MEMS Fabrication of a Peristaltic Pump

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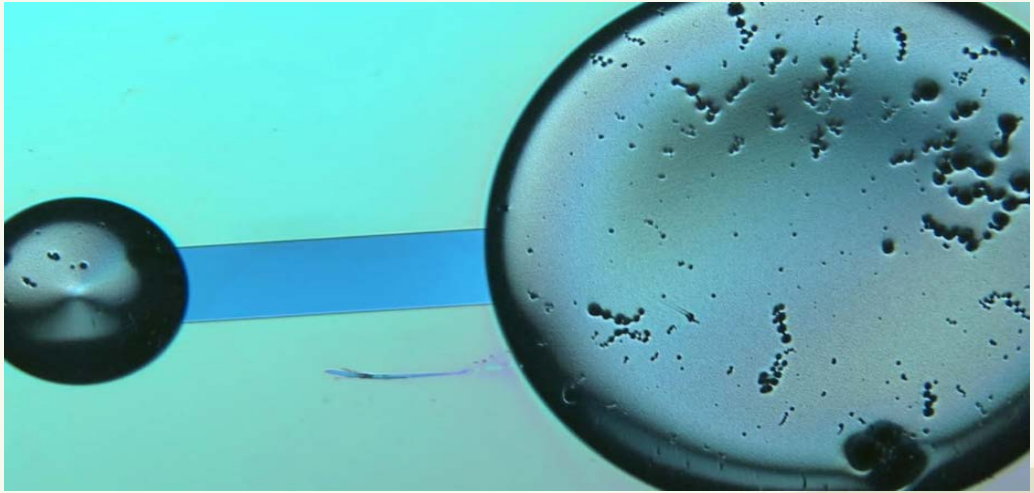
Senior Design Project 2018



Discussion topics

Introduction
- MEMS Micropump history and background
- Goals of the project

Displacement Theory and Peristalsis
- Displacement
- Peristalsis
- Mask Design

Process Flow

Fabrication Errors and Improvements

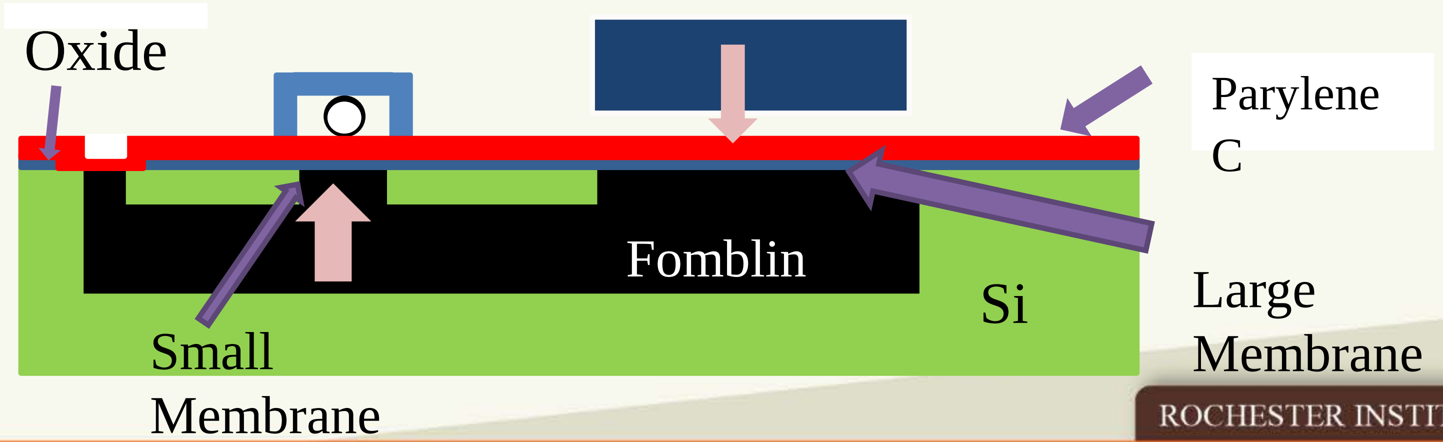
Conclusion and Future Work

History of MEMS Micropumps

- Microelectromechanical Systems (MEMS) have grown increasingly more important throughout the past few decades. Usage of such devices range from accelerometers, micropumps, and pressure sensor and many more devices.
- MEMS can best be described as miniature mechanical and electro-mechanical devices.
- There is a wide variety of pumps throughout history ranging from electrostatic, thermopneumatic, piezoelectric, and electromagnetic.

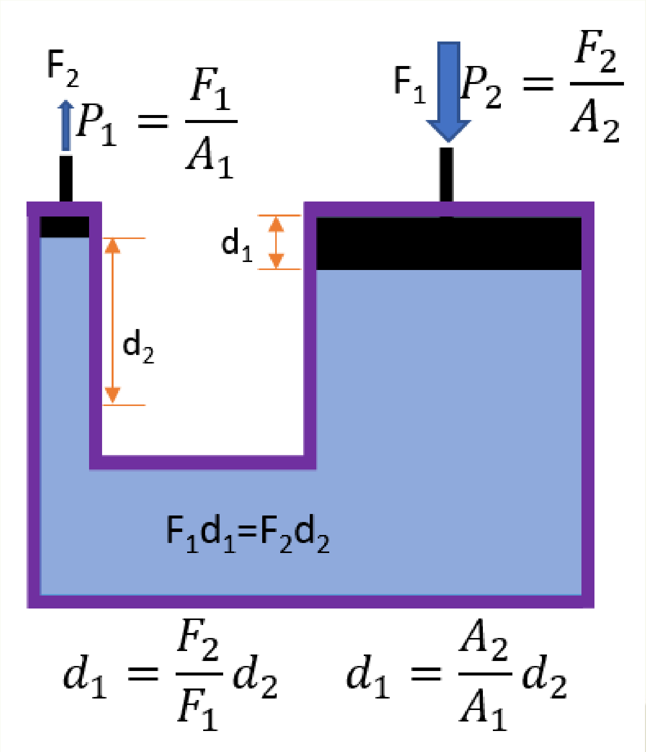
Goals of the Project

- Use micromachining on a silicon substrate to create a micropump.
- Create peristaltic motion using three micropumps in series.
- Reduction of energy used in mechanical and non-mechanical pumps.
- Use Lead Zirconate Titanate (PZT), a piezoelectric material to actuate the larger membrane.



Displacement Theory

- If a small force is applied to the large membrane, the displacement will be minimal.
- Using the displacement theory, there will be an amplification of force and pressure on the small membrane.

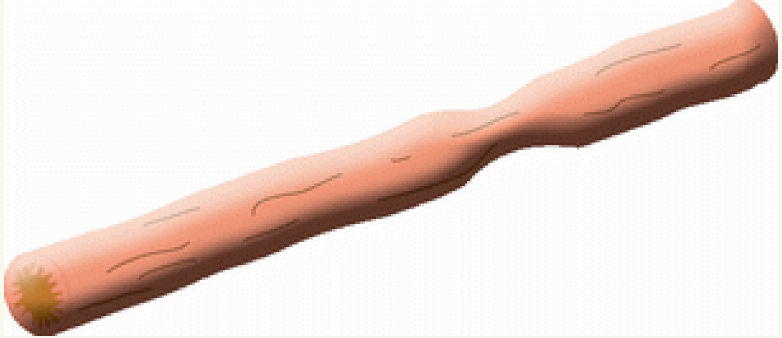


- F = Force
- A = Area = πr^2
- P = Pressure
- d = Displacement of fluid

$r_1 = .5$ mm
$r_2 = 1.5$ mm

What is peristalsis?

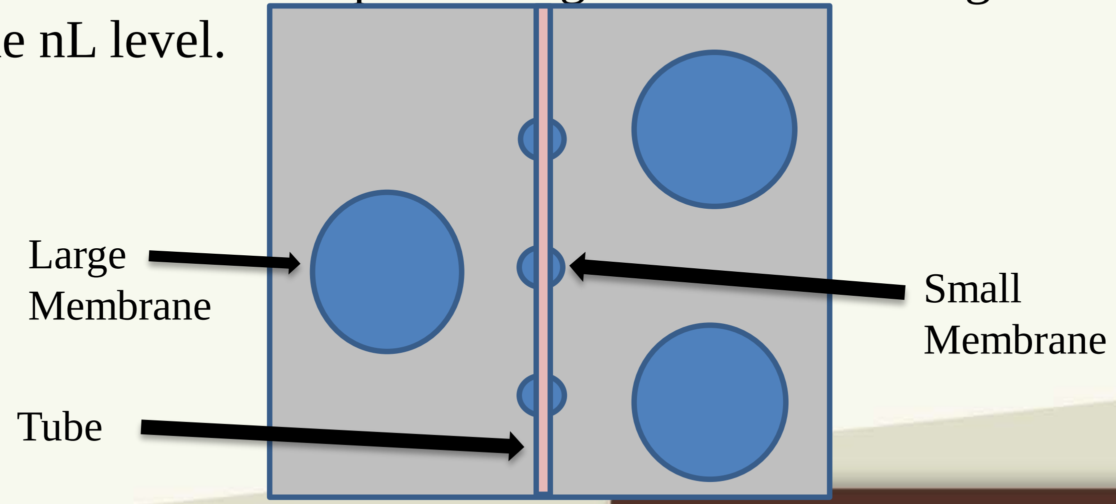
- Peristalsis can be best defined as the “successive waves of involuntary contraction passing along the walls of a hollow muscular structure (such as the esophagus or intestine) and forcing the contents onward”[1].



Peristalsis animation [2]

Peristalsis (cont'd)

- In this project, the membranes of the device act as the muscle flexing and the tube is the lining of the intestine.
- This movement can be created using three micropumps in series. The controlled actuation moves the liquid through the tube. Moving the fluid can be done at the nL level.

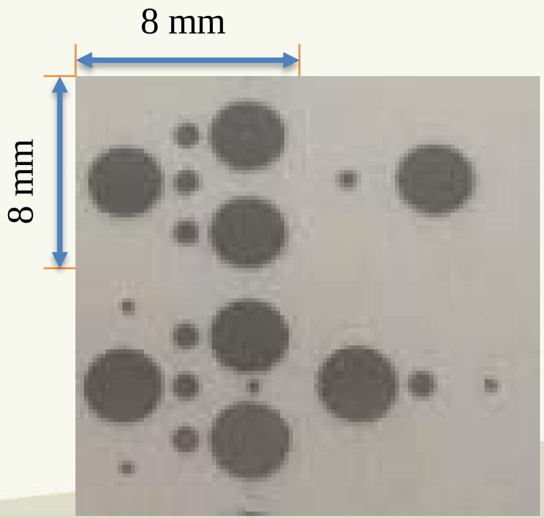


Mask Design

- The first layer, was used to create the chambers of the micropump.
- This layer was used to etched into the oxide layer. Multiple chip designs were made to try different scenarios. i.e. membrane size.

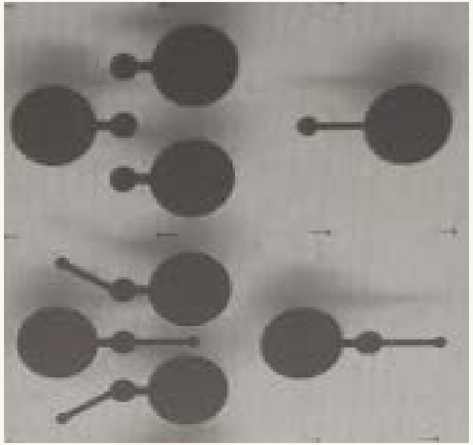
- Looking at the top two chip design, they are based off of fluid filling using the small membrane.

- The bottom two use a fluid port that extends away from the device area.



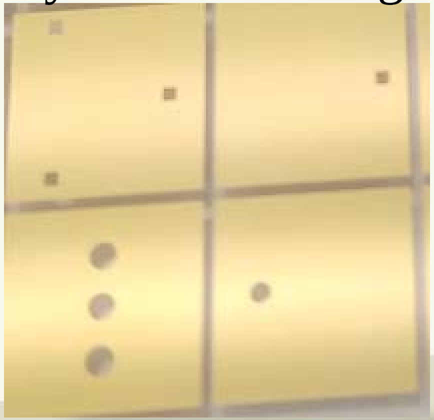
Mask Design (cont'd)

- Layer 2 images the channels that connect each membrane to one another.
- This resist layer stays on in order to help protect the oxide hard mask layer.
- Layer 3 consists of opening up fluid ports and the small membrane. It also creates the chips saw lines.



Layer 2 mask design.

Layer 3 mask design.



Process Flow

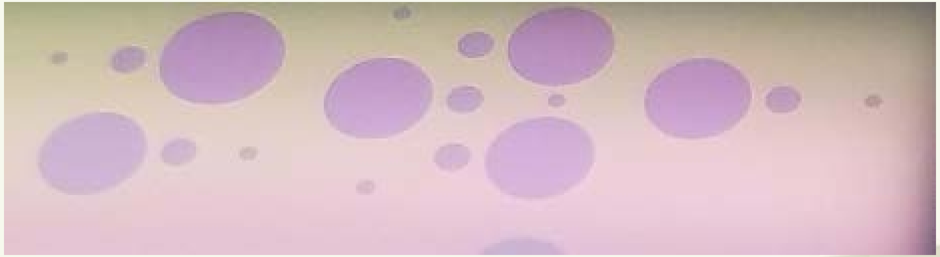
1. Starting Wafer
2. CL01- RCA Clean
3. OX04-Oxide Growth 10000Å
4. PH03-level 1 Channel
5. Coat Wafers backside - for protection
6. ET06-Oxide Etch (chambers)
7. ET07-Resist Strip Recipe FF
8. CL01-RCA Clean
9. PH03-level 2 Chambers
10. Resist Coat for carrier wafer on backside
11. ET68-STS Plasma Etch (2/3 of the way through ~ 355 cycles)
12. ET06- Etch Remaining Oxide for Channel
13. ET68-STS Plasma Etch (~173 cycles)
14. ET07-Resist Strip Recipe FF
15. Anodic bonding
16. PH03- Level 3 Oxide Opening front side
17. ET06- Oxide Etch Front side
18. CL01- RCA Clean device
19. SAW1- Saw wafer
20. Vacuum Filling of Fomblin
21. Temporary seal for device
22. Use Parylene C evaporator to seal fluid port

Fabrication Errors

Mask Errors

- Inverted Masks
- Dark vs. Clear Field

- Solution: Use a negative resist. nLOF 2020.
- Write a correct mask using the Heidelberg.



- Alignment mark errors.

- One set of alignment marks were higher than the other in the y-axis.

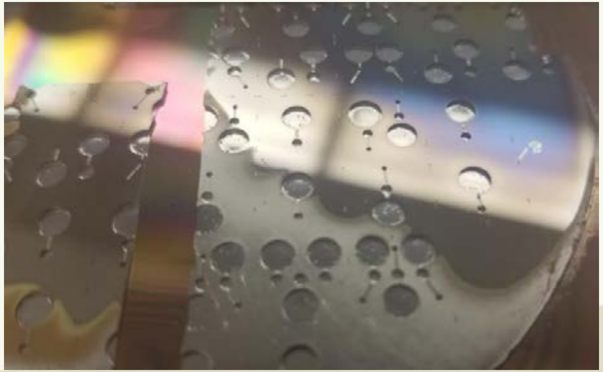
- Solution: Direct write using DWL 66+ laser writer. (h-line ~405 nm)

Fabrication Errors (cont'd)

Hard Mask and STS Plasma Etcher errors

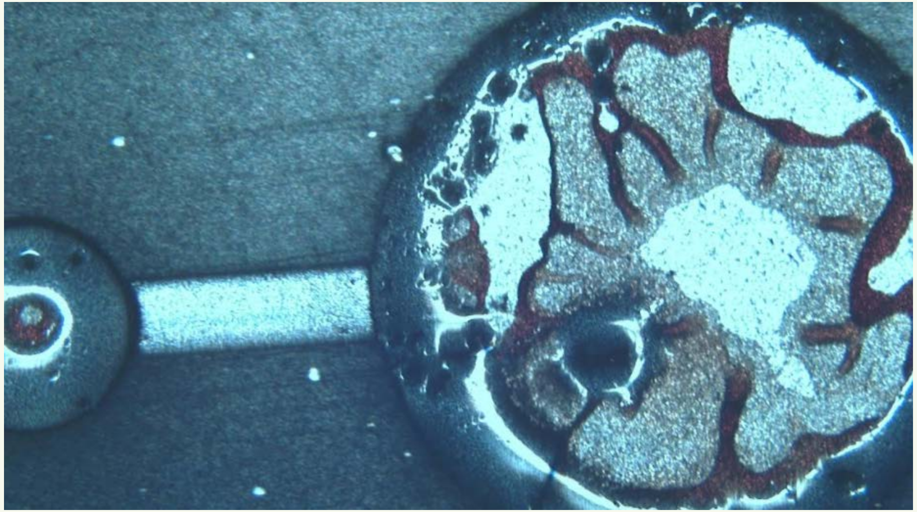
- One micron hard mask didn't allow resist to be spun evenly, caused a build-up of resist.
- Solution: Use a faster rpm rate in order to push more material out of the etched chamber. Place resist halfway to the edge of the wafer.

- STS plasma etcher etches unevenly.
- Etched through oxide and resist mask.
- Debris found in membrane areas.
- Solution option: Rotate wafer evenly throughout etching process.



Conclusion

- This device was design to create peristalsis using three micropumps in series.
- Using the STS plasma etcher caused issues to the device.
- The resulting product was not finished fully.



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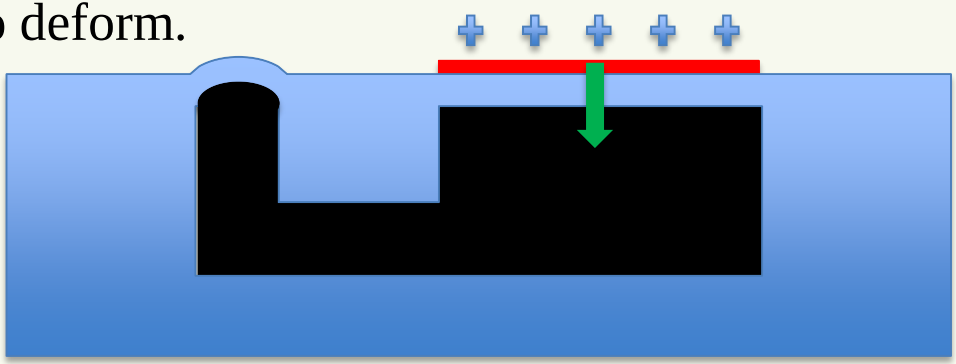
Future Work

- Bonding of the wafers using anodic bonding or using the ATP at a high temperature.
- Vacuum filling Fomblin oil into micropump.
- Adding a Lead Zirconate Titanate (PZT) material to the membrane in order to control the electronic pulses.
- Increase peristaltic motion; closing of the microfluidic tube. Measurement of the microfluid output after the peristaltic pump.

Piezoelectric Effect

- Introducing a mechanical stress which produces a charge. In this case it can work in the opposite direction. A voltage can be applied causing the material to deform.



- An example of a piezoelectric material is Lead Zircanate Titanate (PZT), this material still used though researchers are trying to come up with a new solution since lead is hazardous.

Acknowledgements

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- Dr. Fuller
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References

[1] "Peristalsis." *Merriam-Webster.com*. Merriam-Webster, n.d. Web. 11 Apr. 2018.

[2] Chung-Shao Chao, Pao-Cheng Huang, Ming-Kun Chen, and Ling-Sheng Jang, “Design and analysis of charge-recovery driving circuits for portable peristaltic micropumps with piezoelectric actuators,” *https://www.sciencedirect.com/science/article/pii/S0924424711002743*.