



# Microfluidic Serial DAC for Analog Pressure Regulation

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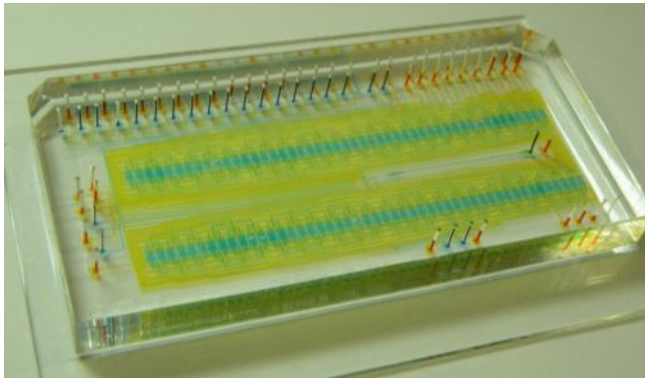
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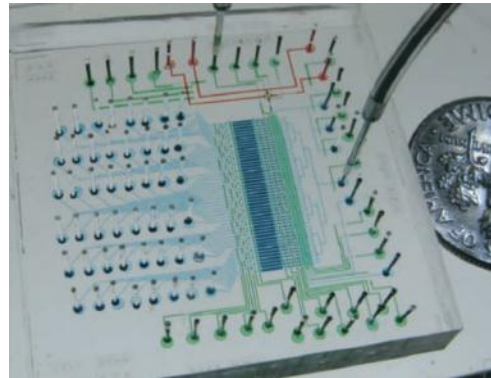
# Multilayer Microfluidic Control



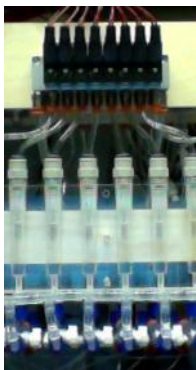
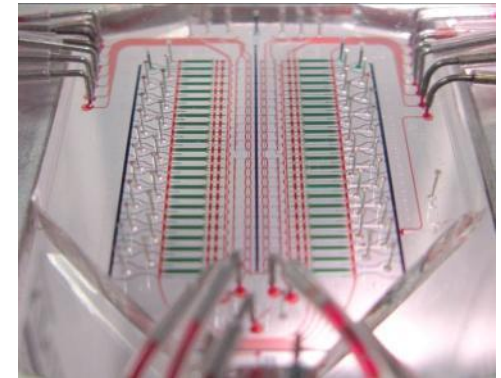
Cell Culture



Haplotyping

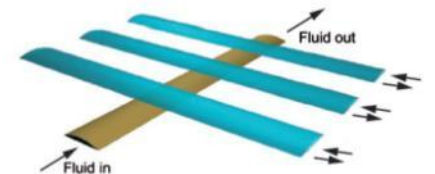
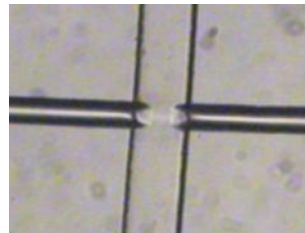


Bacterial Genome

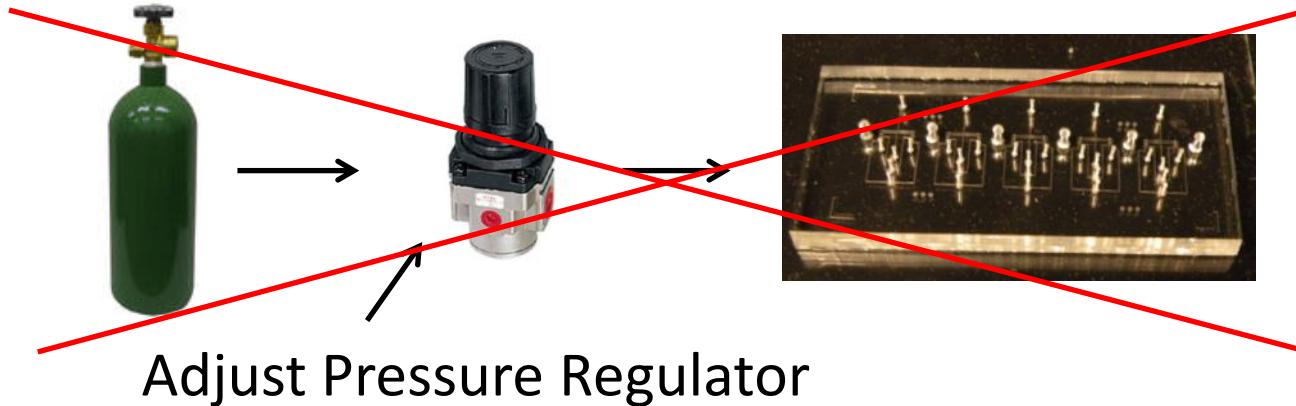


Pneumatic  
Solenoid  
On-Off  
Switch

on-off valves and peristaltic pumps

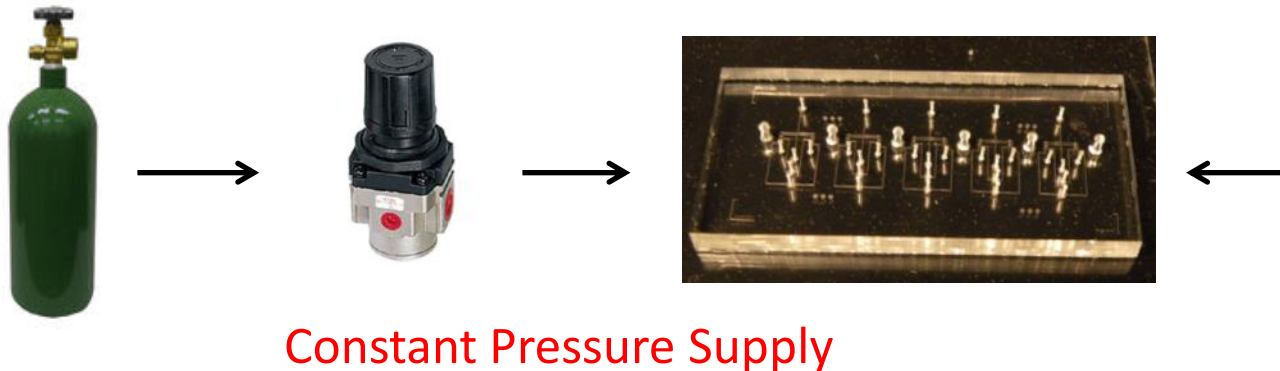


# Adjustable Pressure Valve



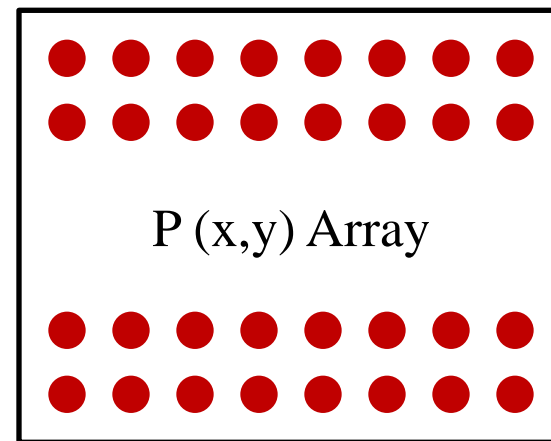
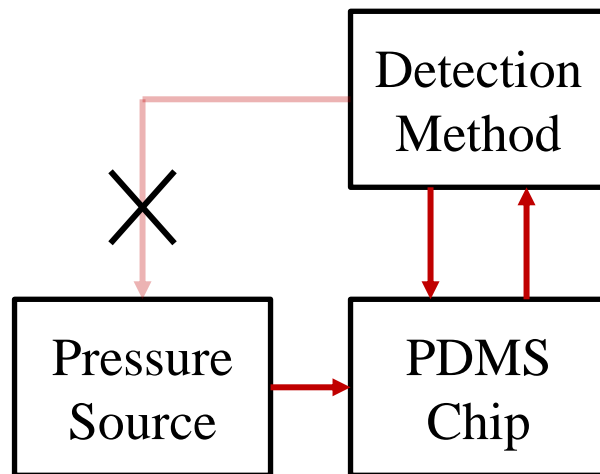
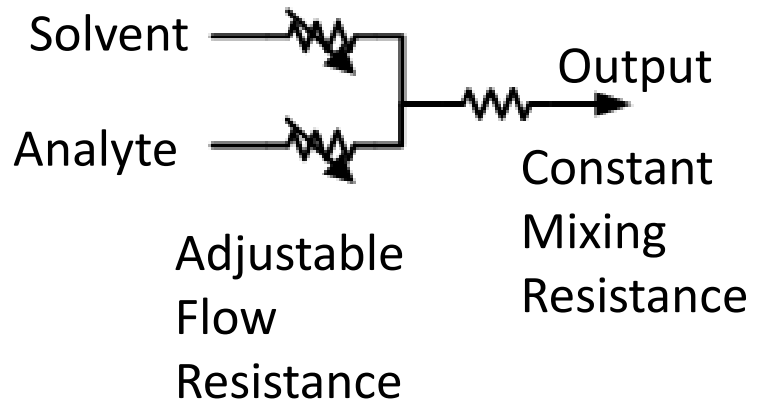
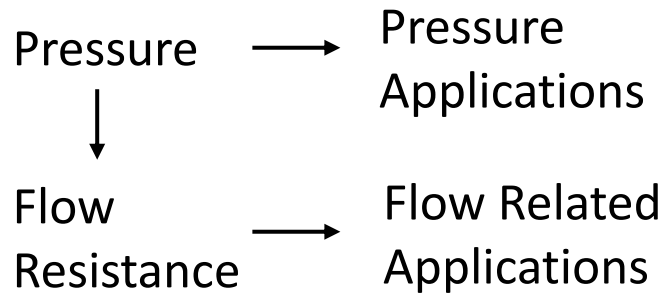
1. Slow
2. Not Scalable
3. Not Easily Automated

**On-chip** method of manipulating valve actuation pressures



Create an on-chip digital to analog pressure converter (DAC) that partially actuates a valve

# Adjustable On-Chip Pressure Valve



# Outline



- Device Design
  - Serial DAC (Digital to Analog Converter) Architecture
  - Principle of Operation
  - Fabrication and Results
- Device Characterization
  - Transfer Function
  - Linearity
  - Frequency Response
  - Application

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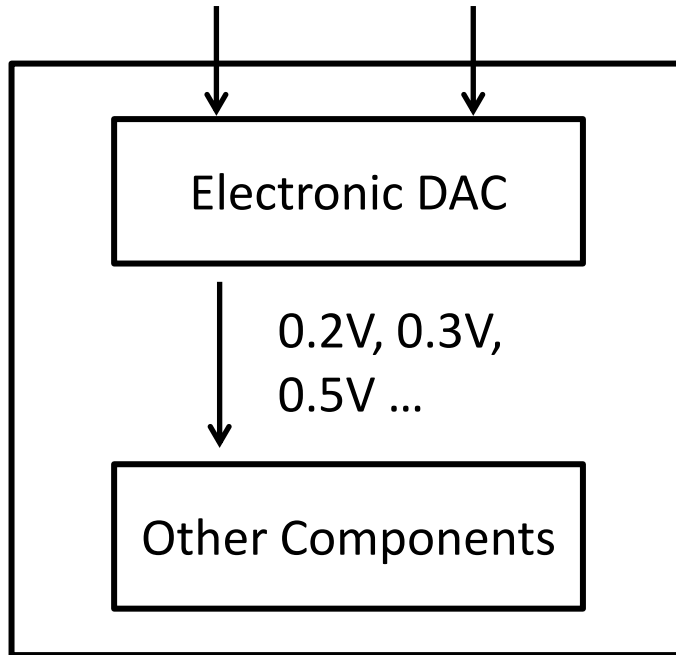
# Digital to Analog Pressure Converter



## Electronic System

Digital Control Bits  
0011, 0101, 1000 ...

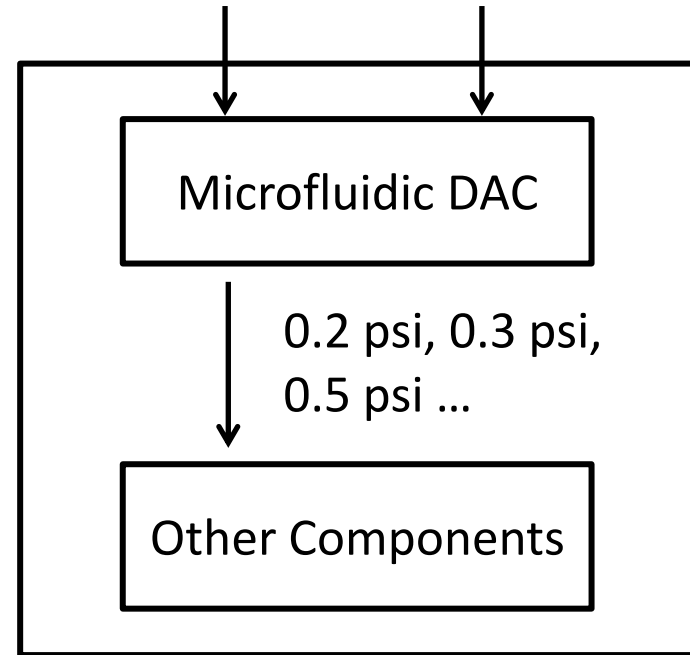
Constant  
Source  
Voltage



## Fluidic System

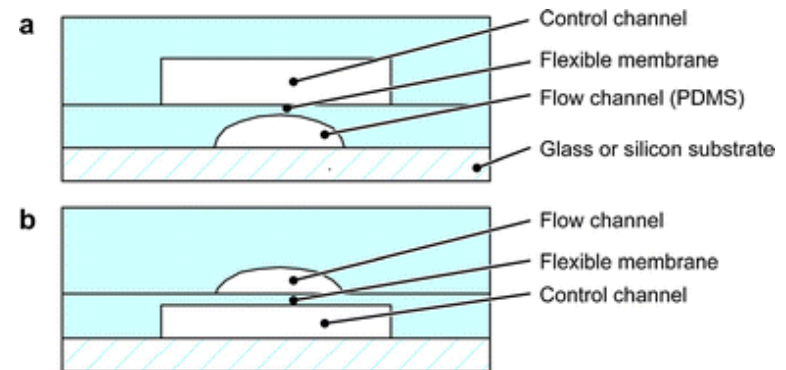
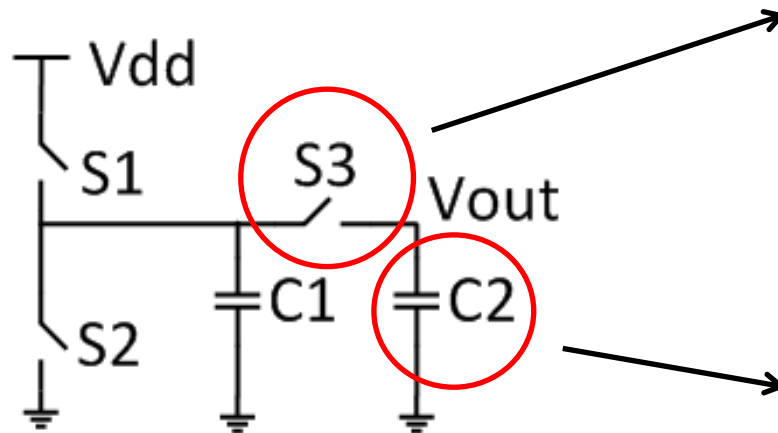
Digital Control Bits  
0011, 0101, 1000 ...

Constant  
Source  
Pressure



# Serial DAC Architecture

Serial DAC architecture uses components that can be replaced by existing microfluidic components, is simple to fabricate, and has a small footprint



Push down or push up valve

1. Elastic Diaphragm
2. PDMS Channel

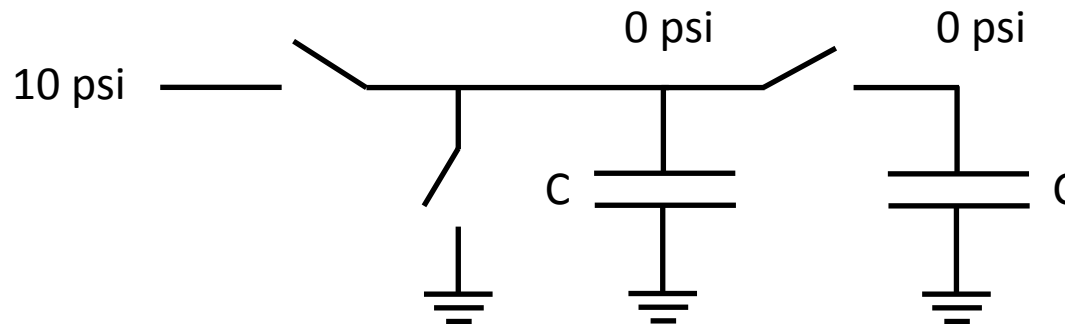


# Operation Principle: Charge Sharing



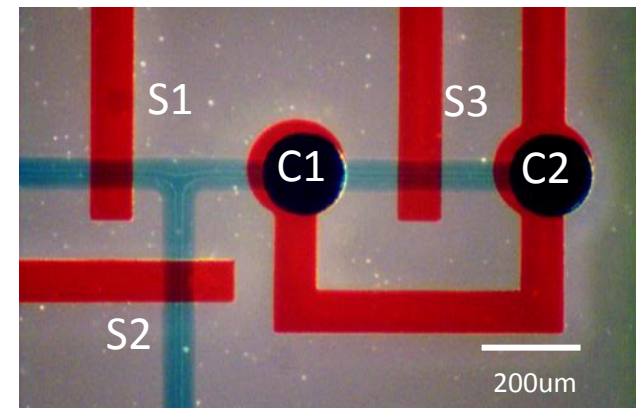
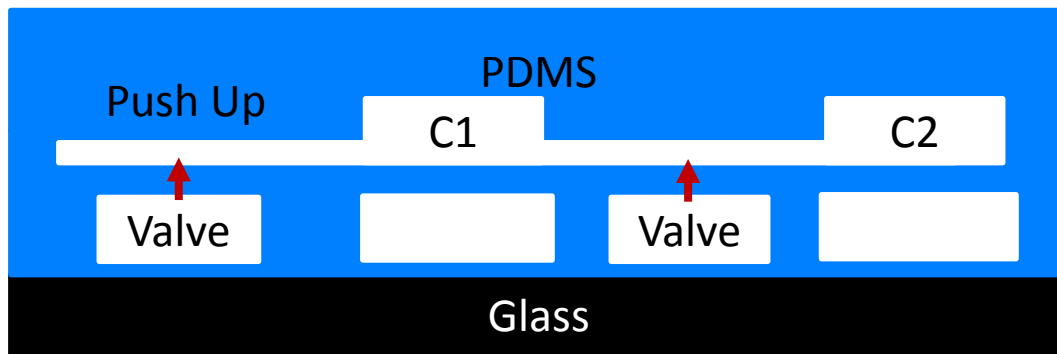
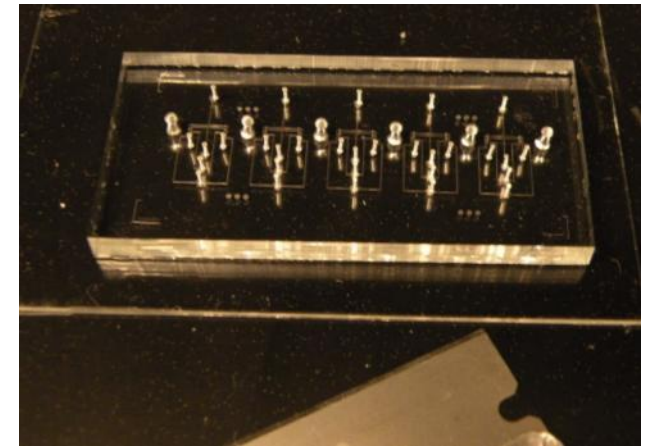
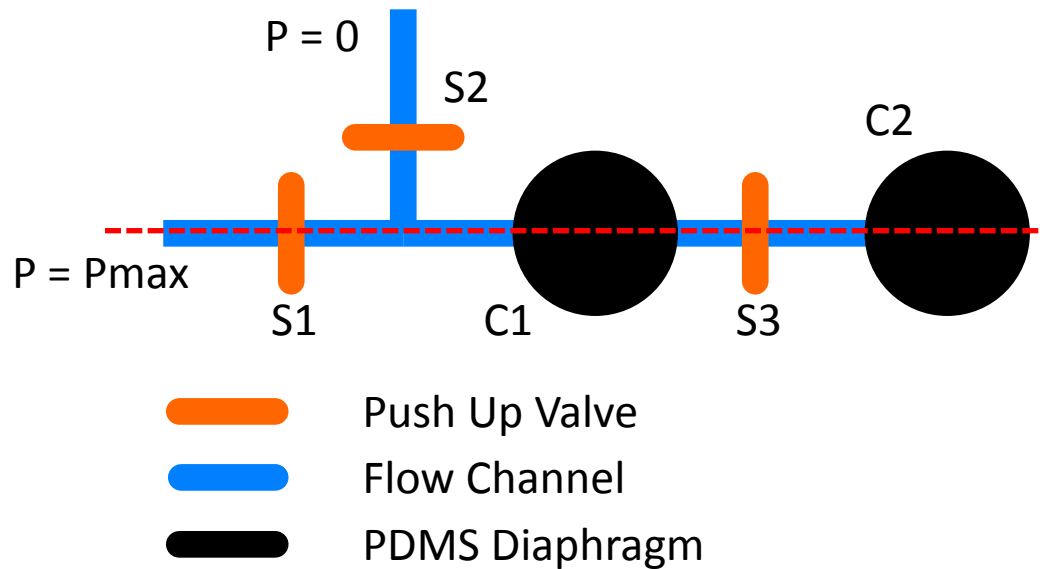
- Using the concept of charge sharing
  - Generate any output voltage (pressure)

10 psi source pressure, 3 bit binary code 101





# Device Fabrication Results



# Outline

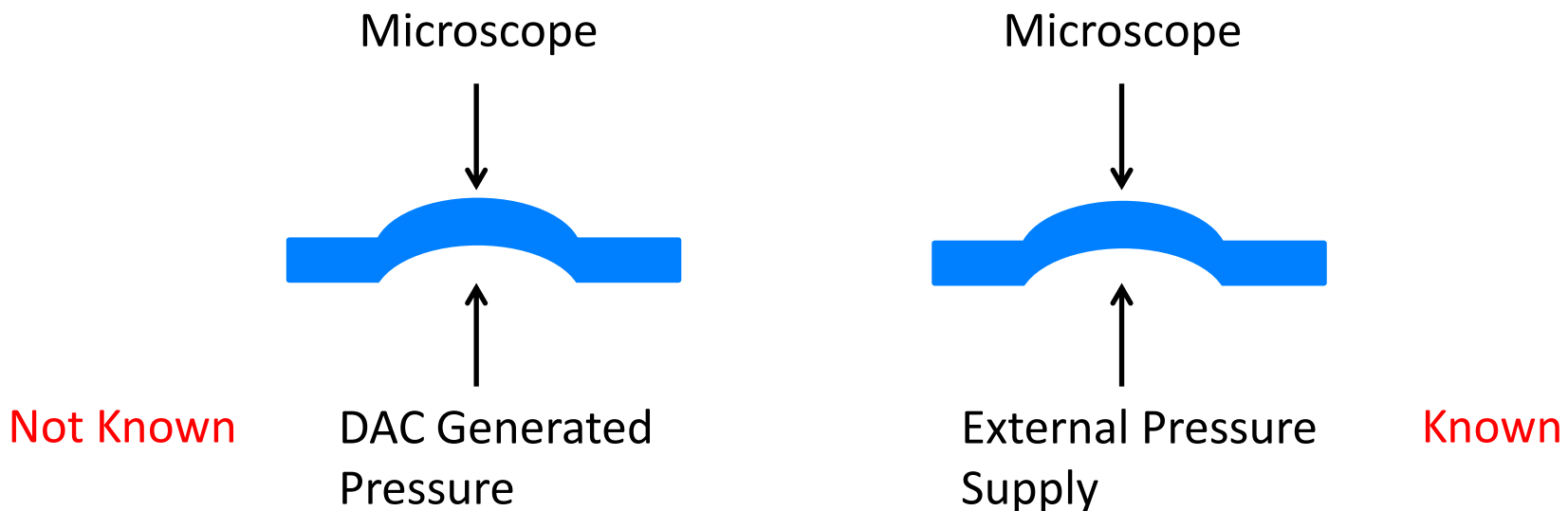


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  - Frequency Response
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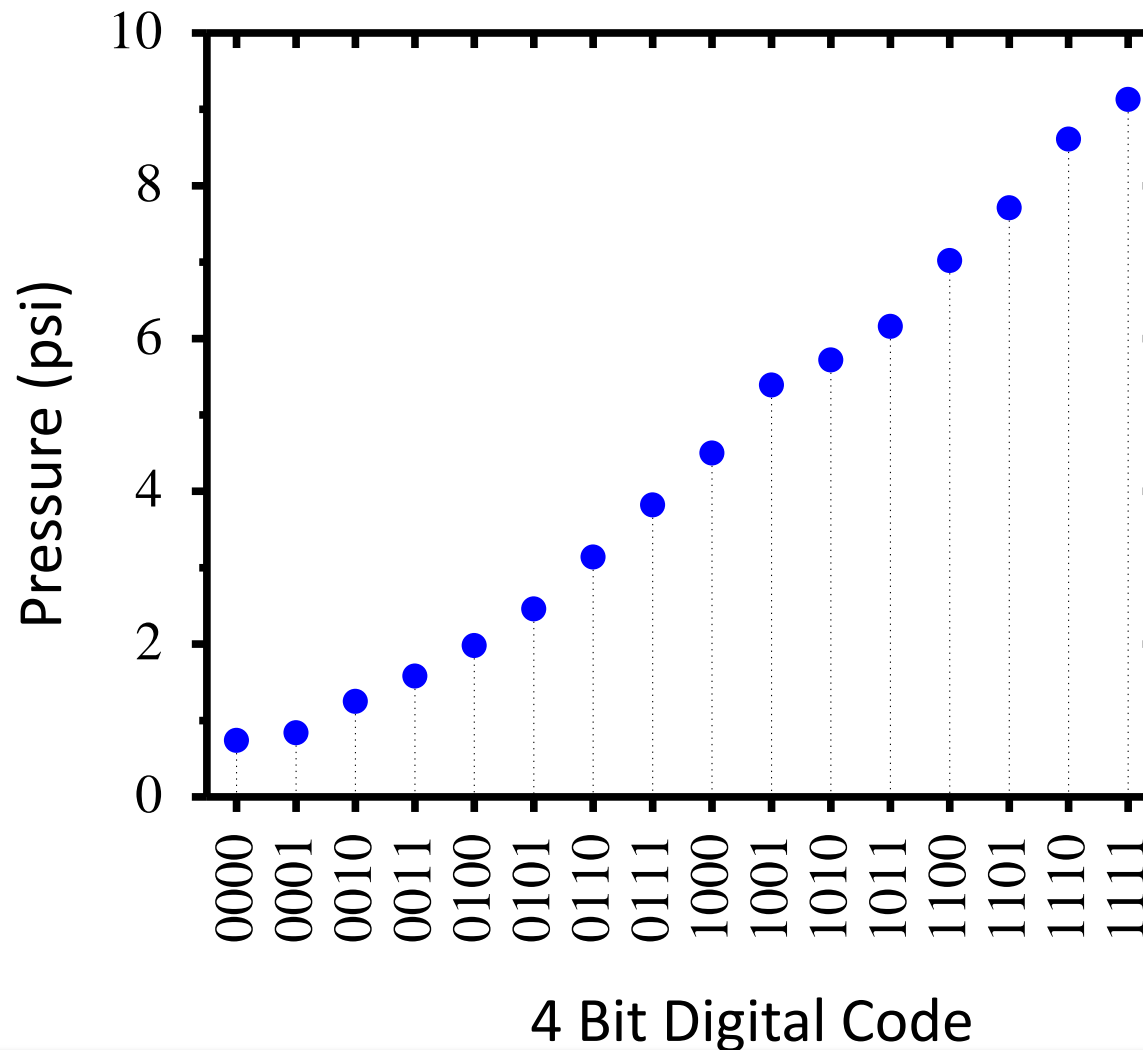


# Measurement Setup

- Actuates DAC with a certain digital code
  - Focus on the center of the C2 diaphragm
- Connect the diaphragm to external pressure source
  - Adjust pressure until the same point comes in focus



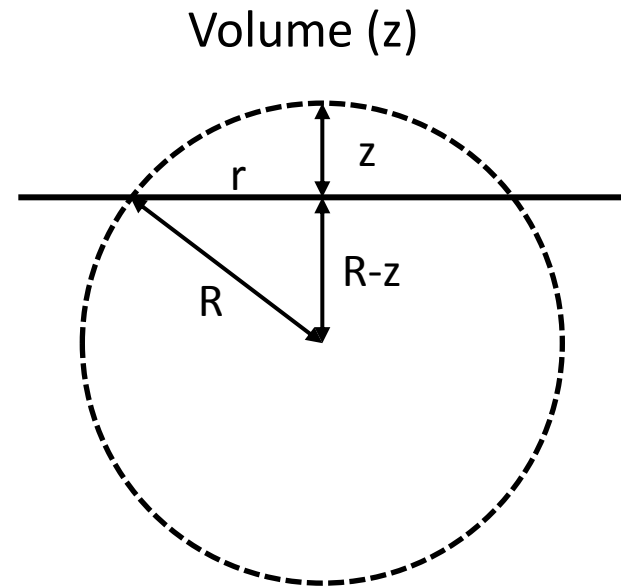
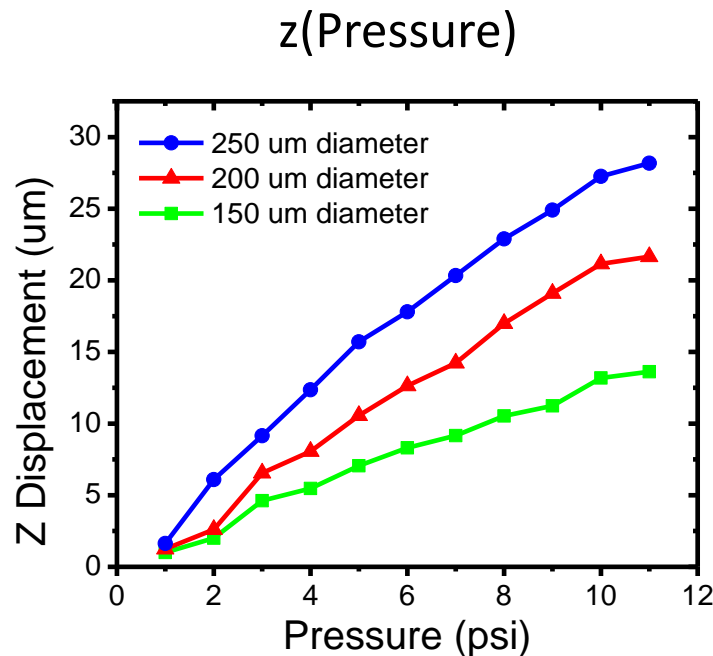
# Transfer Function (250 $\mu\text{m}$ diameter)





# Linearity of Fluidic Capacitors

Linearity of capacitors depends on linearity of Volume ( z (Pressure) )



$$Vol_{cone} = \frac{1}{3}\pi r^2(R - z) \quad \Omega = 2\pi(1 - \cos\theta)$$

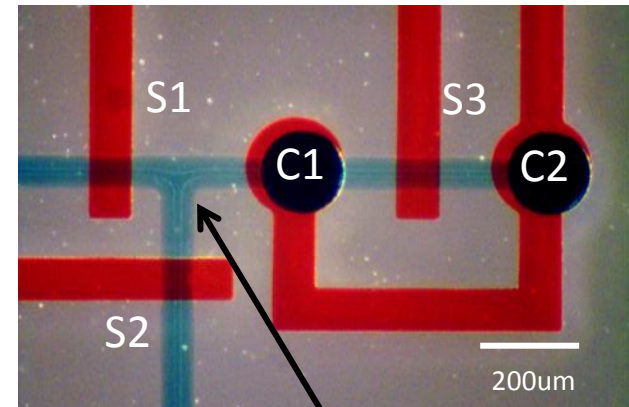
$$Vol_{solid\ angle} = \frac{4}{3}\pi R^3 \frac{\Omega}{4\pi} \quad R = \frac{z^2 + r^2}{2z}$$

$$Vol(z) = Vol_{solid\ angle} - Vol_{cone}$$

$$= \frac{1}{6}\pi(z^3 + 3r^2z)$$

# Fluidic Capacitor Mismatch

- Channels have capacitance too
  - Created simulation model
  - SPICE parameters from FEM
  - C1:C2 ratios
    - 1.50      150  $\mu\text{m}$
    - 1.17      200  $\mu\text{m}$
    - 1.08      250  $\mu\text{m}$
  - Next device will match these channels too
- Explains the non-linearity of transfer curve

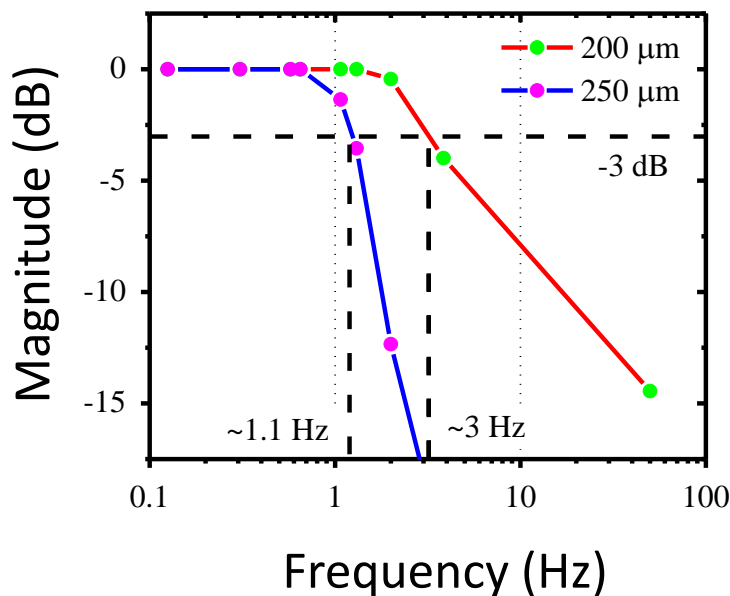


Extra  
Capacitance



# Frequency Response

- Speed of 4 bit DAC actuation
  - Measured with input code of 1010
  - Related to size of capacitive diaphragm
  - Depends on  $R_{\text{channel}} * C_{\text{membrane}}$



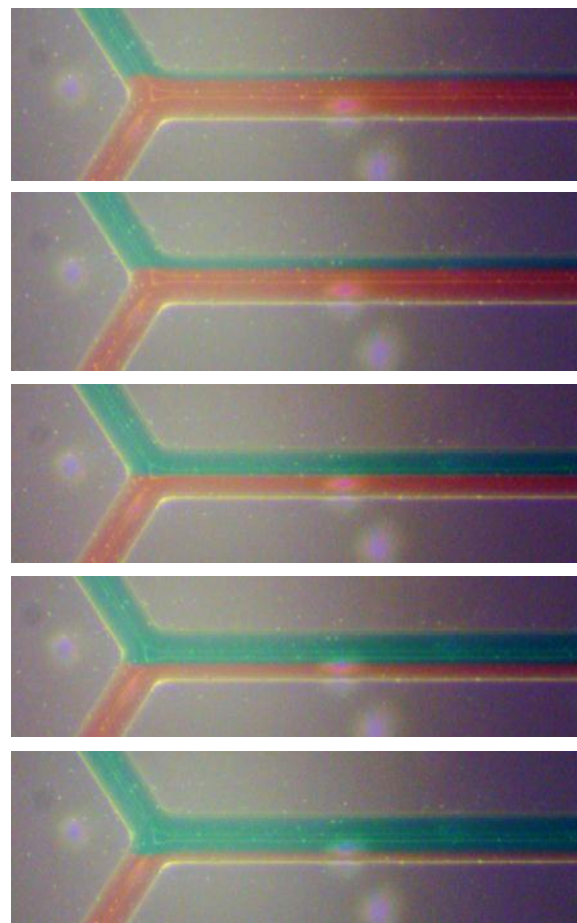
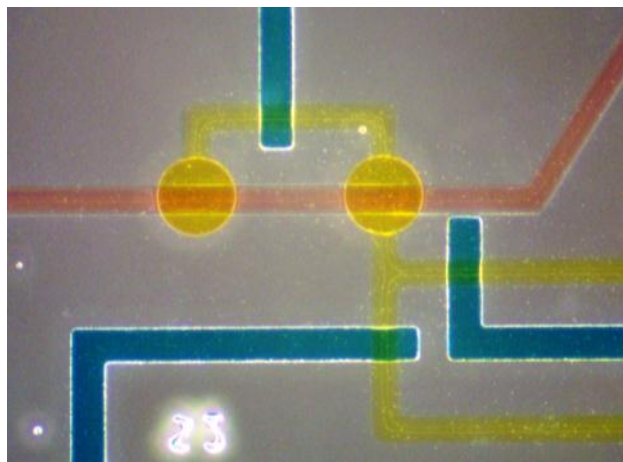
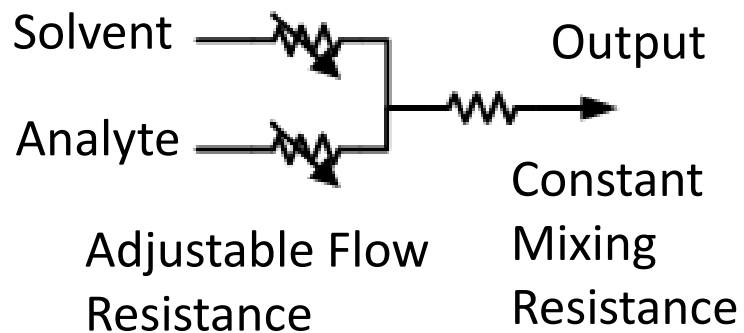
## Comparison With Published Flow-Based DACs

Chen et al.	Flow Based	0.5 Hz
Azizi et al.	Flow Based	0.3 Hz
This work	Pressure Based	3 Hz

Chen et al. Azizi et al.



# Laminar Flow Control





# Conclusions

- Microfluidics can leverage MOS circuit ideas
  - Like a simple serial pressure DAC
- Microfluidic Serial Pressure DAC provides:
  - Simple, small footprint pressure control
  - Can be converted into flow control
- Uses standard manufacturing flow
  - Nice addition to fluidic tool box

# Acknowledgement



## Microfluidic Simulation



Vladimir Kibardin

## Advisors



Prof. Stephen Quake



Prof. Mark Horowitz

## Microfluidic Foundry Staff



## Quake Lab Members

## Horowitz Lab Members

## Chemical and Biological Microsystems Society