaller gaps can detect fewer particles, having applications in airport security, chemical warfare and environmental monitoring. Nano-gaps could also be used for better DNA detection and research in molecular electronics. To achieve these applications, several methods have been undertaken to help increase the resolution of electron beam lithography systems, including the use of thin resist thicknesses, beam interference, limiting apertures and thin membranes.

In this project, the state-of-the-art JEOL JBX-9300FS 100kV system at Georgia Tech was used to obtain high resolution and very precise patterns. A drawback of this system is the backscattered electrons, which can expose unpatterned resist, blurring patterns. This drawback can be nearly eliminated by using thin membranes. To obtain these membranes, the wafer was selectively etched away to leave a layer of silicon nitride with a thickness of a few hundred nanometers. The e-beam pattern was then written on the membranes and the sample underwent a gold lift-off process. Characterization, using the scanning electron microscope (SEM) and atomic force microscope (AFM), has shown successful fabrication of nanometer scale gaps.

Procedure:

The first step in the process was to fabricate the membranes for writing. In order to do this, a process for efficiently and repeatedly achieving these membranes had to be finalized. For our process, type <100> wafers were used due to their etching properties, and it was found that double side polished wafers were also needed.

Our membranes were made of silicon nitride, Si_3N_4. The Si_3N_4 was deposited on both sides of the wafer. The Si_3N_4 served a dual purpose. On the front side of the wafer, the nitride would become the membrane after etching. On the back side, the Si_3N_4 worked as an etch mask. The front layer of nitride was very thin; experimentation was performed with thicknesses from half of a micron to as thin as a few hundred nanometers. The back layer was coated with approximately 1 μm of nitride. For our trials, the deposition was performed with a plasma enhanced chemical vapor deposition system (PECVD).

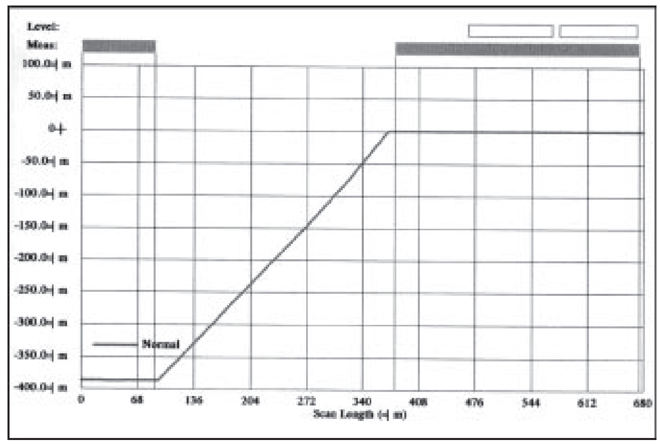

Figure 1: This profile shows the 54.7° etch angle through the wafer.

After deposition, standard photolithography was performed on the front of the wafer. Our pattern was then developed and removed, leaving the pattern in exposed silicon with the developed resist as an etch mask for the nitride etch. At first, a reactive ion etcher (RIE) was used to etch through the nitride, but it could not be kept clean enough to give a good etch. Using an inductively coupled plasma etcher (ICP), the nitride etch worked much better, giving clear pattern transfer and etching all the way through the nitride, exposing the silicon substrate.

With the nitride removed, the silicon etch could be performed. This process used a wet etch with 30% potassium hydroxide (KOH). Due to the <100> orientation, the exposed silicon was etched at a 54.74° angle, as the profile in Figure 1 shows. Etch rates of 1 to 1.6 μm per minute were obtained with etch selectivity of nearly 1000:1, silicon to silicon nitride. After the nitride etch was completed, the membranes were ready for use.

The next step was to use the JEOL JBX-9300FS electron beam lithography tool to write our pattern onto the membrane and substrate. For our pattern, we put part on the membrane and part on the substrate in order to see the contrast between the membrane and substrate. With the exposure and development completed, the imaging could be done. Imaging was done using an SEM. The AFM could not give us the resolution needed.

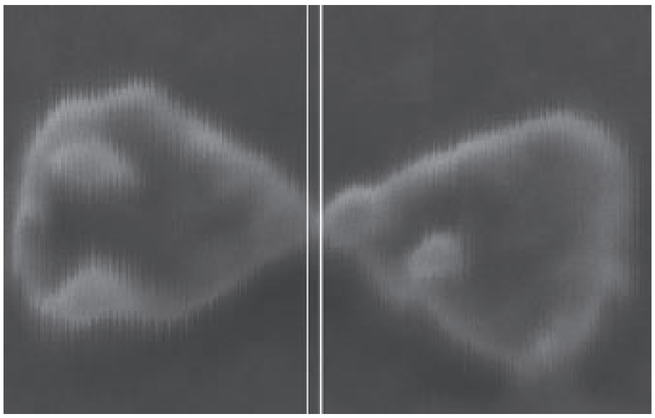

Figure 2: The smallest gap achieved, 5.78 nm, is shown here.

Results and Conclusions:

From our experimentation, very promising results were obtained. The process for fabrication of the membranes was established and optimized. The membrane squares could be fabricated with a high yield per wafer, efficiently, and fairly quickly. The process worked very well and success was achieved for every trial using the double side polished wafers.

The results from patterning were also very promising. While we were able to successfully fabricate gaps as low as 6 nm, there is good reason to believe narrower gaps can be achieved. Figure 2 shows the smallest gap achieved in this series of trials, less than 6 nm. By varying the dosage applied, the gap size varied until a point was reached when the dosage was too high and the pattern merged. While the gap sizes we achieved were good, the most compelling results from our research can be seen in Figure 3 and 4. These SEM images were taken right at the border of where the membrane and substrate-backed patterns met. A clear distinction can be seen between the patterns made on the substrate-backed nitride and the membranes. The patterns that were written on the substrate were merged at a much lower dose, possibly due to the backscatter. The patterns were also skewed and tilted. On the other hand, the patterns that were written on the membrane came out very clear. The membranes produced smaller gaps with much greater precision.

Future Work:

With the promising results and possibilities of this project, we would like to see more work done to find a better etching process. Another idea is to use a metal etch mask for better selectivity. Finally, the use of sacrificial polymers in construction of these membranes is another area of interest.

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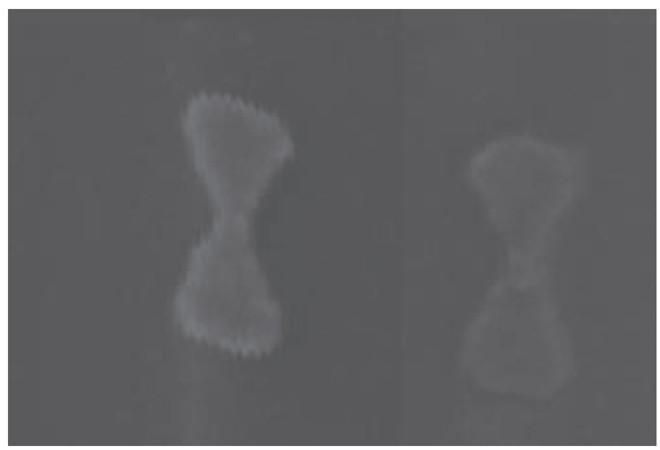

Figure 3: The quality of the substrate written patterns is lower then the membrane patterns.

Figure 4: This image shows the patterns written on the membranes.