Fabricating an SU-8 Support Structure with Non-Vertical Side Walls Using a Diffraction Grating

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ABSTRACT

Fabricating an SU-8 Support Structure with Non-Vertical Side

Walls Using a Diffraction Grating

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Our group and others have developed micro filters that can be fabricated using standard photolithography techniques. Our filters are made with the negative photoresist SU-8 and consist of two layers: a thinner membrane layer, and a thicker support layer. The thinner membrane layer is important for filtration, but by itself is very fragile. The support layer enables the filter to withstand higher pressures without bursting and means it is much less fragile to handle. However the support layer covers some of the pores of the membrane layer decreasing the open area of the filter. The goal of my research is to create a support layer with inward sloping side walls. Since these walls are narrower at the bottom, fewer pores will be covered and overall open area will increase. These walls have been fabricated using a simple diffraction grating. The widths at the bottom of the structure ranged from 20.59 microns to 22.69 microns at an exposure dose of 135 mW/cm^2. This is a 24%-31% decrease in size from the regular 30 micron length. I conclude that the inward slope of the walls is caused by how the diffraction grating changes the intensity of the light being used for exposure.

Contents

Chapter 1

Introduction

1.1 Microfiltration

Microfiltration is the process of separating a fluid from particles or microorganisms contaminating it. It has applications ranging from water purification to identifying tumor cells in blood samples. Our group and others have developed micro filters that can be fabricated using standard photolithography techniques. Using a double exposure these filters can consist of two layers: a thinner membrane layer and a thicker support layer [1]. The support layer enables the filter to withstand higher pressures without bursting and means it is much less fragile to handle. Figure 1.1 shows the membrane layer that is subject to a lot of bending while Figure 1.2 shows a much more rigid membrane layer with the support structure.

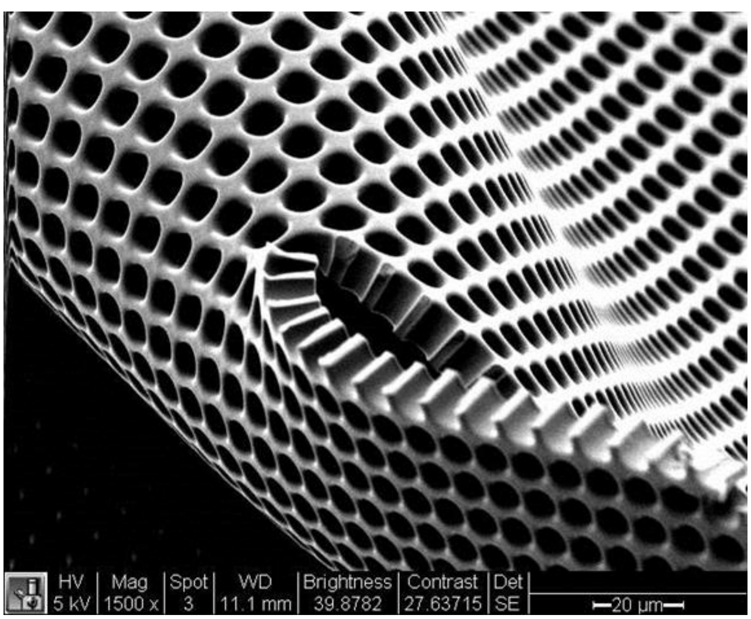

Figure 1.1: SU-8 Membrane Layer

Our filters are made with the negative photoresist SU-8, have 8 micron pores in the membrane layer, and have a support layer that covers some of the 8 micron pores. When the number of open pores decreases, the flow rate at a given pressure also decreases. The goal of my research is to increase the open area of the filter by fabricating a support layer with non-vertical side walls. A support layer with walls that are angled inward (the top of the support layer is wider than the bottom) could increase overall open area in the membrane layer. In the remainder of this introduction, I'll outline background information necessary to understand my project. I'll then give the fabrication process of my support layer and finally detail and discuss the results of this process.

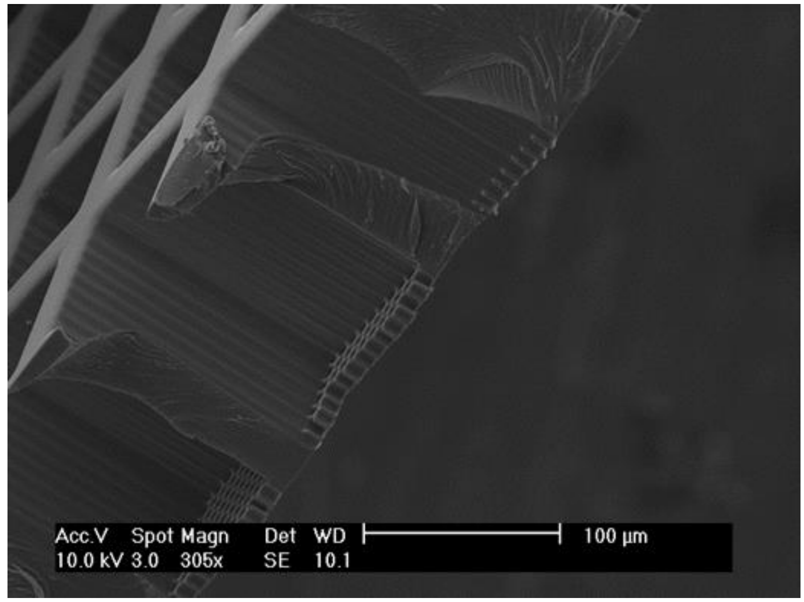

Figure 1.2 Membrane Layer with Support Structure

1.2 Photolithography

Our filters are fabricated using the process of photolithography. During this process, a pattern is created in a photoresist by exposing it to UV light. To begin the process, a silicon substrate is cleaned and heated to evaporate any excess moisture or solvent left on it. The desired photoresist is then uniformly spin cast onto the wafer. By altering the spin speed and time of spin, the thickness of the resist can be changed. The substrate is then heated before exposure (pre-exposure bake or soft bake) to evaporate excess solvent and partially harden the resist. A chrome photomask with the intended pattern etched into the chrome is used for the exposure step. The mask is placed over the wafer and then exposed to UV light. The chrome on the mask is opaque which results in the negative of the chrome pattern being exposed in the photoresist. The mask and the wafer are kept level, in close contact, and perpendicular to the UV light by an aligner. The close contact reduces the effects of light diffraction which minimizes widening of the pattern on the photoresist. In positive resists, the exposed resist becomes soluble, and in negative resists (like SU-8) the exposed portion becomes insoluble. The wafer goes through a post exposure bake to harden the resist more and is then developed. During development, the soluble portion of the resist is dissolved leaving only the desired pattern in the photoresist. In our filters, a final bake is performed after development known as a hard bake or a cure. This hardens the photoresist even more.

1.3 SU-8

SU-8 (MicroChem) is the photoresist we have chosen to use for our filters. It is an epoxy based negative photo resist. It can be used in a variety of micromachining and other microelectronic applications. There are several physical properties that make it particularly useful including being able to spin a wide range of thicknesses, high aspect ratio of developed features, and strong cross linking of the cured SU-8.

By using different spin speeds and viscosities of SU-8, film thicknesses varying from 0.5 microns to 1.5 mm can be achieved in a single coat [2]. It is also convenient that SU-8 is processed in the near UV range (350-400nm) which is already commonly used for other photolithographic applications. SU-8 is very useful for high aspect ratio applications. Because of its high optical transmittance at wavelengths above 360nm, SU-8 has near vertical side walls when imaged, even in thicker films. As a result of this, SU-8 can have an aspect ratio of up to 20:1 [3]. Crosslinking in SU-8 is caused by an acid that is released during exposure. This acid acts as a catalyst in crosslinking the resist. This crosslinking takes place mostly during the post exposure bake and the hard bake after development. Once hard baked, the resist can’t be removed with solvent based strippers. Because of this, SU-8 is usually used as a permanent part of the device being fabricated.

1.4 SU-8 as a Membrane Layer

While SU-8 is often used as a stamp or mold for soft lithography [4], it also has been used as a membrane for microfiltration. Another study [5] details the use of SU-8 lithographic microfilters. They cite several advantages of using these filters. When using lithographic techniques to make a filter, variables such as pore size, shape, and distribution can be easily and precisely controlled. SU-8 has an advantage over other membrane materials such as parylen, silicon, silicon nitride and nickel in that it is much easier to fabricate, requiring no additional pattern transfer steps like reactive ion etching. An SU-8 membrane is also less brittle than a silicon, silicon nitride or nickel membrane.

In addition to horizontal filters, vertical SU-8 filter screens have been fabricated. The ability, “to create multidimensional SU-8 structures by unusual deposition and exposure techniques” [6] is given as the reason for using SU-8 in their system.

1.5 Other Methods of Achieving Non-vertical Side Walls

Non-vertical side walls in SU-8 have been achieved in a number of ways. One way is to tilt the mask and wafer so they are no longer perpendicular to the incoming light during exposure [7]. The process is very similar to the standard photolithography process, but can produce oblique pillars, angled channels, or (if rotated during exposure) truncated cones. Because of the index of refraction of glass, the angles of these structures are less than the tilted angle of the mask and wafer, though this change can be easily calculated and accounted for. A refractor placed on top of the mask could also achieve a similar result.

While the angled method is relatively straight forward, our equipment was ill suited to this process. The MA 150 Karl Suss aligner used in our cleanroom is built to avoid such a tilt in the mask and there was not enough space between the source and the mask vacuum plate to set up a tilting stage. The effect could have been achieved with a tilting stage and a mercury lamp source outside of the aligner, but this would have added a new piece of equipment to our process. We are instead looking to develop a process that is compatible with standard equipment like the Karl Suss aligner.

Another paper has reported achieving positively sloped side walls by simply exposing the SU-8 for much longer than a normal dose [8]. SU-8 that received a 30s dose at 20 mW/cm^2 had nearly vertical side walls, while a dose of 250s at 20 mW/cm^2 created a slope of 7.3 degrees outward. While this method was extremely simple, I was unable to replicate their results. This was perhaps because of differing soft bake times or other inconsistences with their methods.

Chapter 2

Design and Procedure

2.1 Filter Fabrication Process

Our membrane layer is an array of 8 micron circular pores separated by about 2 microns on each side. The membrane is 15 microns thick and is fabricated using SU-8 10 (MicroChem). One important step that is required for the membrane layer is adding a release layer. Since these filters are to be used independently of the silicon wafer, there needs to be a way to remove them. After the dehydration bake of the wafer, but before the resist is applied, a thin layer of Omnicoat (MicroChem), which will be used as a release layer, is spun onto the wafer. The Omnicoat is then baked at 200C for 60 seconds. When the filter is removed, the Omnicoat will be dissolved in developer, and the final filter will be free from the wafer. Once the SU-8 is spun and baked, it receives an exposure dose of 45 mW/cm^2. After developing and hard baking the membrane layer, the support layer is ready to be fabricated.

The support layer is a square grid with walls 30 microns thick and open squares 110 microns wide. It is fabricated with SU-8 2075 (MicroChem). It follows the same fabrication steps as the membrane layer with one slight difference. There is no Omnicoat between the membrane layer and the support layer, but another 15 micron layer of SU-8 10 is spun on the hard baked membrane layer. This helps the SU-8 2075 spin on evenly and without bubbles. The SU-8 10 is soft baked, and then the 110 micron layer of SU-8 2075 is spun on. The fabrication process of a filter is shown in Figure 2.1 where green is soluble resist and red and orange are

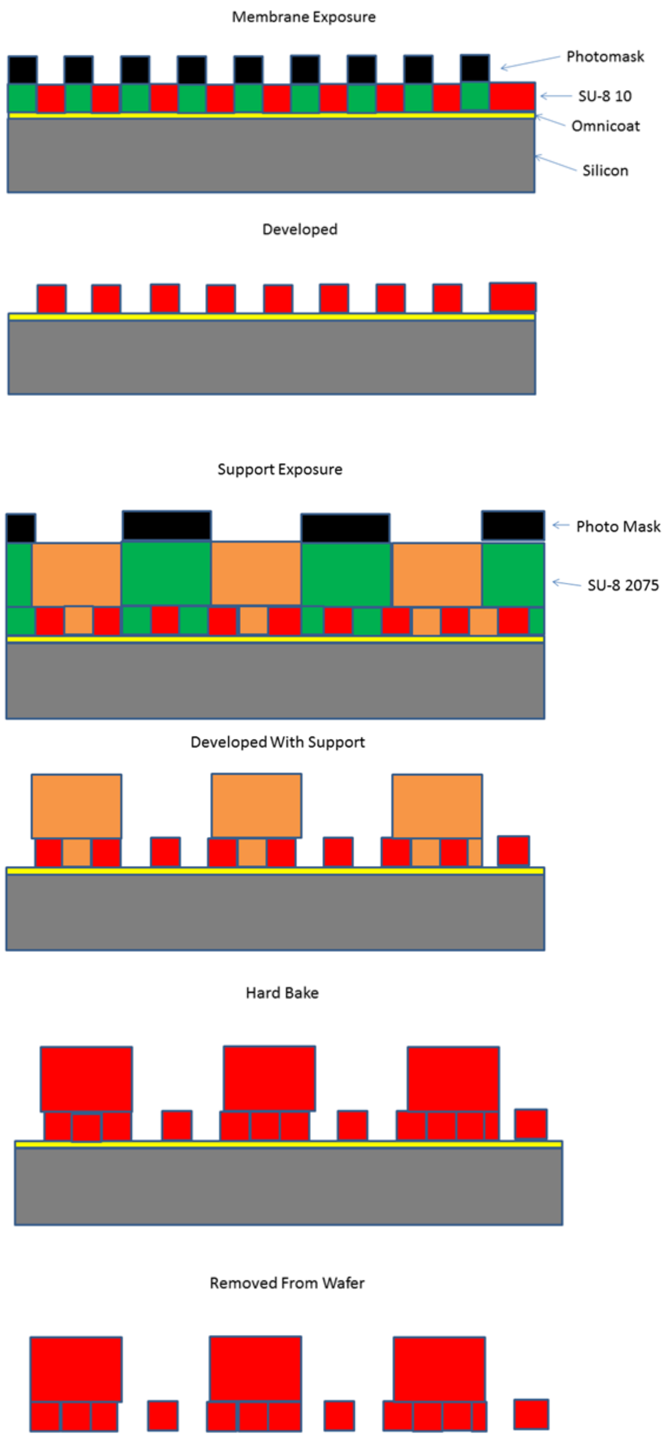

Figure 2.1 Filter Fabrication Process

insoluble resist. Before the support layer developed, non-crosslinked SU-8 fills the pores of the membrane layer, but is removed during development.

When the support layer is hard baked, the support layer and membrane layer are solid enough that they are like one layer. The finished filter can then be removed from the substrate. This is done by rotating the wafer between TEAH and TMAH soaks, each two minutes long. Between each soak, the wafer is sprayed with water and left to soak in water for at least two minutes, longer if it appears the filter is close to coming off. When the Omnicoat is dissolved, the filter will float off of the wafer in the water. How long this step actually takes has seemed to vary widely (15 minutes to over 8 hours), so if necessary, the wafer can be left in the TEAH for a longer period of time.

2.2 Diffraction Grating

We achieved non-vertical side walls in the support layer by using a simple diffraction grating. When the collimated light of the aligner hits the grating, it will spread at an angle determined by the number of lines in the diffraction grating and the wavelength of the light. The light used for exposure is generated by a mercury lamp, so the peaks of the mercury spectrum are the wavelengths to be used when calculating the angle of diffraction. However, because of the optical transmittance of SU-8 and the filter used on the aligner, the only peak important to the exposure of SU-8 is at 365 nm. The diffraction grating used was made from a clear polyester film and contained 500 lines per mm. With this number of lines and the wavelength of light being used, the angle of the first order diffraction is 10.5°.

We originally thought that the diffraction grating would cause the SU-8 to slope outward. Since the diffraction changes the angle of light, we thought the result would be similar to doing a tilted exposure with the advantage that only one exposure would be necessary to obtain sloping walls in one axis of the grid instead of two. This isn't the case though. Even at higher doses the walls would widen, but wouldn't have an outward slope. I'll discuss more details about my results later in the paper.

2.3 Fabrication Process

The support layer can be made with or without the membrane layer underneath. When the membrane layer is omitted, Omnicoat is spun on the wafer using the same process described earlier. SU-8 2075 is spun on in a three step spin process where the steps immediately follow each other. The times and speeds are 5s at 500 rpm, 30s at 2000 rpm, and 2s at 6000s. The last step is to decrease the edge bead, an area of thicker resist on the

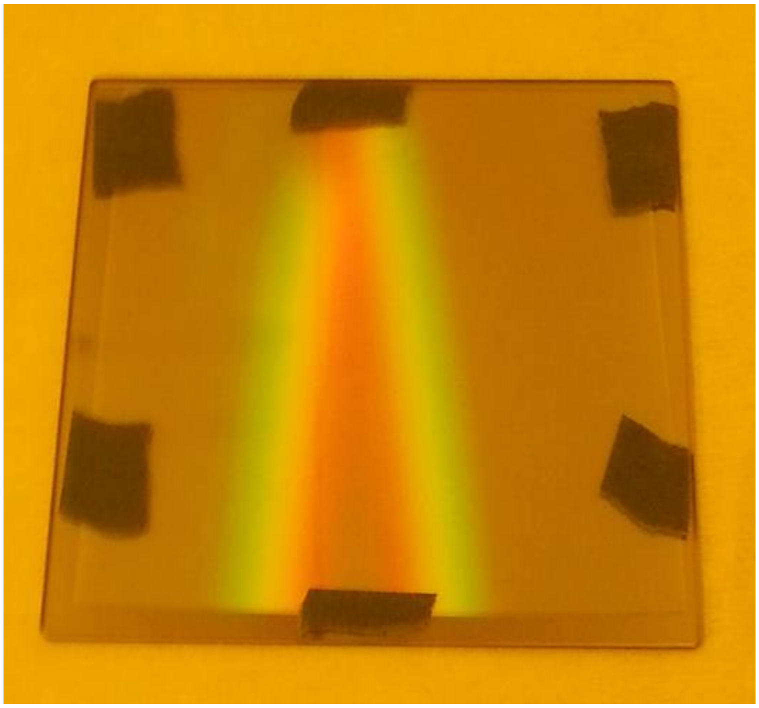

Figure 2.2 Mask with Diffraction Grating

edge of the wafer. Although partially effective, there is still a noticeable edge bead on the wafer following the spin step. The wafer is then soft baked at 65C for 5 minutes and 95C for 20 minutes. The samples are moved directly between the 65C and 95C hotplate instead of letting the temperature ramp up with the wafer still on the hotplate. After the soft bake, the wafer is exposed. The diffraction grating is simply set on top the photomask before exposure. To avoid the problem of the grating moving or not being in close contact with the mask, the grating is taped directly to the mask (Fig. 2.2). Only one layer of the diffraction grating has been used in the experiments so far, but using a second layer rotated at 90° should cause the walls on both axes of the grid to be slanted. The length of the exposure determines to what degree the side walls will be sloped. Shorter exposure time will give have a more dramatic slope while a longer exposure will have walls closer to vertical. The greatest degree of slope was obtained with an exposure time of 18s at an intensity of 7.5 mW/cm^2, but this could be changed depending on the desired slope. After exposure, the wafer is baked for 5 minutes at 65C and 10 minutes at 95C. It is then developed using SU-8 developer (MicroChem). The wafer is developed for 15 minutes while being constantly agitated. After development, the wafer is sprayed with IPA to remove extra developer and dried with a nitrogen gun. The wafer is hard baked at 200C for 5 minutes. After the hard bake, the sample is placed in the PE2 etcher for 5 minutes at 250 watts. This step removes any floor layer that may have formed and also helps to speed up the removal process. If the filter is to be removed from the wafer, the removal process described earlier is used.

Chapter 3

Results and Discussion

3.1 Results

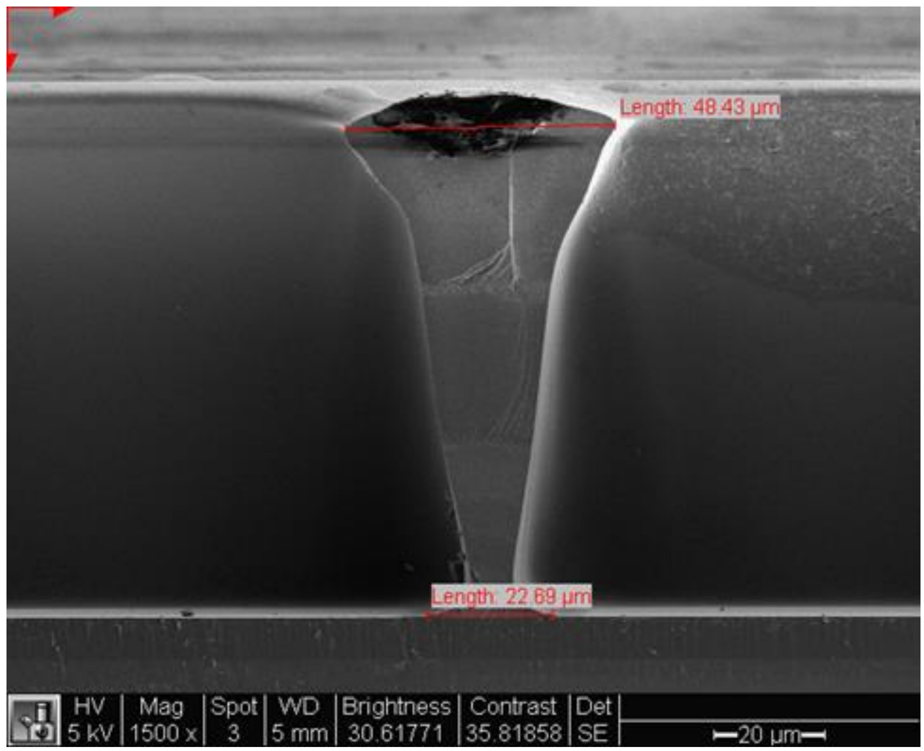

Figure 3.1 18s Exposure

Using the process described here support structures with inward sloping side walls have been created. Figure 3.1 shows the results of an exposure for 18s at approximately 7.5 mW/cm^2. There are several important features of this side wall profile. Perhaps the most important result for increasing open area is the width of the profile at the bottom of the wall. The width of the bottom of four pillars was measured and found to range from 20.59 microns to 22.69 microns. This is a 24%-31% decrease in size from the regular 30 micron length.

In addition to the side walls sloping inward, the top of the pillar is also widened by the diffraction grating. On the sample exposed for 18s, the width of 4 pillars at their widest point was measured. The widths ranged from 47.64 microns to 48.82 microns. The diffracted light seems to be able to cross link SU-8 out to the widest point of the pillar, at which point the intensity is too weak to continue to cause cross linking. From the widest point to about 8 microns

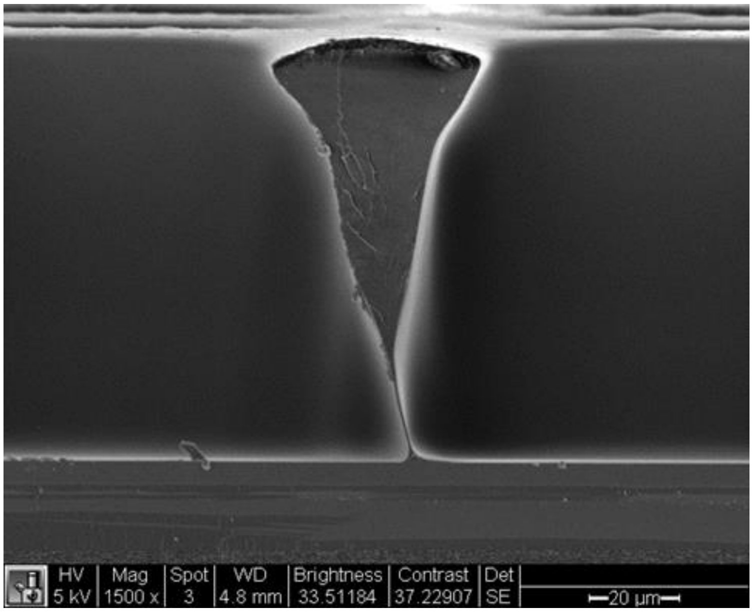

Figure 3.2 16s Exposure

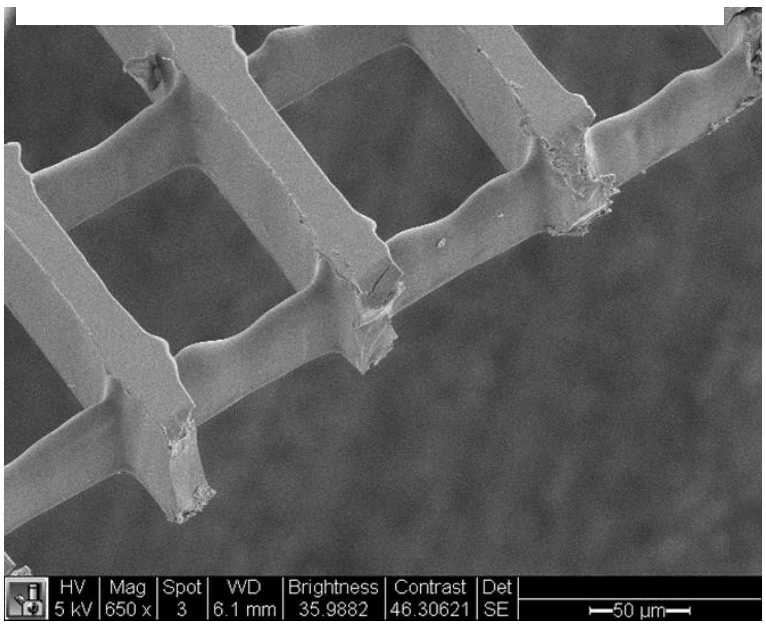

Figure 3.3 20s Exposure at 3.5 mW/cm^2 Viewed from Bottom

below the widest point, the pillar has a greater inward slope. This slope was measured to be approximately 41°.

The taper further down the pillar is less extreme. This slope was measured to be approximately 15°. This more gradual slope seems to come from light which passes directly through the diffraction grating. It also loses intensity as it travels through the SU-8 causing less of the resist to cross link further down the pillar

The pillar actually widens slightly at the bottom into a small foot. Measurements were taken at the bottom of this foot where the pillar actually touches the wafer. The pillar at its narrowest point is approximately 10 microns. If the foot was avoided or removed, open area would increase even more. This could be difficult though due to the strong cross linking in SU-8.

The exposure dose that the sample receives determines the slope of the wall. If the sample is underexposed, the slope will be too extreme and the wall will be to too narrow to provide mechanical support or not extend to the bottom of the wafer (Fig. 3.2, Fig. 3.3). If the sample is overexposed, the side walls will approach their regular width becoming nearly vertical again (Fig. 3.4). Larger exposure doses also cause the features to widen. A longer exposure dose does not give outwardly sloped walls like originally expected. This may be because the diffracted light is not intense enough to cause the SU-8 to cross link through its full path of travel. Any SU-8 that does not receive a high enough exposure dose is dissolved during the development step.

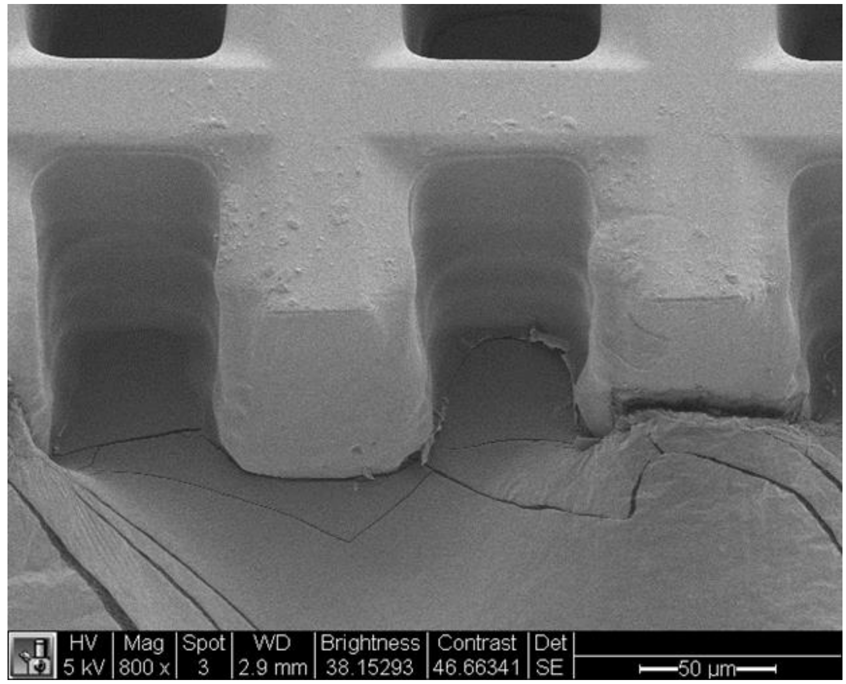

Figure 3.4 250s at 3.5 mW/cm^2

As mentioned earlier, these experiments have only used 1 layer of diffraction grating. Because of this, the two axes of the support grid are shaped differently. The axis that is not subject to diffraction looks similar to a support layer make without using a diffraction grating with some slight differences. There does seem to be a slight inward taper (Fig. 3.5). Four pillars were measured on the 18s sample with the top ranging from 31.76 microns to 33.53 microns and the bottom ranging from 21.8 microns to 24.71 microns. The top does widen slightly and the bottom is less than 30 microns creating an inward slope,

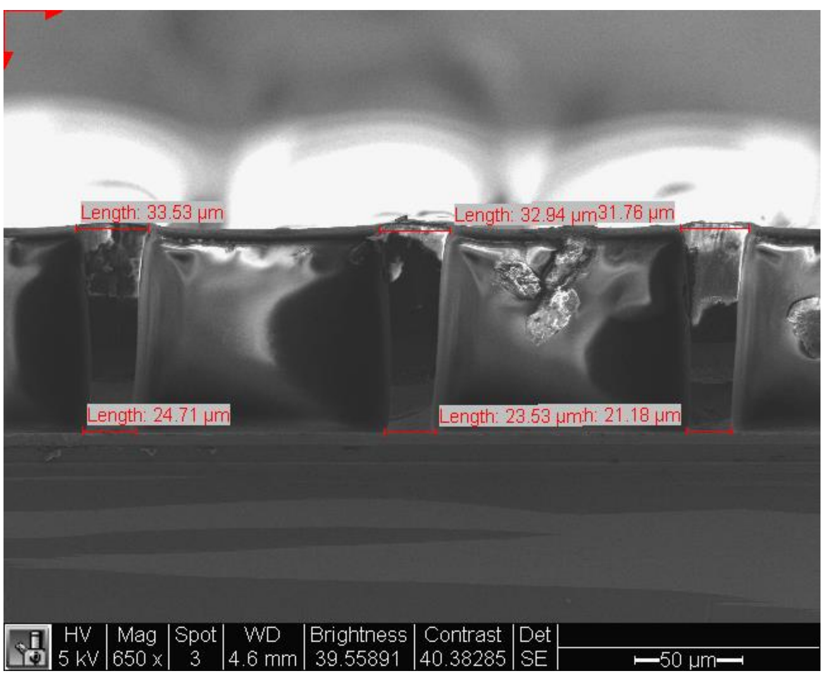

Figure 3.5 18s Exposure on non-Diffraction Axis

although less extreme than the one on the diffracted axis. This slope was measured to be approximately 2.5°. Creating a grid that has the same effects (or nearly the same effects) on both axes by using two offset layers of the diffraction grating would be the next logical step in this project.

Some variably of the width measurements may come from how the images were taken. A small sample was cleaved from are larger wafer to use for imaging, but the cut is never exactly straight. Because of this, some of the pillars are closer to the wall running along the other axis than others. The thickness does slightly increase where two of the support walls meet. Taking measurements on pillars that were clearly near this wall was avoided, but undoubtedly, some of the measured pillars were closer to this wall than others.

3.2 Conclusion

Inward sloping side walls were created in an SU-8 support structure by using a diffraction grating during the exposure process. The widths at the top of a structure receiving an overall exposure dose of 135 mW/cm^2 ranged from 47.64 microns to 48.82 microns while the widths at the bottom ranged from 20.59 microns to 22.69 microns. Both the inward slope and the widening of the top of the pillars seem to be caused by how the diffraction grating changes the intensity of the light being used for exposure. The slope is determined by the exposure dose. A higher dose gives side walls that are closer to vertical and a lower dose gives a more extreme inward slope. By decreasing the width of the support structure at the bottom, open area of the overall filter is increased. Further work would be to remove or avoid the foot at the bottom of the support and to make the two axes of the filter identical.

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