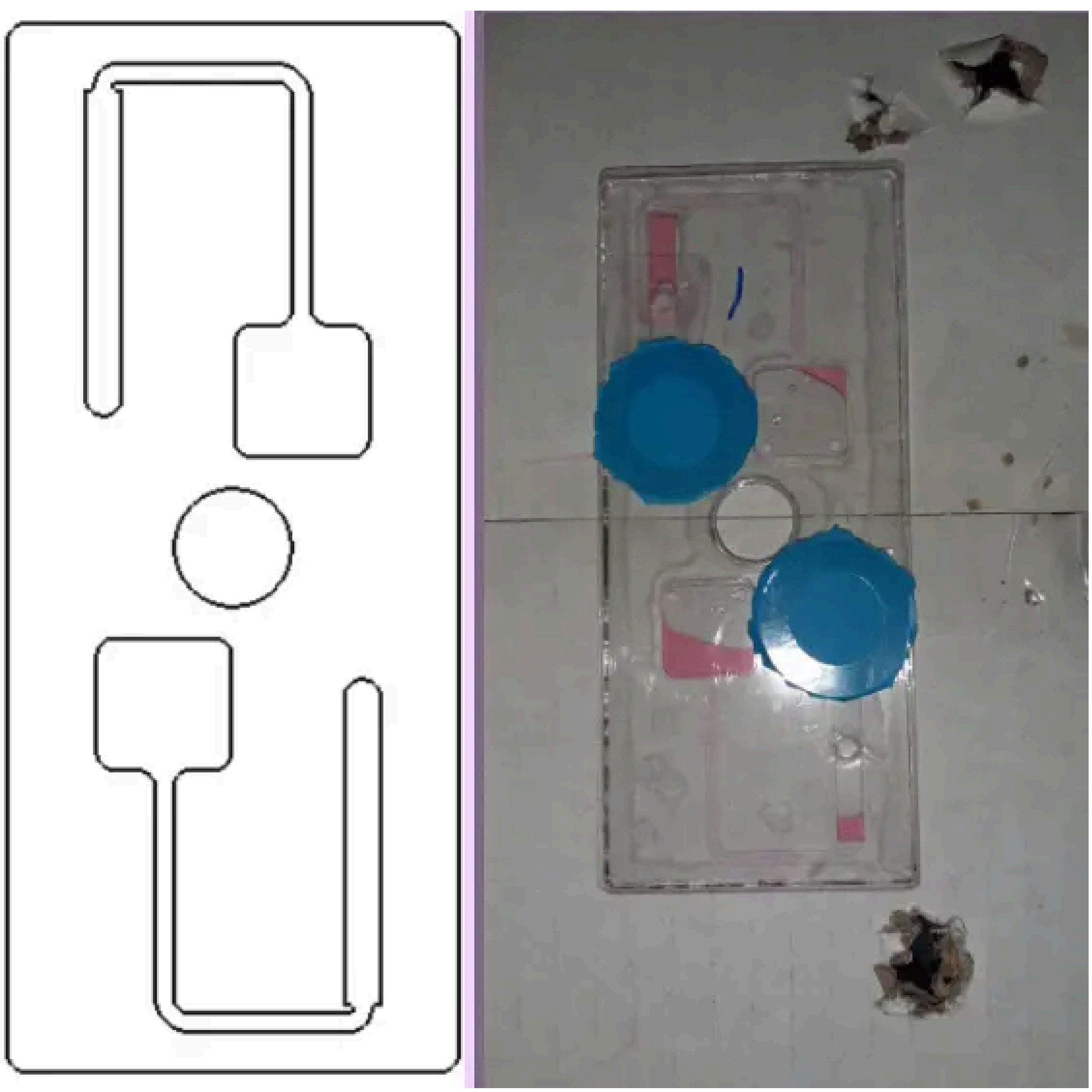
Progress report on microfluidic device and surface modification

Design of the microfluidic device

The first step that was taken was to design the centrifugal microfluidics device. The main parts of the microfluidic circuit are:

1. Source/Inlet chamber
2. Radial channel
3. Isoradial channel
4. Pneumatic chamber



This is the current design for the device, where the circle in the middle represents the hole for mounting on a motor for rotation. The squared chamber is the source chamber. The rest of the components follow the same order as stated before. It is fabricated with 5 layers. From top to bottom, they are as follows: acetate, pressure sensitive adhesive (PSA), PMMA, PSA, PMMA.

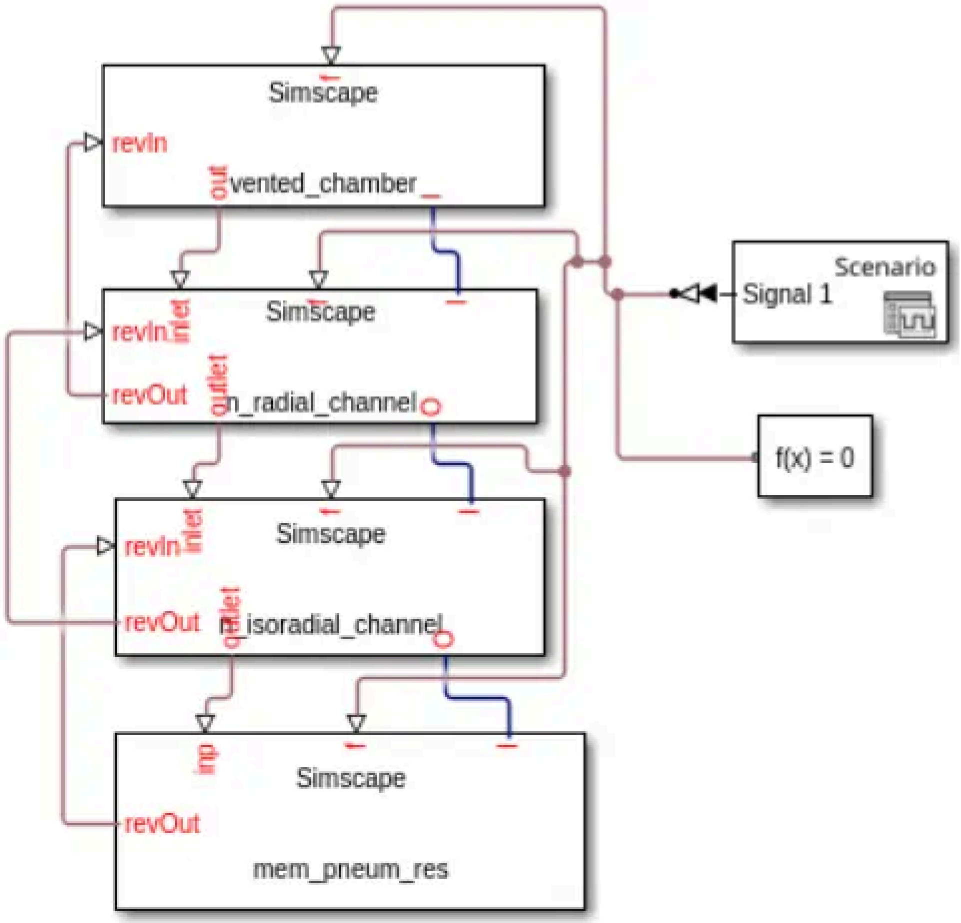
The top acetate layer contains the holes for the inlet and venting of the source chamber and the hole to the latex membrane from the pneumatic chamber. Next, a PSA layer joins the top layer with the middle PMMA layer, where the source and pneumatic chambers are cut with a laser cutter. The microchannels are found in the next PSA layer, being sealed with a bottom PMMA layer. This bottom layer also has holes, where the modified PDMS substrates are intended to be located for the detection.

As the device rotates, the fluid moves up to the pneumatic chamber. As air is not very compressible, a latex membrane is used to seal the end of this chamber, which aids in the accumulation of more pressure. The pressure inside the pneumatic chamber will be the main driver in flow reciprocation, while the centrifugal pressure is the main driver of the forward flow.

Simulation-assisted design

This design is optimized with the help of a lumped-element model simulation using Matlab Simscape. In a lumped-element model simulation, each component in the microfluidic circuit is simulated separately, but global variables, that relate the whole circuit, are shared via connection ports. For instance, the pressure inside the radial channel due to the centrifugal pressure is not shared with the pneumatic chamber, as it has its own pressure. On the other hand, the flow rate will be the same for all components.

The model used is the following:



In this representation of the model, the components have a port (denoted with *f* for receiving the signal of the rotational velocity profile of the device. Accordingly, they have ports for input and output of shared signals and variables (flow rate, for example) denoted with *I* and *O*, respectively. The port out/outlet sends a signal to the next component once it has been fully filled with fluid, while inlet/inp receives said signal so the component can start filling. The analogous ports revOut and revIn have the same function as out/outlet and inp/inlet for the reverse flow (the ports mentioned previously are mainly for forward flow).

The other two blocks or components to the side of the main circuit diagram are the signal generator (built-in Simscape block for providing the velocity profile) and the Solver, which is currently using an ODE solver, which uses 4th Order Runge-Kutta to solve the equations.

The main structure of the component files goes as follows:

```
component component_name
        nodes
                #These are connection or communication ports
                I=CuF.CuF;
                O=CuF.CuF;
        end
```

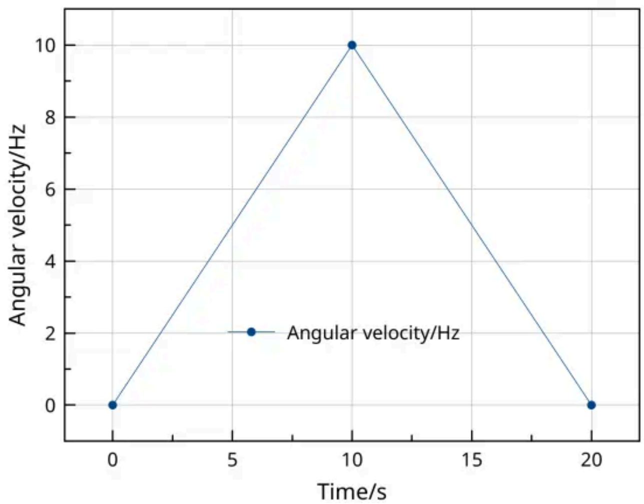
```
        inputs
                #For signals comming into the component
        end

        outputs
                #For signals going out of the component
        end

        annotations
                #The side where the ports are located can be specified
        end

        variables
                #Where all the changing values are defined
        end

        parameters
                #Non-variable values go here
                #In Simpscape interface, these values can be changed by user
        end

        parameters (Access = private)
                #Optional parameters section
                #Parameters not modifiable by the user
        end

        function setup
                #defines variables across a component (i.e. pressure)
                across(p,I.p,[])

                #defines variables through the circuit (i.e. flow rate)
                through(q,I.q,[])

                #Any other initial definition of parameters or variables
goes here
        end

        equations
                #System of equations to solve
                #All equations governing the variables and overall behavior
```

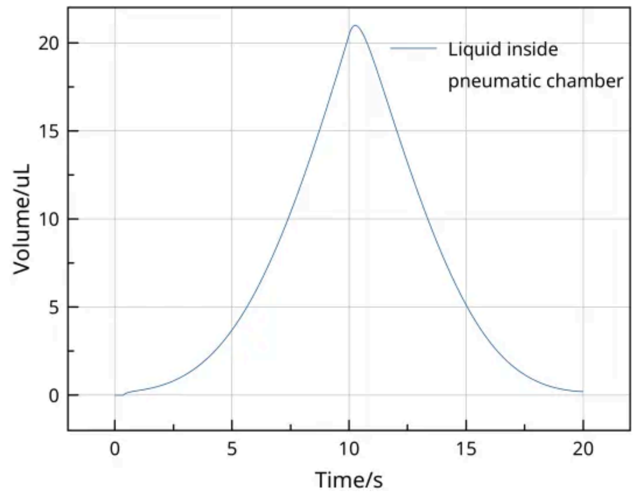
```
        end
end
```

More details of the complete code are elsewhere. However, the parameters defined for each of the components are as follows:

1. Vented chamber:
    1. Azimuthal position of outlet: 0 (centered)
    2. Initial fill level: 1
    3. Depth: 540 μm
    4. Width: 15mm
    5. Length: 15mm
    6. Distance to center: 12.5mm
2. Radial channel:
    1. Width: 2mm
    2. Depth: 40 μm
    3. Inlet radial distance: 27.5mm
    4. Outlet radial distance: 57.5mm
    5. Initial fill level: 0
    6. Contact angle for p_cap: pi/4
3. Isoradial channel:
    1. Width: 2mm
    2. Depth: 40 μm
    3. Length: 21.5mm
    4. Radius: 55.7mm
    5. Initial fill level: 0
    6. Contact angle for p_cap: pi/4
    7. Direction: -1 (flow from inlet is clockwise)
4. Pneumatic chamber:
    1. Azimuthal position of inlet: 0 (centered)
    2. Initial fill level: 0
    3. Depth: 540 μm
    4. Width: 4mm
    5. Length: 36mm
    6. Distance to center: 20.5mm

Additionally, here are some relevant results: velocity profile used during a simulation and the volume that enters the pneumatic chamber.



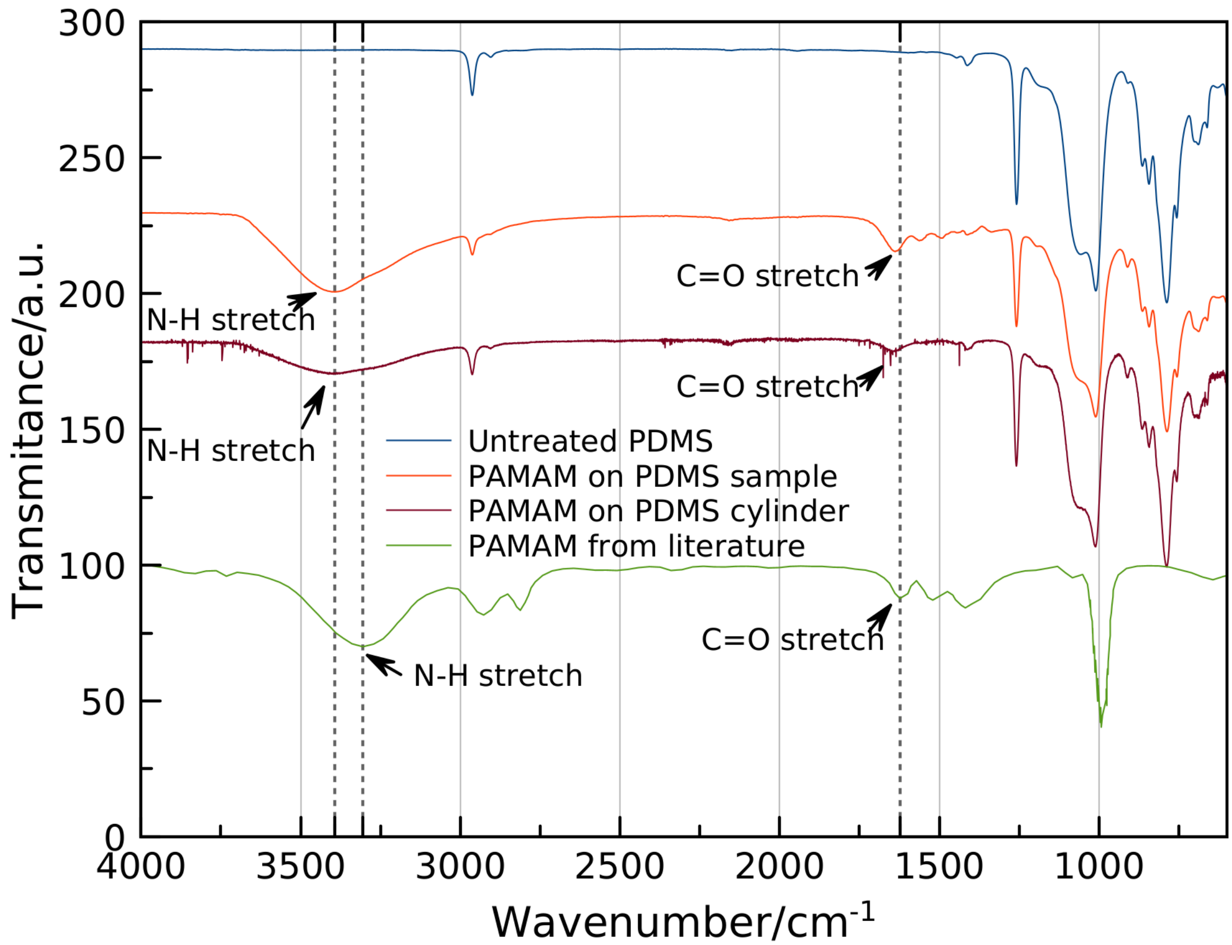


These graphs show that at a maximum angular rotation of 10 rotations per second, the volume that enters the chamber is roughly 20uL. The lenght of the chamber can be easily modified to let more fluid inside the chamber.

For the current working device, it was chosen to use approximately 50mm of length of the chamber for a volume of approximately 40uL to 50uL inside the pneumatic chamber. The overall configuration allows for a total needed volume of no more than 60uL, taking also into account the volume that remains in the channels.

PDMS surface modification

Once the design of the microfluidic device was done, the next crucial step was to modify the PDMS properly, make substrates, and make sure that the chemical modification was retained after inserting the substrates into the bottom layer holes. The analysis was performed by FTIR Spectroscopy.



As the previous figure shows, the bands that indicate the presence of the PAMAM dendrimers appear in the cylinder substrates even after being removed from the device. The device has already been tested for leakages, so this sums up the proper modification of PDMS cylindrical substrates to be used in the centrifugal microfluidic device.