Lecture 18:
Microfluidic MEMS, Applications

Overview

- Microfluidic Electrokinetic Flow
- Basic Microfluidic Components
- Applications of Microfluidics
**Electrokinetics**

The science of using electric fields to move fluids, or to use fluids to generate electric fields.

There are two main electrokinetic phenomena that can be utilized:

(a) Electro-osmotic effect (EO)

(b) Electrophoresis and Dielectrophoresis

These methods utilize electric fields to move fluids, and are primarily used in microfluidics.

**Fluid Transport by Electro-osmotic Flow**

An electrochemical reaction will occur at liquid/solid interfaces, when an electrolyte solution is present, causing an electric polarization of the channel wall.

For the glass surfaces used in microfluidics, the electrolytes will cause deprotonation of the wall surface, producing a negatively charged wall. Where deprotonation is the removal of a proton (H\(^+\)) from a molecule.

Here, water molecules absorbed by the glass wall will be subject to deprotonation, resulting in a negative charge distribution on the surface of the glass.
Fluid Transport by Electro-osmotic Flow

The charged wall will attract ions from the bulk liquid, and they will form an ion layer called a ‘electric double layer’ on the wall surface.

If an electric field is applied parallel to the wall, these ions adjacent to the wall will move in response to the E-field, and will ‘drag’ the surrounding fluid. This fluid flow is called ‘electro-kinetic flow’.

Fluid Transport by Electrophoresis

Here, the electric field is used to act upon the particles within the fluid, for the purposes of separation, transportation and characterization.

The force exerted on a ‘particle’ due to the electric field can be defined as: $$\vec{F} = Q\vec{E} + (P \cdot V)\vec{E}$$

Where:
- $Q$ - Charge
- $P$ - Polarization
- $E$ - Electric Field
Fluid Transport by Electrophoresis

Electrophoresis force is defined as: \( \vec{F} = EQ \)

Dielectrophoresis force is defined: \( \vec{F} = (\vec{P} \cdot \nabla) \vec{E} \)

Capillary Gel Electrophoresis

Size-based separation of biological macromolecules such as DNA restriction fragments and proteins.

http://www.ceandcec.com/
http://ntri.tamuk.edu/ce/ce.html
Basic Microfluidic Components

- Microfluid channels and chambers for transporting and storing fluid
- Microfluid pumps for moving fluid
- Microfluid valves for isolation of fluid
- Mixers structures to prompt mixing at the micro scale
- Electrodes (metal) for provide potential or current, or to detect signals
- Sensors flow parameter sensors and chemical parameter sensors

Fabrication of Micro-Channels

Micro-Channels are often fabricated in Glass or Pyrex Substrates using Isotropic Wet Etching Processes.

(a) Glass
(b) Chrome Mask
(c) Isotropic Etch
(d) Remove Mask
(e) Bond Overlying Layer of Glass to Create Channel

Fabrication Process Sequence for creating Micro-Channels in a Glass Substrate [Image from Chang Liu]
Fabrication of Micro-Channels

Micro-Channels fabricated using Silicon Substrate, and subsequent wafer to wafer bonding.

Step (a): Create pattern in silicon bulk using isotropic, anisotropic or DRIE etch process.
Step (b): Conformal growth of layer (i.e. silicon nitride) to create channel wall.
Step (c): Bond original wafer to main wafer using anodic bonding.
Step (d): Selectively etch away original silicon material, without removing Silicon Nitride channels, to create structure shown.

[Images from Chang Liu]
Pumping of microfluids can be done in a number of ways, including:

- Pressure driven flow
  - fluid flow caused by pressure differential
- Electrokinetic flow
  - fluid flow caused by movement of charged particles or molecules
- Surface acoustic wave
- Capillary force driving

Review of Macro-Scale Pumps

Recall two conventional technologies for pumping fluids:

[Images of Centrifugal Water Pump and Peristaltic Pump]
Pressure Drive Flow in Microchannels

To create flow in the micro-channel, a conventional macro-scaled pump pressurizes the fluid, and is connected to the chip via flexible tubes.

Micro-Pump with One-Way-Valves

Micro-Pump using a pair of one-way valves. Pump membrane is actuated using an external magnetic field.
Surface Acoustic Wave Driven Flow

Piezoelectric-Actuator driven flow


Micro-Mixers

Increase interfacial area to reduce diffusion length
- sinusoidal, square-wave, or zigzag channels
- divide and conquer approach
- lamination-splitting

Lamination Splitting Mixer

LIGA Micro-Mixer
Micro-Magnetic Stir Bar

Fabrication Process to create the Micro-Magnetic Stir Bar in a Channel [Chang Liu]

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Case Study 13.2: Electrophoresis in Microchannels

(a) A buffer injection is done to fill in the entire channel
(b) Analyte injection using electrokinetic flow
(c) Sample introduction and analyte electrophoretic separation

Optical detection is done near the waste port.

[Image from Chang Liu]
Case Study 13.4: PDMS Microfluid Channels

- PDMS (polydimethyilsloxane) is part of the ‘silicone’ group of plastics.
- They produce a ‘thermoset’ plastic, that is transparent and flexible.
- Additionally, PDMS is porous, allowing liquids and gasses to slowly diffuse through the material.
- Microchannels are made using micro-molds

Case Study 13.6: PDMS Pneumatic Valves

- Soft membrane micro-valves actuated by air pressure

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Case Study 13.6: PDMS Pneumatic Valves

Fig. 13.16 Fabrication of peristaltic pump
[Image from Chang Liu]

Microscopic Images of PUMP
[Image from Chang Liu]

Fluid VLSI
[Image from Chang Liu]