Design, Simulation and Study of MEMS Based Micro-needles and Micro-pump for Biomedical Applications

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Presented by

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Outline

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- **Device design**
  - **Development of the micro-needle and micro-pump models**
- **FEM based behavioral simulations**
  - **Study of mechanical simulations**
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Introduction

Introduction

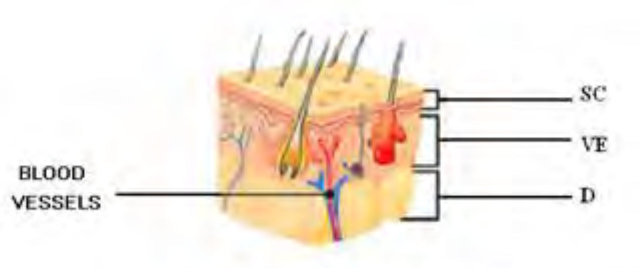
Problems with metallic hollow needles

- ➢Insertion pain
- ➢Tissue trauma
- ➢Incapable of sampling and insertion of microscopic volume of fluids
- ➢Difficulty in providing sustained drug release and continuous sampling of body fluids

Solution → Hollow needles of microscopic dimensions (Micro-needle)

Advantages of micro-needle

- ✓Minimum tissue trauma and insertion pain
- ✓Capability of sampling and insertion of microscopic volume of fluids
- ✓Capable of hypodermic operation (important in vaccination and immunization)
- ✓Minimum risk of infection



Three layers of the human skin

Motivation for Micro-pumps

Need for controlled fluid flow, for various medical applications have motivated research in MEMS based micro pumps.

- Their various uses are in controlled biological fluid flow for PCR (polymerase chain reaction) in DNA analysis, lab-on-a-chip devices, micro-total analysis systems (µTAS), and drug delivery systems.

- Other applications for such devices are in micro-pump and micro-channel based liquid cooling mechanisms for electronic integrated circuits.

- By integrating diagnostic as well as therapeutic functionalities, micro-needles and micro-pumps will be capable of personalized drug delivery in response to a patient’s specific health conditions.

Development of the Micro-needle and Micro-pump models

Design of Micro-needles

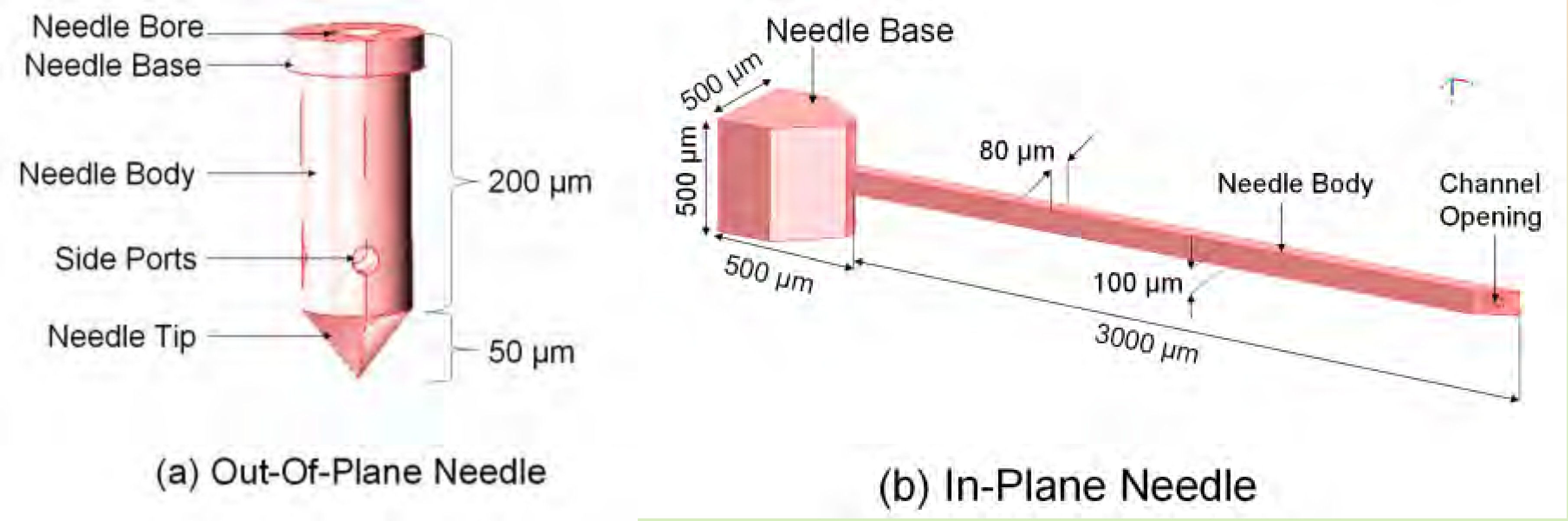


Figure 1: Structure and dimensions of the Out-of-plane and In-plane micro-needles

Out-of-plane needle, length 250 micron [Figure 1(a)] reaches the dermis layer
in-plane needle, length 3000 micron [Figure 1(b)] reaches the subcutaneous fat layer

- **The needle bore cross-section area must be larger than the diameter of monocytes (15 µm), the largest blood corpuscles**
  - ✓ **Bore diameter of the out-of-plane needle = 40 µm**
  - ✓ **Channel cross-section of the in-plane needle = 24 µm × 36 µm**

Design of Micro-pump

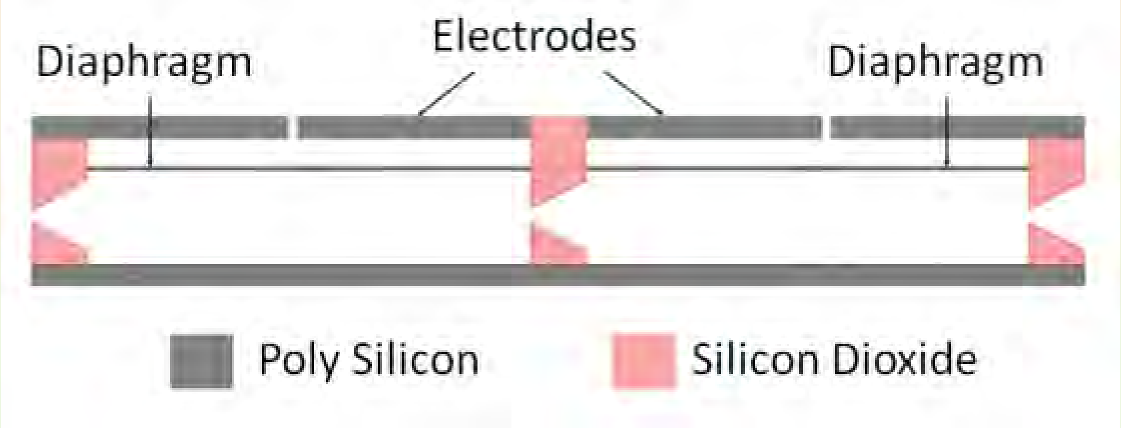
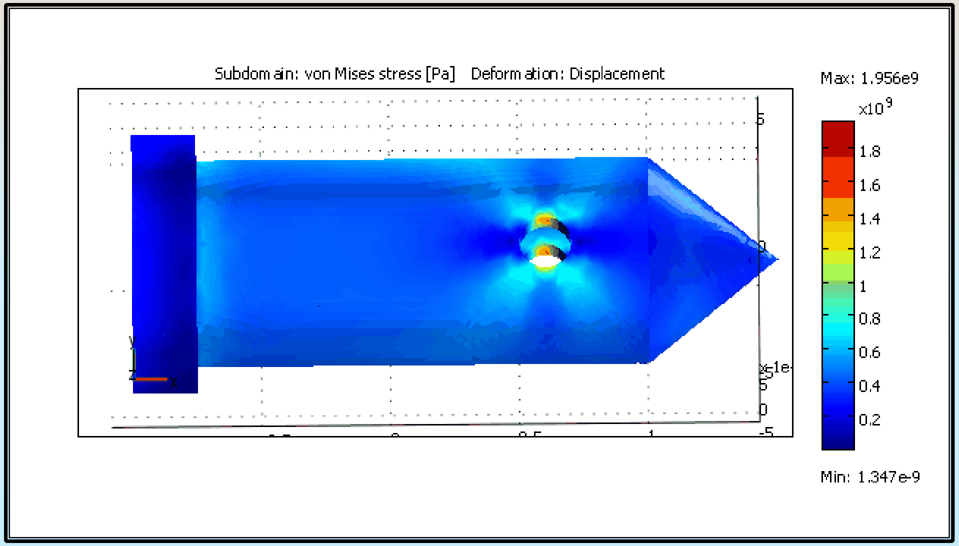


Figure 2:Electrostatically actuated micro-pump

- **Electrostatically actuated diaphragm pump consists of two chambers in series and three diffuser/ nozzle type elements to control the flow of fluid**
- **Dimension of pump chambers = 1mm×1mm×50µm**
- **Thickness of the diaphragm = 2µm**
- **Separation between the diaphragm and the electrode = 10µm**

Simulation & analysis of Micro-needles and Micro-pump

Simulation Results of Micro-needles



Boundary condition

The base of the Micro-needles are attached to some other device. So the base surfaces are fixed with respect to the rest of the micro-needle.

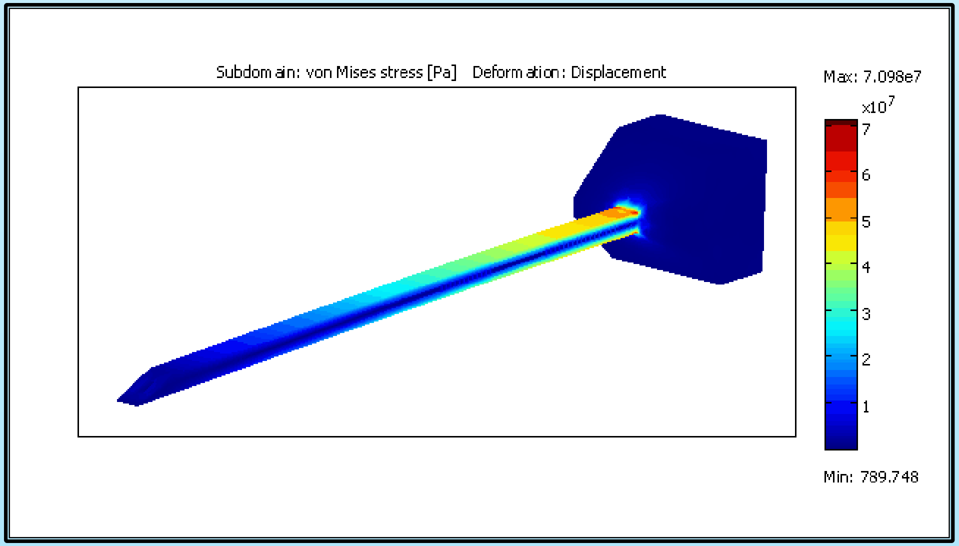


Figure 4 (a) and (b): Region of maximum stress in the out-of-plane and in-plane needles for buckling and bending forces respectively.

Study of Simulation Results

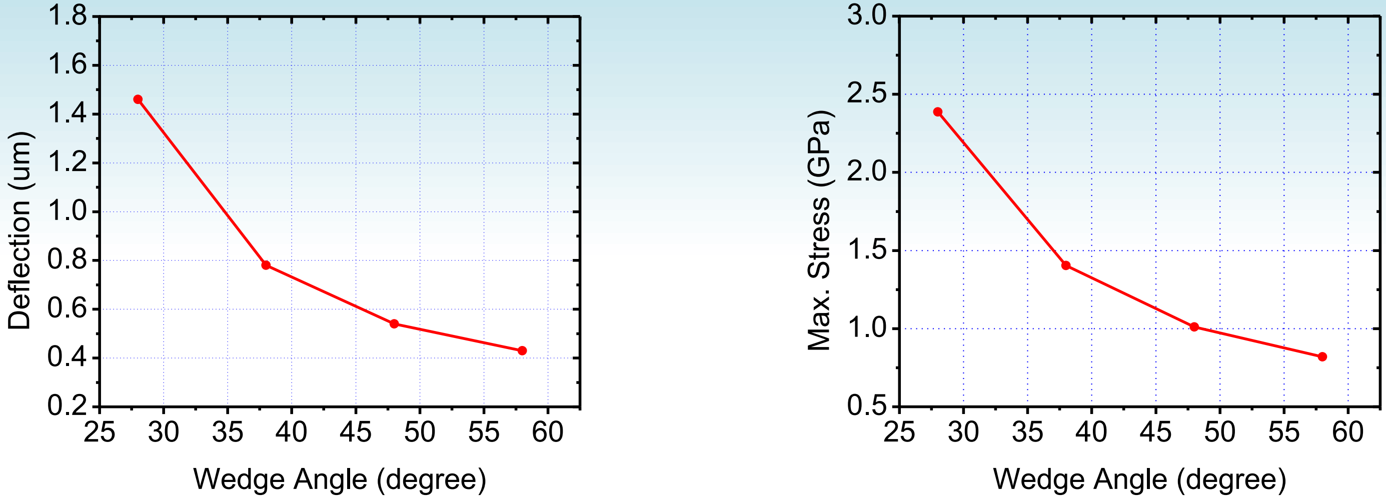


Figure 5 (a) and (b): Variation of deflection and maximum stress with tip angle for out-of-plane needle

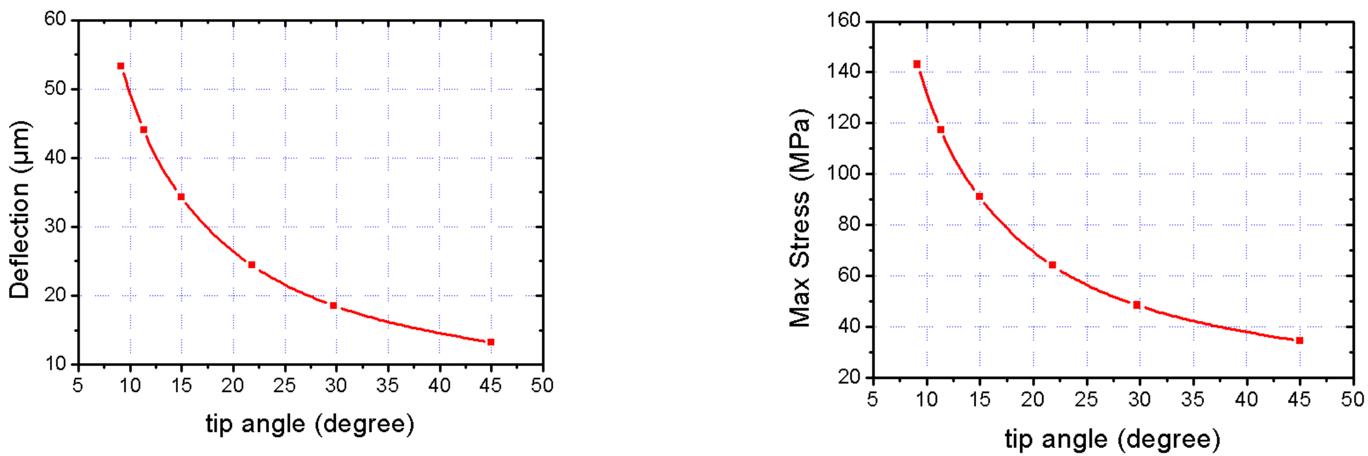
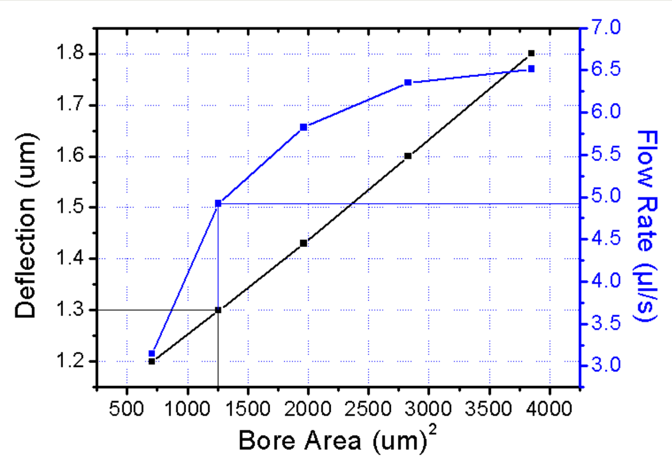


Figure 6 (a) and (b): Variation of deflection and Maximum stress with tip angle for in-plane needle

Study of Simulation Results



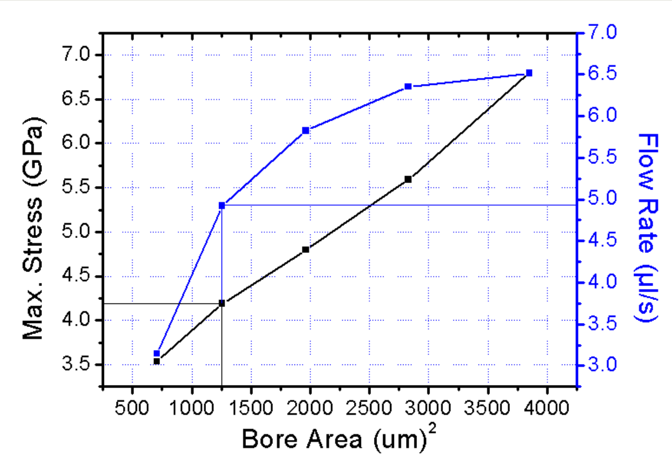
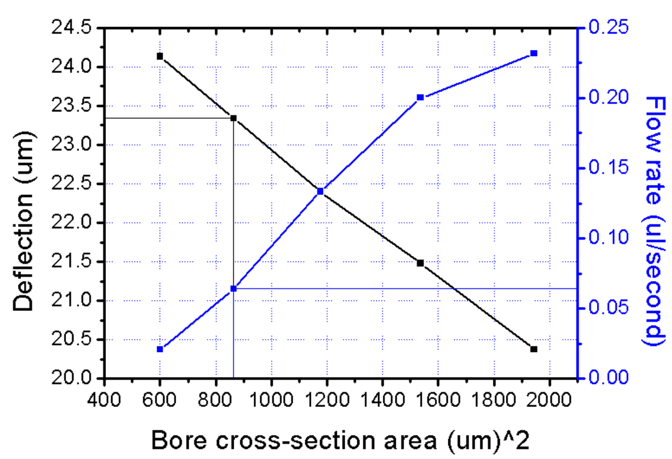


Figure 7 (a) and (b): Variation of deflection, maximum stress and flow rate with needle bore area for out-of-plane needle



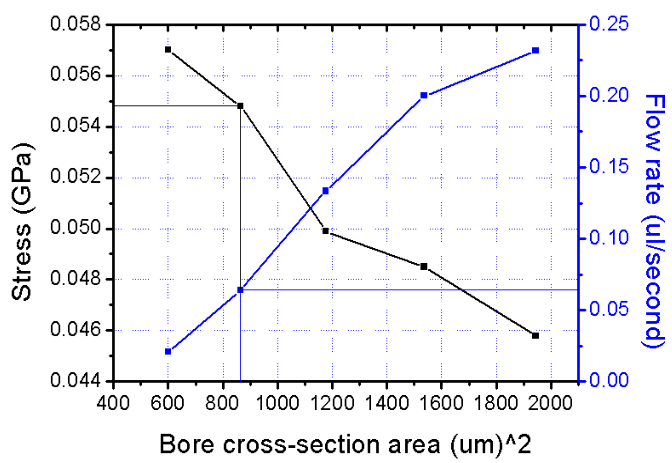


Figure 8(a) and (b): Variation of deflection, maximum stress and flow rate with needle bore area for in-plane needle

Simulation Results of Micro-pump

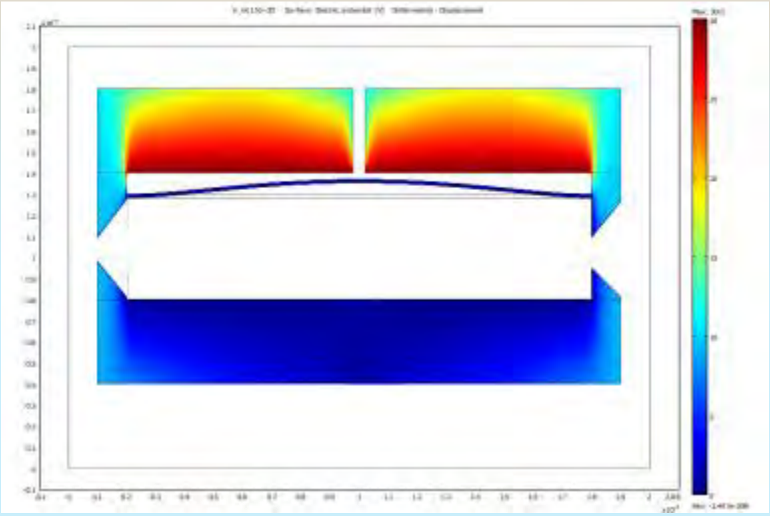


Figure 9: Potential distribution in a single chamber of the micro-pump

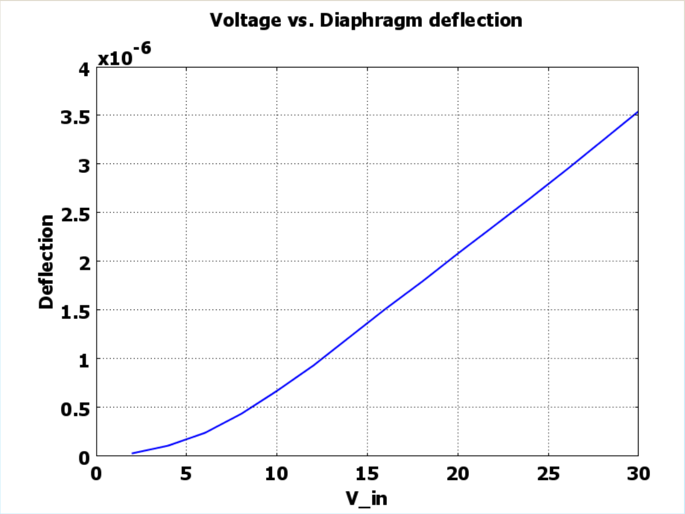


Figure 10: Variation of diaphragm deflection with applied potential

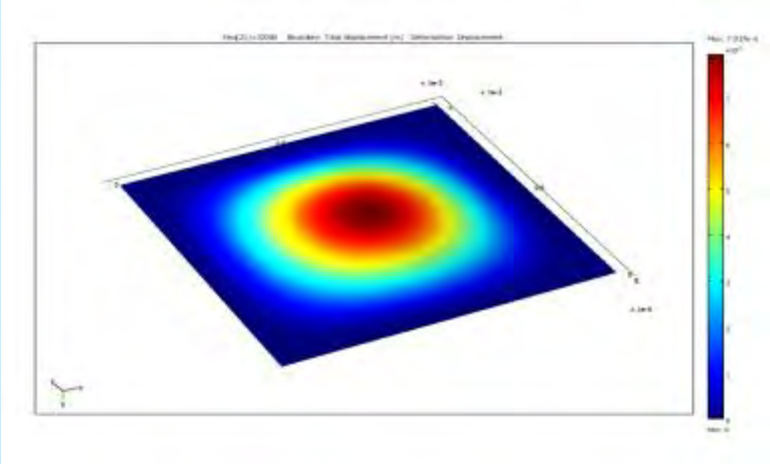


Figure 11: Deflected pump diaphragm

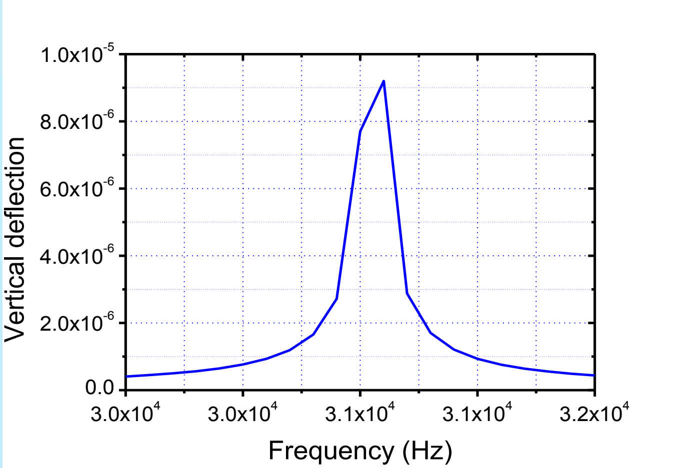
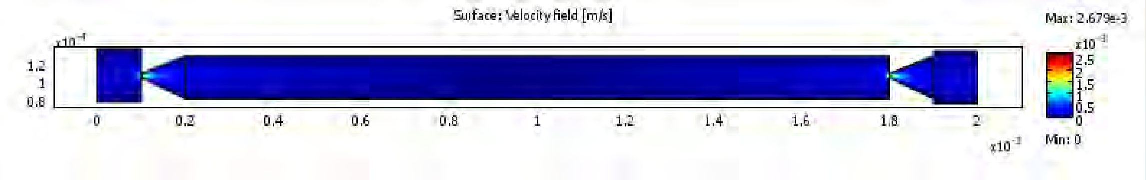
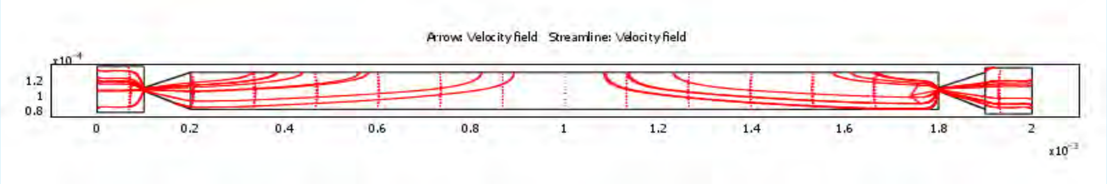


Figure 12: Frequency response of diaphragm deflection

Simulation Results of Micro-pump



(a)



(b)

Figure 13: (a) Fluid velocity and **(b)** streamlines within a pump chamber when the diaphragm is pulled upward

The fluid velocity at the narrowest sections and pressure drops across the nozzle and diffuser elements were obtained from the fluidic model. These values were then used to find the pressure loss coefficients of the nozzle and diffuser elements.

The net pump volume flow rate at zero pressure across the pump

$$\phi = 2V_0 f \left(\frac{\sqrt{\eta} - 1}{\sqrt{\eta} + 1} \right) = 0.167\mu l$$

Conclusions

Summary & Conclusions

- **The 250 µm long out-of-plane needle is capable of extracting or inserting fluid into the dermis layer, while the 3000 µm (3 mm) long in-plane needle can access the subcutaneous fat layer of human skin.**

- **The bore cross-section of both the micro-needles (40 µm diameter for out-of-plane needle and 24 µm × 36 µm rectangular for in-plane needle) allow passage to the largest blood corpuscles (15 µm).**

- **The structures of both the micro-needles are strong enough to withstand the forces under normal operational condition. The flow rate of water through the needle-channels were in the order of µl/second, which can be increased manifold by integrating 2-D or 3-D arrays of similar micro-needles.**

- **An electrostaticlly actuated diaphragm based micro-pump was proposed. The electrostatic and microfluidic analyses provide valuable information regarding the working principle, actuation voltage, operating frequency and geometric parameters of the device.**

Future Work

In future, the following developments are possible :

- **Fabrication and testing of the micro-needle.**
- **Simulation and fabrication of the 2 dimensional array of micro needles. Development of 3 dimensional arrays by combining multiple 2 dimensional arrays.**
- **Design and coupled multiphysics simulation of a two chamber electrostatically actuated micro-pump. Exploration of fabrication processses and testing of the fabricated micro-pump.**

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Thank you