Faculté des sciences et techniques de l'ingénieur

Exploring the limitations of the channel depth of the SMR v2

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Executive summary

This report provides an overview of a semester project lead at the CMi focused on optimizing stepper exposures and exploring the limitations of the channel depth for the microfabrication of Suspended Microchannel Resonators (SMRs). The project aimed in the first place, to determine the optimal dose and defocus parameters during the exposure step of the fabrication process. The report begins with an introduction to the project's objective and process flow. It then details the various steps involved in the microfabrication process, including exposure, dry etching, wet etching, and inspection under the Scanning Electron Microscope (SEM). The report presents the results obtained at each stage and concludes by identifying the optimal dose and defocus settings for stepper exposures. The findings contribute to improved fabrication techniques for SMRs.

Contents

1 Introduction

The goal of this project is to optimize the Suspended Microchannel Resonators (SMRs) microfabrication procedure by investigating various channel depths and optimizing the process with the thick resist. The use of the AMS dry etcher was already exploited in past projects and the process was optimized for a depth of 6 um.

The ALCATEL AMS 200 SE and the SPTS Rapier DSE, two distinct dry etchers available at CMi, were used to etch silicon in order to obtain the required depths. These etching tools are ideal for the fabrication process since they have unique functionalities and performance characteristics.

The ALCATEL AMS 200 SE is a plasma-based dry etcher widely used in semiconductor manufacturing and microfabrication processes. It offers versatility and reliability for etching various materials, including silicon, silicon dioxide, and metals. With its reactive ion etching (RIE) capability, the AMS 200 SE provides precise control over etch rates and selectivity, enabling the fabrication of high-quality microstructures.

On the other hand, the SPTS Rapier DSE is another advanced dry etcher employed in this project. It utilizes deep silicon etching techniques, making it suitable for creating deep channels in the silicon substrate. The Rapier DSE offers excellent etch uniformity, profile control, and high aspect ratio capabilities, essential for achieving the desired depths of 6 um and 10 um in the SMRs.

This study tries to determine the best suitable dose and defocus reaching the desired channel depths by analyzing and comparing the different depth in the silicon etched on the two dry etchers.

Through this project, insightful information and suggestions will be made available, supporting the creation of high-performance microfluidic and resonant sensor devices as well as the improvement of microfabrication techniques for SMRs.

2 Process Flow

In order to fabricate Suspended Microchannel Resonators (SMRs), the microfabrication process flow used in this study included several important steps.

The coating of photoresist using the thick resist M35G with a thickness of 1100 nm was the first step in the process. For the purpose of patterning afterwards, this procedure ensured a consistent and controlled layer of resist.

02	*Photoresist coating* Material: M35G Machine: TEL ACT-8 Thickness: 1100 *nm* The use of a Bottom Anti-Reflective Coating (BARC) is not critical for the process, hence it was chosen not to use one for an easier stripping and cleaning process.	
03	*DUV lithography + Development* Machine: *ASML PAS 5500/350c + ACS200*	

Figure 1: Figure showing the stepper exposure steps

The TEL Unity Me etcher was then used to dry etch the silicon nitride layer. This process made it possible to precisely remove the silicon nitride material and shape it into the necessary shape for the SMRs.

04	*Dry etching* Material: *ls-SiNx* Machine: *TEL Z02* Depth: *500 nm*	

Figure 2: Figure showing the dry etching step of the silicon nitride

The silicon substrate then underwent to dry etching using the Rapier and AMS etchers. These etchers provides the capabilities required to etch the silicon material with great control and precision, achieving the desired channel depths for the SMRs. The resist was then removed using the Tepla GiGAbatch before inspecting the diameter of the openings under the SEM.

05	*Dry Etching* Material: *Si* Machine: *AMS 200 or SPTS Rapier* Thickness: *6 µm*	

Figure 3: Figure showing the dry etching step of the silicon

The Zeiss Leo 1550 scanning electron microscope (SEM) was used to examine the channel depths in cross-section. This inspection made it possible to precisely measure and assess the etched channels, guaranteeing that the specified size and homogeneity were attained.

The process of wet etching was then carried out using 3 different baths. The initial step of the procedure included selectively etching particular materials using a bath of buffered hydrofluoric acid (BHF). Following this, the silicon material was further etched using a bath of 40% potas-

sium hydroxide (KOH) and isopropyl alcohol (IPA). Hydrochloric acid (HCl) at a concentration of 37% was then used in a final 2-hour neutralization procedure to remove any leftover of Si and guarantee the stability of the fabricated SMRs.

07	*Immersing to remove residues* Solution: *40% KOH : IPA 90:10* Arias Base wet bench Z14	
08	*2h neutralization HCl 37%* Arias Acid wet bench Z14	

Figure 4: Figure showing the wet etching steps

3 Exposure

The exposure step was critical for getting perfect patterning when Suspended Microchannel Resonators (SMRs) had to be microfabricated. In this project, the ASML PAS 5500/350c machine was used to carry out the exposure. M35G, a resist with a thickness of 1100 nm, was employed for the exposure, providing an adequate layer for outlining the necessary designs.

A range of dosages was investigated to optimize the exposure process, ranging from 21 mJ/cm^2 to 45 mJ/cm^2. This range permitted a thorough evaluation of the effect of the dose on the patterning quality and resolution of the SMRs. The dose was increased in increments of two, allowing for a methodical analysis of how the exposure affected the critical dimension of channels.

The defocus parameter was taken into account in addition to the dose variation. The focal plane's deviation from its ideal position is represented by defocus. The defocus range investigated in this experiment was from -0.6 m to 0.6 m, with steps of 0.2 m. The project's objective was to systematically alter the defocus in order to assess its impact on the diameter of the openings.

In order to achieve the desired patterning accuracy, resolution, and dimensional precision for the SMRs, the project thoroughly examined the effects of various dosages and defocus settings during the exposure process.

Scanning electron microscopy (SEM) was used to carefully analyze the openings' diameters of the channels after the exposure process. The results obtained showed a variety of opening widths, from 270 nm to 312 nm, while maintaining a constant defocus setting. The dosages ranged from 27 mJ/cm2 to 39 mJ/cm2. This shows a significant correlation between the exposure dose and the measured opening diameter. Similar to this, the defocus adjustment produced opening sizes between 276 nm and 357 nm, with defocus values between 0.6 m and -0.4 m, when taking a constant energy level into account. These results highlight how crucial it is to precisely regulate the dosage and defocus parameters during the exposure process to achieve the necessary opening

dimensions and allow successful microfabrication of the SMRs.

After the exposure process, special attention was focused on the right side of the wafer in order to achieve the desired opening diameter of 330 nm. The reason behind that is after inspecting the channels under the optical microscope, it was clear that the exposure didn't go well for the left part of the wafer and further inspection under the SEM showed that the openings where not wide enough for the left part as well. With this goal in mind, it was hoped to improve the circumstances for fabrication and increase the possibility of obtaining openings with the specified dimensions. This targeted strategy, as shown in the figure below, made it possible to fabricate SMRs with the desired opening diameter of 330 nm more precisely and under better control.

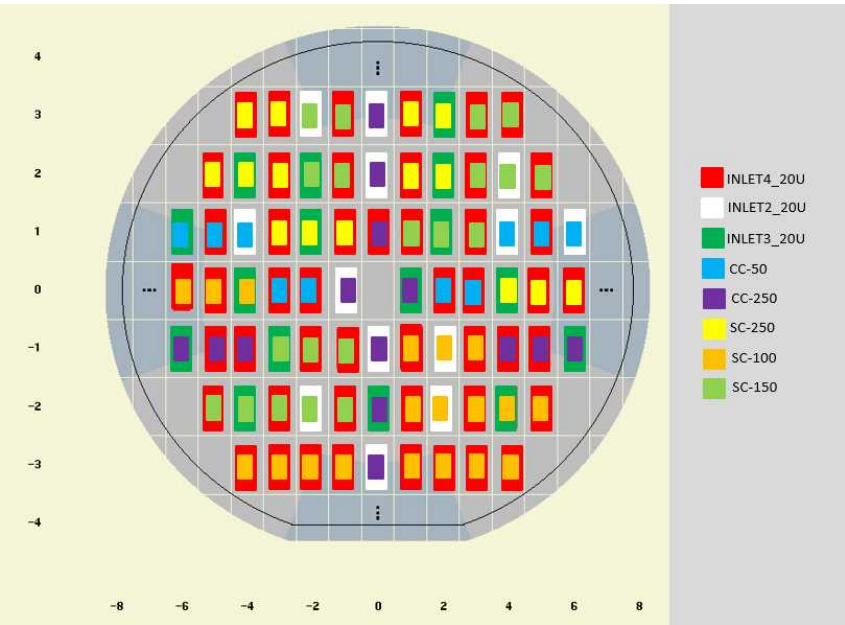


Figure 5: Map of the applied dose and defocus on the different channels and inlets during the exposure job

4 Dry Etching

The etching of the silicon nitride layer and the silicon substrate was the main objective of the dry etching phase in the following stage of the microfabrication process. The silicon nitride layer was etched using the TEL Unity Me etcher, which successfully defined the appropriate structure for the SMRs. The silicon layer was then precisely controlled during the etching process using the AMS and SPTS Rapier etchers. Through cross-section inspections, the investigation aimed to determine the effects of various dosage values on the depth of the channels. These inspections, carried out following the dry etching stage, gave important information regarding the depths attained and the overall quality of the etched channels.

4.1 Dry Etching of ls-SiNX

The goal was to remove the silicon nitride layer. The silicon nitride was to be etched to a target thickness of 500 nm. End-point detection was used to calibrate the etching time and guarantee accurate silicon nitride removal. The end point detection allowed for precise control of the etching process by tracking specific signals. The etching time for the silicon nitride layer in this project was determined to be 4 minutes and 13 seconds. The recipe employed for this specific etching process was CMI.SIN.OX, ensuring consistent and reliable results throughout the fabrication of the SMRs.

4.2 Dry etching of Si in AMS

The silicon layer was etched with the ALCATEL AMS etcher during the microfabrication's dry etching process. The silicon had to be etched to a target thickness of 6 and 10 um. For the AMS's 6 m depth, an optimal process had already been established, with an estimated etching time of 1 min 38 sec. Using this optimized process as a foundation, it was found that 2 minutes and 44 seconds were needed to complete the etching process in order to reach a depth of 10 m. This adjustment in the etching time allowed for the desired depth to be achieved while maintaining the integrity of the fabricated structures. The recipe employed for the etching process on the AMS was SOI_accu++++, which provided a reliable and consistent etching performance throughout the fabrication of the SMRs.

4.3 Dry etching of Si in SPTS Rapier

The SPTS Rapier etcher was also used to etch the silicon layer during the microfabrication's dry etching process. The silicon had to be etched to a target thickness of 6 and 10 um. The "noDescum" recipe was used for this etching process. The machine had not yet been fully optimized because this was its first use for this particular process. However, it gave important information about the deepest that could be reached without risking the channels' structural integrity. 15 loops were used to etch to a depth of 6 m, and 40 loops were used to etch to a depth of 10 um in order to obtain the needed depths.

4.4 Results

The removal of the resist came next when the silicon etching procedure was finished. The resist material was successfully removed from the wafers using the Tepla GiGAbatch system's resist stripping process. The wafers were then cleaved, enabling cross-section examination using the scanning electron microscope (SEM). This inspection was crucial since it gave precise information about the dimension, depth, and overall state of the etched channels. The figure below shows the sample picked for the crossection inspection:

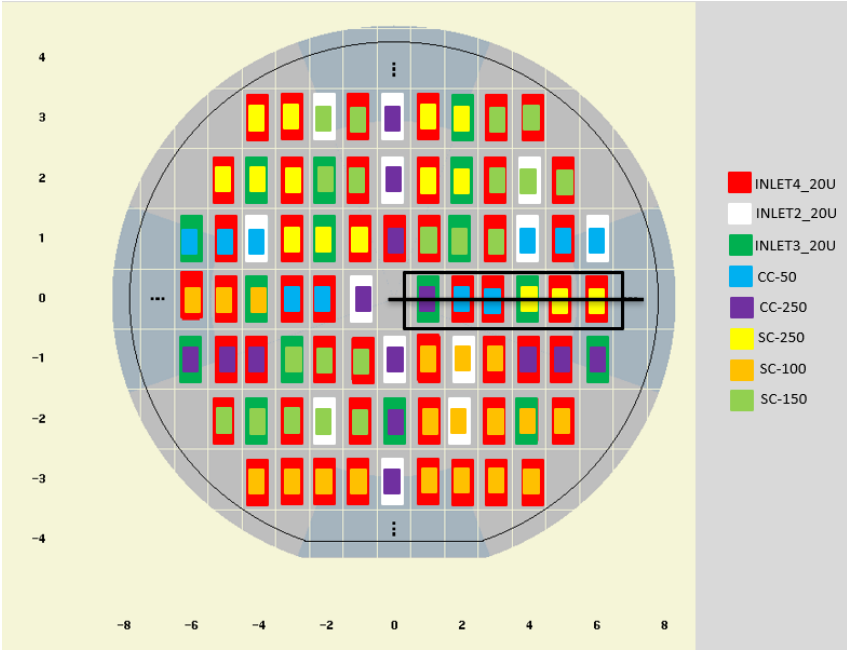
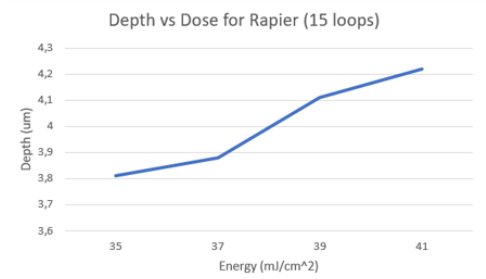
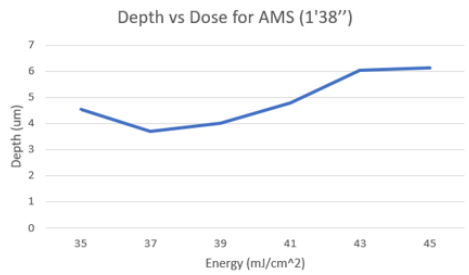


Figure 6: Sample picked for the crossection inspection

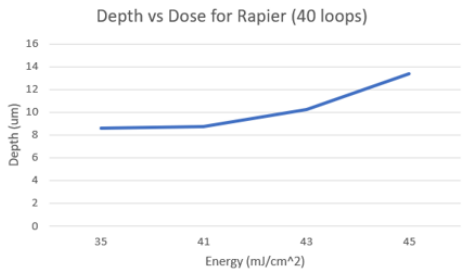
In the analysis of the results, it was observed that the depth of the channels varied with different dose values across the four samples. The findings indicated a clear relationship between the dose and the depth of Si etching. Higher dose values corresponded to deeper etching of the silicon material, which aligned with the expected outcome. This connection can be attributed to the wider openings in the resist at higher doses, allowing for increased exposure and subsequent etching of a larger surface area. Consequently, the channels exhibited greater depth as a result of the expanded exposure area. The plots below present the variation of the depth of channel for different energy values:



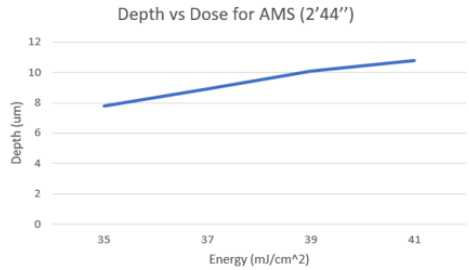
(a) Curve showing the variation of the depths of channels for different energy values for Rapier applying 15 loops



(b) Curve showing the variation of the depths of channels for different energy values for AMS for an etching time of 1 minute 38 seconds



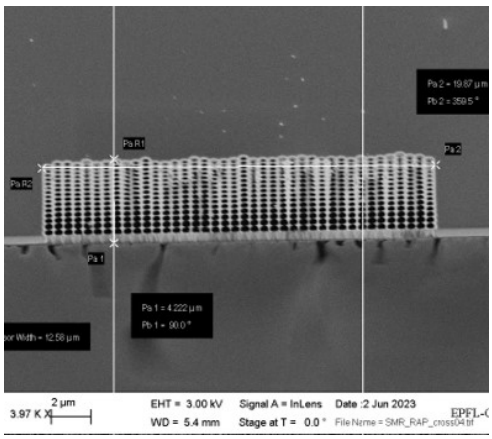
(c) Curve showing the variation of the depths of channels for different energy values for Rapier applying 40 loops



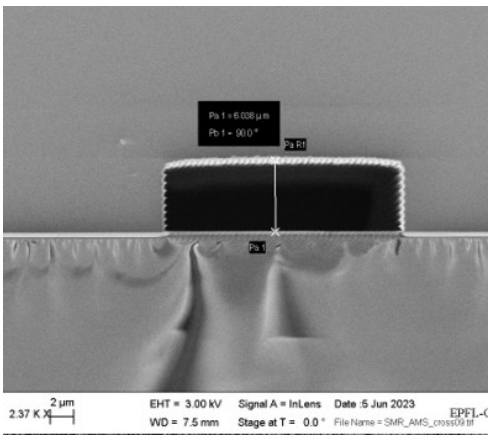
(d) Curve showing the variation of the depths of channels for different energy values for AMS for an etching time of 2 minutes 44 seconds

Figure 7: Curves showing the variation of the depth of the channels for different energy values

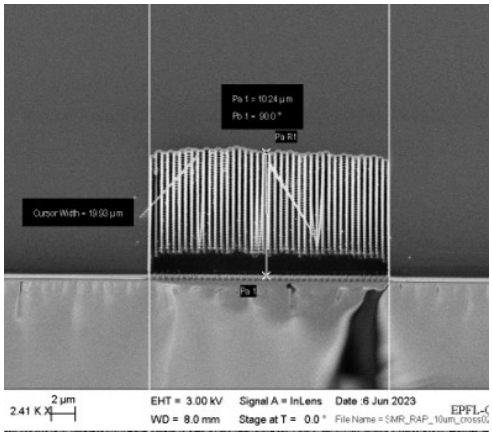
Below are the results of the cross-section analysis, showcasing the achieved target depths for the channels using the two different etchers. The reported energy and defocus settings for each etcher are provided alongside the corresponding results.



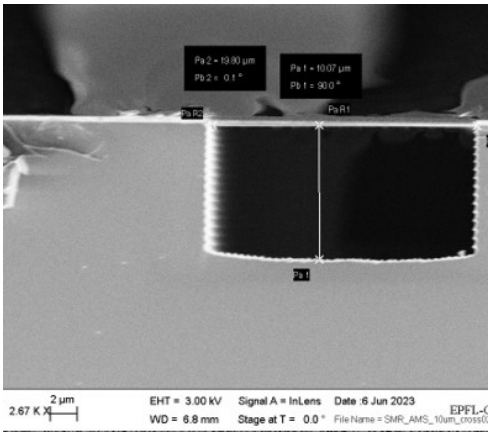
(a) Rapier sample with 6 um target depth with an energy of 39 mJ/cm^2 and 0 defocus



(b) AMS sample with 6 um target depth with an energy of 37 mJ/cm^2 and 0 defocus



(c) Rapier sample with 10 um target depth with an energy of 43 mJ/cm^2 and 0 defocus



(d) AMS sample with 10 um target depth with an energy of 43 mJ/cm^2 and 0 defocus

Figure 8: Curves showing the variation of the depth of the channels for different energy values

5 Wet Etching

In the post-dry etching stage, a wet etching process was employed to ensure the thorough cleaning of the channels and removal of any residual residues. The wet etching step comprised three baths. Prior to initiating the wet etching, a careful inspection was conducted using an optical microscope to assess the condition of the channels and inlets, which were found to be in good state across all samples.

The first bath involved the use of buffered hydrofluoric acid (BHF) with an etching time of 30 seconds.

Subsequently, the second bath utilized a solution consisting of a 40% mixture of potassium hydroxide (KOH) and isopropyl alcohol (IPA) in a ratio of 90:10. The etching process lasted for 2 minutes and 30 seconds, and the bath temperature was maintained at 30 degrees Celsius. This step aimed to further cleanse the channels and ensure the removal of any remaining residues.

The third bath consisted of hydrochloric acid (HCl) with a concentration of 37%. The wafers were submerged in this bath for a duration of 2 hours, allowing for thorough neutralization and cleaning.

Following the wet etching process, another inspection using an optical microscope was carried out to evaluate the survival rate of the channels and inlets for both the AMS and Rapier samples. The survival rate was determined to be 8 out of 14 for Rapier and 10 out of 14 for AMS, indicating a relatively high success rate in maintaining the integrity of the channels after the wet etching process.

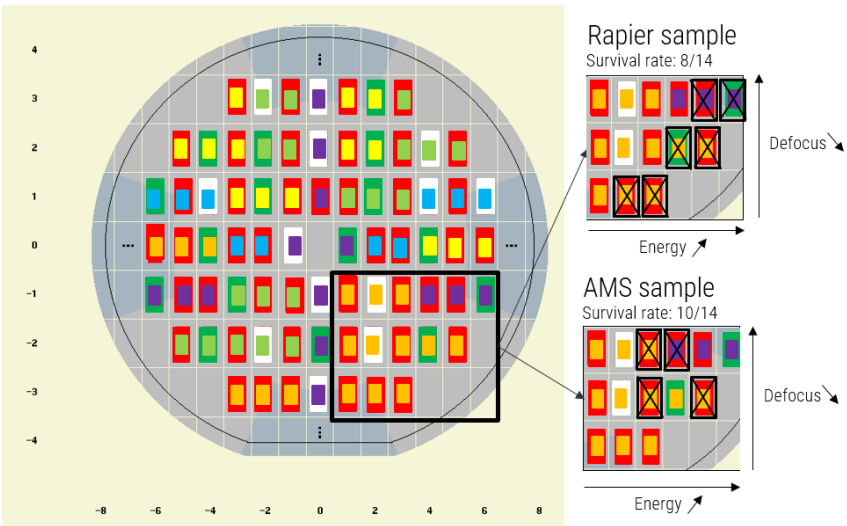
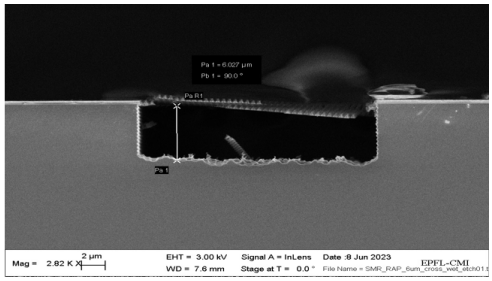
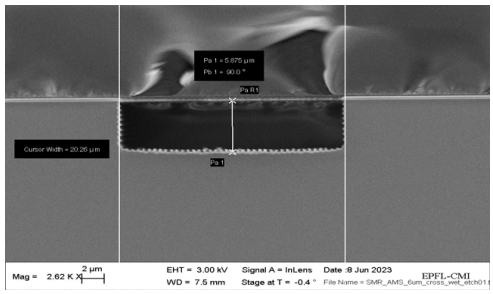


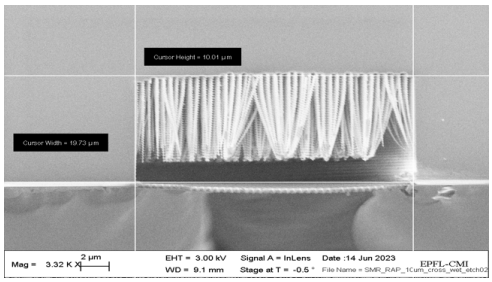
Figure 9: Sample picked for the crossection inspection before and after wet etching and the survival rate for the 2 two samples used on the AMS and Rapier



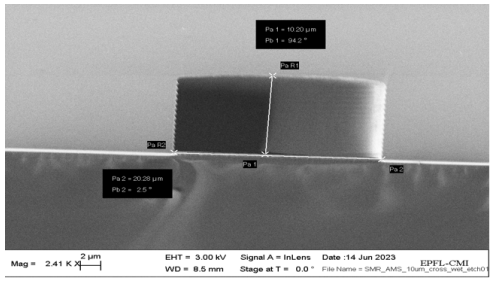
(a) Rapier sample with 6 um target depth with an energy of 43 mJ/cm^2 and 0.4 um defocus



(b) AMS sample with 6 um target depth with an energy of 43 mJ/cm^2 and 0.4 um defocus



(c) Rapier sample with 10 um target depth with an energy of 41 mJ/cm^2 and 0.4 um defocus



(d) AMS sample with 10 um target depth with an energy of 41 mJ/cm^2 and 0.4 um defocus

Figure 10: Results of the cross-section analysis, showcasing the achieved target depths for the channels after wet etching using the two different etchers. The reported energy and defocus settings for each etcher are provided alongside the corresponding results.

Results show that the target depth of 6 um was successfully achieved with an energy of 43 mJ/cm^2 and a defocus of 0.4 um, while the target depth of 10 um was reached by applying energy of 41 mJ/cm^2 and a defocus of 0.4 um. It is important to keep in mind that larger openings were correlated with higher energy levels, which increases the likelihood of channel breaking. A different approach for dealing with the issue would involve lowering the energy levels while increasing the etching time. This modification might make it possible to reach the required depths without risking the channels' structural integrity. By carefully balancing the energy and etching parameters, it is possible to achieve precise depth control and minimize the risk of channel breakage, ensuring the successful fabrication of suspended microchannel resonators.

6 Conclusion

In conclusion, this project aimed to optimize the microfabrication process and explore the limitations of the channel depth of Suspended Microchannel Resonators (SMRs) through various steps including exposure, dry etching, and wet etching. The target depths were successfully achieved for high energy values, specifically at 43 mJ/cm^2 and 0.4 µm. However, it was observed that lower energy levels combined with longer etching times could achieve the same target depths while minimizing the risk of broken channels and inlets. This finding highlights the importance of balancing energy levels and etching time to ensure both depth accuracy and structural integrity of the fabricated SMRs. Furthermore, future work could involve the closing of the channels using low-pressure chemical vapor deposition (LPCVD) to examine the survival rate and overall performance. This step would provide valuable insights into the robustness and reliability of the fabricated SMRs.

References

[1] CMi website. https://www.epfl.ch/research/facilities/cmi/equipment/etching/ (Consulted on 29st of June 2023)