Simulation of CMOS Compatible Sensor Structures for Dielectrophoretic Biomolecule Immobilization

IHP - Frankfurt (Oder) - Germany

Honeyeh Matbaechi Ettehad, Subhajit Guha, Christian Wenger

innovations
for high
performance
microelectronics

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COMSOL CONFERENCE 2017 ROTTERDAM

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Agenda

1. Introduction
2. Theory and use of COMSOL Multiphysics
3. Computational Methods
4. Results

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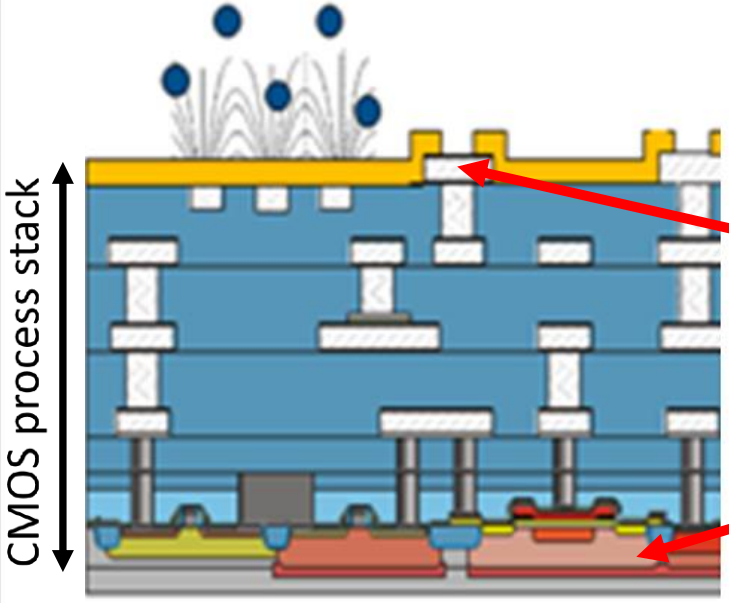
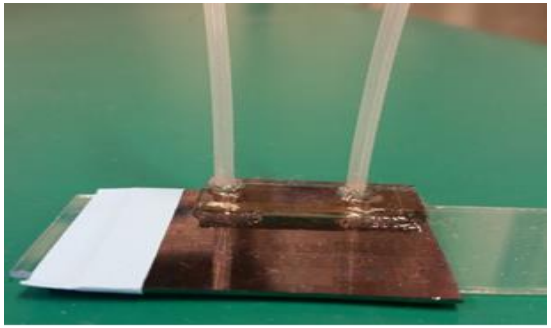
Introduction

Development of a lab-on-chip device for virus immobilization and detection

- ❑ Electrical immobilization of viruses on immobilizing electrodes - > Dielectrophoresis
- ❑ Sensing and analysis of the immobilized viruses -> All electrical biosensor
- ❑ Silicon microelectronics compatible -> operating in CMOS/BiCMOS technology



Single chip: immobilization and sensing



Target : To establish RF biosensors for immobilizing and sensing

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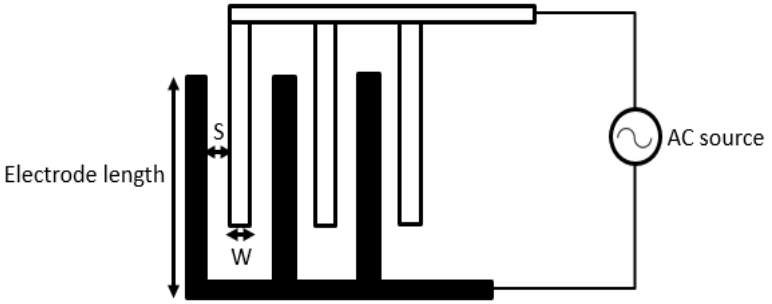
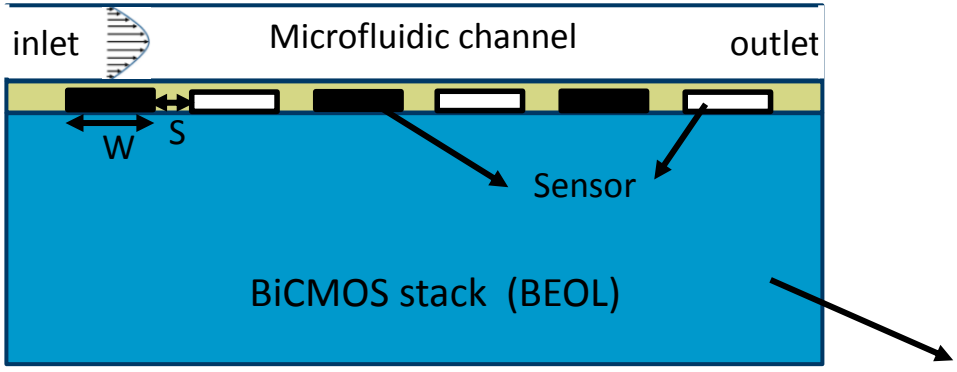
Theory: electrode structure

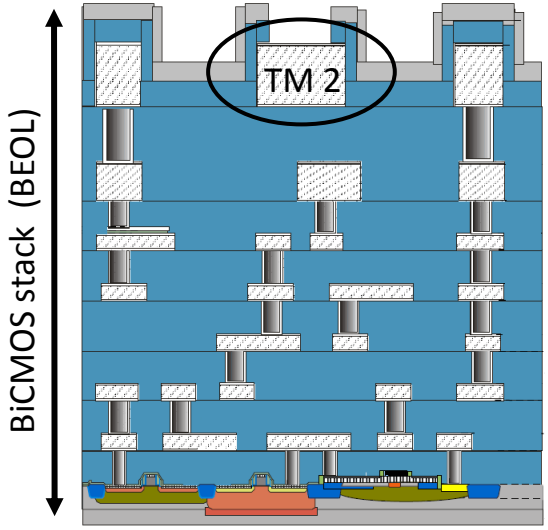
Established electrode structure for RF sensing

- Interdigitated electrodes (IDE) -> used as sensor
- Same electrode structure -> used for immobilizing of viruses





Cross-sectional view of electrode structure with microfluidic channel



Theory: Dielectrophoresis (DEP) principles

Dielectrophoresis -> electrical immobilization of particles

- Non Uniform electric field effect on particles
- Dependent on -> permittivity, conductivity, particle size and electric field

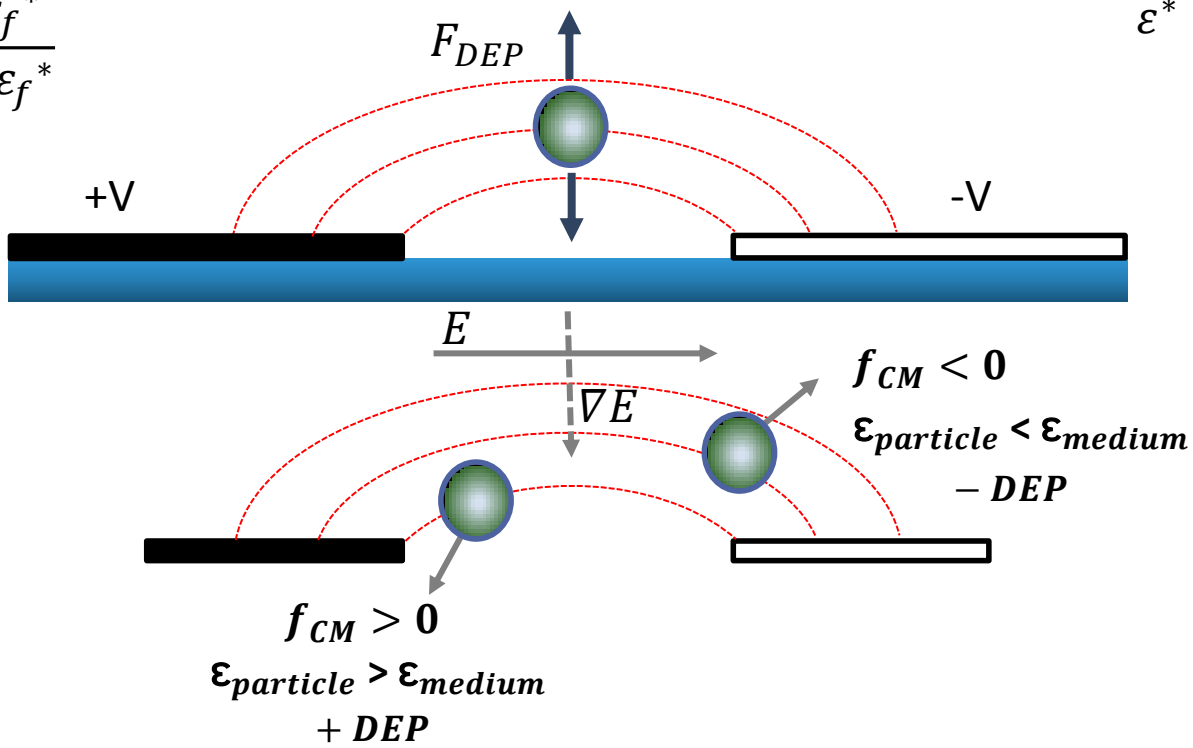
Clausius-Mosotti factor

$$f_{CM} = \frac{\varepsilon_p{}^* - \varepsilon_f{}^*}{\varepsilon_p{}^* + 2\varepsilon_f{}^*}$$

$$F_{DEP} = 2\pi r_p{}^3 \varepsilon_f \, Re(f_{CM}) \, \nabla|E|^2$$

Complex permittivity

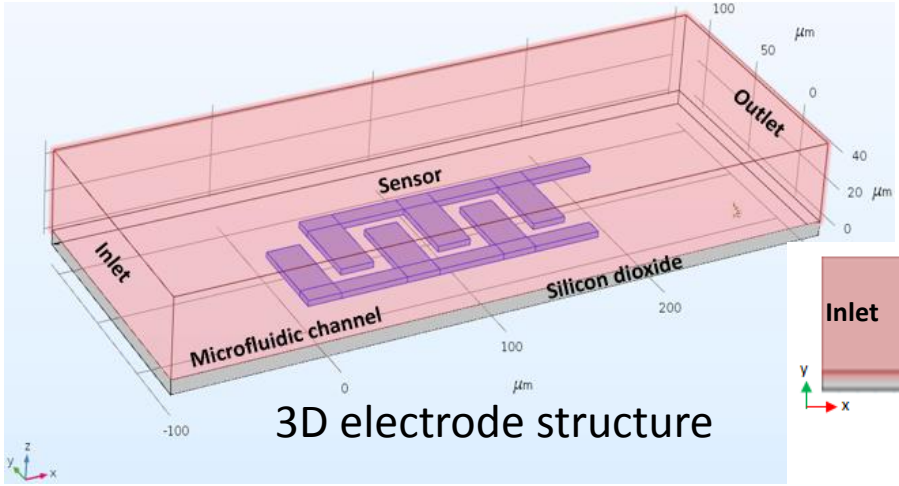
$$\varepsilon^* = \epsilon - j\frac{\sigma}{\omega}$$



Use of Comsol Multiphysics (version 5.3)

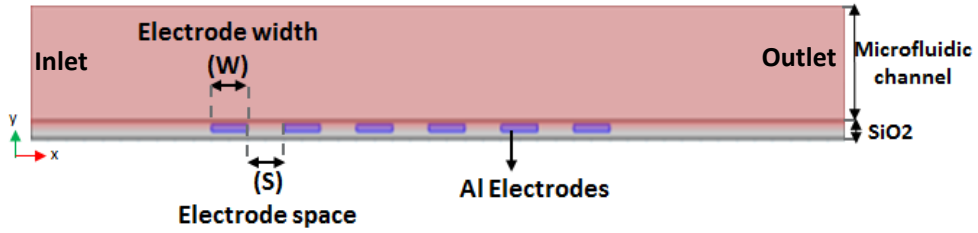
Multiphysics tool COMSOL is used -> immobilization analysis

- Three modules used : Electric current, fluid flow, particle tracing
- Governing equations:
  - Electric field : $\mathrm{E} = -\nabla V$
  - Fluid flow : $0 = \nabla \cdot \left[-pl + \mu(\nabla u + (\nabla u)T) - \frac{2}{3}\,\mu\,(\nabla \cdot u)l\right] + F$
  - Drag Force: $F_{Drag} = \left(\frac{1}{\mathrm{T}_p}\right) \cdot m_p(u - v)$
  - Dielectrophoresis : $F_{DEP} = 2\pi {r_p}^3\, \varepsilon_f\, Re(f_{CM})\, \nabla|E|^2$



3D electrode structure

2D electrode structure



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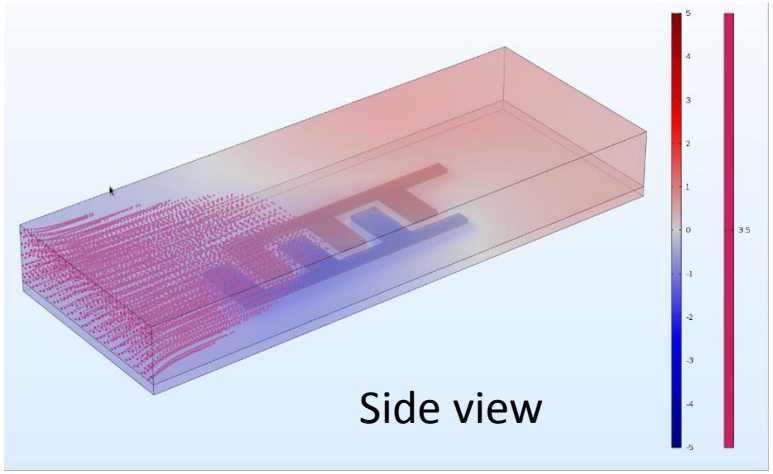
Computational Methods

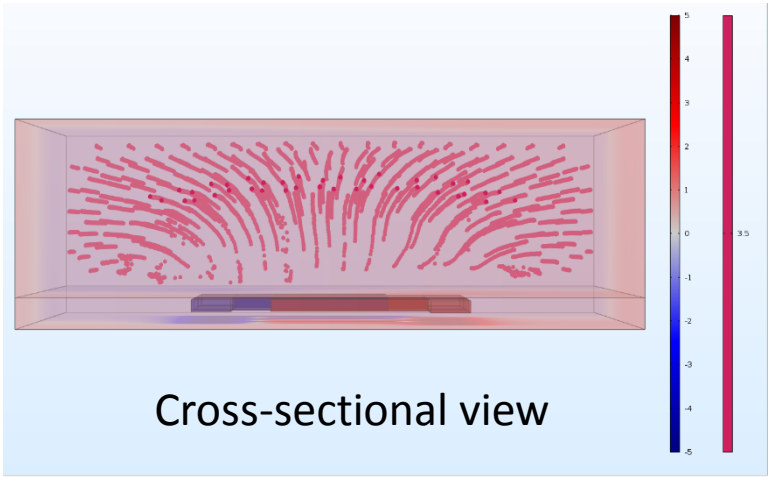
Generation of non-uniform electric field gradient using IDE

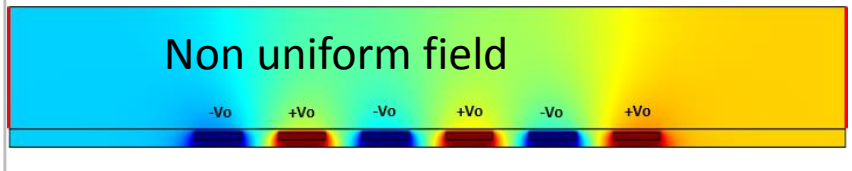
- Positive DEP for applied voltage: particles are attracted
- Tuning parameters: voltage, flow-velocity, IDE geometry

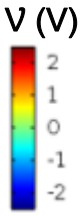
Spatial variation of the electric potential in the microfluidic channel

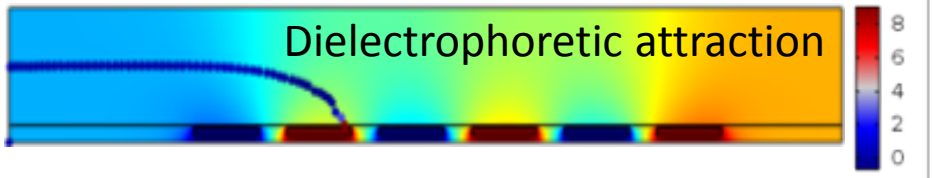


Particle trajectory influenced by DEP force









Simulation studies were all done in 2D to reduce the computational time

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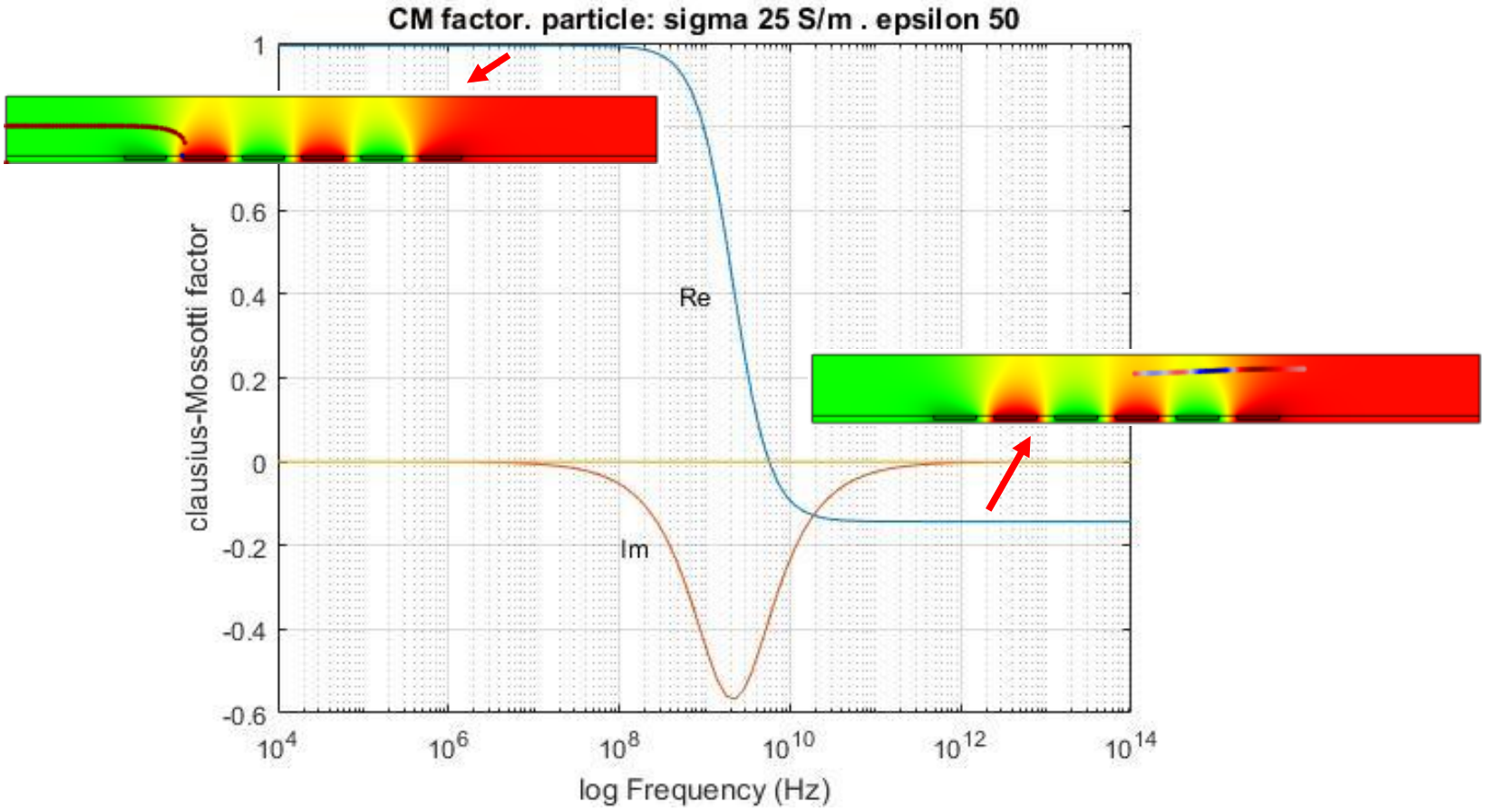
Results: Clausius-Mosotti factor

Clausius-Mosotti factor -> function of permittivity & conductivity

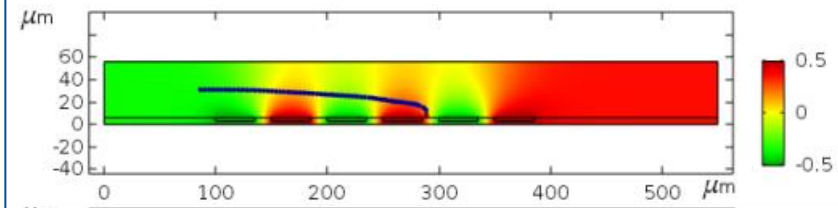
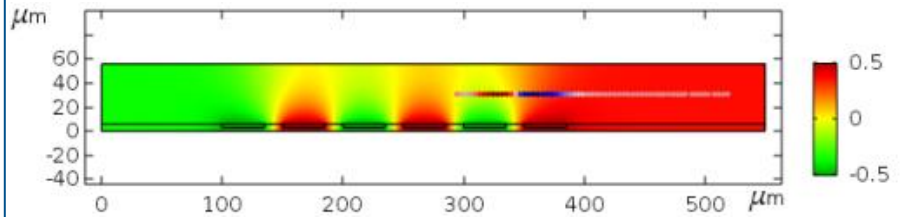
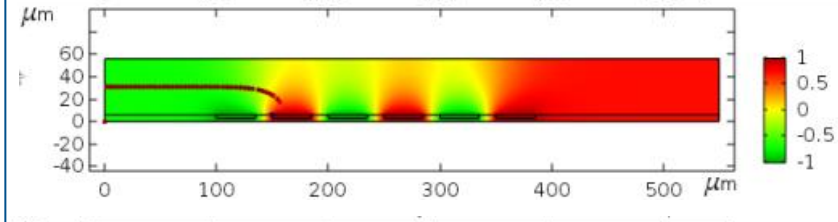
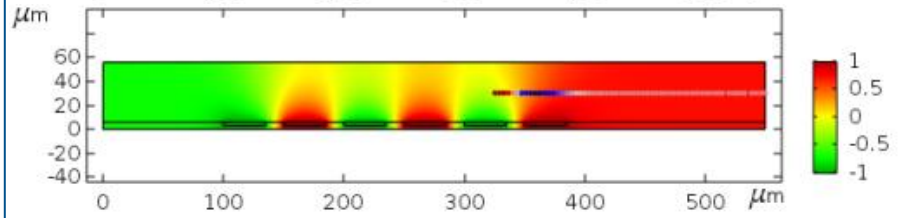
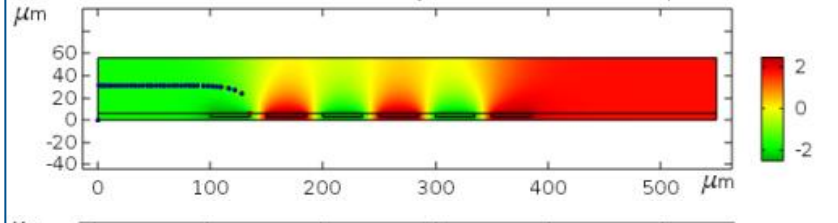
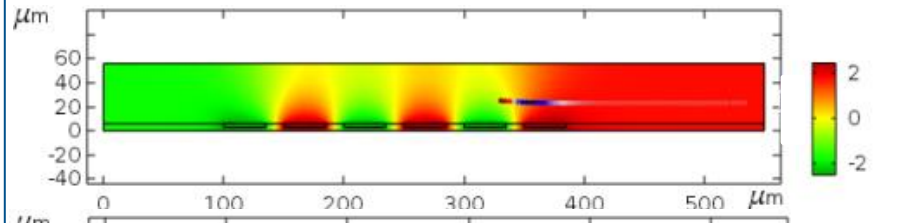
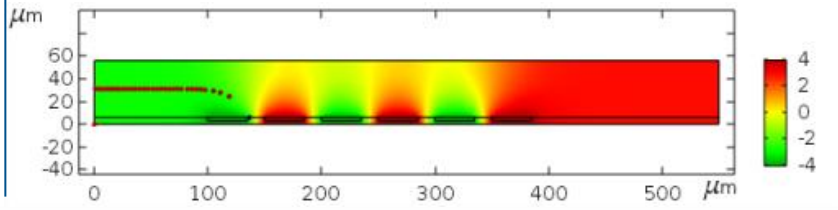
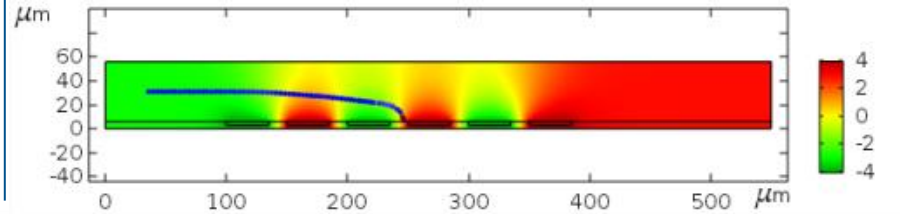
- Frequency dependent parameter : positive and negative dielectrophoresis
- Choice of operating frequency -> for positive dielectrophoresis



Results: Influence of voltage

The applied voltage influences the particle attraction

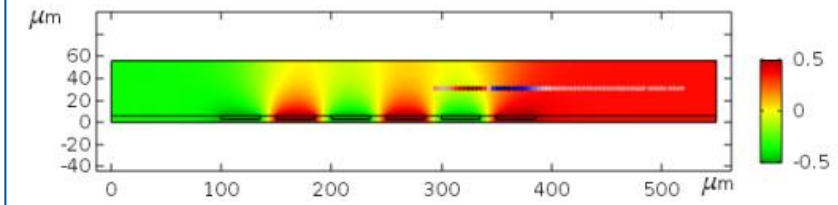
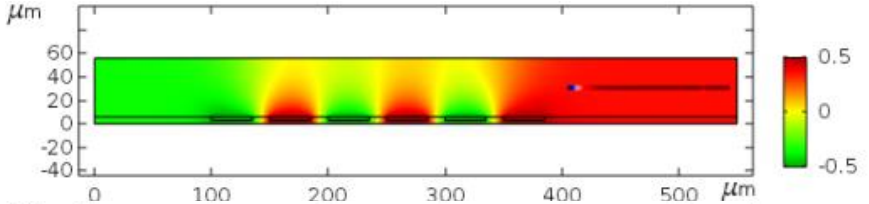
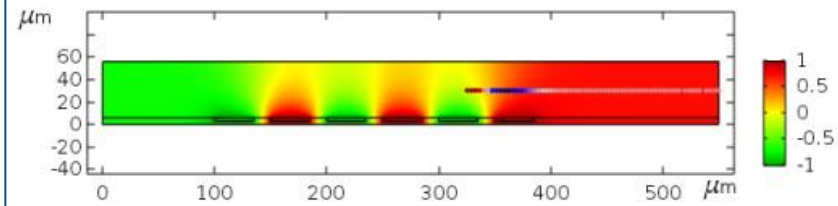
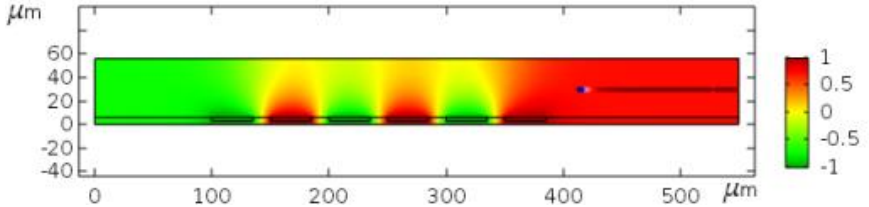
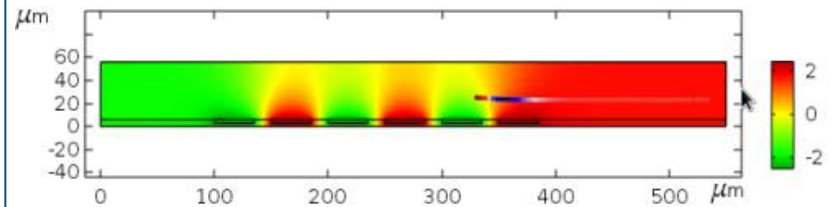
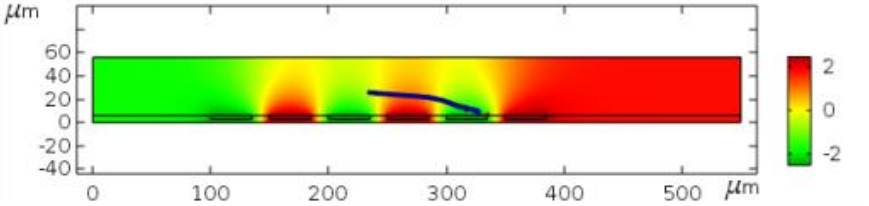
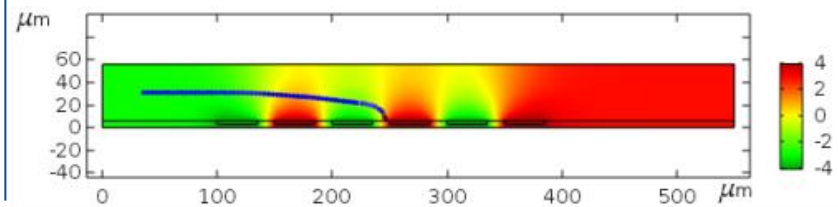
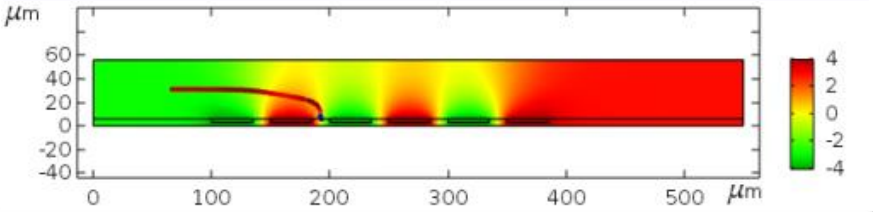
- Dependent on the size of the particle
- Smaller particles require higher voltage with the same fluid velocity

Voltage	Fluid velocity = 50 µm/s; Particle size : 3.5 µm	Fluid velocity = 50 µm/s; Particle size : 0.5 µm
1 V		
2 V		
5 V		
8 V		

Results : Influence of fluid velocity

The attraction of the particle is dependent on fluid velocity

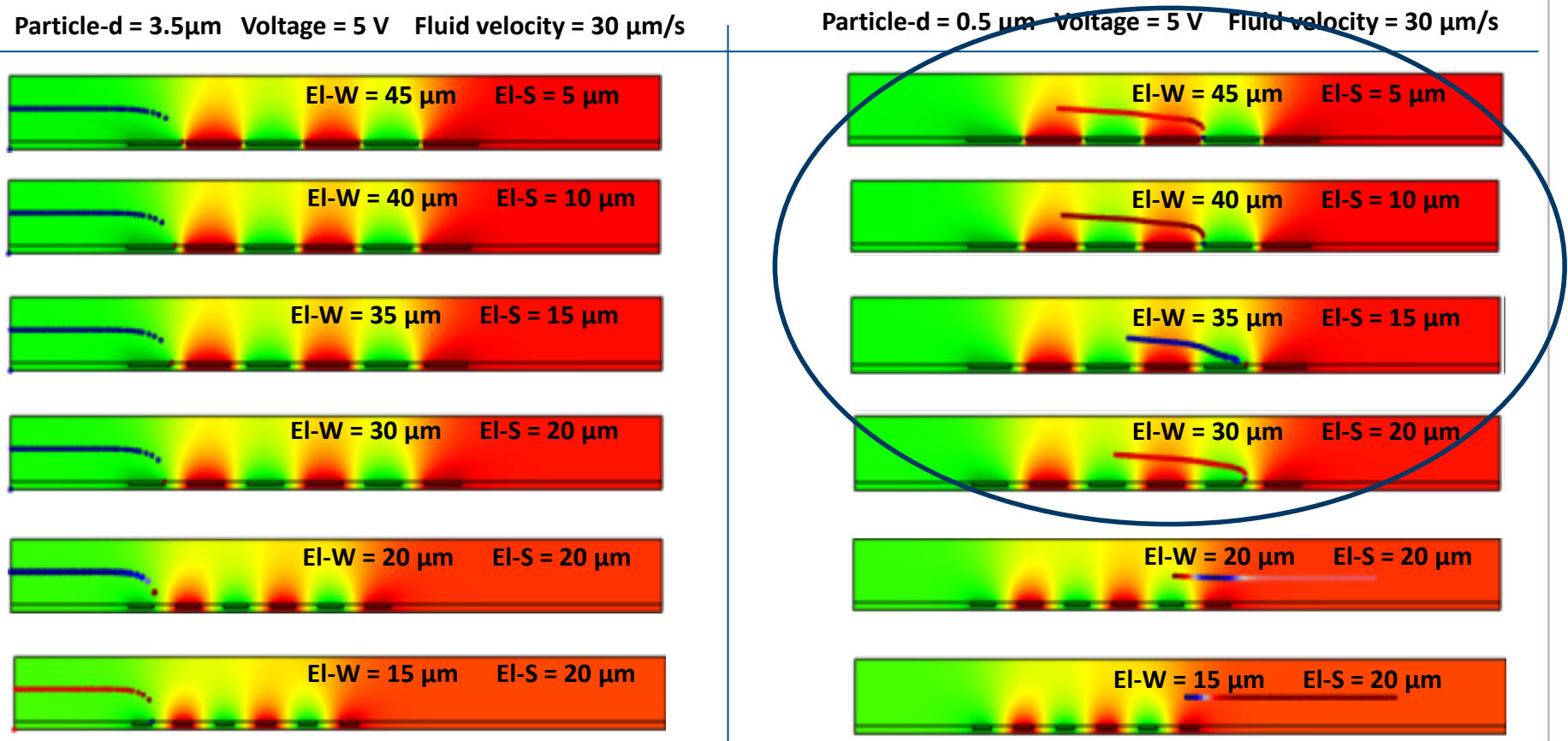
- Attraction of the particle takes place when DEP force nullifies the drag force
- For same voltage, lower fluid velocity aids in better attraction

Voltage	Fluid velocity = 50 µm/s; Particle size : 0.5 µm	Fluid velocity = 30 µm/s; Particle size : 0.5 µm
1 V		
2 V		
5 V		
8 V		

Results: influence of electrode geometry

Electrode geometry helps in forming non-uniform electric field

- Asymmetric geometry : unequal width and spacing of electrode is better
- Width of electrode > spacing, the influence of non uniform field is higher



Conclusion and Acknowledgement

- Electrode structure which is used for RF sensing can be also be used for immobilization.
- COMSOL Multiphysics is a useful tool for such for co-simulations.
- Dielectrophoresis is dependent on the voltage, flow velocity and geometry of the electrode.
- In CMOS compatible Technology for a given geometry of electrodes the only variation parameter is fluid velocity.

EUROPÄISCHE UNION
Europäischer Fonds für Regionale Entwicklung

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Thank you for your attention!

Matbaechi Ettehad, Honeyeh

IHP – Innovations for High Performance Microelectronics
Im Technologiepark 25
15236 Frankfurt (Oder)
Germany
Phone: +49 (0) 335 5625 663
Fax: +49 (0) 335 5625 681
Email: matbaechi@ihp-microelectronics.com

www.ihp-microelectronics.com

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