Numerical Analysis of the Optimal Design Parameters of a Thermoelectric Microfluidic Sensor

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Outline

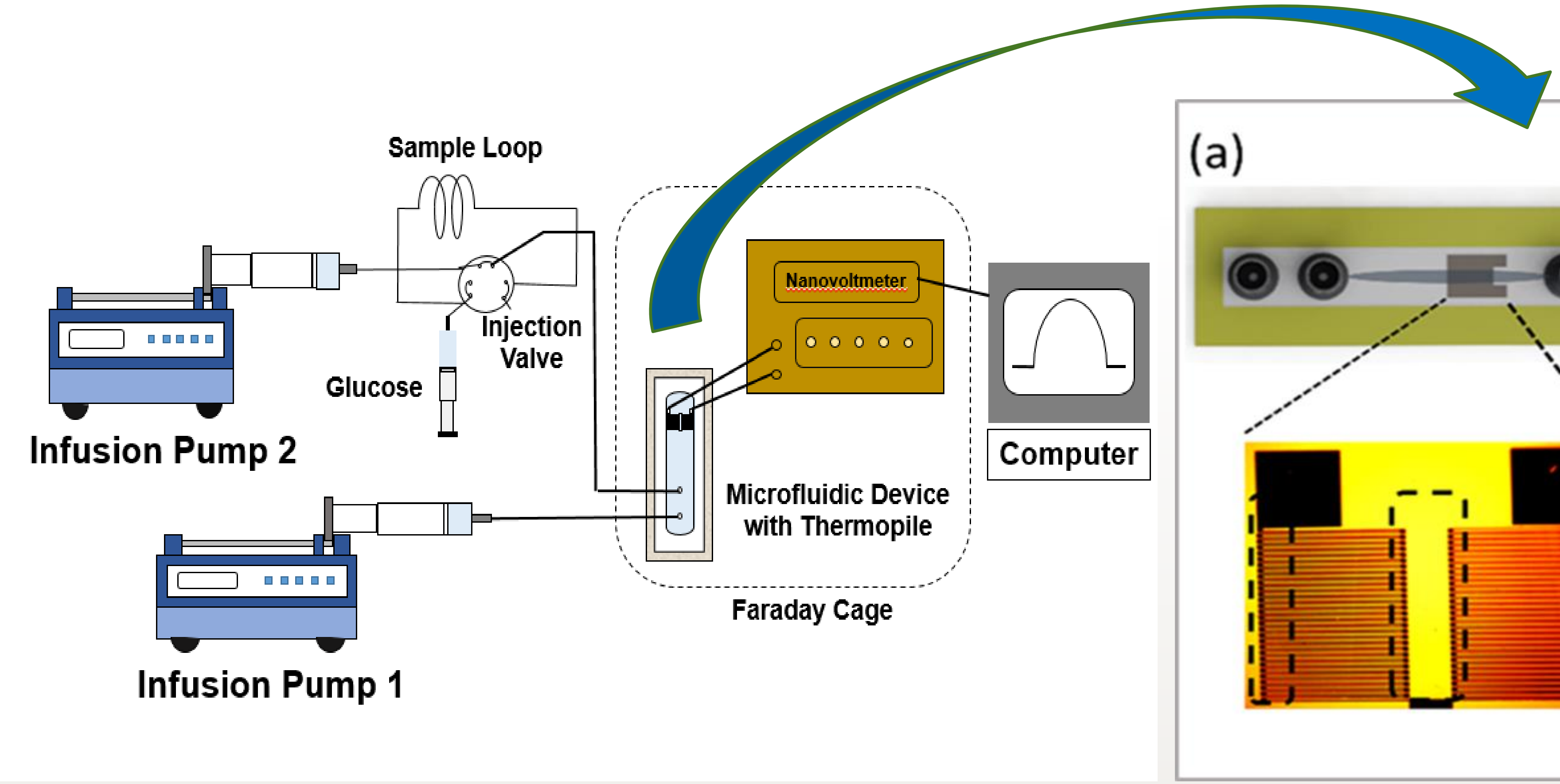
- Background and Motivation
- Experimental Setup
- Numerical Model
- Results
- Conclusion
- Acknowledgements

Background and Motivation

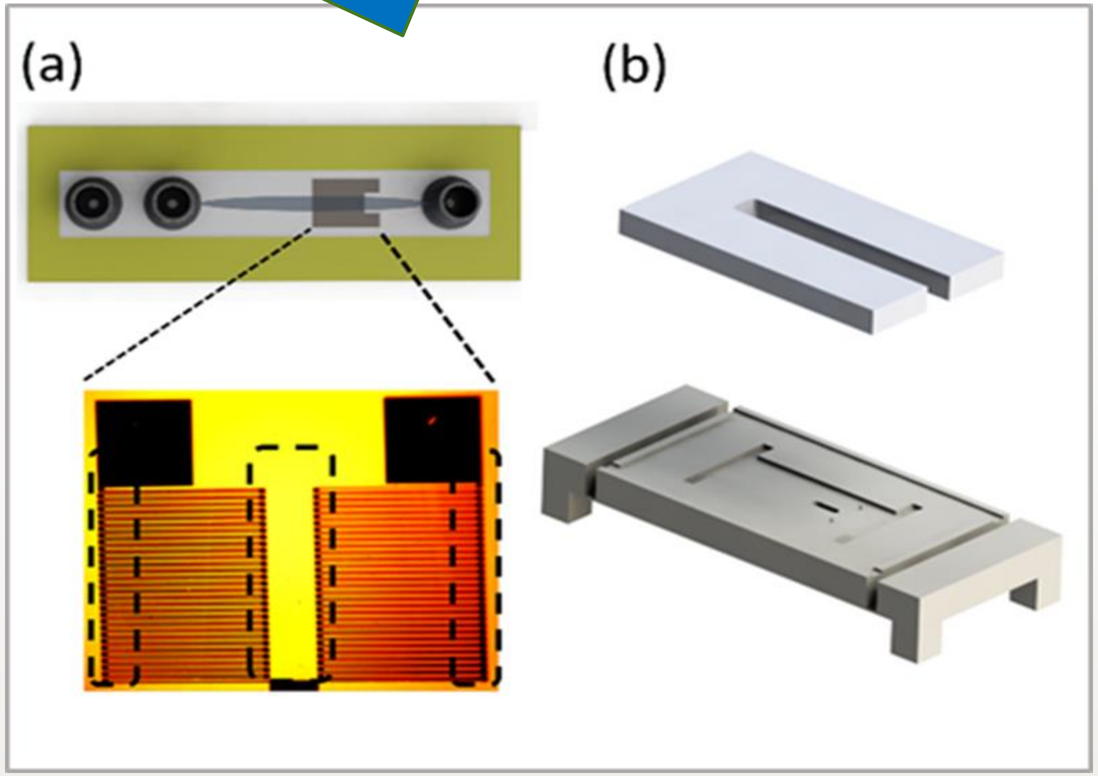
Microfluidics in detecting biochemical analytes

- Precise fluidic control
- High-throughput analysis
- Reduced cost compared to commercially available enzyme-based methods
- Numerical modeling can assess impacts of various parameters to reduce the experimental complexity

Experimental Setup



Bari, Saif Mohammad Ishraq, Louis G. Reis, and Gergana G. Nestorova. "Calorimetric sandwich-type immunosensor for quantification of TNF-α." Biosensors and Bioelectronics 126 (2019): 82-87.



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Numerical Model

Laminar flow

$$\rho \frac{\partial u}{\partial t} + \rho u.\nabla(u) = -\nabla p + \nabla.[\mu(\nabla u + \nabla u^T)] + F_b$$ **(Navier-Stokes equation)**

$$\nabla.u = 0$$ **(Continuity equation)**

Transport of diluted species

$$\frac{\partial c_i}{\partial t} = \nabla.(D_i c_i) - u.\nabla c_i$$

Heat transfer in fluids

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p u.\nabla T = \nabla.(k\nabla T) + \tau \cdot \nabla u + Q$$

Heat Source, $Q = k_g \times c_{Gox} \times c_g \times E_g$

$$\text{Glucose} + O_2 + H_2O \xrightarrow{\text{Glucose } Oxidase} \text{Gluconic acid} + H_2O_2 + 79\ \frac{kJ}{mol}$$

u = Velocity vector

p = Pressure (Pa)

F_b = Body forces (N)

c_i = Concentration of glucose ($\mathrm{mol\ m^{-3}}$)

D_i = Diffusion coefficient of glucose ($\mathrm{m^2 s^{-1}}$)

τ = Viscous stress tensor

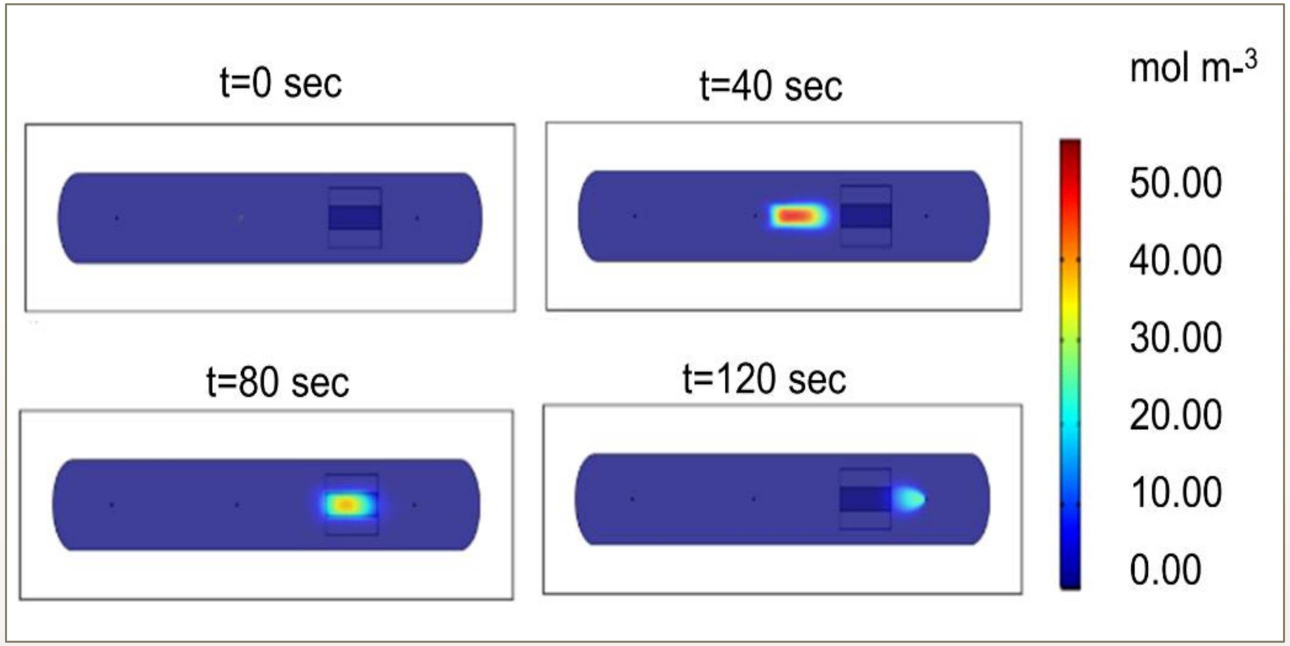
k = Thermal conductivity ($\mathrm{W\ m^{-1}\ °C^{-1}}$)

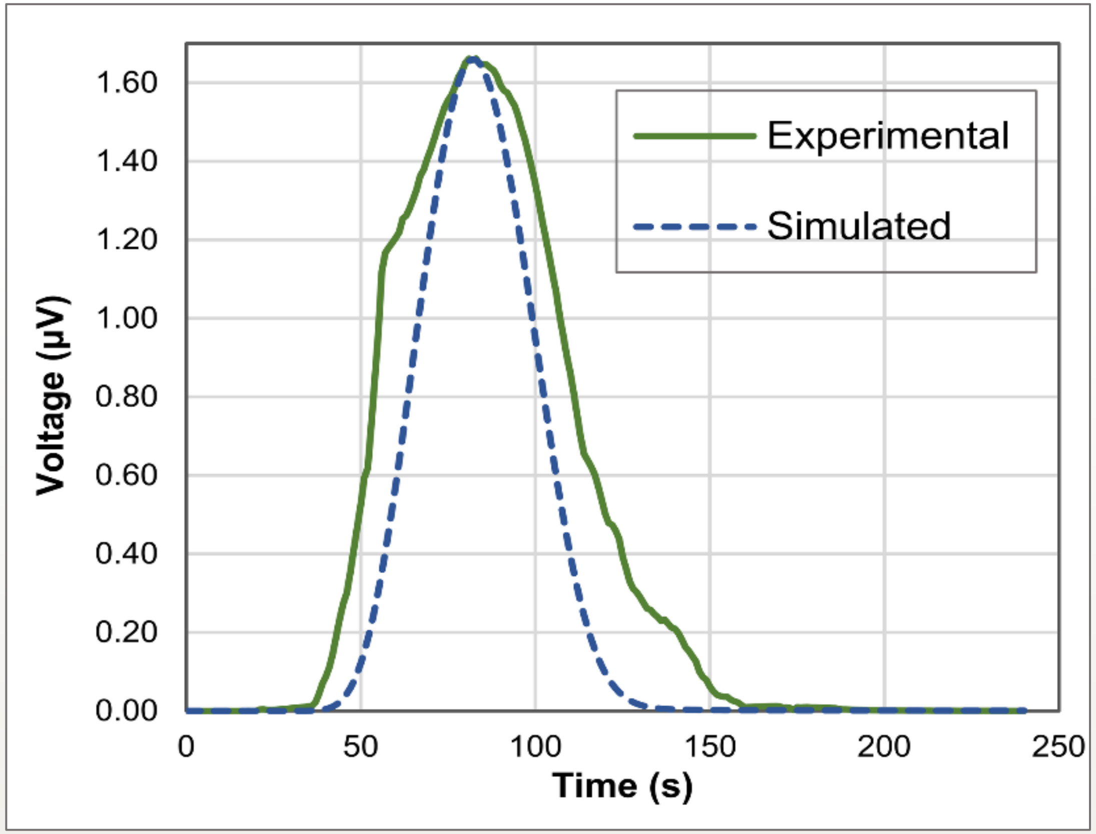
Q = Heat rate ($\mathrm{W\ m^{-3}}$)

k_g = Reaction rate constant ($\mathrm{mol\ m^{-3} s}$)

E_g = Enzymatic reaction energy ($\mathrm{J\ mol^{-1}}$)

Validation of the Numerical Model





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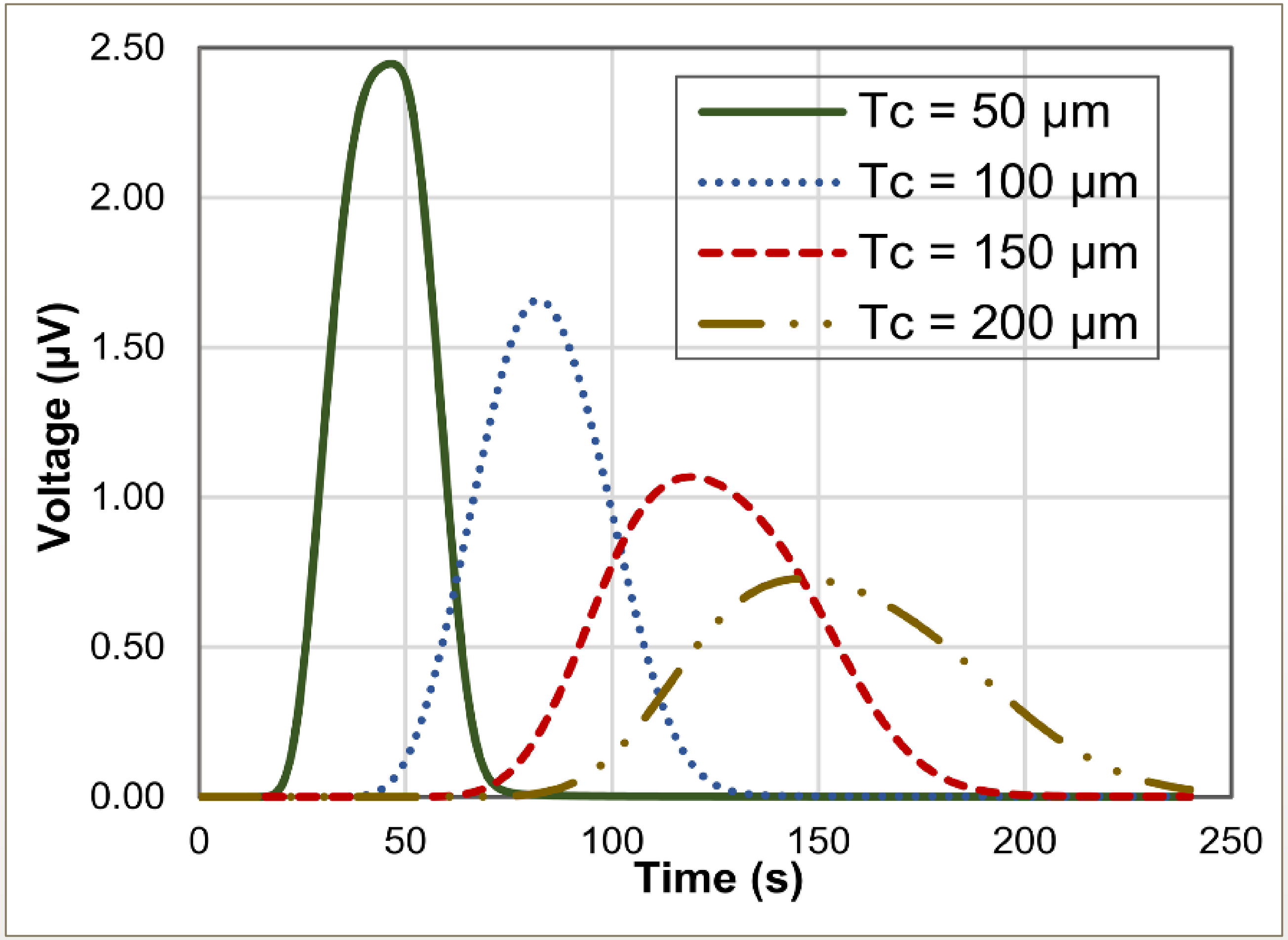
Device Sensitivity vs Channel Height



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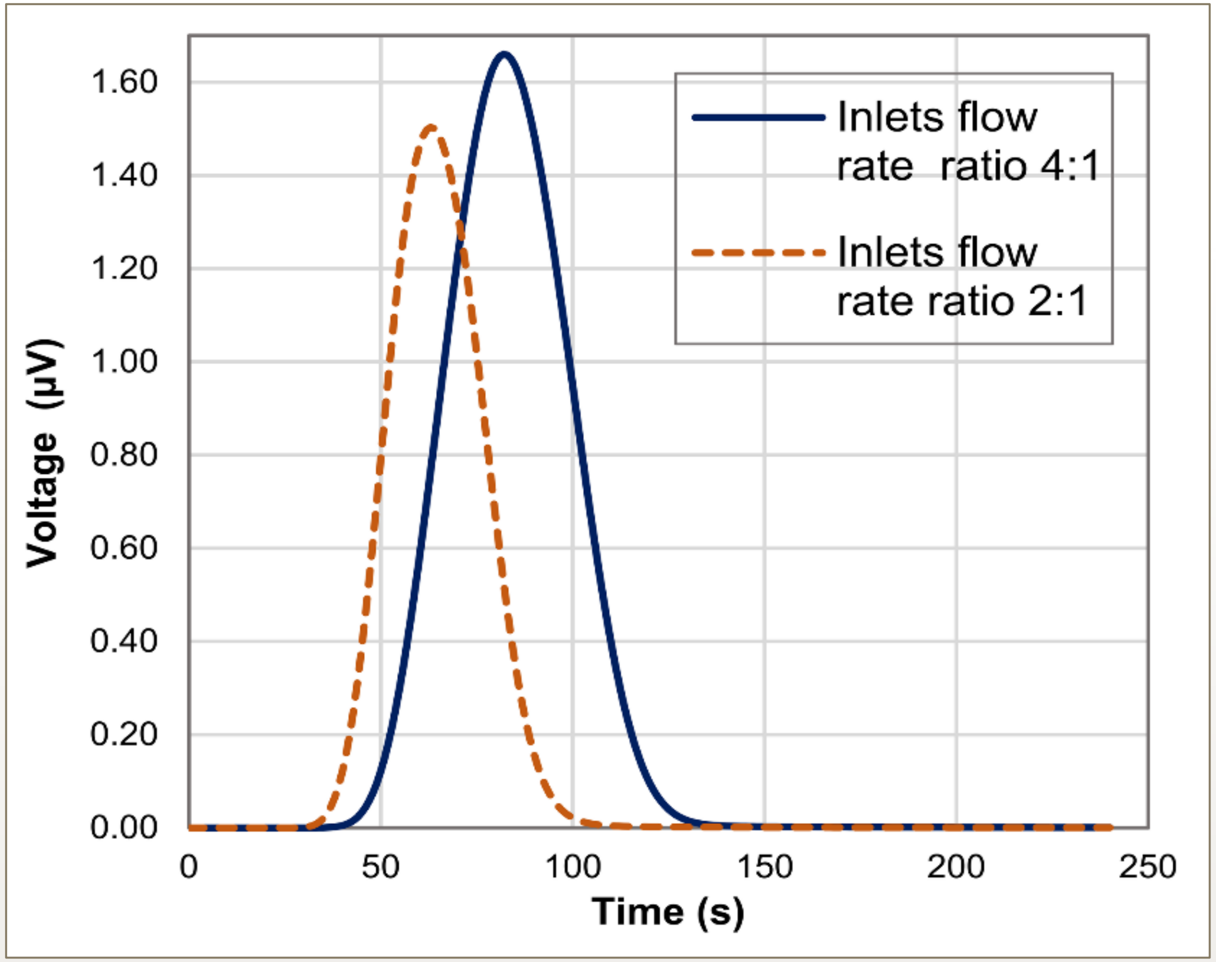
Effect of Inlets Flowrate Ratio on Sensitivity



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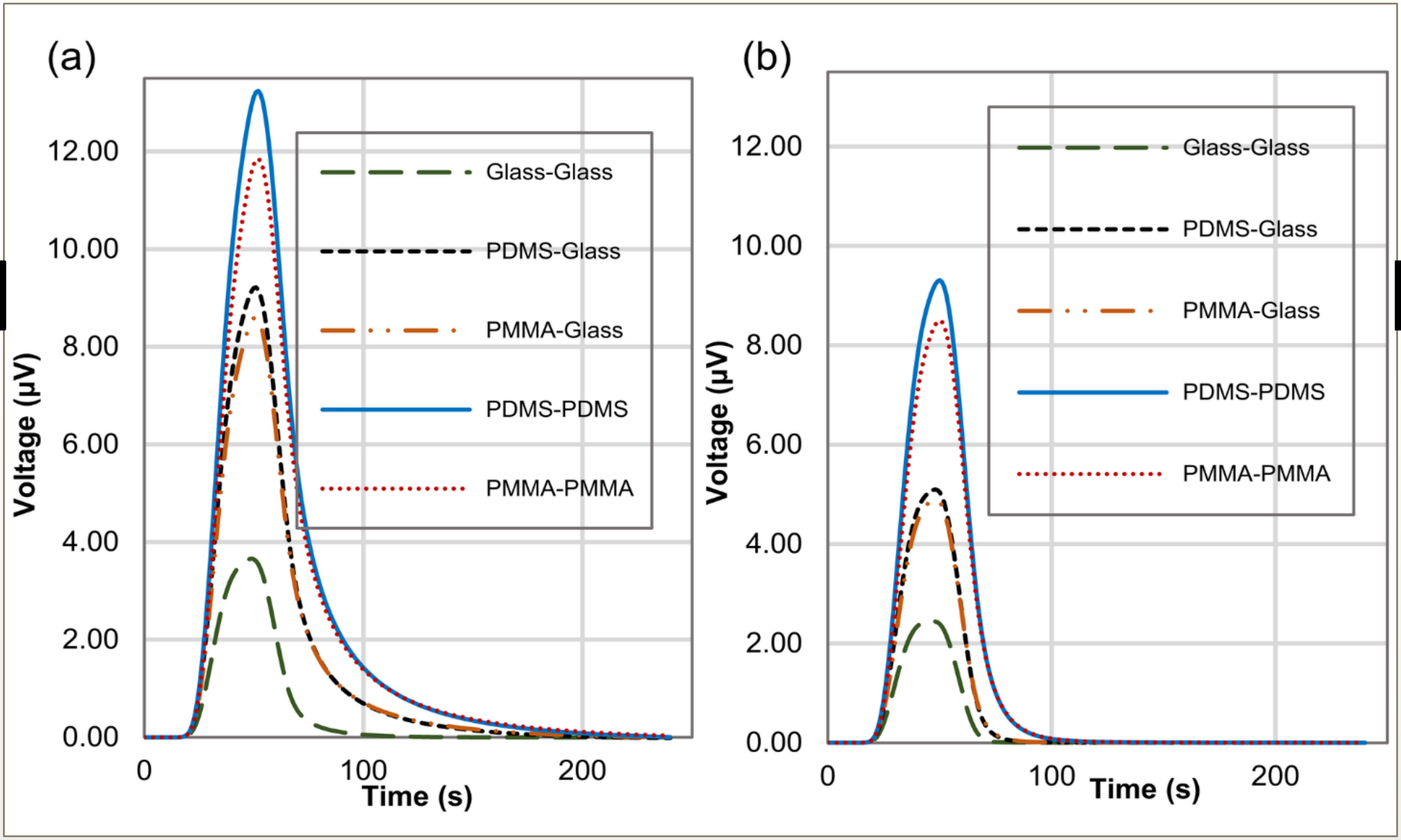
Material Thermal Properties vs Sensitivity



Reference junctions at room temperature

Reference junctions in contact with heat sink

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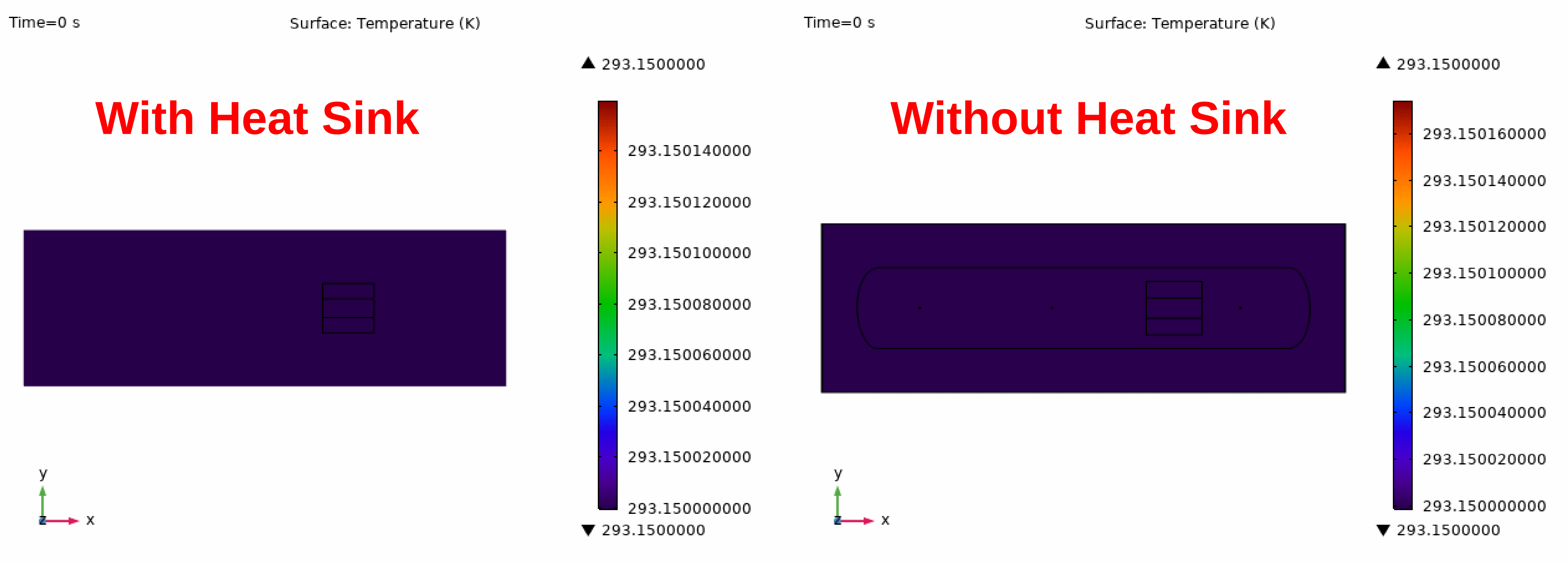
Effect of the Heat Sink



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Conclusions

- Critical operational parameters for enhanced device sensitivity were identified.
- Magnitude of the thermoelectric signal is ***inversely proportional*** to the channel height and inlets flow rate ratio.
- Using ***less thermal conductive material*** and eliminating heat sink could increase the device sensitivity by 783%.

Acknowledgement

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Thank you! Questions?

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