MEMS-Based Microdroplet Generation With Integrated Sensing

William Rone

Adviser: Prof. Pinhas Ben-Tzvi

Robotics and Mechatronics Lab

The George Washington University

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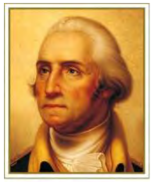
Introduction

- Background
- Design Concept
- Finite Element Model
- Simulations and Analysis
- Conclusion

Background



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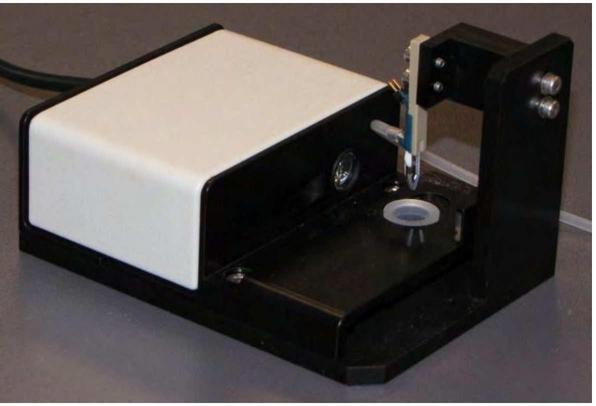
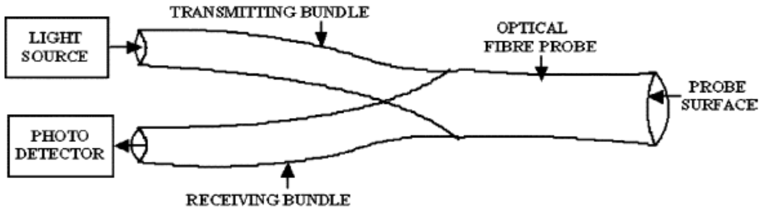


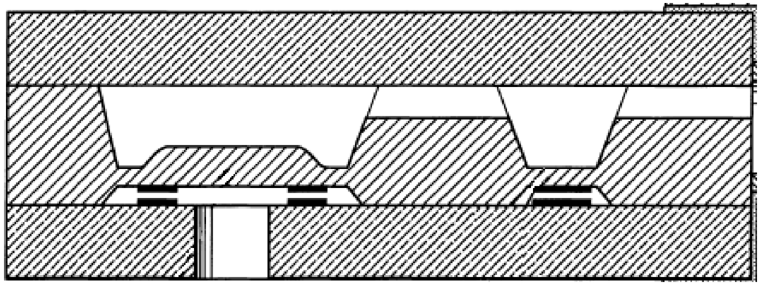
Photography

Weighing[1]



Optical[2]

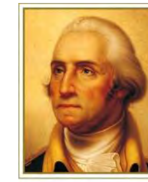
Capacitive[3]



Current Sensing Tools

- External Instrumentation
  - Photography
  - Weighing
- Integrated Sensing
  - Optical
  - Capacitive

Introduction & Background



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Current & Future Applications

Biological/Chemical Synthesis/Analysis

- DNA/Protein Microarray Generation
- Mass Spectrometry Sample Preparation
- Solid Support Creation/ Modification

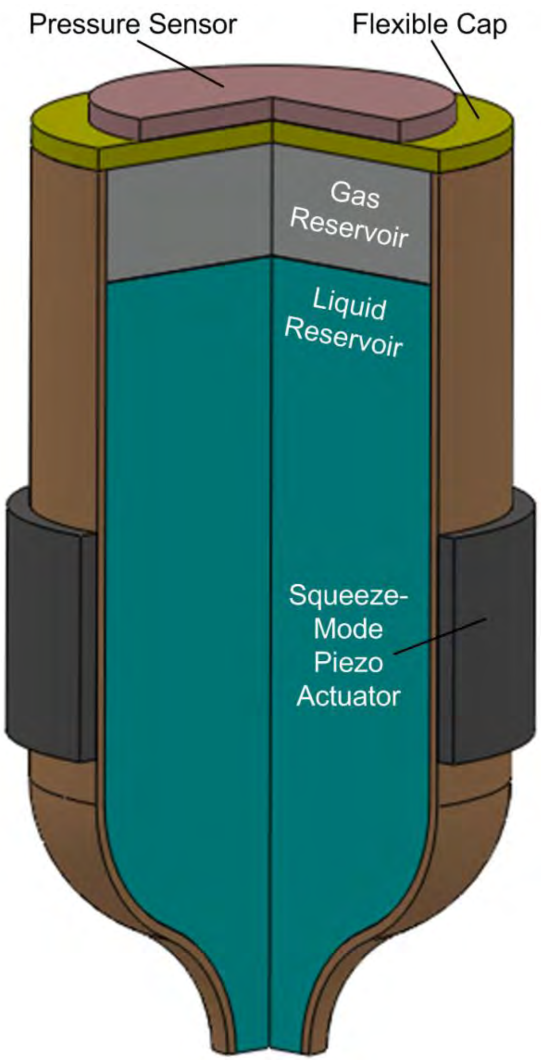
Medicine

- Oral Drug Delivery
- Transdermal Drug Delivery
- Tissue Engineering

Manufacturing

- Surface Coating
- Electrical Component Manufacturing
- Net-Form Manufacturing

Design Concept



- Two fluids in single chamber
  - Compressible gas
  - Incompressible liquid
- Gas pressure/volume changes when liquid volume dispensed
- Pressure/volume changes can be related analytically to dispensed volume

Finite Element Model

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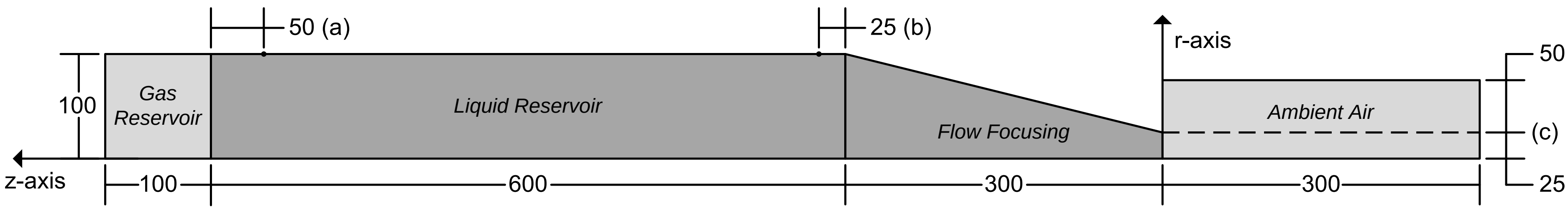
- Geometry



- Notes
  - (a) – Defines BC for Interface Slip
  - (b) – Defines BC for Actuation Modeling
  - (c) – Domain Subdivision Aids in Meshing

Finite Element Model

- Governing Equations

$$\frac{\partial \rho}{\partial t} + \rho \nabla \cdot \boldsymbol{u} = 0$$

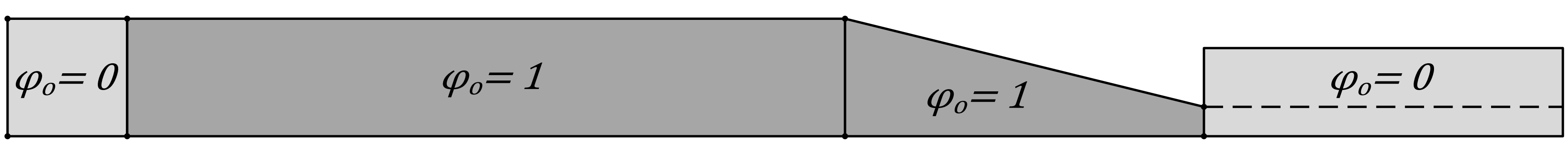
Conservation of Mass

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u} \cdot \nabla)\mathbf{u} = \nabla \cdot \left[-p\boldsymbol{I} + \mu(\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^{\mathrm{T}}) - \frac{2}{3}\mu(\nabla \cdot \boldsymbol{u})\boldsymbol{I} \right] + \rho \boldsymbol{g} + \boldsymbol{F}$$

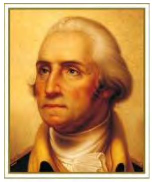
Conservation of Momentum

$$\frac{\partial \phi}{\partial t} + \nabla \cdot (\boldsymbol{u}\phi) = \gamma \nabla \cdot \left(\varepsilon_{ls} \nabla \phi - \phi(1-\phi)\frac{\nabla \phi}{|\nabla \phi|} \right)$$

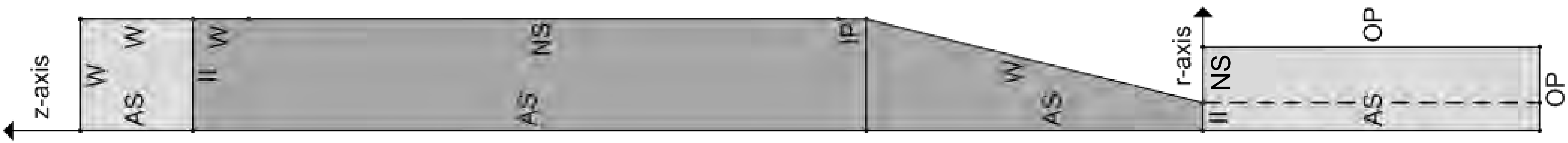
Level-Set Equation



Finite Element Model

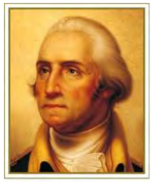


- Boundary Conditions

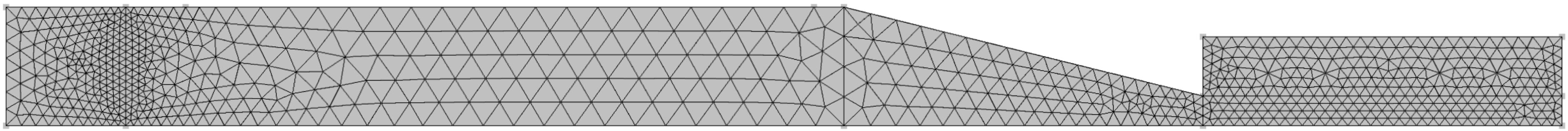


AS	Axial Symmetry	II	Initial Interface
IP	Inlet – Pressure, No Viscous Stress	OP	Outlet – Pressure, No Viscous Stress
NS	Wall – No Slip	W	Wall - Wetted

Finite Element Model



- Mesh



  - Unstructured Triangular Mesh
  - Mesh Refinement
    - Liquid/Gas Boundaries – Gas Reservoir and Nozzle
    - Downstream of the Nozzle

Simulations and Analysis

- Two-Stage Solution
  - Initialization of level-set variable over fluid interfaces
    - PARADISO direct solver
  - Full-scale solution of the four variables
    - Solved from 0 to 8 μs
    - Generalized-α time stepping
    - SPOOLES direct solver
- Input pressure magnitudes ranging from 1.0 to 1.8 MPa were simulated

Simulations and Analysis

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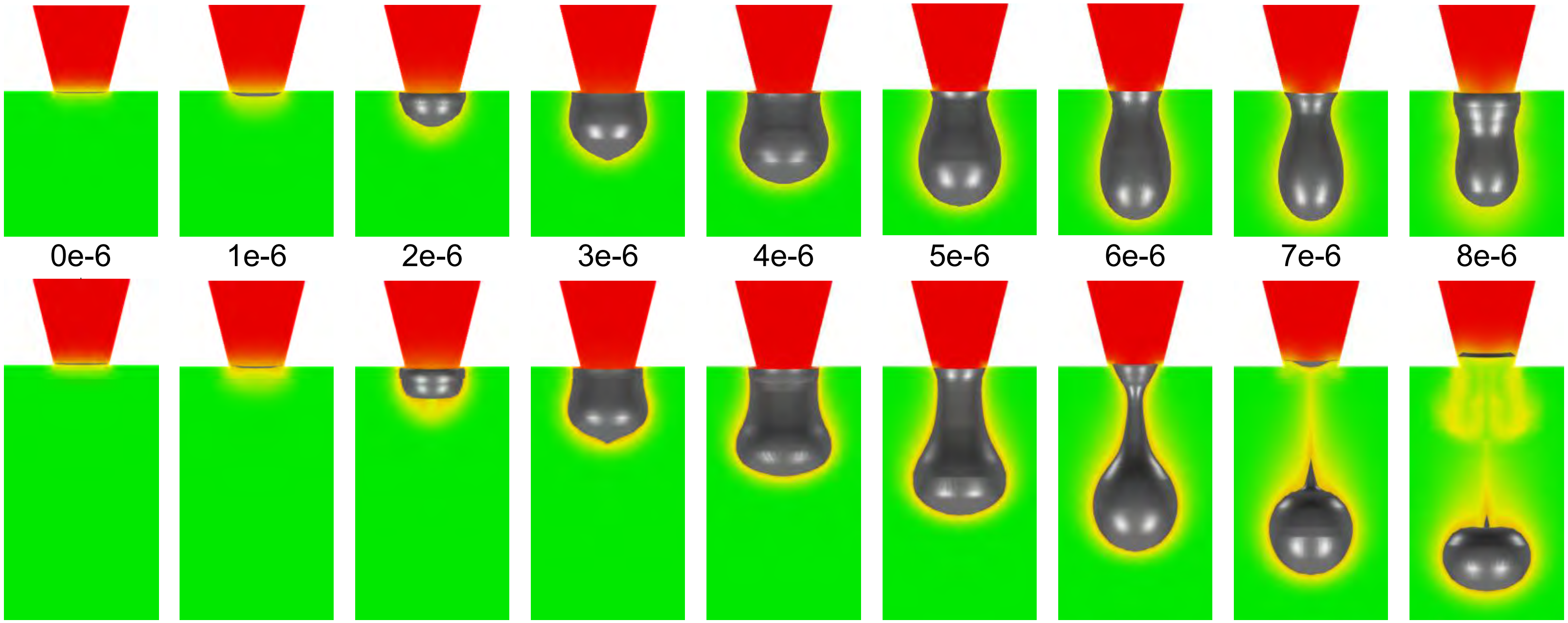
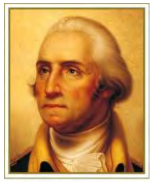
- Visualizations



Simulations and Analysis



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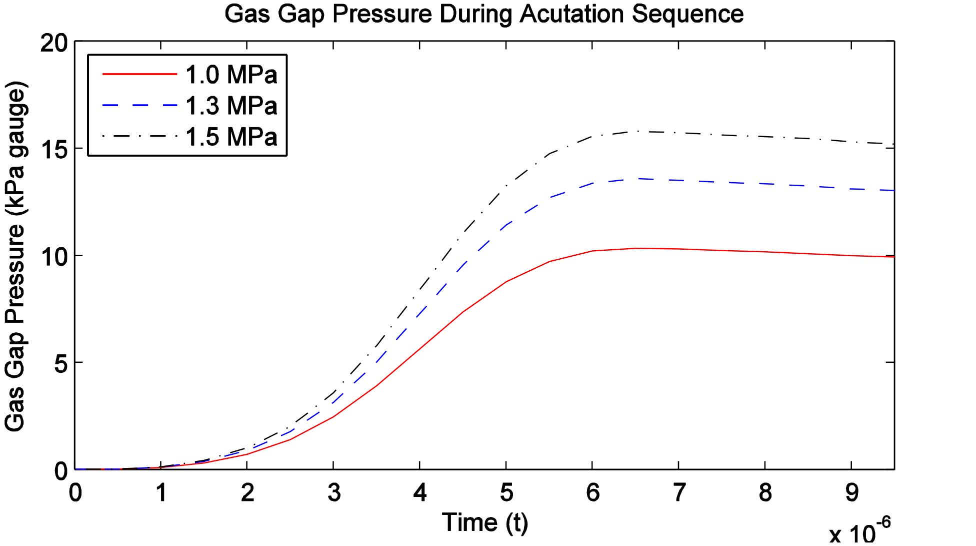
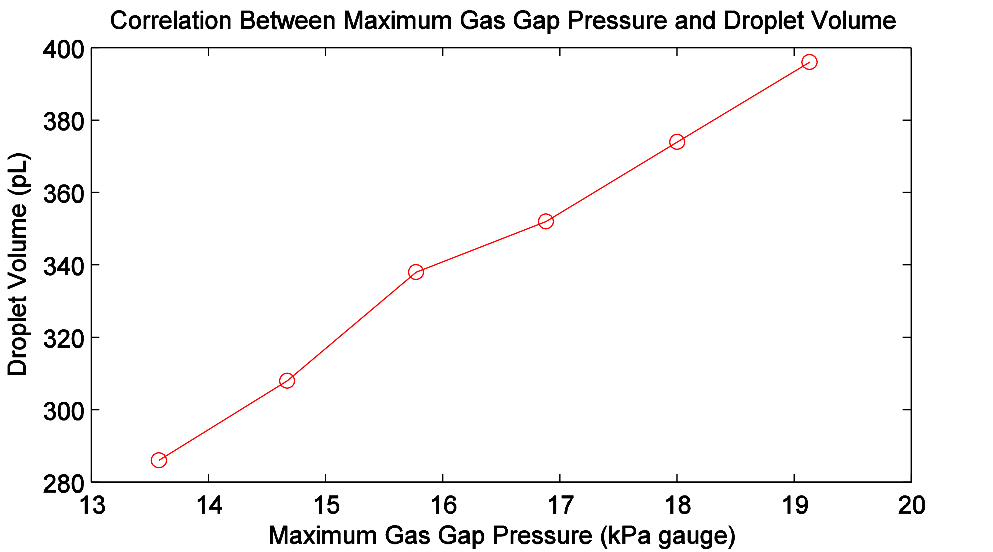
- Results
  - Maximum reservoir pressure chosen as control variable
  - Relationship between pressure and droplet size shown to be linear
  - Minimum actuation pressure determined empirically





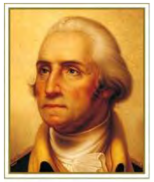
Conclusion

- Summary
  - Concept for sensing strategy to enable closed-loop droplet generation was numerically validated
- Future Work
  - Incorporating fluid-structure interaction and piezoelectric modeling into simulation
  - Experimental validation of design concept
  - Prototype development and optimization

Questions?

Thank You.

References



- [1] Mettler Toledo, "XP26 MicroBalance," http://us.mt.com/us/en/home/products/Laboratory_Weighing_Solutions/MX-UMX/XP26.html.
- [2] Chang, T. N., *et al*., 2006, "Automated Liquid Dispensing Pin for DNA Microarray Applications," IEEE Trans. Autom. Sci. Eng., 3, pp. 187-191.
- [3] Szita, N., *et al.*, 2001, "A Micropipettor with Integrated Sensors," Sens. Actuators A Phys. 89, pp. 112-118.