COMSOL CONFERENCE
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Effect of high frequency field on the electric double layer surrounding a biomolecule in a fluid

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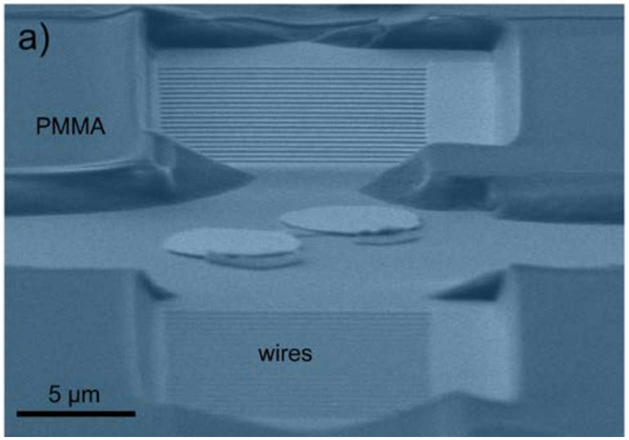
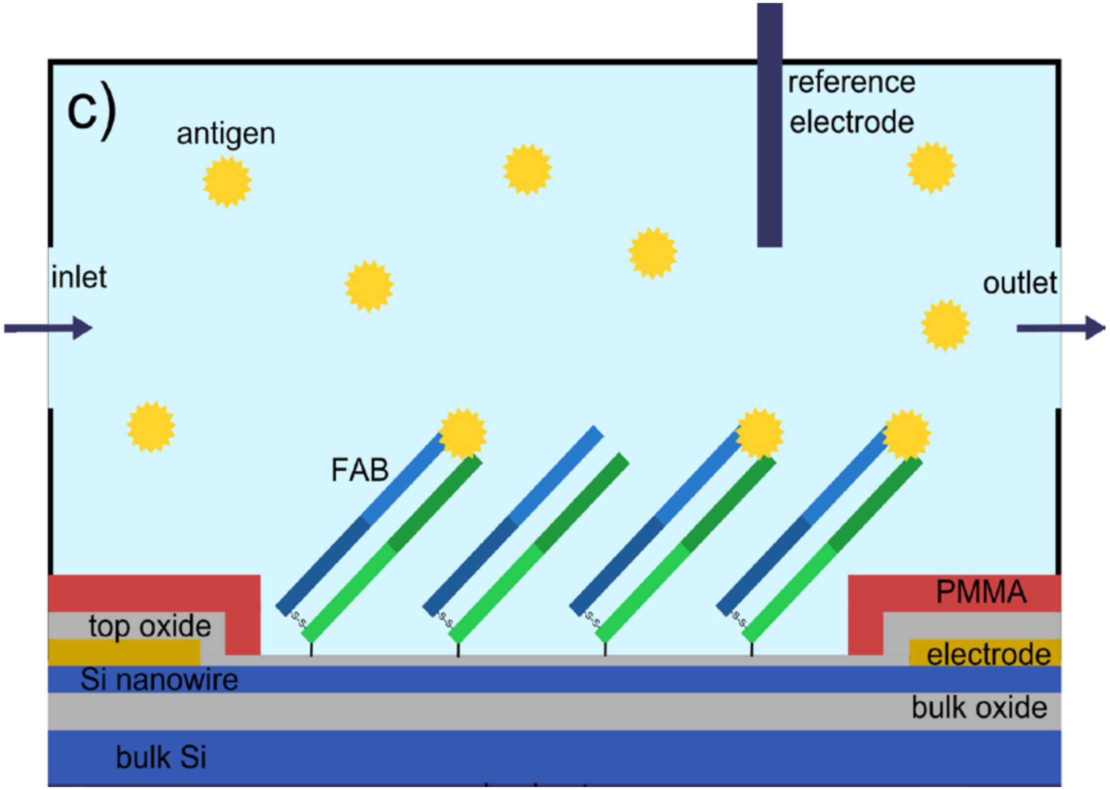
Overview

- Silicon nanowire based biosensor
- Debye screening
- Nernst-Planck equation and Poisson equation
- Frequency dependence
- Conclusion

Silicon nanowire based biosensor



Conductance variation measurement



Carsten Maedler et al "Detection of the melanoma biomarker TROY using silicon nanowire field-effect transistors", (2013), arXiv:1312.7532

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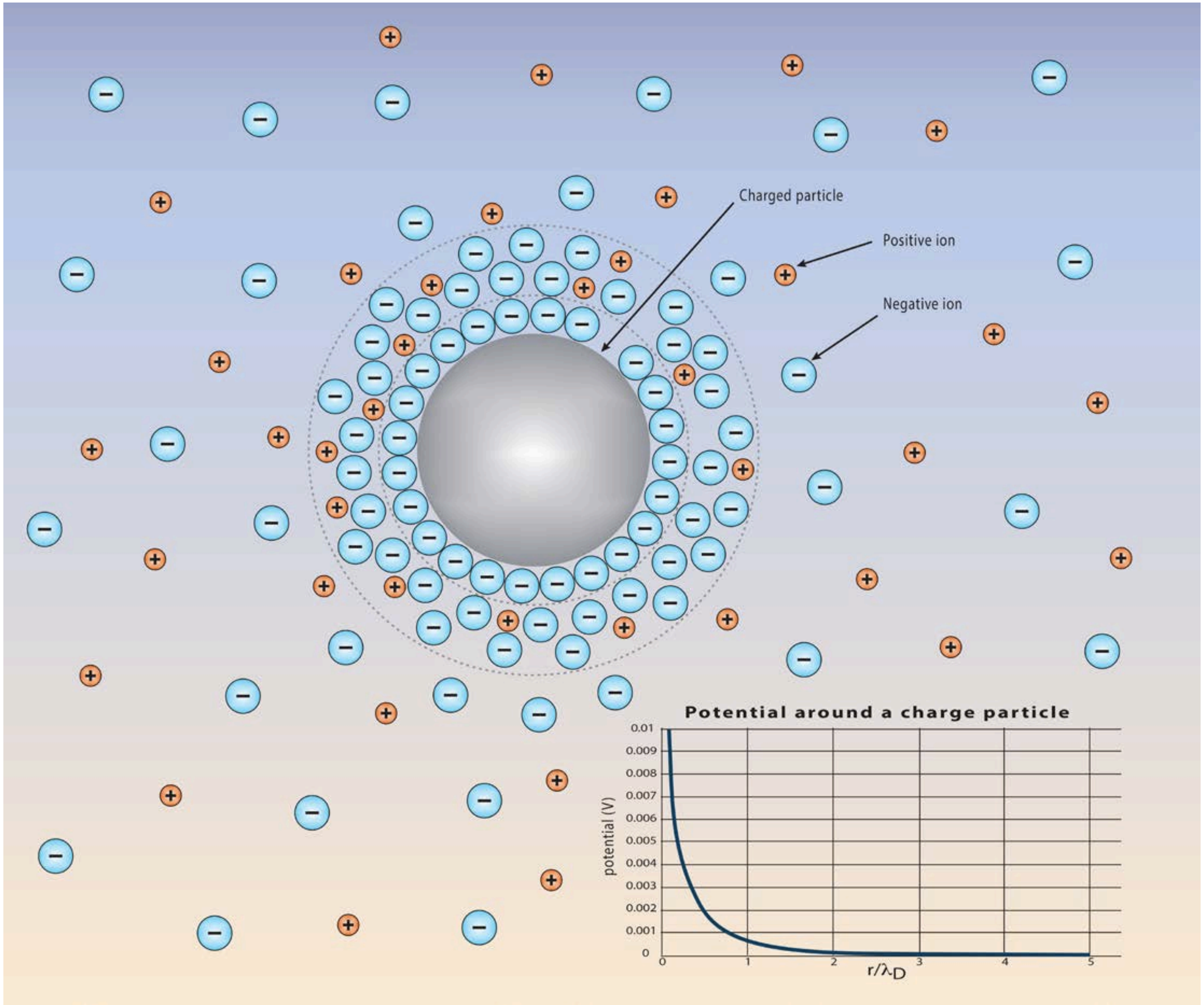
Debye screening



Debye length

$$\lambda_D = \sqrt{\frac{\varepsilon k_B T}{\sum_i n_i^0 {Z_i}^2 e^2}}$$

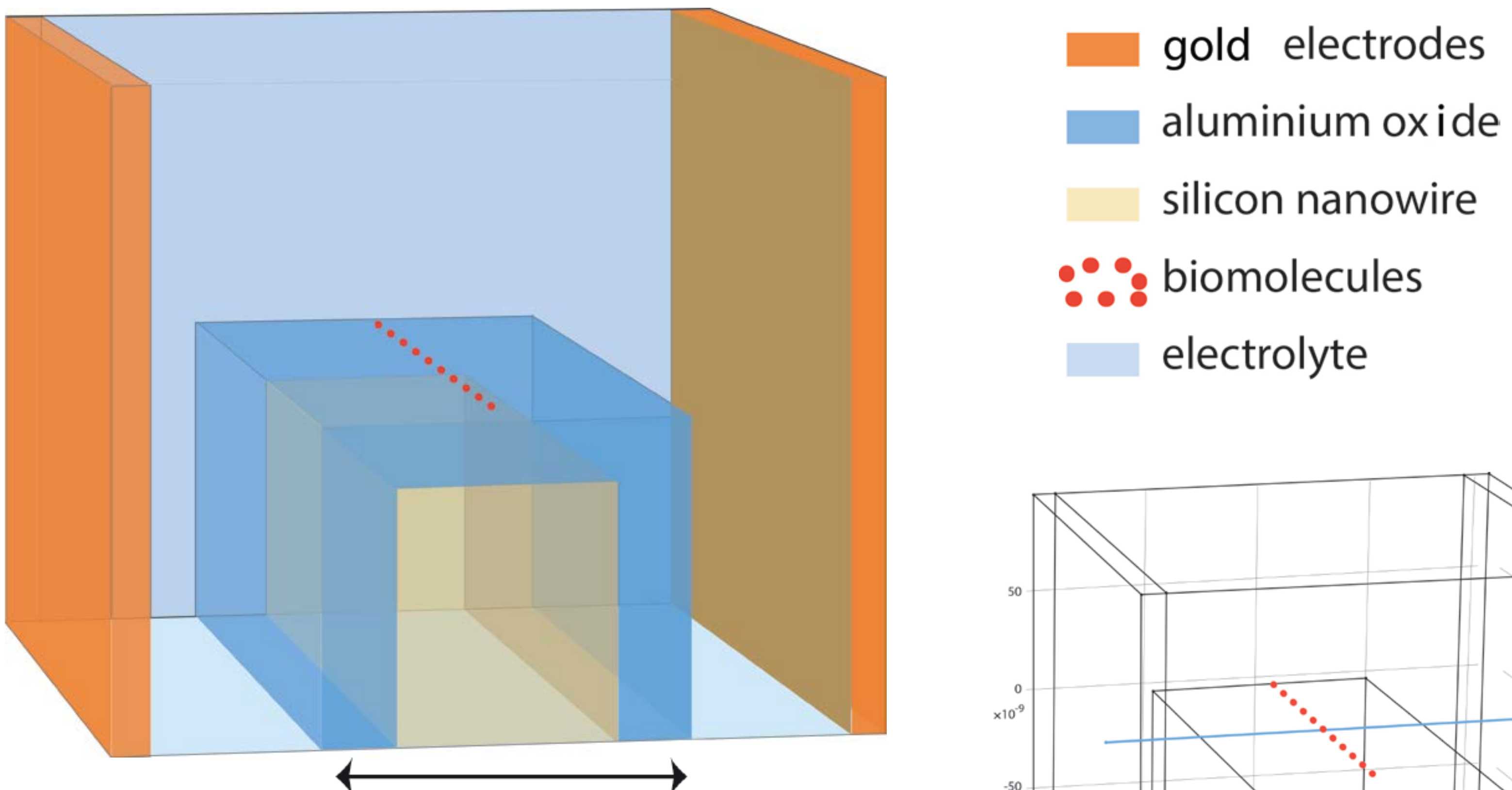
n_i^0 Average particle density of the ion i

Z_i Charge number of the ion i

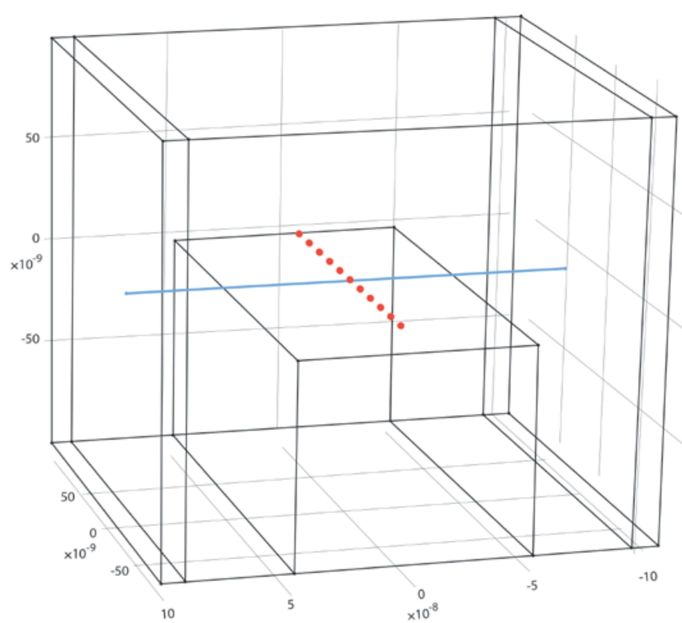
For a salt solution (Na^+, Cl^-), for a temperature of 298 K

Concentration ($mol.m^{-3}$)	1	10	150 (blood concentration)
Debye length (nm)	9.7	3.1	0.79

Geometry



100 nm



x axis

Model

- Model: coupling between Nernst-Planck equation and Poisson equation

$$\frac{\partial n_i}{\partial t} = \nabla\left(D_i \nabla n_i + n_i \frac{eZ_iD_i}{k_BT}\nabla\phi\right)$$

$$\nabla^2\phi = -\frac{1}{\varepsilon}\sum_i n_i Z_i e$$

n_i Density of the ion i

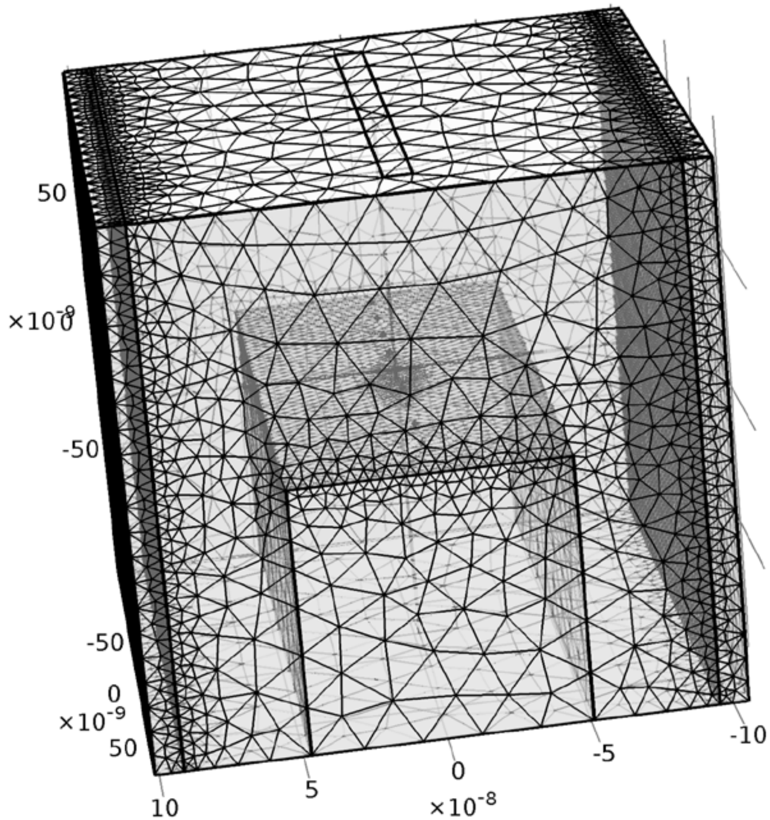
ϕ Electric potential

D_i Diffusion coefficient of the ion i

- Characteristic frequency

$$\omega_c = \frac{D}{{\lambda_D}^2}$$

Mesh

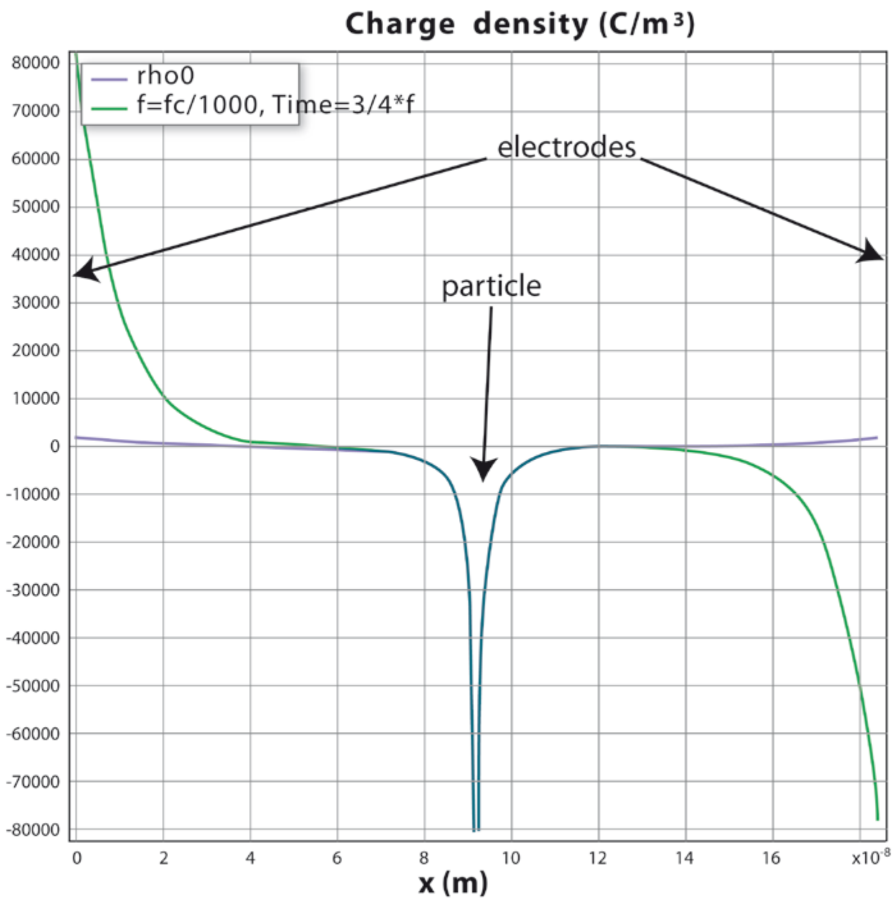


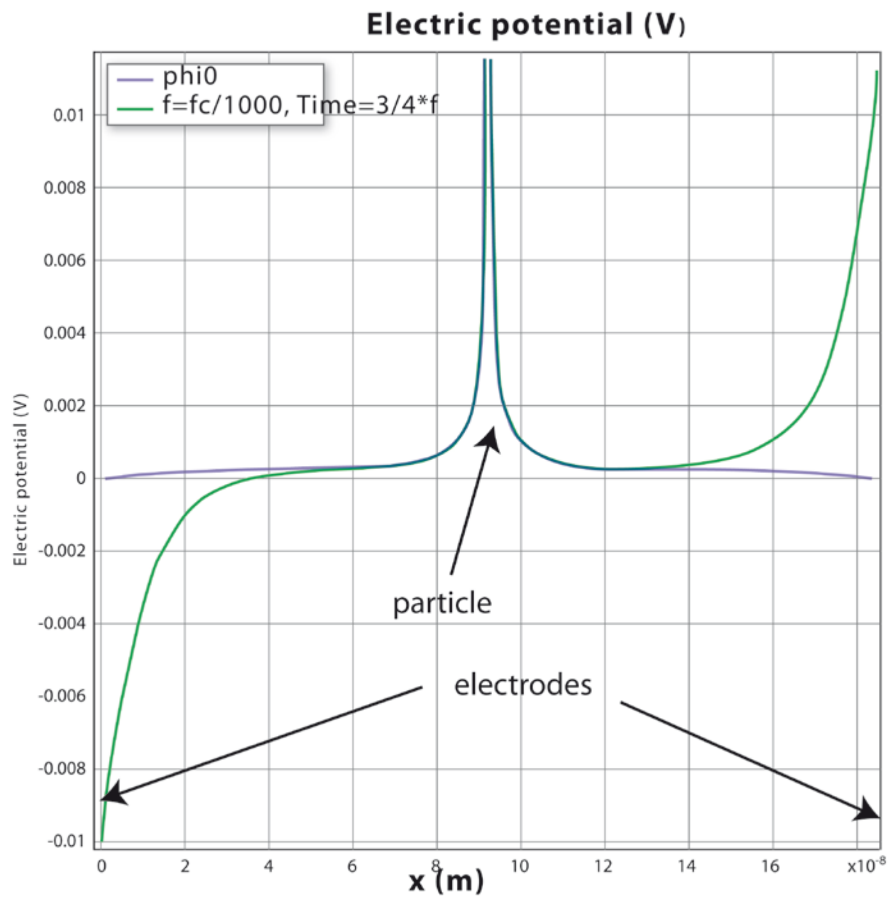
200 000 elements

Computer memory is an issue

Behavior for low frequency

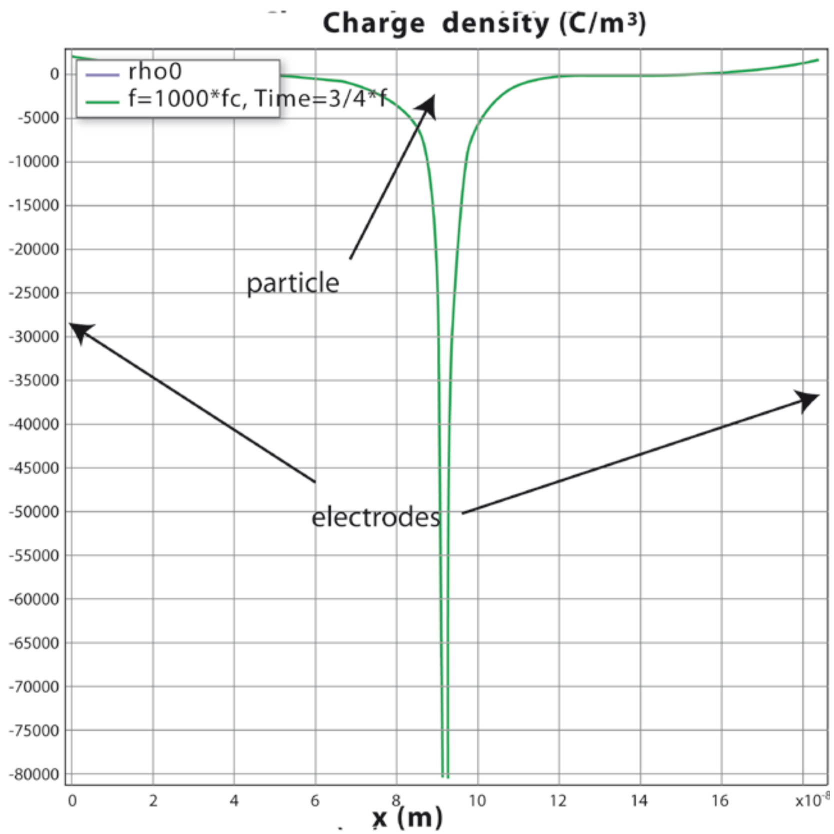
$$\nabla\left(D_i \nabla n_i + n_i \frac{eZ_i D_i}{k_B T} \nabla \phi\right) = 0$$

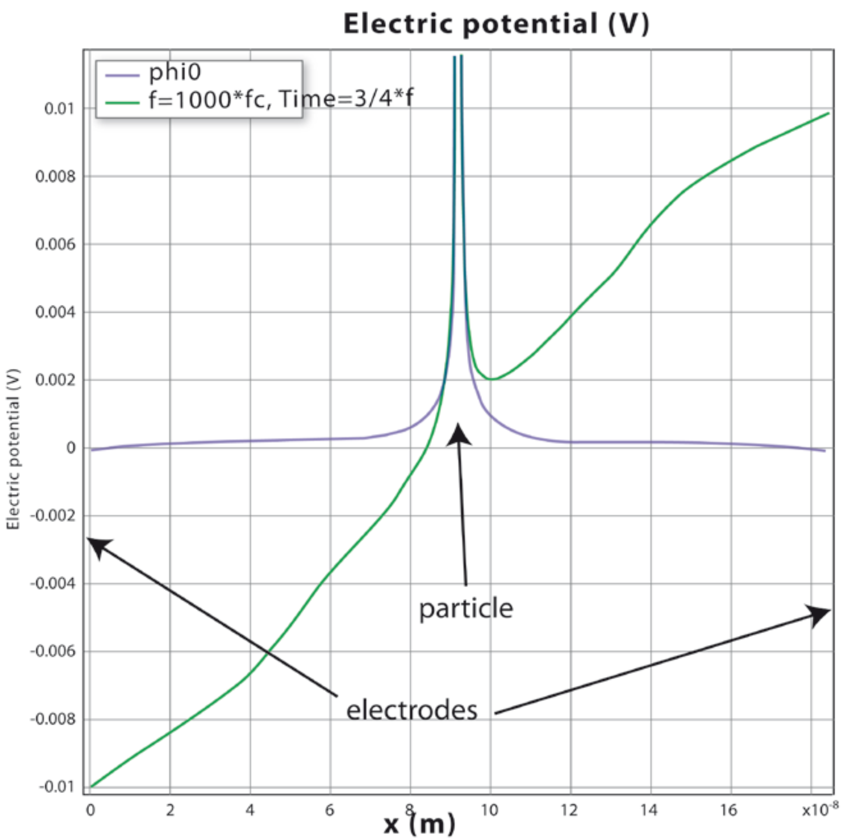




Behavior for high frequency

$$\frac{\partial n_i}{\partial t} = 0$$





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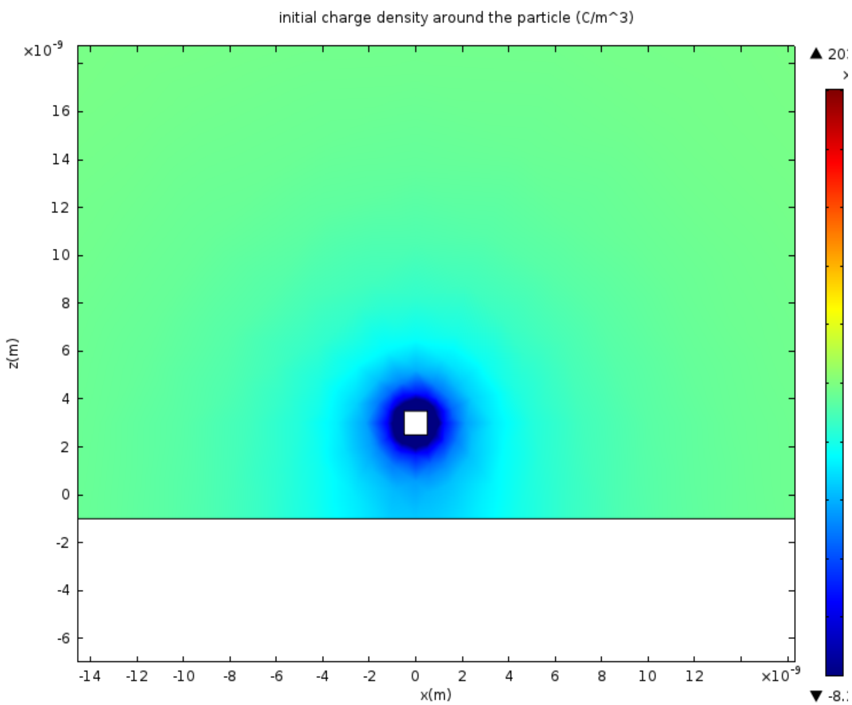
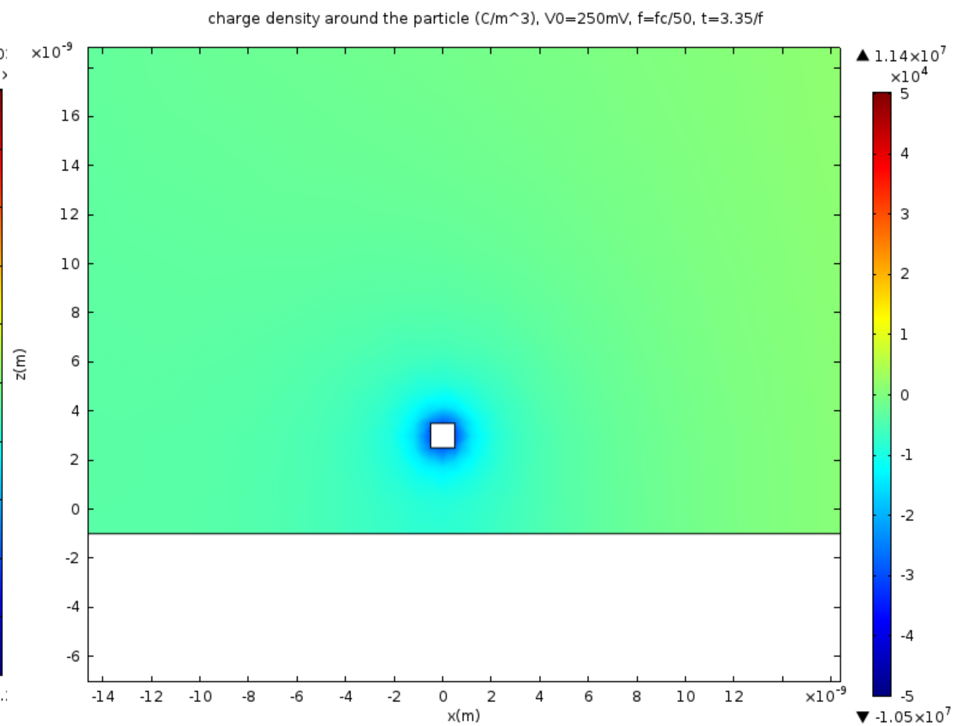
Effects on the Debye Layer around the characteristic frequency





Conclusion

- Efficiency of silicon nanowire based biosensor affected by the Debye screening
- Debye screening attenuation for a frequency range weakly inferior to the characteristic frequency
- Further work: simulation of the coupling with the nanowire physics, validation with experiment

Acknowledgment

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Shyam Erramilli (Boston University)

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