Sensitivity Optimization of Microfluidic Capacitance Sensors using COMSOL Multiphysics

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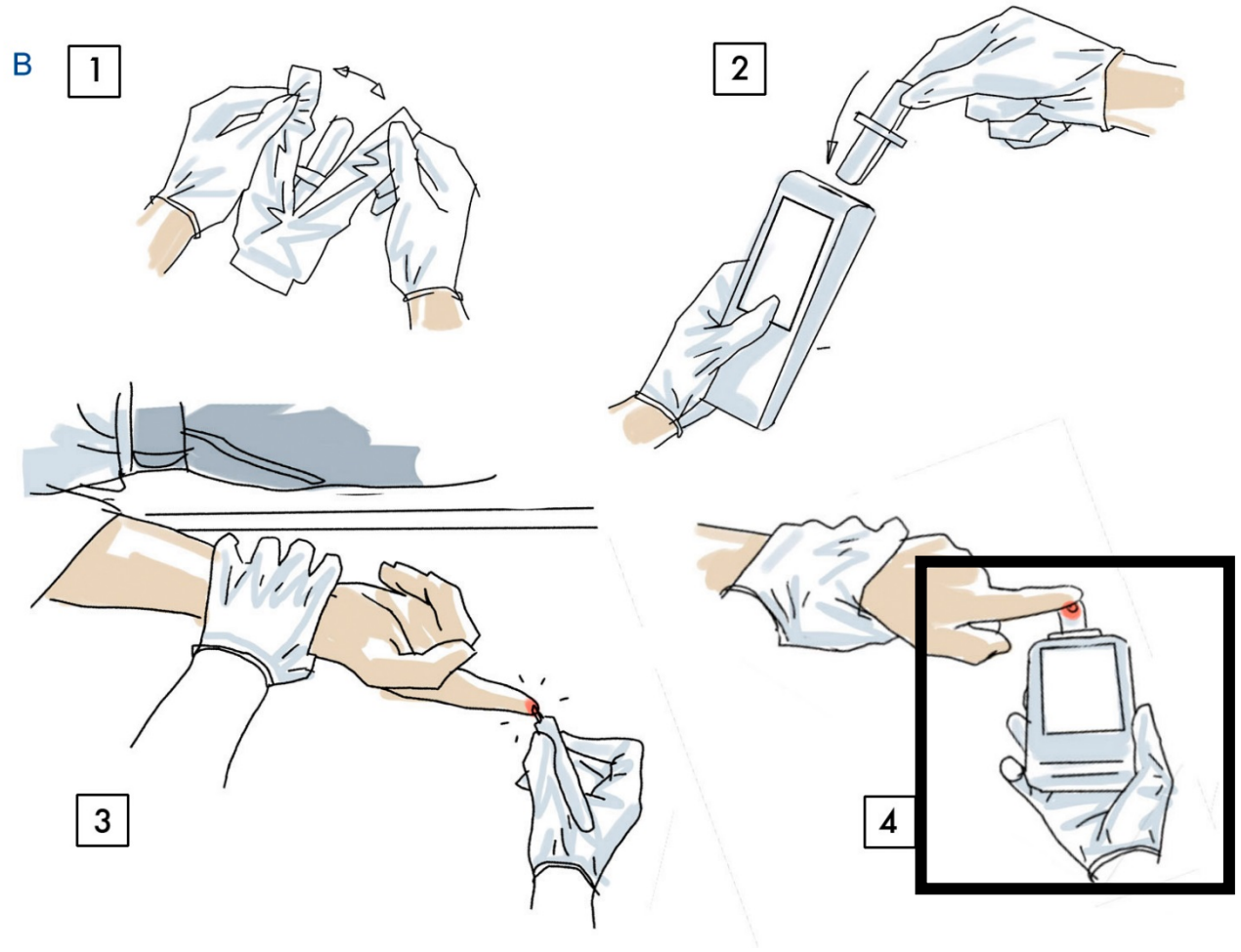
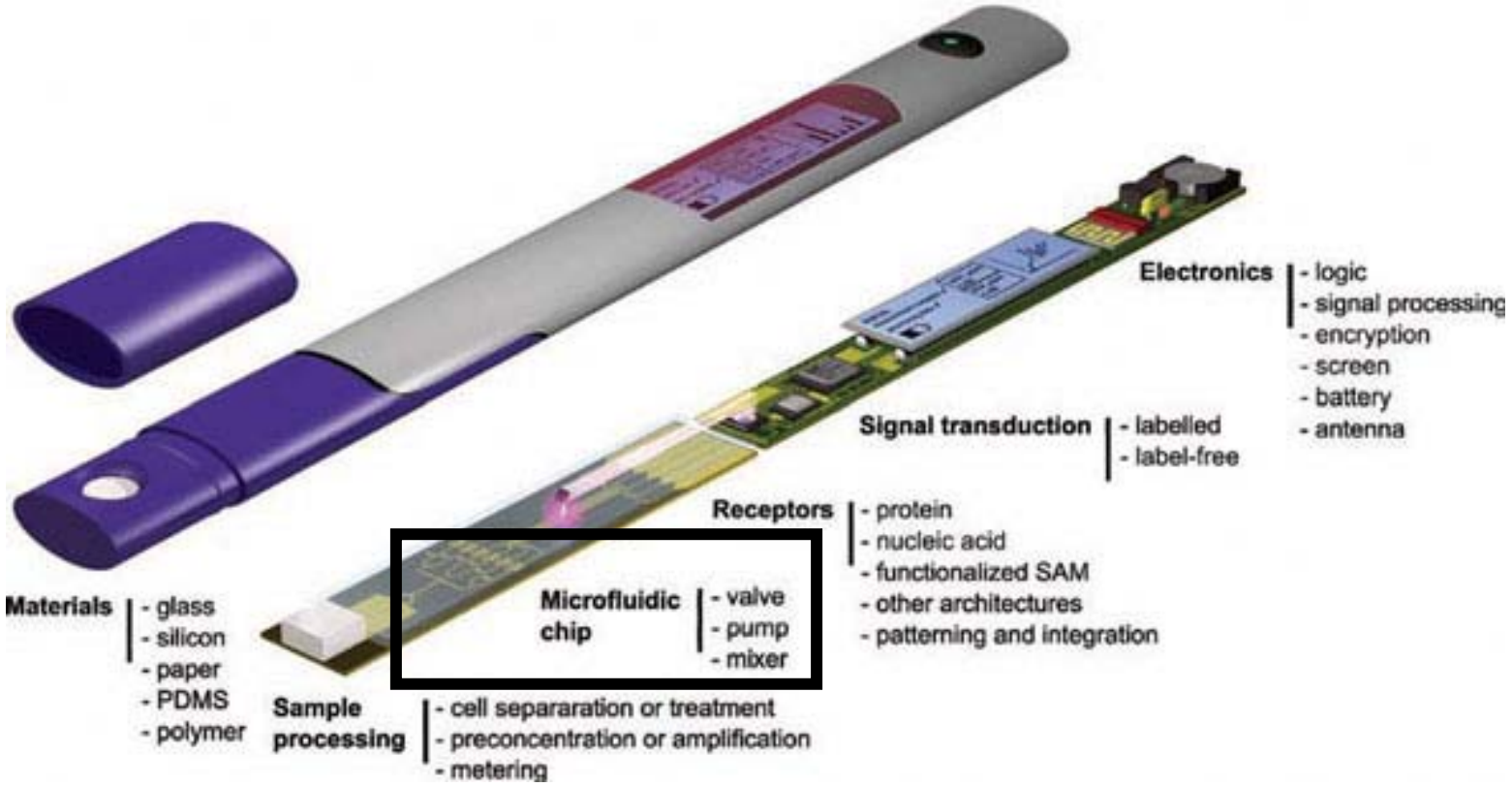
COMSOL CONFERENCE BANGALORE2013

Introduction Point of care diagnostics



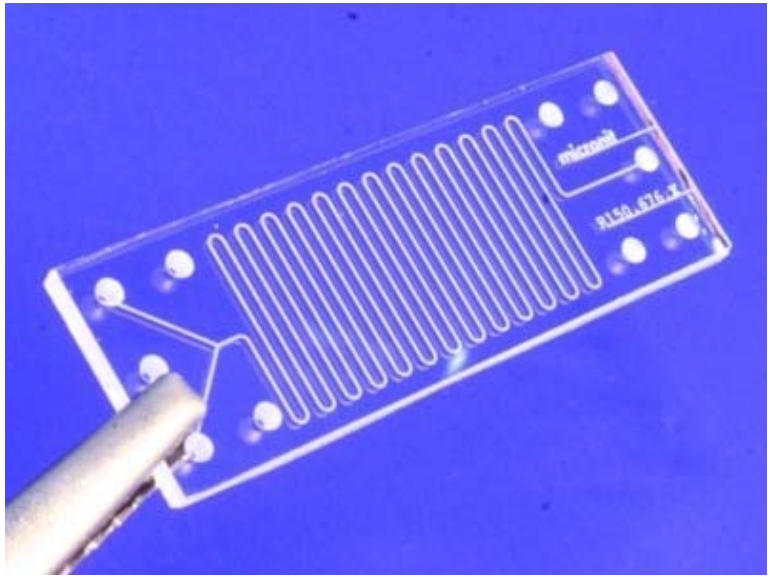
[1] Adapted from Philips Handheld Diagnostics

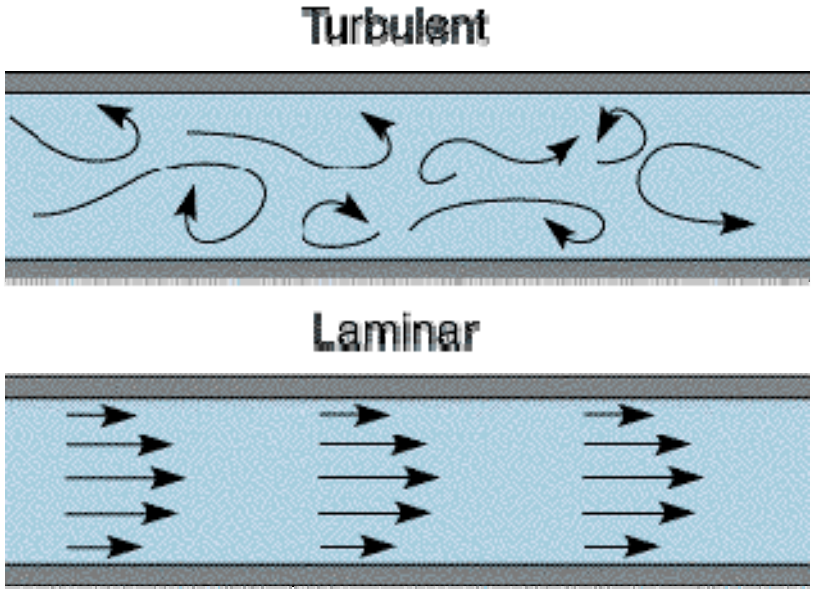
Introduction Point of care diagnostics 2



[2] Luc Gervais et al. Advanced Materials

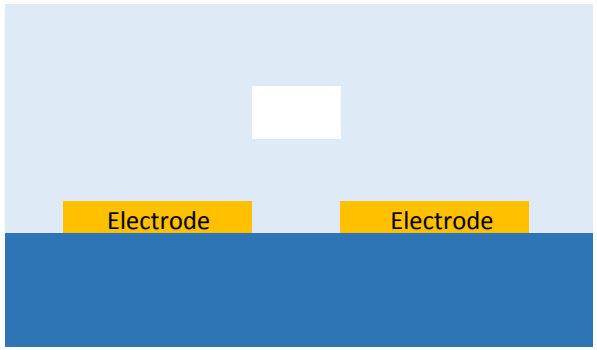
Introduction Microfluidics



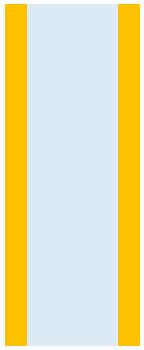


[3] Micronit Technologies, [4]

Introduction Capacitance sensing



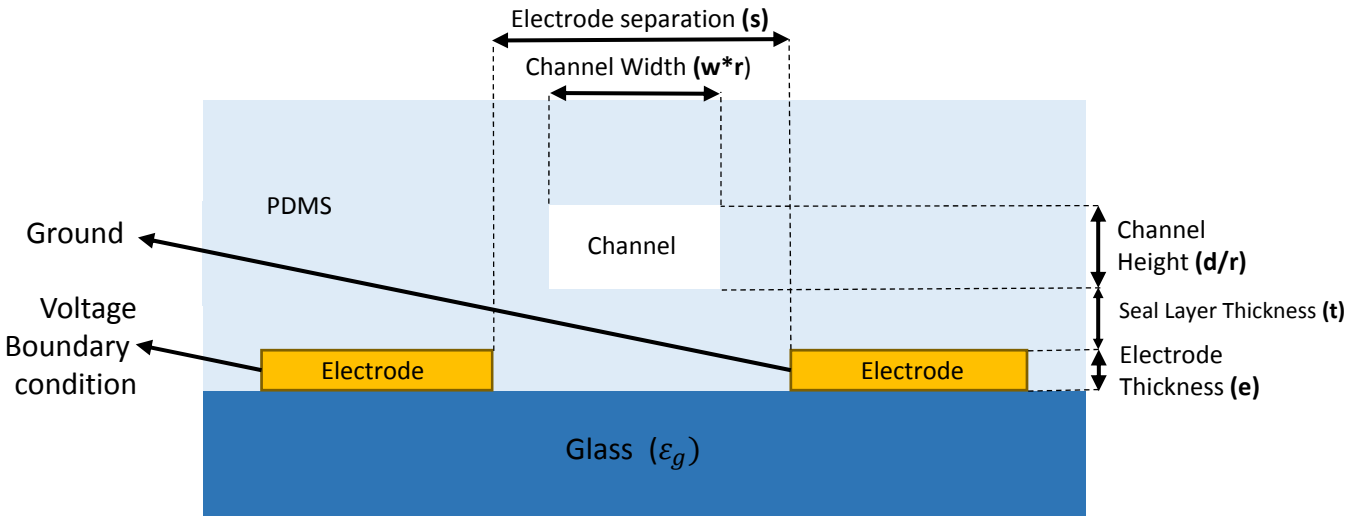
versus



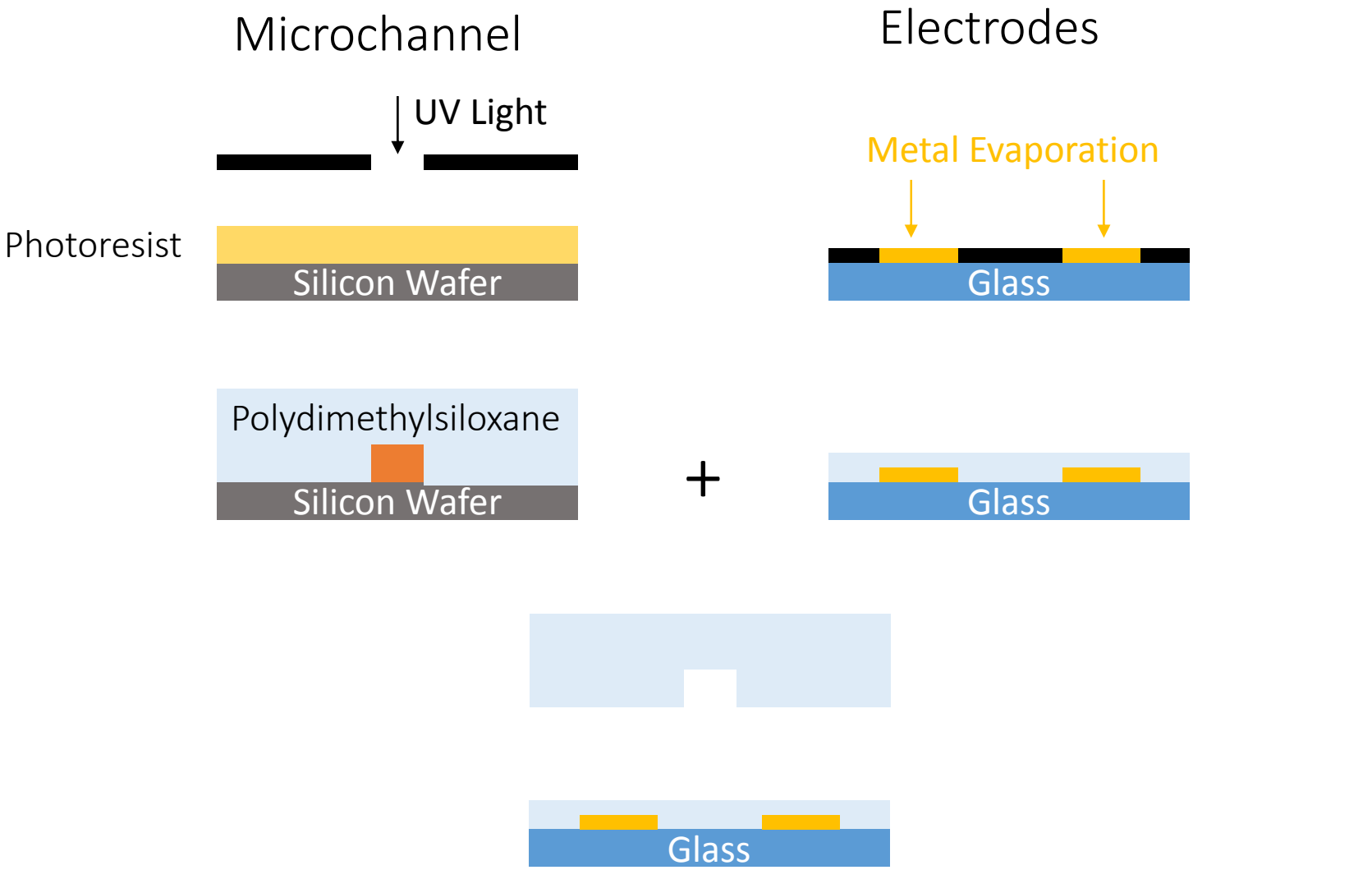
Capacitance majorly due to **fringing field**

Capacitance majorly due to **direct field**

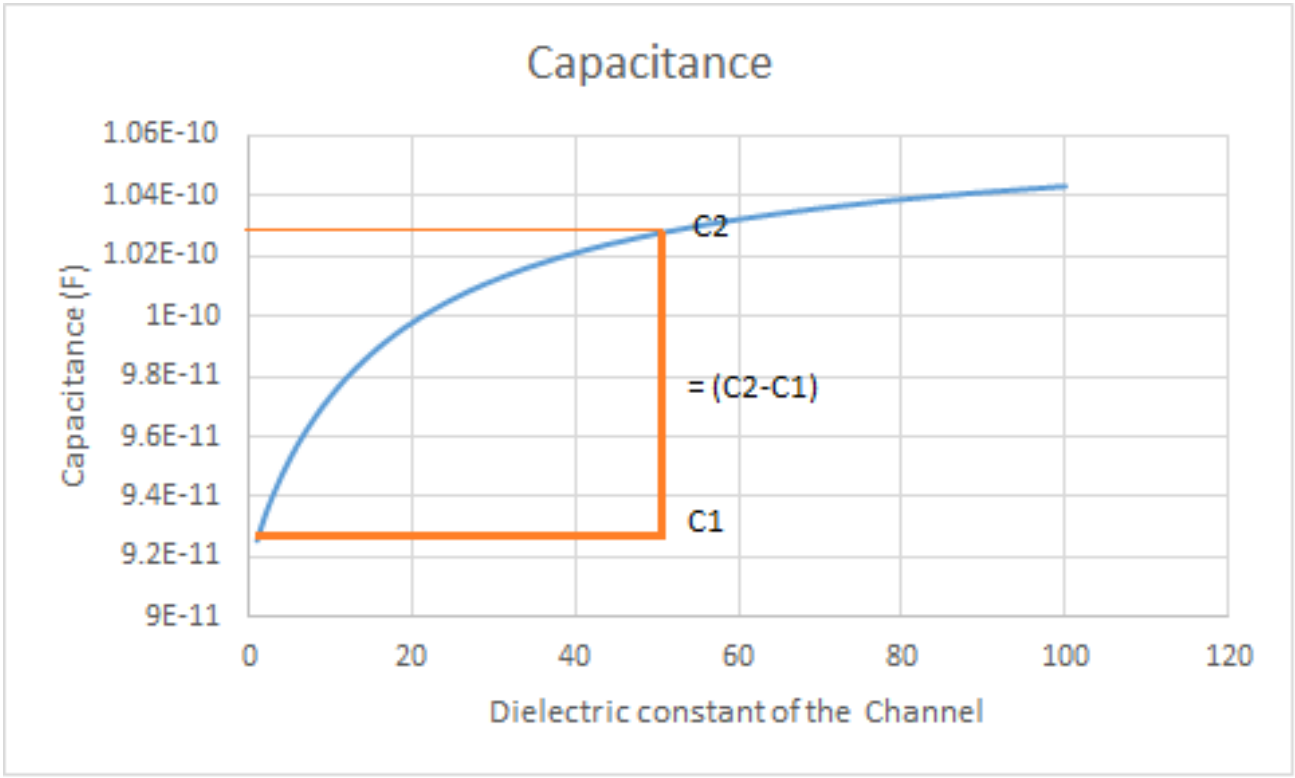
Geometry


Electrode separation **(s)**
Channel Width **(w*r)**
PDMS
Channel
Ground
Voltage
Boundary
condition
Electrode
Electrode
Glass (ε_g)
Channel
Height **(d/r)**
Seal Layer Thickness **(t)**
Electrode
Thickness **(e)**

Fabrication and Materials

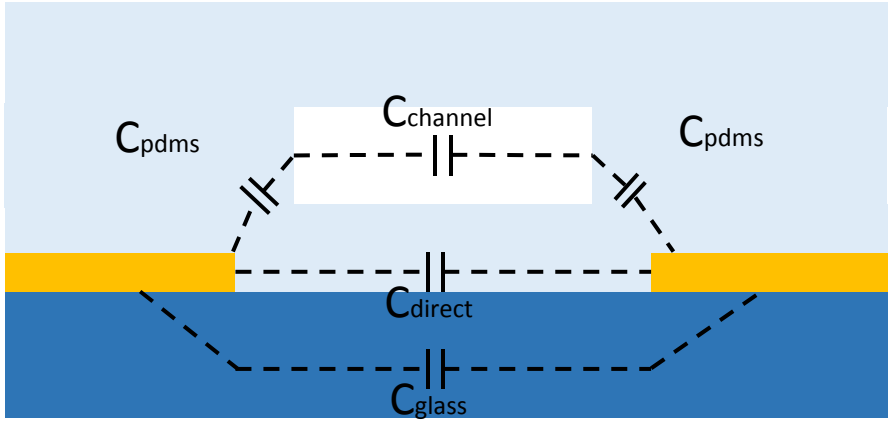


Sensitivity metric



$$Sensitivity = \left(\frac{Capacitance_{\ dielectric\ of\ 50}}{Capacitance_{\ air}} - 1\right) \times 100$$

Lumped Capacitor model



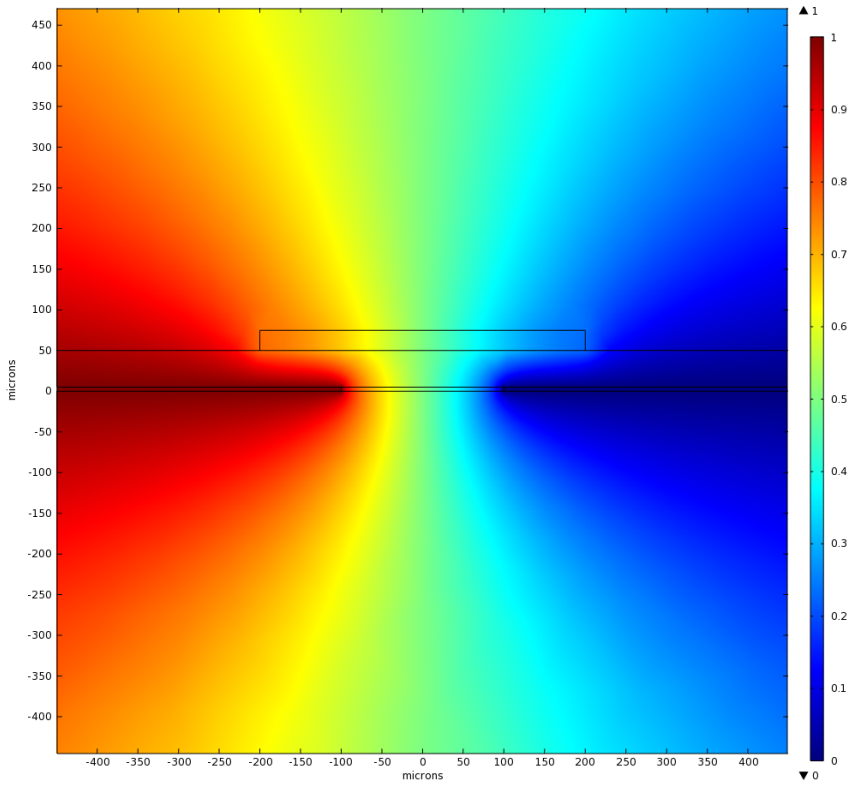
- Parallel capacitances add a constant value to the measured capacitance
- PDMS capacitance add up in series causing non linearity in total output capacitance

$$C_{measured} = C_{glass} + C_{direct} + \frac{2\,C_{channel}C_{pdms}}{C_{channel} + C_{pdms}}$$

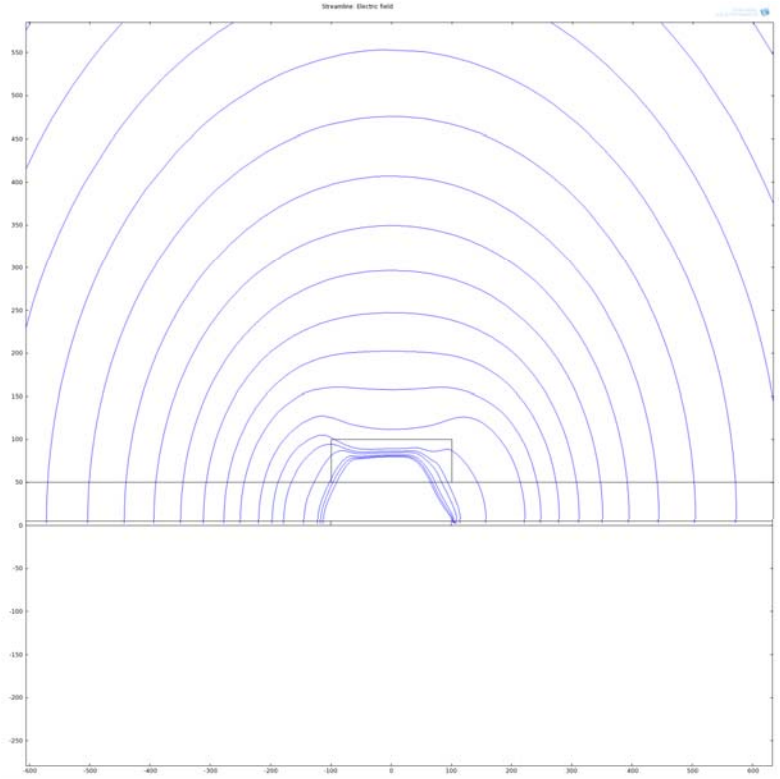
COMSOL model Salient features

- Electrostatics module
- Stationary, two dimensional study
- Parameterized geometry
- Dielectric constants obtained from literature
- Capacitance numerically calculated using COMSOL's inbuilt es.C11 function
- Capacitance output of parameter sweep was post processed

Simulations Potential and Electric field



Electric Potential



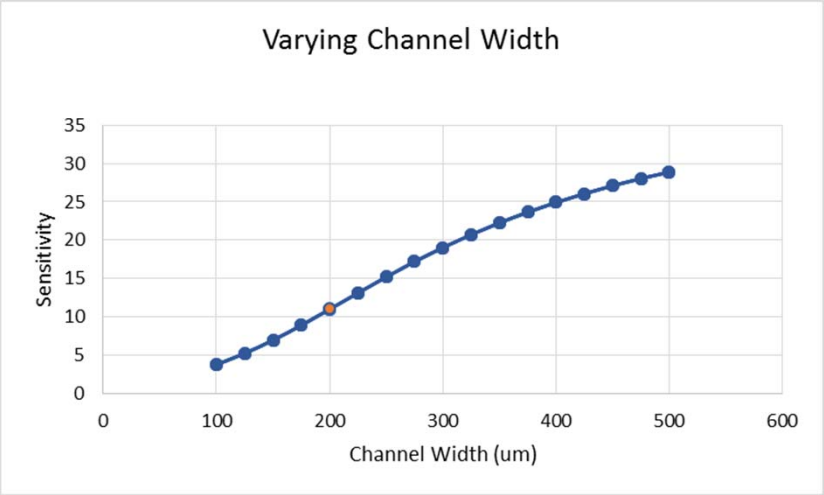
Electric Field

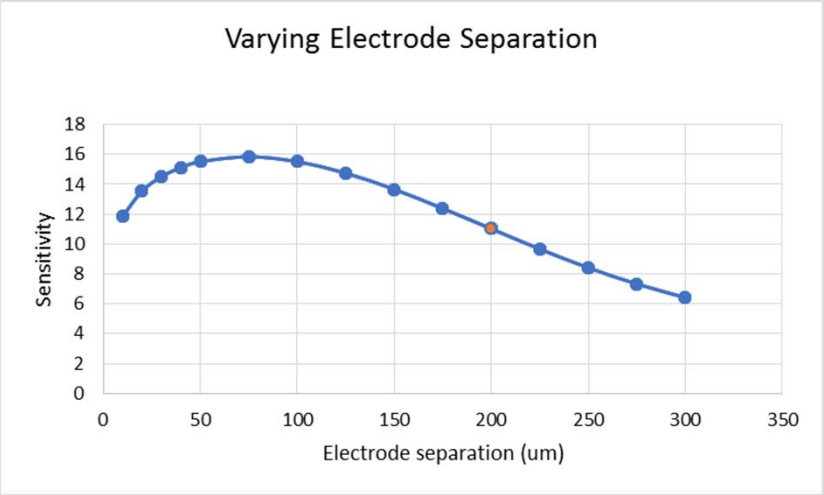
Simulations Straight electrodes

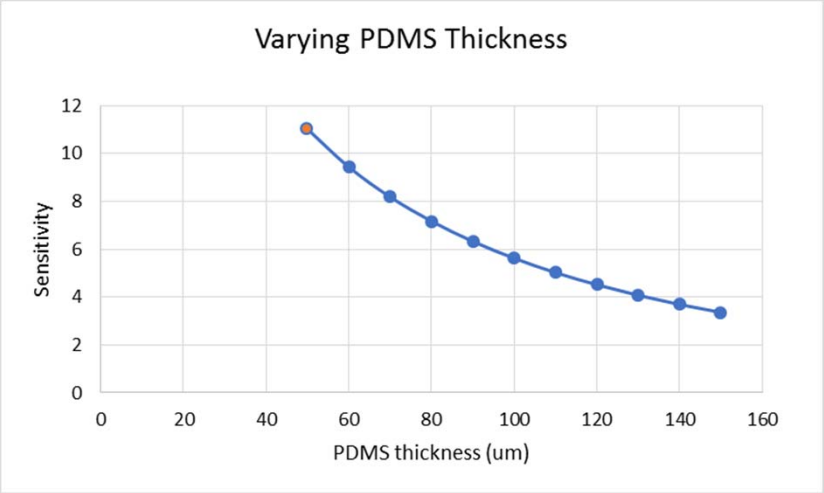
- The following parameters were varied on the basis of whether they could be influenced by the fabrication process

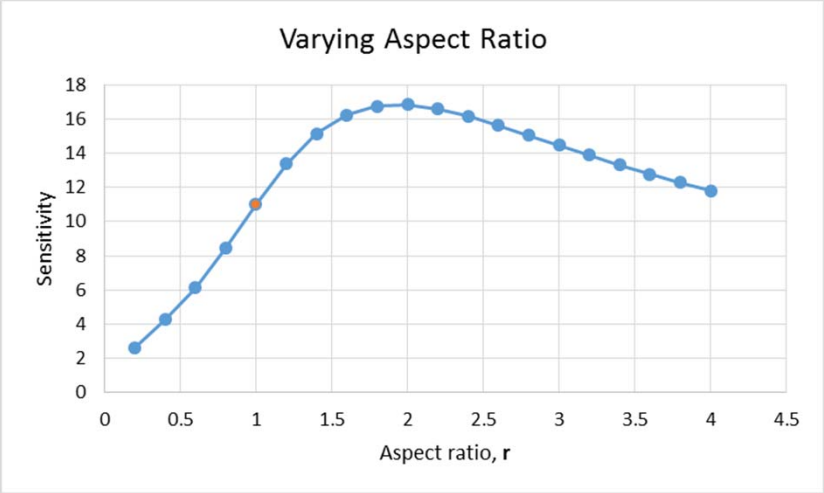
- Aspect ratio
- Channel height
- Channel width
- Electrode separation
- Electrode thickness
- Thickness of the insulating layer

Results Straight electrodes, varying









Discussion Straight Electrodes

Channel Width

- Increasing channel width monotonically increases sensitivity
- $C_{channel}$ increases with width

Electrode Separation

- Sensitivity peaks at a given electrode separation
- At small separations, C_{direct} dominates
- C_{pdms} dominates at large separations

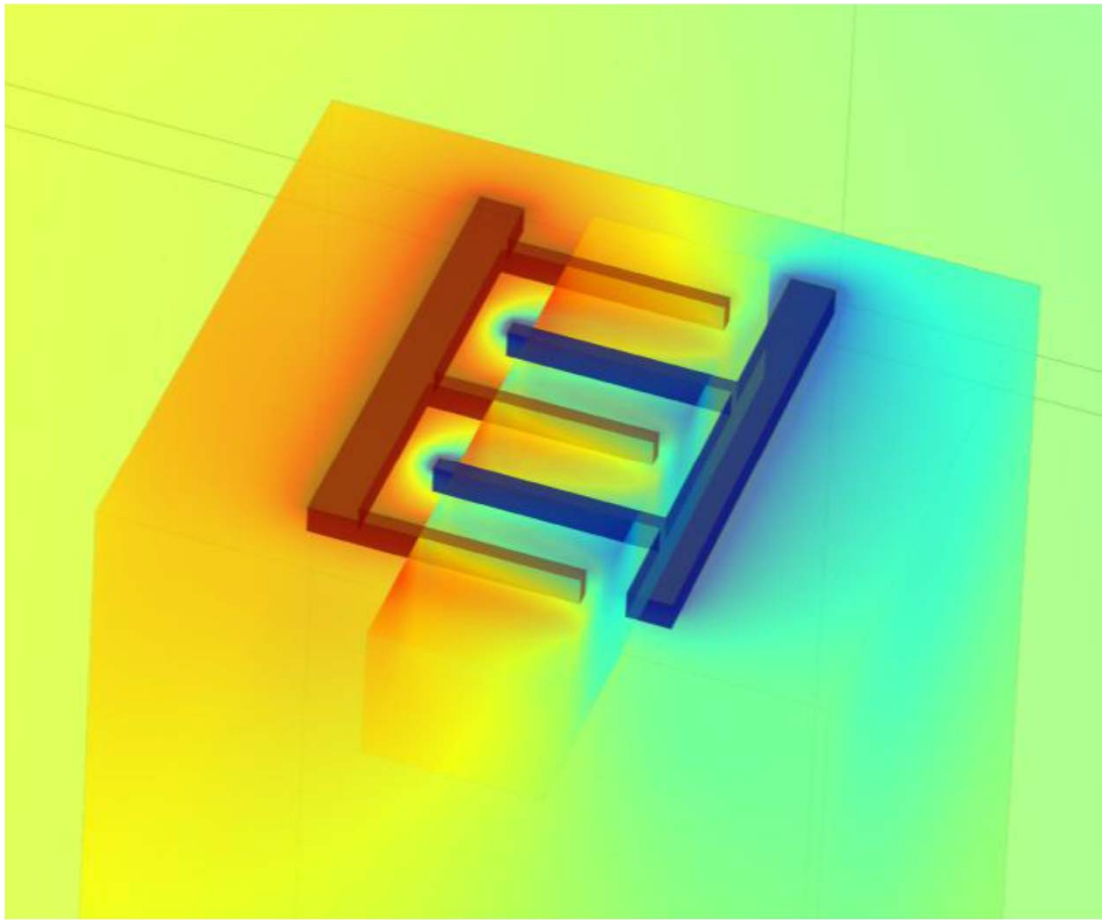
PDMS Thickness

- Decreasing thickness leads to lower C_{pdms} and stronger fringes
- However, the thickness cannot be very small due to fabrication issues

Aspect Ratio

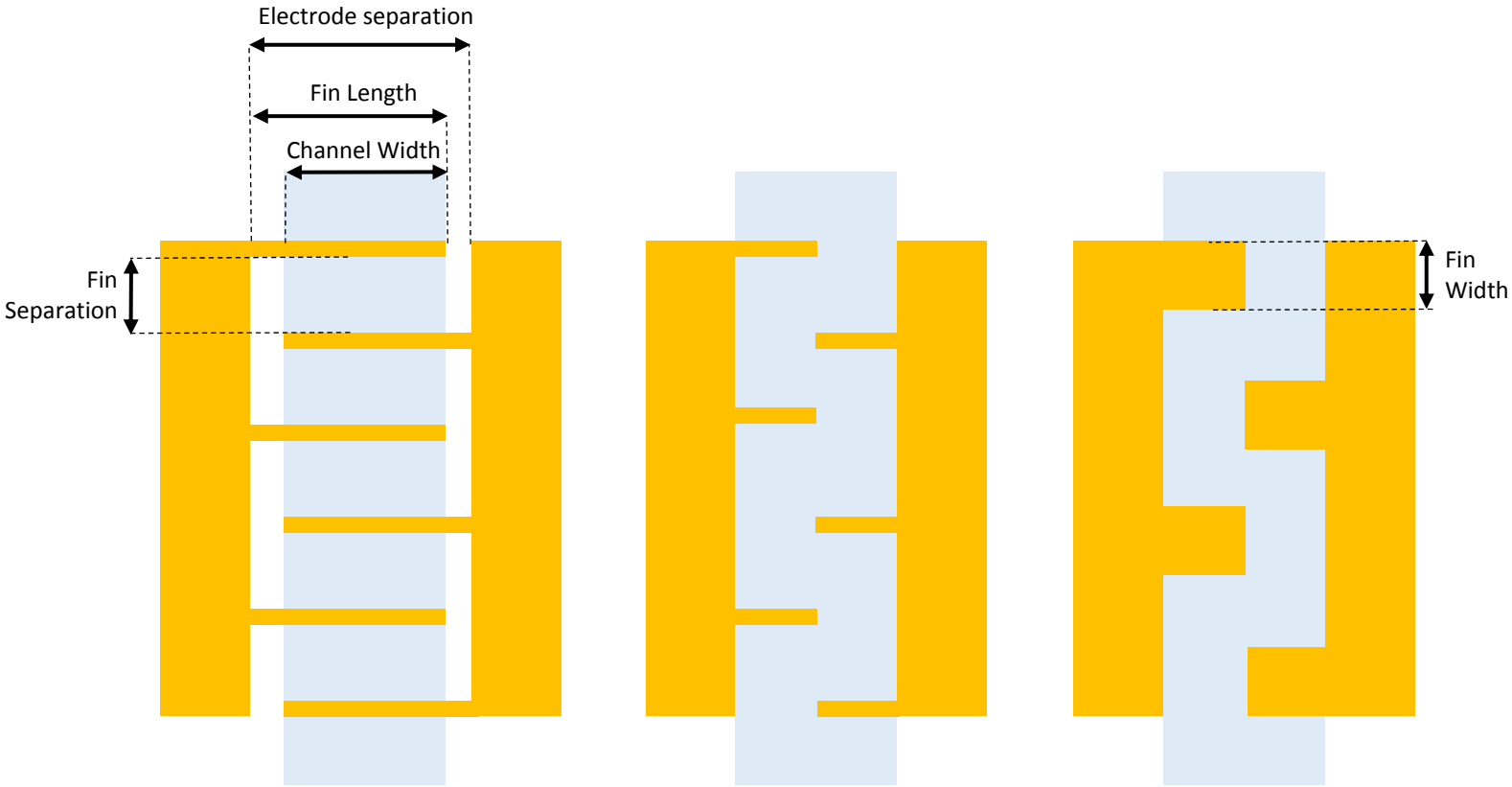
- Neither infinitely long, not wide channels are highly sensitive
- When channel width is 4 times height, sensitivity peaks

Simulations 3D electrodes



- 3D studies
- Parameterized geometry

Trends Interdigiated Electrodes



Discussion Interdigiated electrodes

- Interdigiation is equivalent to increasing the effective length of the channel under the electrodes
- Fringing field between the electrodes should pass through the microchannel
- The sensitivity is further maximized, when the separation between the two pairs of electrodes is equal to the maximized separation for the straight electrode case

Conclusions

- Geometrical parameters in a capacitance sensor were identified and optimized
- Electrode separation should be 2.6 times smaller than the channel width
- Channel width must be 4 times that of channel height
- Observed results explained through a lumped capacitor model
- Trends for interdigiated electrodes were observed

Future work

- Application based design
- Fluid velocity measurement though bubble injection
- Blood glucose measurement
- Low cost fabrication processes

Acknowledgements

I'd like to thank my guide, Prof. Baghini for placing such faith in an undergrad, agreeing to supervise me and providing great feedback to ensure I was on the right track.

Yaksh Rawal, for his guidance in the fabrication of the device.

My friends, who still continue to bear with me on discussions about lumped capacitors and negative capacitances

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