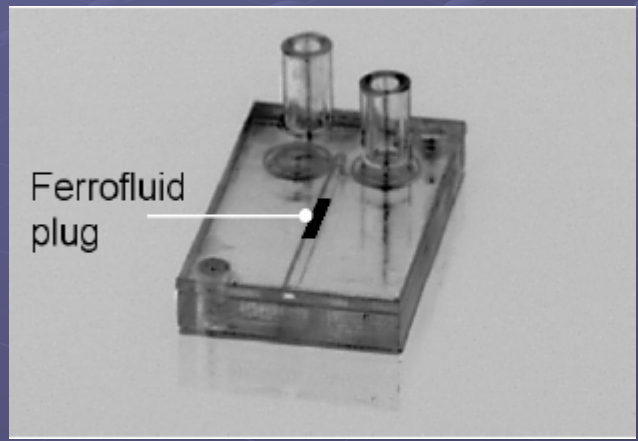
Application of Ferrofluid as a Valve/Pump for Microfluidic Devices



Ferrofluid micropump Yamahata et al. 2003

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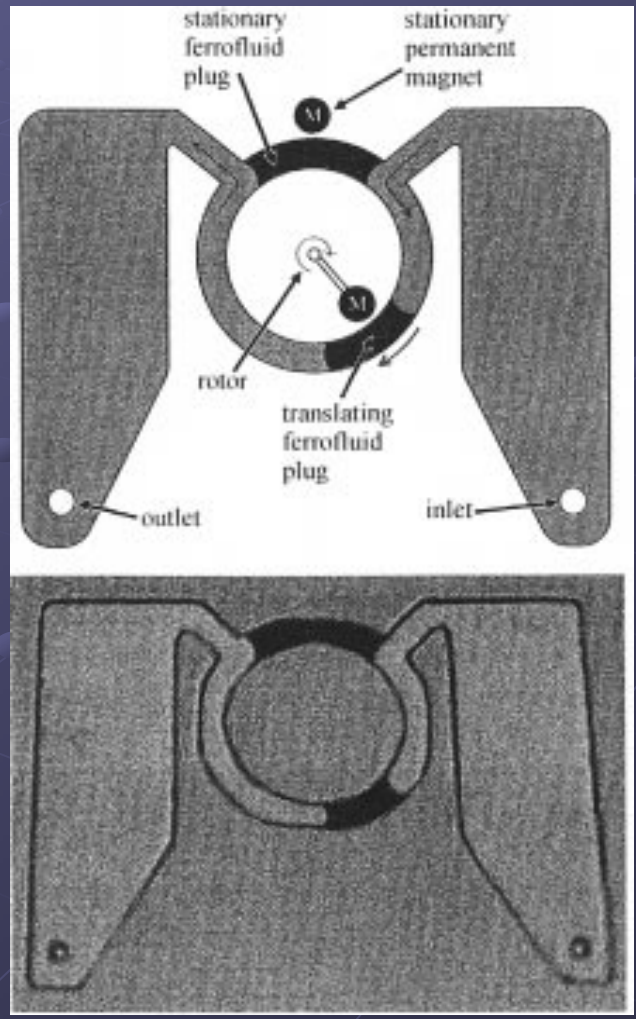
Objective

- To design a simple valve/pump which can be:
  - Easily fabricated and cost efficient
  - Readily controlled
  - Compatible with many microfluidic devices
- Our method: using oil-based ferrofluid (FerroTec) or a mixture of paraffin wax and ferrofluid
  - Wax provides good sealing
  - Ferrofluid easily controlled by magnet

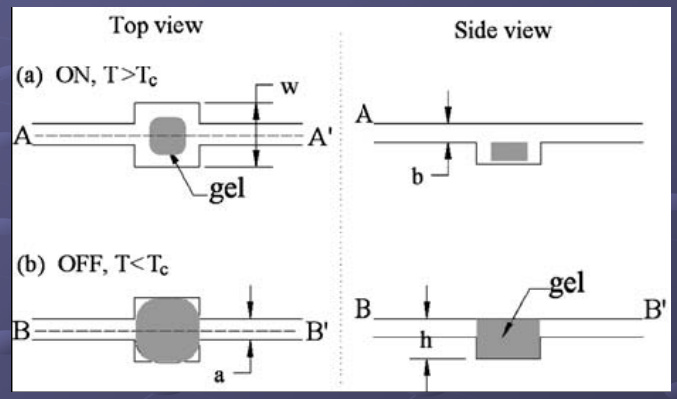


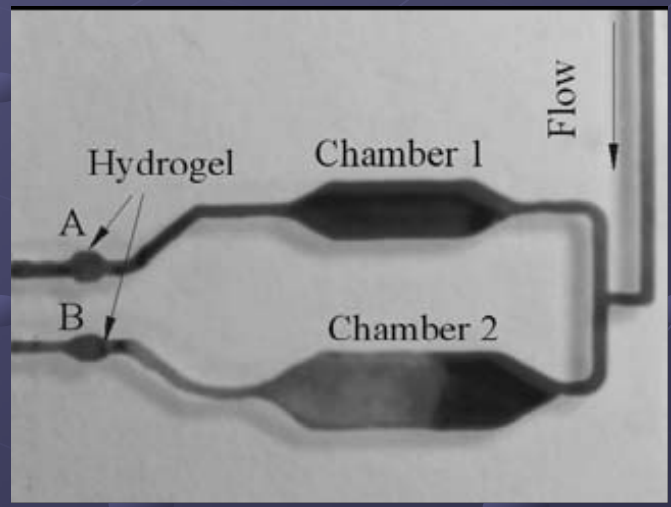
Ferrofluid pump/valve using rotating magnet for manipulation

Hatch et al. *J. Microelectromechanical Sys.* 2001, **10.**

Background

- Microfluidics incorporates the study and application of precise control and manipulation of micro to nano liter volumes of fluid
- Current valve/pump methods:
  - Hydrogel
  - Phase-changing
  - Electrical actuation
  - Paraffin wax or ferrofluid alone
- Some Issues
  - Electromechanical and kinetic actuation are usually expensive and complicated
  - Ferrofluid by itself cannot sustain a pressure differential

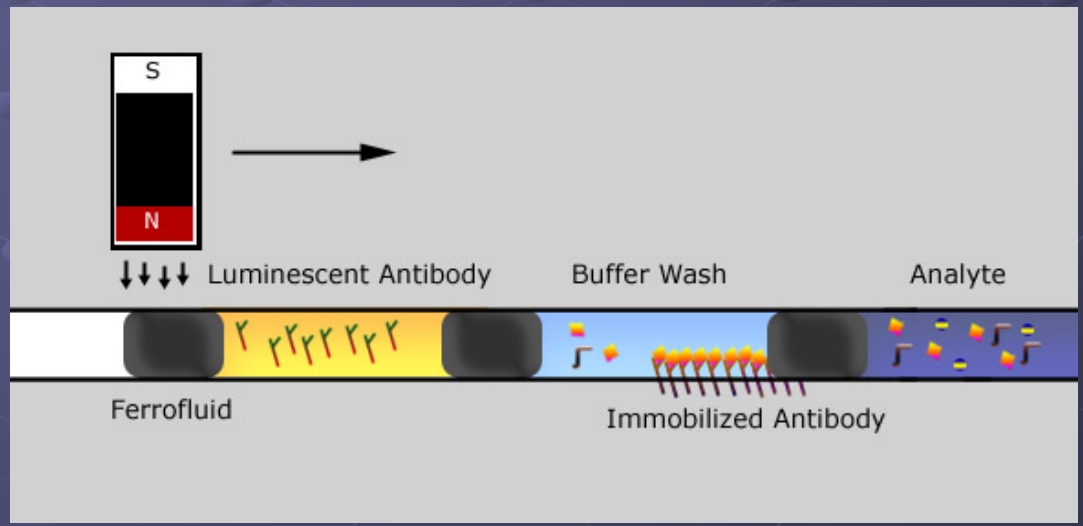




Top: Illustration of volumetric changes in response to liquid filling
Bottom: Hydrogel valves

Application

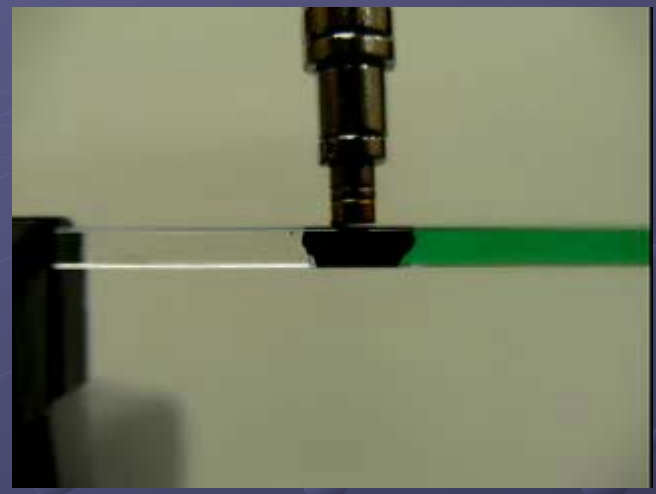
- “Fluid train” propelled by magnet where different aqueous samples are separated by immiscible slugs
  - Rapid tests for protein analysis in a solution
  - Design utilizes chemiluminescent technology where specific antibodies bound to the ligand emit light with the addition of detection reagent



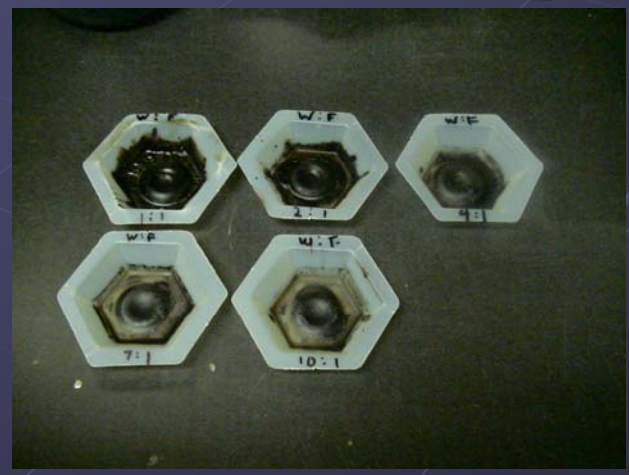
Prototype design for microfluidic chip

Preliminary Steps

- Mixing different volumetric ratios of paraffin wax and ferrofluid
- Ferrofluid/ferro-wax pump in macroscale glass tube
- Observing the behavior of ferrofluid with or without water on the surface of PC (film deposition, hydrophobicity, leakage)



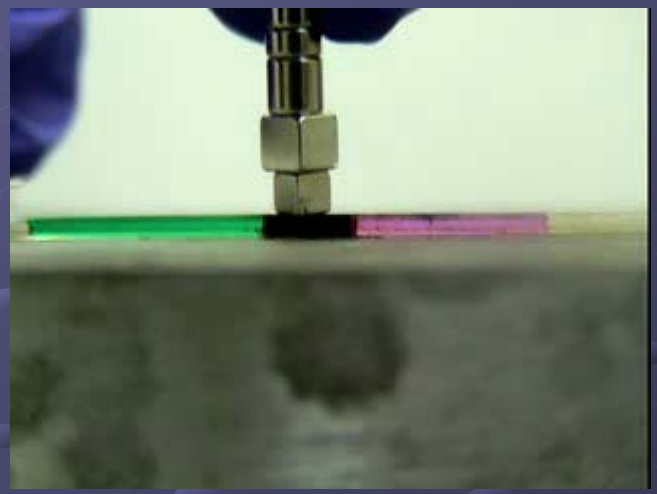
Ferrofluid slug separating clear and dyed water



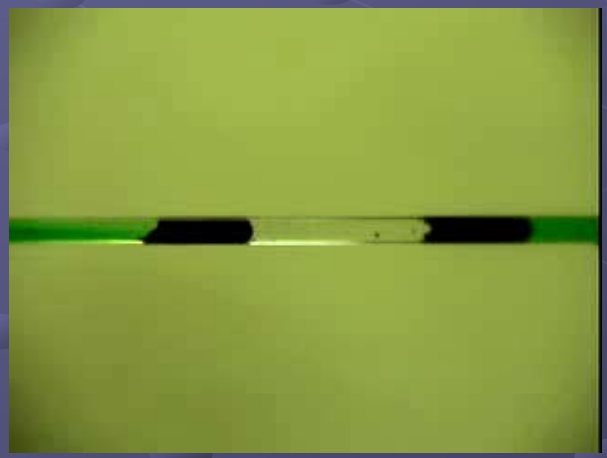
Different ratios wax : ferrofluid

Preliminary Steps

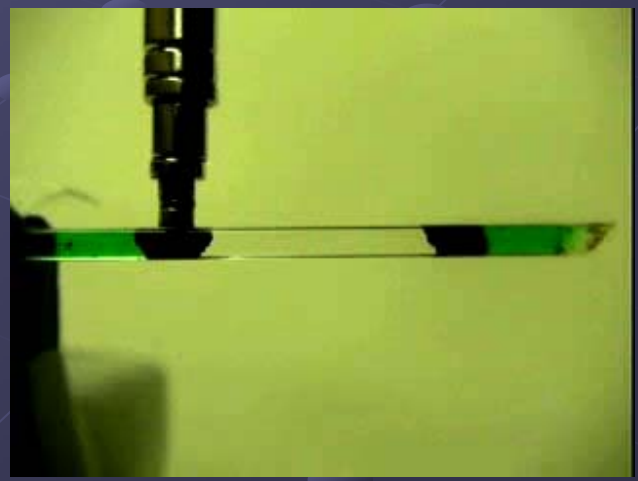
- Ferro-wax pump operated at ~80 °C to allow magnetic control
- Only one ferrofluid slug and magnet to drive a train of fluids
- Ferrofluid pump in PC micro channel



Ferro-wax separating slugs of dyed water on hot plate



3 ferrofluid slugs

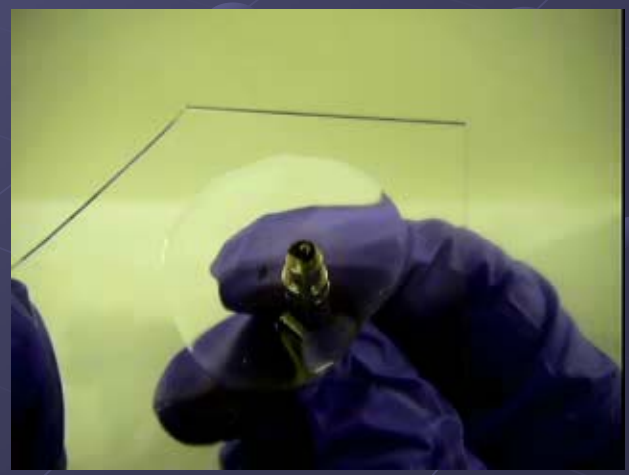


2 ferrofluid slugs

Observations / Preliminary Results

- Ferrofluid leaves coating on PC surface (hydrophobic), unlike glass (hydrophilic)
- Ferrofluid / molten ferro-wax between two water slugs in glass capillary
  - No noticeable film, residue, or leakage when moving fluid slowly
  - Faster movement creates more film deposition and leakage
- For the ferro-wax pump presumably the entire operating area is heated; as a result, this device cannot contain heat-sensitive solutions

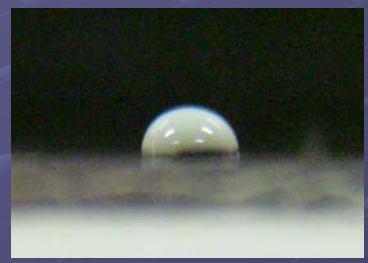
Ferrofluid on PC



Ferrofluid on glass

Surface Treatments

- Film left by ferrofluid may cause issues with biocompatibility in channel
- Various treatments tested to render PC channel hydrophilic, such that ferrofluid behaved like in a glass capillary
- O_2 (<10º), Ar (47º)
- Spin-on Glass (SOG; i.e. SiO_2) (~35º)
- Polyvinylpyrrolidone (PVP) following treatment by argon plasma or acetone activation (~10º)



Untreated PC

Glass

O_2 Plasma

PVP

Results of Surface Treatments

- To test channels, pieces fixed together temporarily by vice
- Ar plasma
  - Left some film even during slow movements
- O_2 plasma
  - No film even during relatively fast movement
- SOG
  - No film during slow movement
- PVP
  - No film even during fast movements
  - Capability of pumping multiple slugs

Untreated

O_2 plasma

Argon + PVP

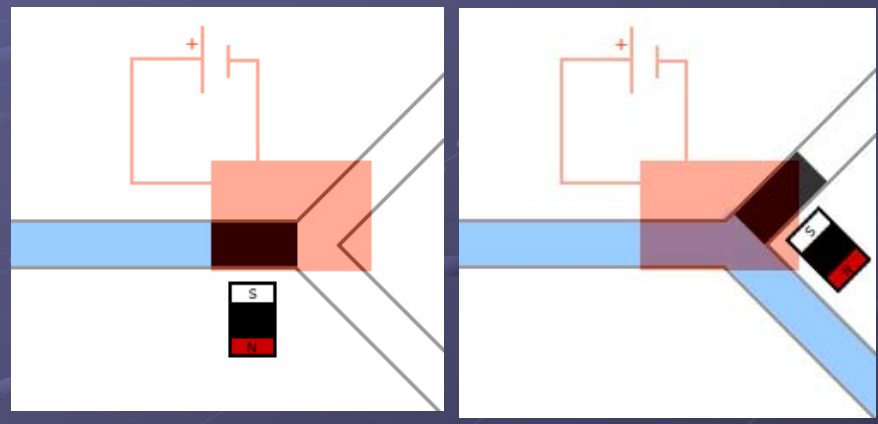
SOG

Conclusion

- Most appealing results using PVP treatment
  - Ability to treat channel after thermal bonding
  - Some PVP sealing for PC chips
  - Pump multiple slugs of ferrofluid without noticeable leakage
- Thermal bonding of PC reverses plasma treatment
- For chemiluminescence application, it was found that applying film of ferrofluid to a membrane before addition of detection reagents, and rinsing it did not affect the emitted light
- Acetone eats through PC depending on exposure time, however PVP coating fills holes produced from the acetone

Future Work

- Ferro-wax valve tests in PC micro channel
- Further experimentation with plasma bonding for PC
- Investigation of PVP bonding
- Leakage measurements of aqueous liquids across the ferrofluid pump
- Designing a microfluidic chip utilizing ferrofluid pumps and chemiluminescent technology for disease diagnosis purposes



Ferro-wax valve design

Acknowledgements

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Questions