Microfluidic Lab-on-a-Chip

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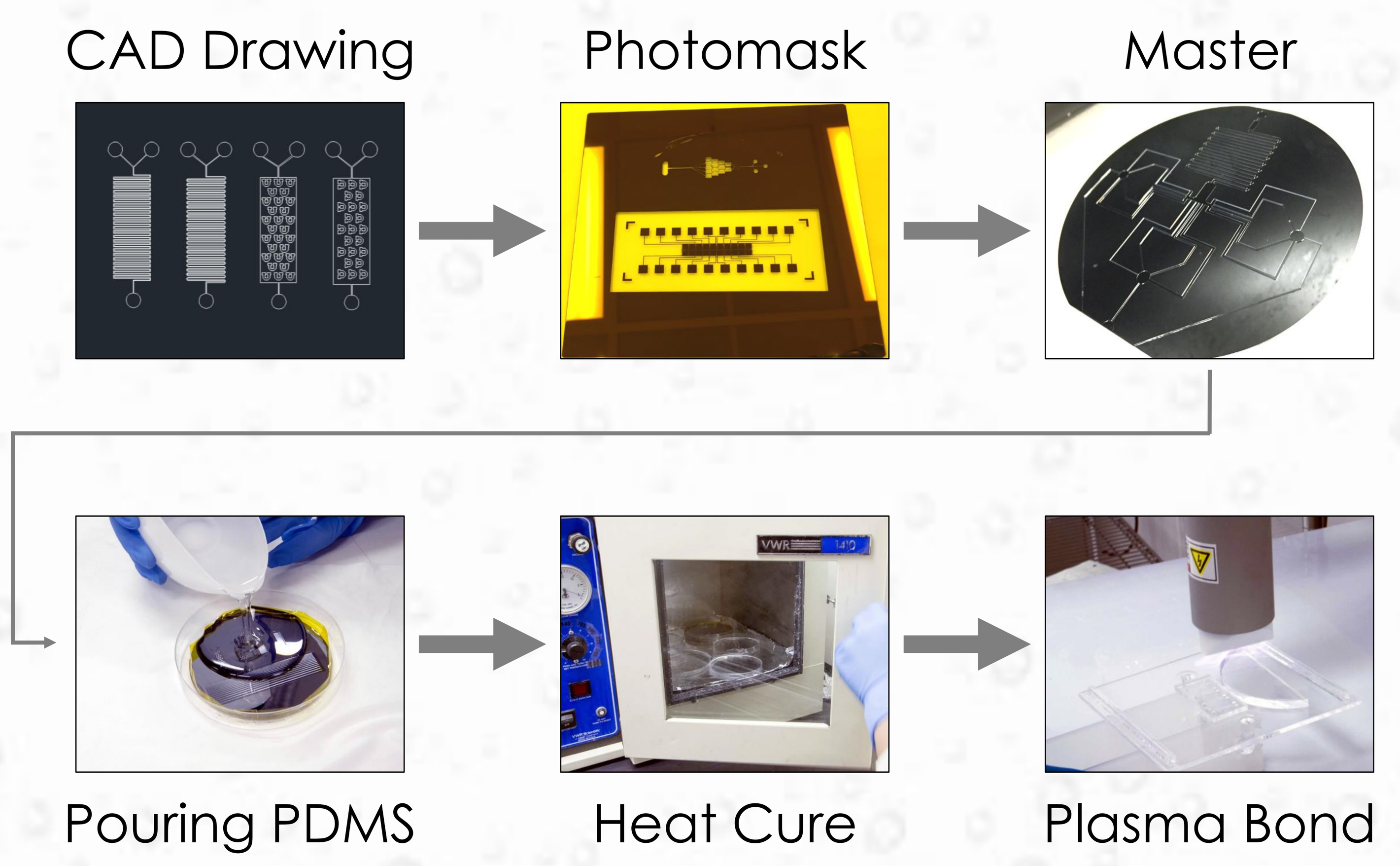
Background

Microfluidics is a disciplinary field with applications in the design of systems dealing with small volumes of fluids, typically in the range of micro to nanoliters. In microscale devices, physical properties that are naturally intuitive in the macro-world often scale down in unexpected ways. Our team was tasked with designing a total of eight microfluidic-related devices which could be used in high school and college level labs to introduce and teach students about the nuances in micro engineering. The microfluidic devices are often called lab-on-a-chip (LOC), so called for their ability to integrate laboratory-sized functions into chip-sized devices. They are made from a nontoxic biocompatible silicone polymer material called polydimethylsiloxane (PDMS). These devices needed to be interactive, low cost, and clearly demonstrate the unique scaling effects of a particular microfluidic phenomena and its applications.

Objective

- Each LOC demonstrates a particular scaling law and how it's used in real-world microfluidic applications.
- Educational presentations, which accompany each device, were made to teach background concepts.
- The purpose of the LOCs is to educate both high school and college-aged students about the non-intuitive world of micro-engineering.
- All devices must be safe, easy to use, interactive, and low in cost.

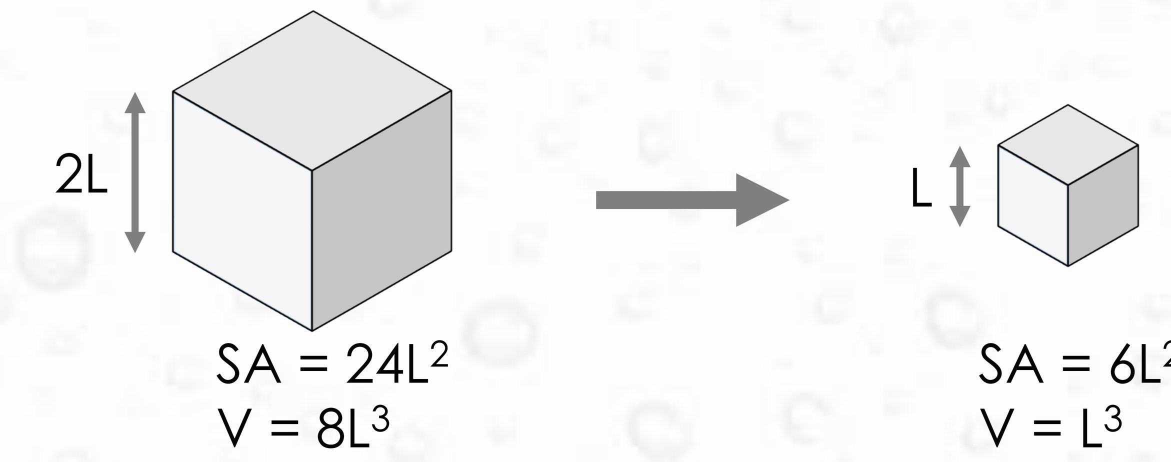
Design Methodology



Scaling Laws

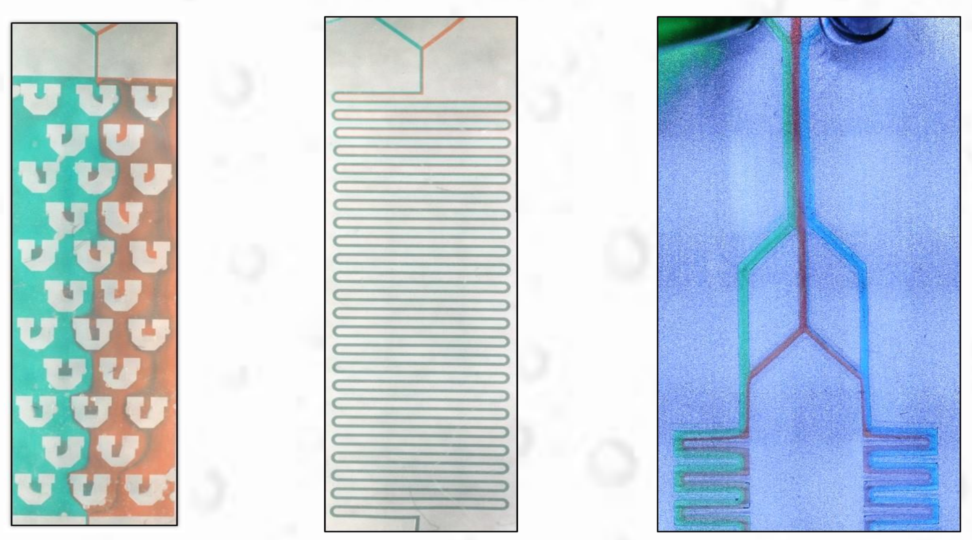
Physical properties of microsystems do not always scale linearly, and special care must be taken as an engineer designing these systems in order to ensure the device works as expected.

For example, consider reducing the size of a cube, with side length 2L, by half. Looking at the algebraic equations used to calculate volume V and surface area SA, $V \propto L^3$ and $SA \propto L^2$. A 50% reduction in the length of the sides results in a 75% reduction in surface area and an 87.5% reduction in volume.



Similar analyses can be performed on other properties such as mass, flow rate, mixing rate, Reynolds number, electrostatic forces, and more.

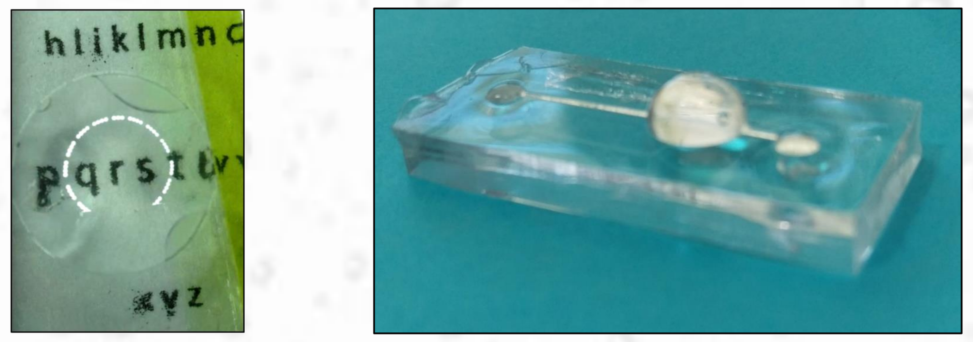
Micro Mixers



Microscale fluid flow is typically laminar rather than turbulent. Because of this, mixing must be induced through unique channel geometries such as serpentine channels and blockades within the channel. Applications that utilize micro mixing include the preparation of DNA for analysis and detection of chemical content.

- **This channel demonstrates both laminar flow characteristics and mixing through serpentine channels.**

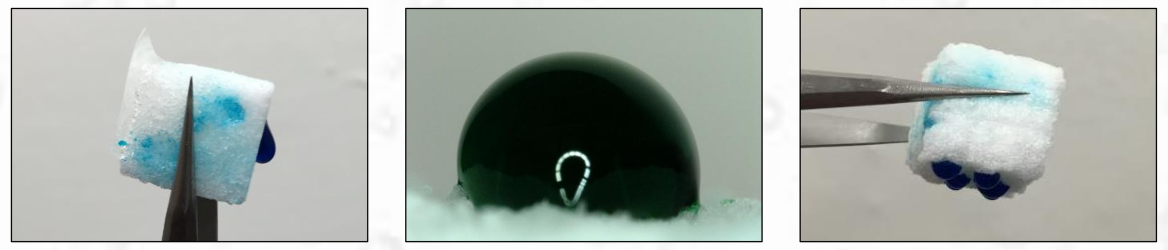
Tunable PDMS Lens



In microfluidic applications such as cytometry (measurement of characteristics of cells), lenses are used to focus and manipulate light to improve device sensitivity. The tunable PDMS lens can achieve various lens radii depending on the amount of liquid pumped into the chamber. These lenses can be placed over cell phone cameras to produce optical zoom up to 37X. This allows one to capture microscope quality images with their cell phones.

- **This device illustrates the application of lenses in microfluidics and how various lens diameters effect magnification.**

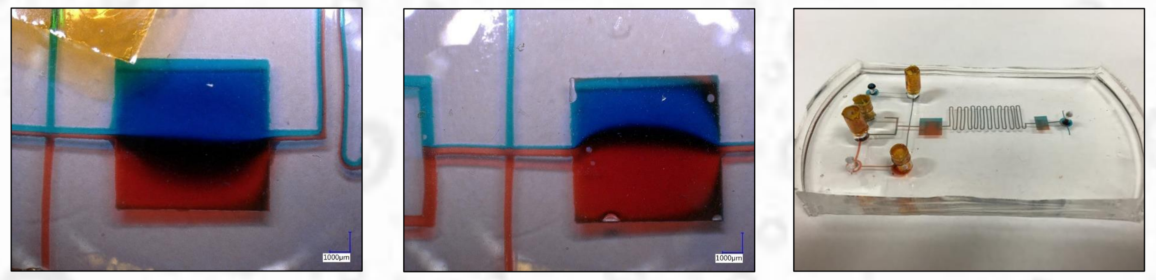
Hydrophobic PDMS Cubes



Hydrophobic surfaces - surfaces that repel water and minimize contact with the surface - are used in myriad engineering applications, such as self-cleaning surfaces. By adjusting surface roughness and creating a lower liquid-solid contact area the surface can become nearly super hydrophobic, meaning the surface has weak solid/liquid interactions, making it an optimal water-repelling surface. These PDMS cubes have had their surface roughness increased using both granulated and powdered sugar to increase and exhibit greater hydrophobicity than their untreated counterparts.

- **These cubes demonstrate that surface roughness changes the contact angle of a droplet, changing from $\theta = 67.3°$ to $\theta = 90.8°$ for an untreated and treated surface, respectively.**

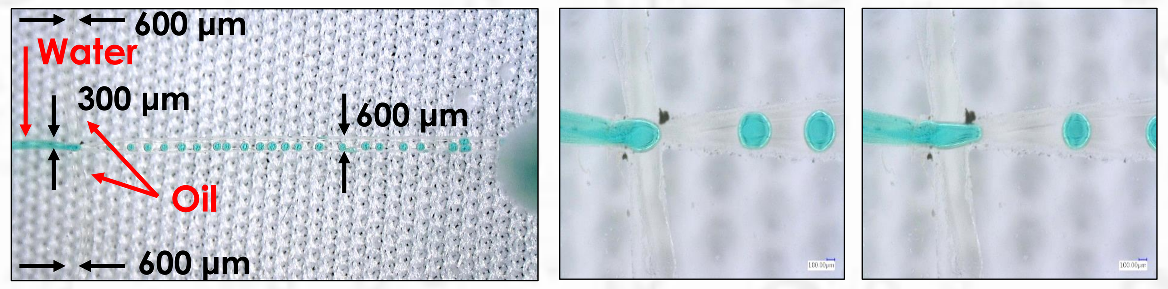
Micro Pin Valves



Many microfluidic applications involve flowing fluids with an external power source. Remote areas of the world may not have access to power to run a device. The manually actuated micro pin valves are an electricity-free solution to controlling fluid flow with on/off PDMS pins. On the micro-level, channel size greatly affects the relative turbulence of the flowing fluid: a fluid flowing through a smaller channel will cause a more turbulent, dominating flow over the fluid going through a larger channel.

- **The pins, which can change what channel the fluid flows through, demonstrates how channel size affects the relative turbulence of smaller and larger channels.**

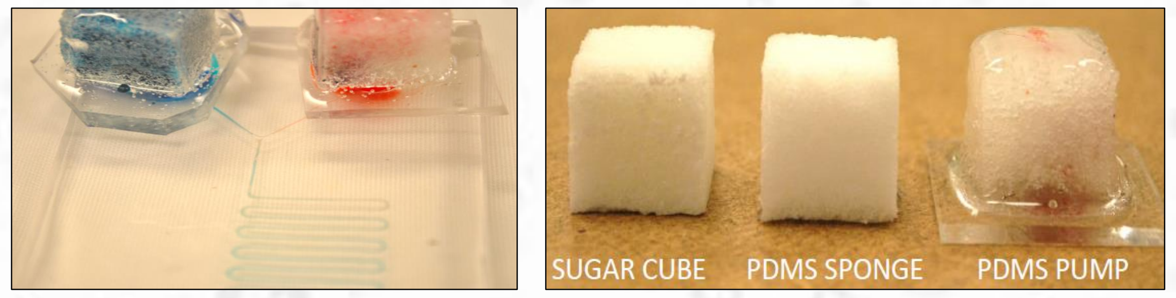
Micro Droplet Formation



Micro droplets are found in, but not limited to, portable microfluidic devices that perform diagnostic testing, and chemical analyses. They are used to lower cost by reducing residence time, reagent consumption, and power usage. The micro droplet device uses two streams of oil to disperse the water causing it to form water droplets, and shows how changing flow rates can change droplet size and quantity while creating interest in how they are implemented in real-world applications.

- **This device demonstrates the formation of micro droplets, and how droplet volume can be controlled by flow rate.**

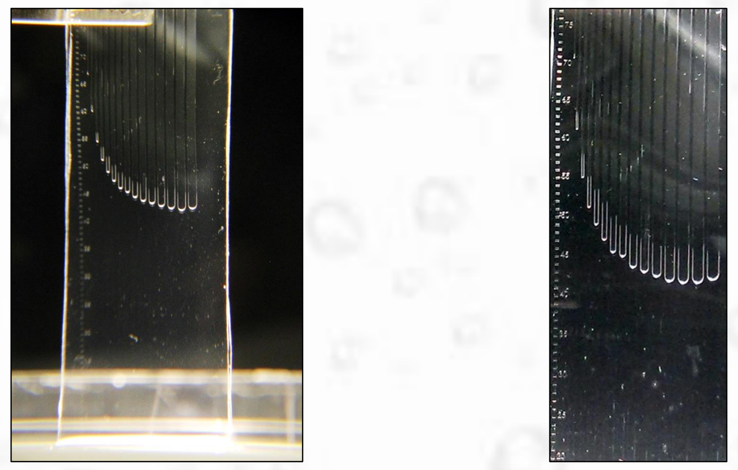
PDMS Pumps



Using microfluidic devices for biological testing is ubiquitous, but sometimes they are needed in places that don't have power readily available. These PDMS pumps are used with a gradient mixer to show how a user can manually pump two fluids to be mixed without the use of electric pumps, and how they are utilized in situations where they are beneficial. They are fabricated by infusing sugar cubes with PDMS by capillary action. After curing, the sugar is dissolved and the remaining PDMS sponge is coated with more PDMS.

- **The PDMS pumps demonstrate manually actuated fluid mixing without the use of external electric pumps.**

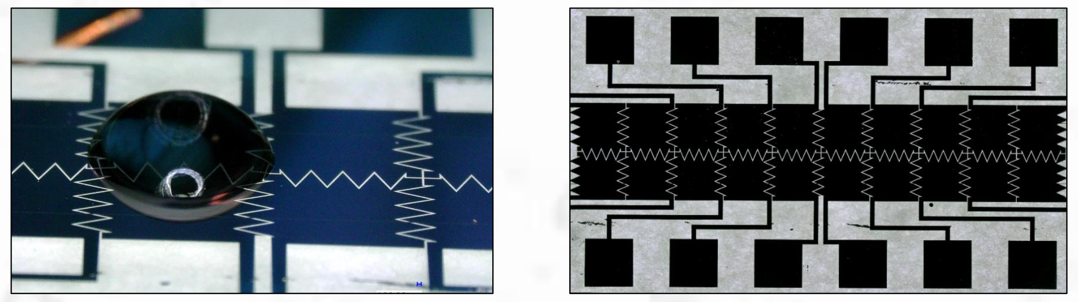
Capillary Action



The phenomenon of capillary action is nearly everywhere. It relies on the cohesive and adhesive properties of fluid and can be seen in the suction of sponges, the wicking of towels, and even naturally in trees and plants. The greatest height water can be drawn up a tube by a pressure difference is ~10.3 m. Tall trees get around this by using capillary channels that progressively become smaller as it gets taller to draw up water.

- **The capillary channels in this device are able to draw fluid up to the theoretical values within 8% error.**

Electrowetting



There are several applications that require the precise measurement and placement of fluids such as the dispensing of medicine or the manipulation of liquid samples. Electrowetting is one method by which the position and motion of a liquid droplet can be altered using only a strong electric field. This interactive device demonstrates the principles of electrostatics and its effect on the surface properties of water. By applying a voltage to a neighboring area, a water droplet can be manipulated to a different position.

- **This device successfully demonstrates the ability to move a water droplet using only electrostatics.**