MFBM, Exercise 4, 10.2.2021

This exercise is based on the article *Capillary-driven multiparametric microfluidic chips for one-step immunoassays*, Gervais et al. Biosensors and Bioelectronics 27, 64-70, 2011.

Read/browse through the article and figure out how the chip works and what design choices have been made. The goal is that you should recognize many concepts, phenomena and parameters that have been discussed so far on the course and you should now understand the role of many of them.

You can answer the following questions. You can also come up with questions of your own about the of the chip that we can discuss at the end. Let's take about 30 minutes to study the article and then about 15 minutes to discuss and answer these questions together.

You can work either alone or in small groups. If you want to work in small group there are Breakout rooms available.

1. What are the overall dimensions of the chip.

1.7 cm x 3.4 cm.

Most chips are few cm in size.

2. What is the total volume of the chip?

Pumps have a volume of 2 µl.

>1 µl is somewhat higher volume than the average chip. High volume is needed here so that the capillary pumps can operate for a longer time.

3. What are the volumetric flow rates that the chip achieves?

0.46 nl/s – 3.3 nl/s (in abstract), but 1.1 nl/s – 6.3 nl/s in Table 1, reason for discrepancy is unknown.

A reasonably slow flow rate. In the reaction chamber the average linear flow rate is of the order 1 mm / s.

4. How long does it take to fill the chip?

10 min – 72 min times varied for the kinetics of the capture

I interpret this to mean the capture lines were exposed for flowing solution for this amount of time.

5. Make a list of the key components of the chip.

Inlets/oulets, dAb reservoir, mixer, reaction chamber with antibodies, (splitter), fluidic resistors, capillary pumps

6. What are the dimensions of the channels?

Reaction chambers depth 20µm, other parts of the chip 180µm (160µm + 20µm). The reaction chamber is likely less deep to make diffusion to the capture antibodies faster, since they are only at the top wall.

Mixer width x height: 100µm x 180 µm

Reaction chamber: 2mm long 100µm wide, 20 µm deep

7. What materials is the chip made of and can you think of reasons why these were chosen?

Silicon and PDMS.

Silicon for accurate fabrication,

PDMS for ease of bonding and transparency. Also, in this paper PDMS hydrophobicity is used for hydrophobic adsorption of the capture antibody lines.

8. Figure 2 shows the fabrication of the channels. How many etching steps are there in the process? Why is this number of etching steps needed?

There are 3 etching steps, one for patterning a silicon oxide masking layer (2c), one to pattern the deeper channel segments (2g) and one to pattern the shallower reaction chamber (2h). Two different etching steps are needed for two depths, and the third is used here to have two masking layers, one of silicon dioxide and one of photoresist, already on the wafer before silicon etching.

9. How are the capture antibodies patterned and where?

A stencil mask is used to define the areas. A stencil is a metal or polymer plate with some through-holes in it. Adsorption just by hydrophobic effect.

PDMS self-sealing and hydrophobicity helps with resolution so that the antibodies do not spread under the stencil.

10. How are the dissolved antibodies patterned and where?

Inkjet printing and drying, on the silicon chip

11. How is nonspecific adsorption taken into account?

PDMS blocked by BSA. Silicon chip is treated with Pluronic.

Blocking by BSA is key for not getting false positive by nonspecific binding. The purpose of the Pluronic treatment of the silicon chip is not 100% clear but it is likely for reducing adsorption and setting the contact angles.

12. How does the mixer work and why is it used?

Dean flows, causes extra lateral flows that make mixing faster compared to pure diffusion. It is used here since complete mixing is very important since the antibodies only come from one side and if mixing is incomplete that would bias the quantitative results.

13. How are the different flow rates achieved?

6 *different* flow resistors for 6 *identical* capillary pumps

This makes sense design-wise. Since Q=P/R, you can achieve different flow rates by changing either one or both the P and R, in this case the capillary pressure of the capillary pumps and the hydraulic resistance of the flow resistors. A capillary pump is more complicated to design and characterize than a flow resistor, so that is a natural choice.

14. What are the hydraulic resistances?

$0.38*10^{18}$ m^{-3} – $2.2*10^{18}$ m^{-3}

note: they are given in the article in units R_h/μ, so that the total resistance given does not include the viscosity term. Remember that the unit of viscosity was Pa * s, so multiplying m^{-3} by this gives unit of Pa * s/m^3, which is the familiar unit for hydraulic resistance.

15. What is the liquid that is flowing on the chip and what is its viscosity?

The liquid is serum at 20 Celsius and for its viscosity the value used was 1.8 mPas

16. What is the capillary pressure of the pumps?

-2.8 kPa to -7.2 kPa, depending on the position of the liquid meniscus in the capillary pump.

The capillary pump is a large chamber with pillars on it instead of a simple channel, the main reason for this design is to reduce the increased hydraulic resistance that comes from the pump and to increase the volume of the pump per area. The pump is made from many channels in a parallel configuration, leading to lowering of overall hydraulic resistance.

17. For calculating capillary pressure, what was the surface tension, what were the contact angles and what were the channel dimensions used?

20° for silicon, 116° for PDMS. The surface tension of the serum was taken to be 56.2 mN/m.

In the article it is not 100% clear if they measured the contact angles themselves or whether they are advancing angles. They should be.

Also, 116° is a typical value for the advancing contact angle of native PDMS. But in this chip they blocked the PDMS with BSA, which should also lower the contact angle? I did not find any answer in the article, maybe it is there or maybe this is a good reminder that all articles contain oddities, omissions and/or errors.

18. Did you notice anything else in the article that was related to the topics we have covered on the course?

There were dimensionless numbers, the Reynolds number