Design of a microreactor with an amperometric sensor

Intro to MEMS

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Outline

- Part 1 - Design and analysis of a micro-channel for performing the magnetic immunoassay
  - Motivation
  - Concept
  - Initial analysis
  - Design
  - Simulation
  - Fabrication

- Part 2 - Analysis and Design of a sensor
  - Motivation
  - Analysis
  - Design
  - Fabrication

- Conclusions
To do..

- Design a microreactor for performing the “magnetic immunoassay”
- Simulating the fluid flow in the micro channel
- Fabricate the prototype in ABS plastic using rapid prototyping and mold in Poly dimethoxy silane (PDMS)
- Test the microreactor with a basic reaction
Motivation

- **Coronary heart diseases**
  - Ranked number one for the highest % of deaths
- **Current diagnostic procedures**
  - Electrocardiogram (EKG) tracings
  - Clinical history
- **Recent technique**
  - Rise and fall in cardiac markers
- **Need for Point of Care (POC) device**
Magnetic immunoassay complex

Second Part
- pNPP
- Alkaline phosphatase
- Biotinylated antibody

First Part
- Myoglobin
- Secondary antibody
- Para magnetic microsphere

MMS
Analysis

- Factors to consider
  - Mixing
  - Inlet Velocities (Three inlet streams)
  - Diffusion dominated

- Residence time: 20 minutes
- Total volume of the components: 250 µL
Analysis

- Assume (after iterations to fit in a 3 in. Silicon wafer)
  - Volume of the reactor - 100 µL
  - Length of the connector - 0.2 cm
  - Volume of each reaction chamber - 32 µL
  - Hence, volume of the connectors - 100 - 3 * 32 = 4 µL
  - Square cross section

- Depth of the connectors
  - \( \sqrt{\frac{\text{Volume of each connector}}{\text{Length of the connector}}} \) = 0.1 cm

- Area of Cross section of the reaction chamber
  - \( \frac{\text{Volume of each chamber}}{\text{Depth of the chamber}} \) = 0.36 cm²

- Volumetric flow rate
  - \( \frac{\text{Volume of the reactor}}{\text{Residence time}} \) = 5 µL/min
Problems and Solutions

- **Problems**
  - Formation of eddies at the corners
  - Smallest feature fabrication is not possible with the existing facilities

- **Solutions**
  - Different design with circular chambers and same dimensions
New design
Flow Contours

Contours of Velocity Magnitude (m/s)

FLUENT 6.2 (3d, dp, segregated, lam)
Flow path lines

(zoomed in at the inlet)
Pressure pathlines
(zoomed in at the inlet)
Fabrication (Rapid prototyping)

- **Materials**
  - ABS plastic
  - Sylgard 184 Silicone elastomer
  - Sylgard 184 Silicone curing agent

- **Equipment**
  - Stratsys FDM 3000 rapid prototyping
  - Bell jar
  - Vacuum pump
  - Microscope slide
  - Tubing
  - Syringe pump
Fabrication

- Model created using Rapid prototyping in ABS plastic
Fabrication

Oven set at 65ºC
Fabrication

- PDMS channel peel off
- Create reservoir using a hole punch tool
- Sealing with a glass slide
  - Air/Plasma treatment produces Si-O-Si bonds
  - Lasts pressures up to 40 psi
Part 1 - Design and analysis of a micro-channel for performing the magnetic immunoassay
  - Motivation
  - Concept
  - Initial analysis
  - Design
  - Simulation
  - Fabrication

Part 2 - Analysis and Design of a sensor
  - Motivation
  - Analysis
  - Design
  - Fabrication
Motivation

- Difficulties in collecting the product
- Prevent any side reactions (photochemical reaction) and reduce the secondary signal
- More compact and easier handling
Amperometric Biosensors

The diagram illustrates the components of an amperometric biosensor, including the receptor and detector, as well as the flow of physical or chemical changes to an electrical signal for analysis.
Optical Biosensors
Amperometric Sensors

Selected applications of CE microchips with electrochemical detectors

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Working electrode</th>
<th>Detection mode</th>
<th>Potential (V)</th>
</tr>
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<tbody>
<tr>
<td>Amino acids</td>
<td>Gold film</td>
<td>Amperometry</td>
<td>+0.8</td>
</tr>
<tr>
<td>Catecholamines</td>
<td>Platinum</td>
<td>Amperometry</td>
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<td>Palladium film</td>
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<td>Organophosphate pesticides</td>
<td>Carbon</td>
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<td>-0.5</td>
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<tr>
<td>Nitroaromatic explosives</td>
<td>Carbon</td>
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<td>-0.7</td>
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<tr>
<td></td>
<td>Gold</td>
<td>Amperometry</td>
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</tr>
<tr>
<td>Nucleic acids</td>
<td>Platinum</td>
<td>Amperometry</td>
<td>+0.8</td>
</tr>
</tbody>
</table>
Analysis

- Current produced - \( 0 \text{ (nA) } \) \{ order of nano amperes \}
- Resistivity of gold (\( \rho \)) - \( 2.44 \times 10^{-8} \Omega \text{-m} \)
- Voltage applied (with reference to the reference electrode) - 800 mV
- Assume length of the electrode - 2.5 mm
- Resistance = \( R = \frac{V}{I} = \frac{\rho \, L}{A} \)
- Calculating \( A = 7.85 \times 10^{-15} \text{ m}^2 \)
  - Thickness of the electrode - 50 nm
Schematic of the proposed sensor

Reference electrode

Working electrodes

Counter electrode

Working electrodes
Fabrication

- Seal the glass with the electrodes, with the PDMS channel
- Final device with an in-built sensor
Conclusions

- A microreactor is fabricated in PDMS using rapid prototyping
- Testing is done numerically using FLUENT
- An amperometric sensor is designed to detect the reaction
Future work

- Improve the microreactor into a completely functional “Lab on a chip”
- Perform the magnetic immunoassay on the chip
Acknowledgements

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References


R. Bashir, “BioMEMS: state of the art in detection, opportunities and prospects", *Advanced Drug delivery reviews*, 56: 1565-1586

Questions????
Appendix-I

- Fabrication of micro channel using soft lithography

1. Mask, Photo Resist, Silicon Substrate
2. After UV Exposure/Etching
3. PDMS, Curing PDMS
4. Molds Of PDMS, Sealed with glass
Appendix-II

- **Working Electrode** - The electrode in a 3 electrode cell where all the action takes place
  - Examples - Platinum, Gold, Carbon

- **Reference Electrode** - An electrode that has a well known and stable electrode potential. It is used as a reference point against which the potential of other electrodes are measured
  - Examples - Ag/AgCl, Calomel electrode, Hydrogen electrode

- **Counter/Auxiliary electrode** - An electrode in a three-electrode cell that is used only to make an electrical connection to the electrolyte so that a current can be applied to the working electrode