Microvalve is a pressure-containing mechanical device used to shut off or otherwise modify the flow of a fluid that passes through it.

**Microvalve**

- **Active valve**
  - Needs external energy for its operation
  - Needs actuators
- **Passive valve**
  - Utilizes energy from the flow itself for its operation
  - Needs no actuators
- **Mode**
  - Normally open
  - Normally closed valve

**Biochemical Microfluidic Detection System**
- Microfluidics
- Microtubes
- Magnetic beads

**LOC Platform**

- **Microvalves**
- **Micropumps**
- **Micromixers**
- **Microreactors**
- **Microfilters**
- **Detectors**
- **Microreservoirs**

**LOC is a Combination of Microfluidic Devices**

- for on/off control of fluids
- in LOC (lab-on-a-chip)
- in in-vivo/in-vitro drug delivery system

**Microvalves are Essential Devices**

- Simple device structure and disposable microvalves for life sciences applications
[Microvalve] Specifications

- A Good Microvalve has
  - Zero leakage
  - Zero dead volume
  - Low power consumption
  - High closing force (pressure range)
  - High valve capacity
  - Fast response time
  - Insensitive to environment such as temperature
  - Reliable
  - Biocompatible
  - Ability to work with any fluid

[Microvalve] Classification

<table>
<thead>
<tr>
<th>Categories</th>
<th>Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>Mechanical</td>
</tr>
<tr>
<td></td>
<td>Magnetic (Lecture 17)</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
</tr>
<tr>
<td></td>
<td>Piezoelectric</td>
</tr>
<tr>
<td></td>
<td>Thermal</td>
</tr>
<tr>
<td></td>
<td>Bistable</td>
</tr>
<tr>
<td>Non-mechanical</td>
<td>Electrochemical</td>
</tr>
<tr>
<td></td>
<td>Phase change (Lecture 17)</td>
</tr>
<tr>
<td></td>
<td>Rheological</td>
</tr>
<tr>
<td>External</td>
<td>Modular (Lecture 11)</td>
</tr>
<tr>
<td></td>
<td>Pneumatic (Lecture 12)</td>
</tr>
<tr>
<td>Passive</td>
<td>Mechanical</td>
</tr>
<tr>
<td></td>
<td>Check valve (Lecture 18)</td>
</tr>
<tr>
<td>Non-mechanical</td>
<td>Capillary (Lecture 10)</td>
</tr>
</tbody>
</table>

[Microvalve] Actuation Mechanism

- **Electrostatic Actuation**
  - Two electrodes
  - High voltages for large forces
  - Small strokes

- **Piezoelectric Actuation**
  - PZT films
  - High forces
  - Small strokes

- **Pneumatic Actuation**
  - Large forces
  - Pressurized chamber
  - External pneumatic control system

**Thermal Actuation**
- Large forces and strokes
- Pressurized chamber
- Slow and heat transfer to fluids

**Bi-metallic Actuation**
- Heaters on bimetal film
- High current for large forces
- Slow and heat transfer to fluids
**[Microvalve] Active Microvalves—Mechanical**

**SMA Actuation**
- Shape Memory Alloy
- High forces and large strokes
- Slow and heat transfer to fluids

**Magnetic Actuation**
- Large forces and strokes
- Rapid response with relatively low power consumption
- Low IC-compatible driving voltages
- Assemble flexibility between magnetic actuators and valve parts

---

**Advantages**

<table>
<thead>
<tr>
<th>Actuation Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrostatic actuation</td>
<td>Simplicity of materials, Fast actuation response</td>
<td>Trade-off between magnitude of force and displacement, Susceptible to pull-in limitation</td>
</tr>
<tr>
<td>Piezoelectric actuation</td>
<td>Fast response possible, Capable of achieving moderately large displacement</td>
<td>Requires complex material preparation, Degraded performance at low frequencies</td>
</tr>
<tr>
<td>Thermal actuation</td>
<td>Capable of achieving large displacement (angular or linear), Moderately fast actuation response</td>
<td>Relatively large power consumption, Sensitivity to environmental temperature changes</td>
</tr>
<tr>
<td>Magnetic actuation</td>
<td>Capable of generating large angular displacement, Possibility of using very strong magnetic force as bias</td>
<td>Moderately complex processes, Difficult to form on-chip, high-efficiency solenoids</td>
</tr>
</tbody>
</table>

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**[Microvalve] Ball Microvalve by External Magnetic Fields**

**Solenoid Plunger**
- In 1979, a miniaturized electromagnetic microvalve was accomplished by using a solenoid plunger, which was physically connected to a silicon micromachined membrane by Terry et al [3].
- The microvalve was the first active micromachined valve, a component of an integrated gas chromatography system.

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**[Microvalve] ④ Ball Microvalve by External Magnetic Fields**

**Ball Microvalves Before Assembling**
- Nickel Ball
- Diameter of the metal ball is 768 μm with 625 μm ID x 1190 μm OD tubing
- Diameter of the metal ball is 1190 μm with 1750 μm ID x 2450 μm OD tubing

**Flow Rate of Ball Microvalves**
- Operation
  - Operation current: 500 - 800 mA
  - Flow rate: 30 - 1300 L/min @ 0.3 psi

**Leakage flow rate vs. the input pressure for DI water**
- Flow rate of DI water vs. actuation current @ 0.3 psi

**Pinch Microvalve by External Magnetic Fields**
- Pinch Microvalve with Zero Dead Volume
- Pinch actuation on flexible tubing for fluidic switching
- Easily achievable pinch actuation using point force from plunger
- Compressive spring-loaded plunger to make normally-closed mode
- Flexible tubing with thin wall thickness to reduce the pinch force
- Biomedical grade silicone tubing
- Surface mountable scheme

**Prototyped Pinch Valve**
- Solenoid: STP1717-016
- Compressive spring-loaded plunger
- Biomedical grade silicone tubing (735 μm ID x 1200 μm OD)
- Bottom layer: guided groove for the tubing, round groove for the plunger

**Flow Rate vs. Actuation Current (DI Water)**
- Prototyped Pinch Valve
  - Operation
    - Pressure: 0 - 1190 μm (2X water)
    - Flow rate: 0 to 15 psi per 25 μl
    - Power consumption: 1.4 watts with 12 Volt
  - Reliability Test
    - 10% duty cycle: at least 24480 on/off (1-sec-on/9-sec-off)
    - 50% duty cycle: at least 10000 on/off (1-sec-on/1-sec-off)
    - 24 VDC: 6 μA at 12 Volt

**Microvalves by Integrated Magnetic Inductors**
- Magnetic Actuator
  - Planar solenoid inductors
  - Ni/Fe electroplated through-holes to confine the magnetic field
- Microvalves
  - Polyimide valve seats to reduce leakage flow rate
  - Ni/Fe permalloy to prevent buckling
  - Low stress Ni/Fe permalloy
- Motherboard
  - Fluidic channels and gold tracers
  - Low temperature biochemically compatible bonding
**Microvalve**④ Microvalves by Integrated Magnetic Inductors

- Bonded and Assembled on Microfluidic Motherboard
- Developed and fabricated in the microactuators laboratory
- Low temperature biochemical compatible Teflon bonding technique
- Ready to test by connecting inlet and outlet

**Flow Rate Without MESA**

<table>
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<tr>
<th>Actuation Current (mA)</th>
<th>Flow Rate for H2 Gas</th>
<th>Flow Rate for DI Water</th>
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<tbody>
<tr>
<td>100</td>
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<td>0.2 μL/min</td>
</tr>
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</tr>
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**Microvalve**① Approach for Ferro-Wax Microvalve

- Thermally Actuated Ferro-Wax Microvalve
  - A reversible microvalve without external pneumatic air/vacuum systems

**Ferro-Wax**

- Homemade new meltable magnetic material

**Ferrofluid**

- Developed by NASA in the 1960s, ferrofluids are used today in many applications such as loudspeakers, CD-ROMs, computers, and semiconductor fabrication.
- A stable colloidal suspension of sub-domain magnetic particles in a liquid carrier (an average size of about 10 nm).
- The magnetization of the ferrofluid responds immediately to the changes in the applied magnetic field and when the applied field is removed, the moments randomize quickly.

**Paraffin Wax**

- The wax present in petroleum crudes primarily consists of paraffin hydrocarbons (C18 - C36) known as paraffin wax and naphtenic hydrocarbons (C30 - C60).
- Hydrocarbon components of wax can exist in various states of matter (gas, liquid or solid) depending on their temperature and pressure. When the wax freezes it forms crystals.

---

**Phase Change Microvalves**

- Simple device structure and disposability
- For life sciences applications
- In-vivo/in-vitro drug delivery systems

**Thermally Actuated Paraffin Microvalves as the Meltable Plug**

- A reversible microvalve with external pneumatic air/vacuum systems
  - Anal Chem 76 3740–3748 2004
- An irreversible microvalve without external pneumatic air/vacuum systems
  - Sensors and Actuators B 98 328–336 2004

---

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**Hydrocarbon Based Ferrofluid + Paraffin Wax**
- Success of mixing

**Diester Based Ferrofluid + Paraffin Wax**
- Failure of mixing
  - Precipitation of ferrite particles

**Volume of ferrofluid : volume of paraffin wax = ~ 1 : 2**
- Ferrofluid: Hydrocarbon-based ferrofluid (Liquids Researches, SHGS4-U, 450 Gauss, 200 cp)
- Paraffin Wax: paraffin hydrocarbons (C18 - C36) known as paraffin wax (Fluka, 76232, paraffin wax, purum, platelets, sp 68 – 74 °C)

**Ferro-Wax Microvalve**
- Si/Glass
  - Structure: inlet/outlet/stem ports and Y-branch
- Heater
  - Embedded a heater with a built-in sensor
  - The same amount of resistances to those of the heater/sensor of TMC-1000
  - Temperature control by TMC-1000

**Ferro-Wax Microvalve Operation**
- N2 Gas Line
- Pressure Regulator
- Pressure Controller
- Liquids
- Sensor
- Heater
- Magnet
- Microvalve
- Y-junction
- Inlet
- Outlet
- Pipette Tip

**Melting Temp. Measurement**
- TMC-1000 system + MicroPCR chip
- Range of Melting Temperature: Paraffin Wax (68 – 74 °C)
- Ferrofluid : Paraffin (1 : 2)

**Ferro-Wax Plug**
- Magnetic
- Fluidic

**SiO2 Patterning**
- Back-side Etching
- Glass Etching

**Poly Si & Cr/Au Patterning**
- Hole Sand Basting
- Anodic Bonding
### Sol-Gel Microvalve
- Thermo-reversible polymer material (Sol-Gel; Methyl Cellulose)
- PCR reaction temp > phase change temp > Room temp
- Automatic valving during PCR

#### Deswelling of Hydrogel by Electrolysis Actuation
- pH-sensitive hydrogel
- Electrolysis Actuation
  - Anode (+): Acid (pH ↓)
    - $2\text{Cl}^- \rightarrow \text{Cl}_2 \uparrow + 2e^-$
  - Cathode (-): Base (pH ↑)
    - $2\text{H}_2\text{O(l)} + 2e^- \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$

### Hydrogel Microvalves
- Deswelling of Hydrogel by Electrolysis Actuation
- Applications in LOC (Lab-On-a-Chip) or Drug Delivery System
- Useful in drug delivery system for in-vivo/in-vitro diagnosis and therapy
- Useful in microsensors & microactuators

### Summary
- Phase Change Microvalves
  - ① Ferro-Wax Microvalve
    - World 1st microvalve using a melttable magnetic materials
  - ② Sol-Gel Microvalve
  - ③ Hydrogel Microvalve
- Applications in LOC (Lab-On-a-Chip) or Drug Delivery System
  - Useful in disposable biochip applications due to relatively low cost
  - Useful in some applications, where valving time is not critical, such as micro PCR
  - Useful in drug delivery system for in-vivo/in-vitro diagnosis and therapy
  - Useful in microsensors & microactuators
- Magnetically-Driven Microvalves
  - Biochemical Detection System
  - Membrane-type, ball-type, and pinch-type microvalves