# A Novel Micromachined Flow Sensor Using Periodic Flapping Motion of a Planar Jet Impinging on a V-shaped Plate

Gwo-Bin Lee, Tzu-Ying Kuo, and Wan-Yu Wu

Department of Engineering Science
National Cheng Kung University
Tainan, Taiwan, R.O.C

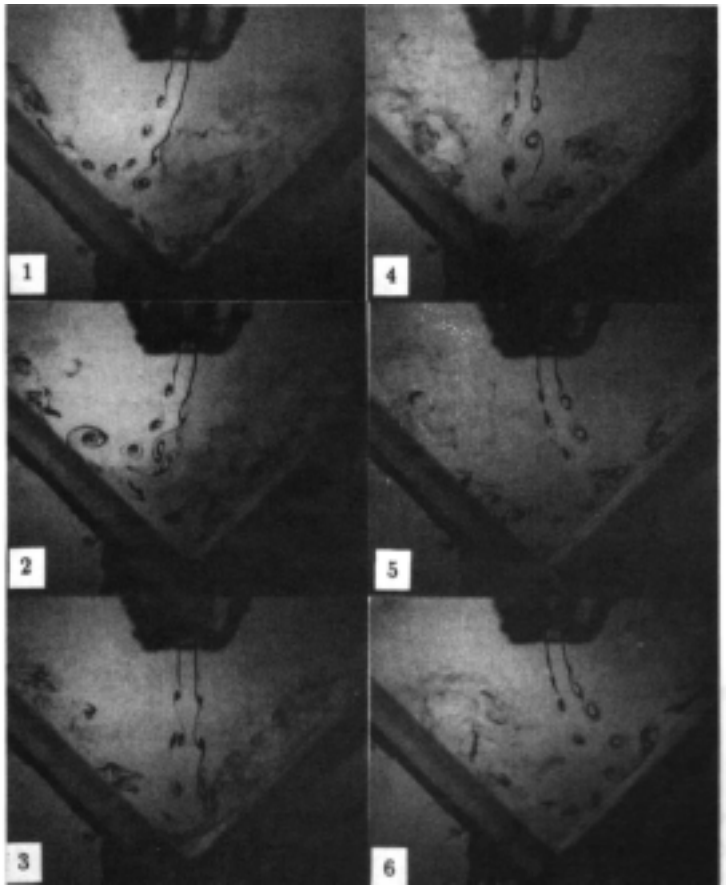
Email: gwobin@mail.ncku.edu.tw
http://140.116.175.13

# Outline

- **Introduction**
- **Design and fabrication of micro flow sensors**
- **Experimental data**
- **Conclusions**

# *Introduction*

Water channel experiment




•Impinging jet column appears to flap in a periodical motion with time.

Strouhal number

$$S_t = \frac{f_F L}{U_j} = const$$

Frequency --> velocity

$f_F$: flapping frequency

*Uj*: flow velocity

L: distance from apex of V-shaped plate to nozzle exit

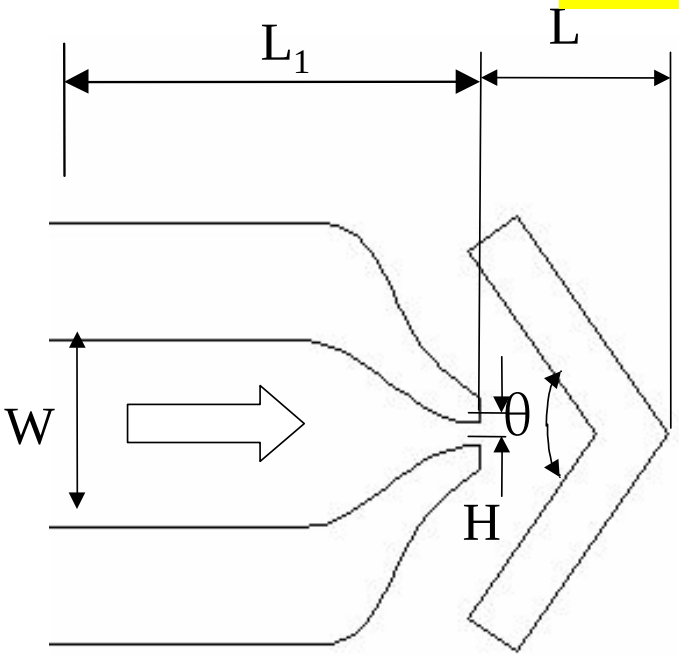
# Motivation

- Most micro flow sensors encounter a serious problem while measuring extremely small volumes of flows since low signal to noise ratio is inherent while measuring DC current or voltage.

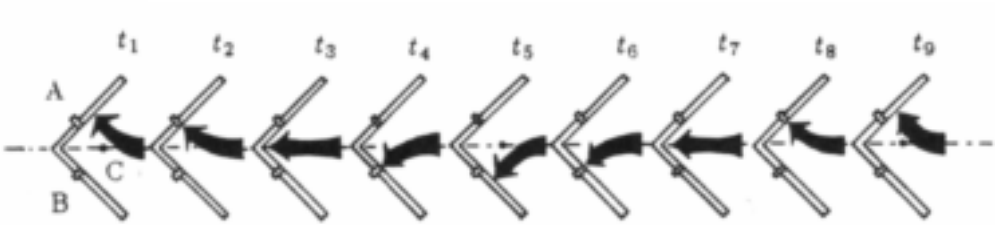
- The present study is therefore aimed to demonstrate a novel micromachined flow sensor capable of detecting extremely small amounts of volumetric flow rate ( down to 2 nl/s) and extra-low fluid flow velocity ( 0.15 mm/s).

- The innovative flow sensor detects a periodic flapping motion of a planar jet impinging on a V-shaped plate. Instead of detecting DC current or voltage signals induced by small volumes of flow, the micro flow sensor detects the oscillating frequency of the periodic flapping jet, resulting in a higher sensitivity and a larger dynamic range than existing products.

# Sensor design



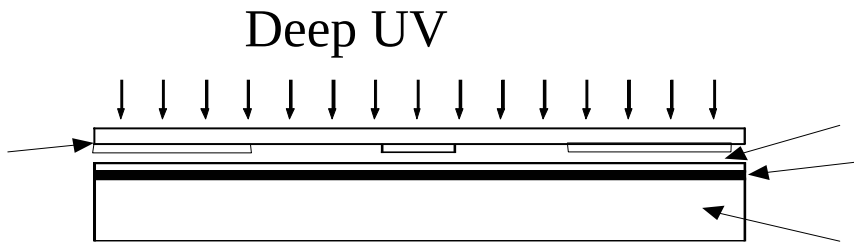

- Planar micro chamber integrated with built-in sensors
- Flapping frequency detected by sensors




| Sensors | W (μm) | H (μm) | L (μm) | L/H | θ (°) |
|---|---|---|---|---|---|
| 1 | 2250 | 360 | 2790 | 7.75 | 70 |
| 2 | 2250 | 360 | 1440 | 4 | 110 |

# Fabrication Process

(1) Lithography




(2) PR developing

(3) Cr etching

(4) PR stripping

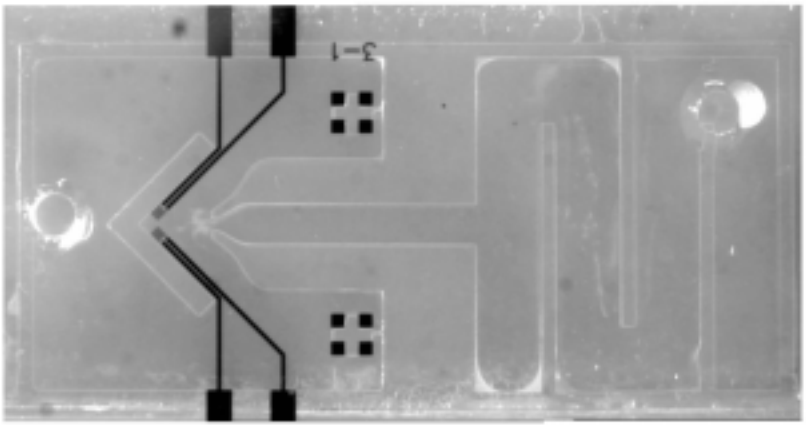
(5)quartz etching

(6) deposition/patterning of sensing resistors

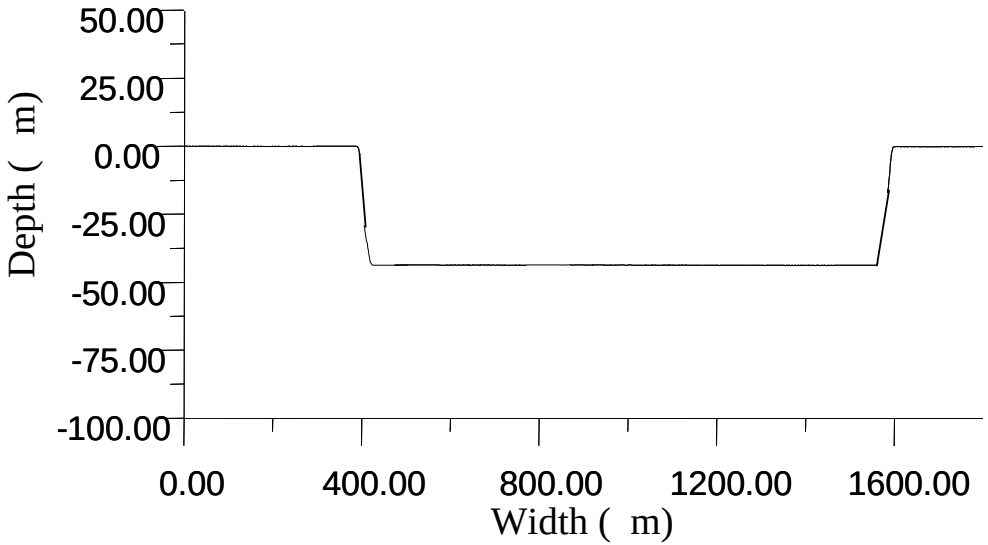
(7) drilling and bonding

# Micro flow sensor

## Picture




## Surface profile

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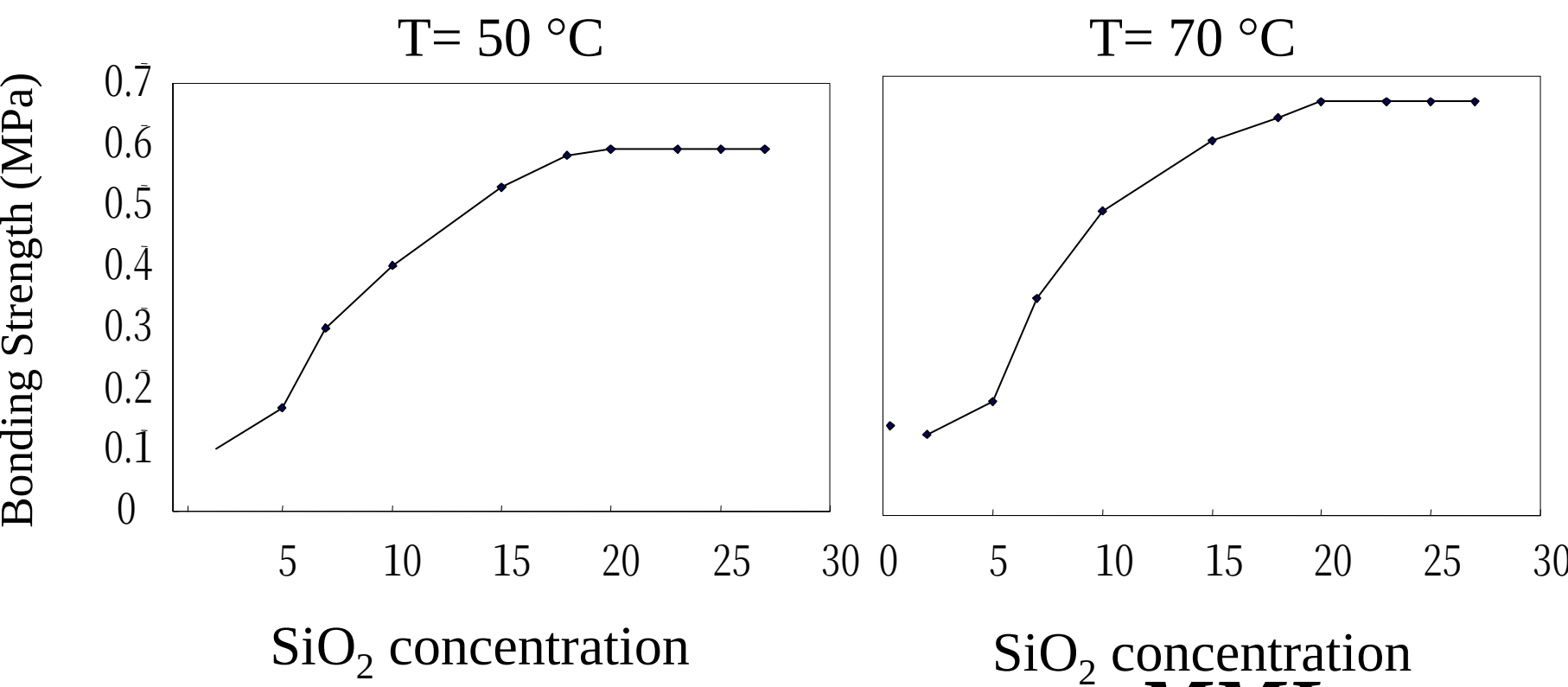
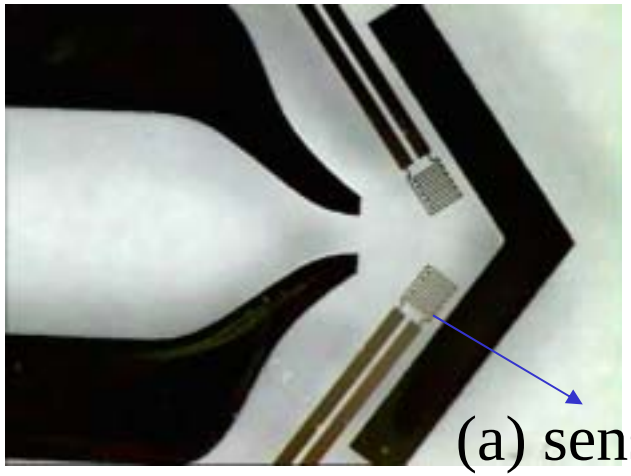
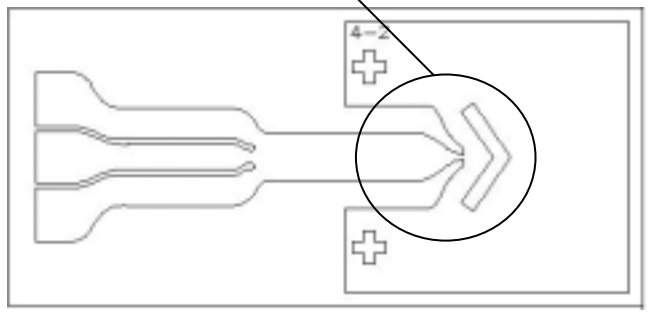
# Bonding Strength

- Low-temperature bonding technique for quartz substrates
- Sodium silicate solution ($SiO_2$:NaOH) spin-coated on the surface
- Heated for at least 8 hours.

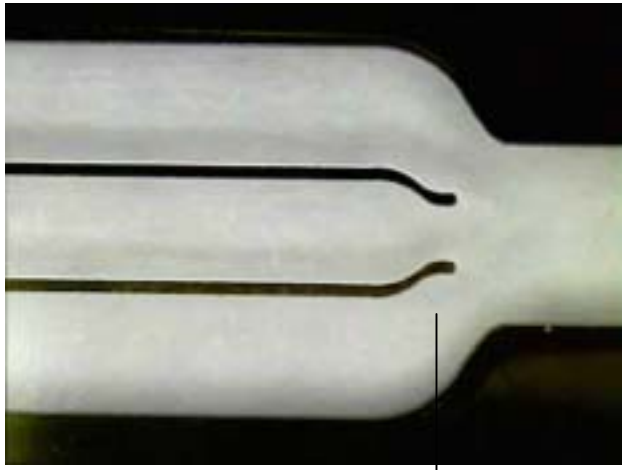


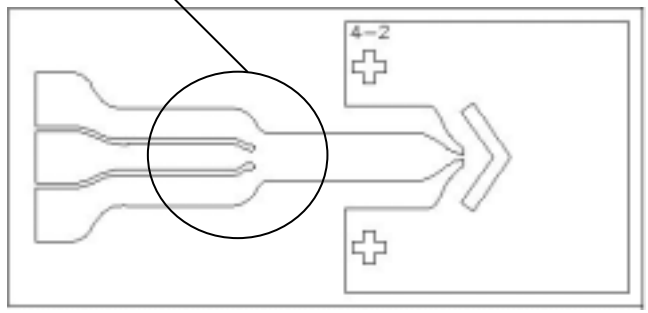
# Close-up picture of the sensor





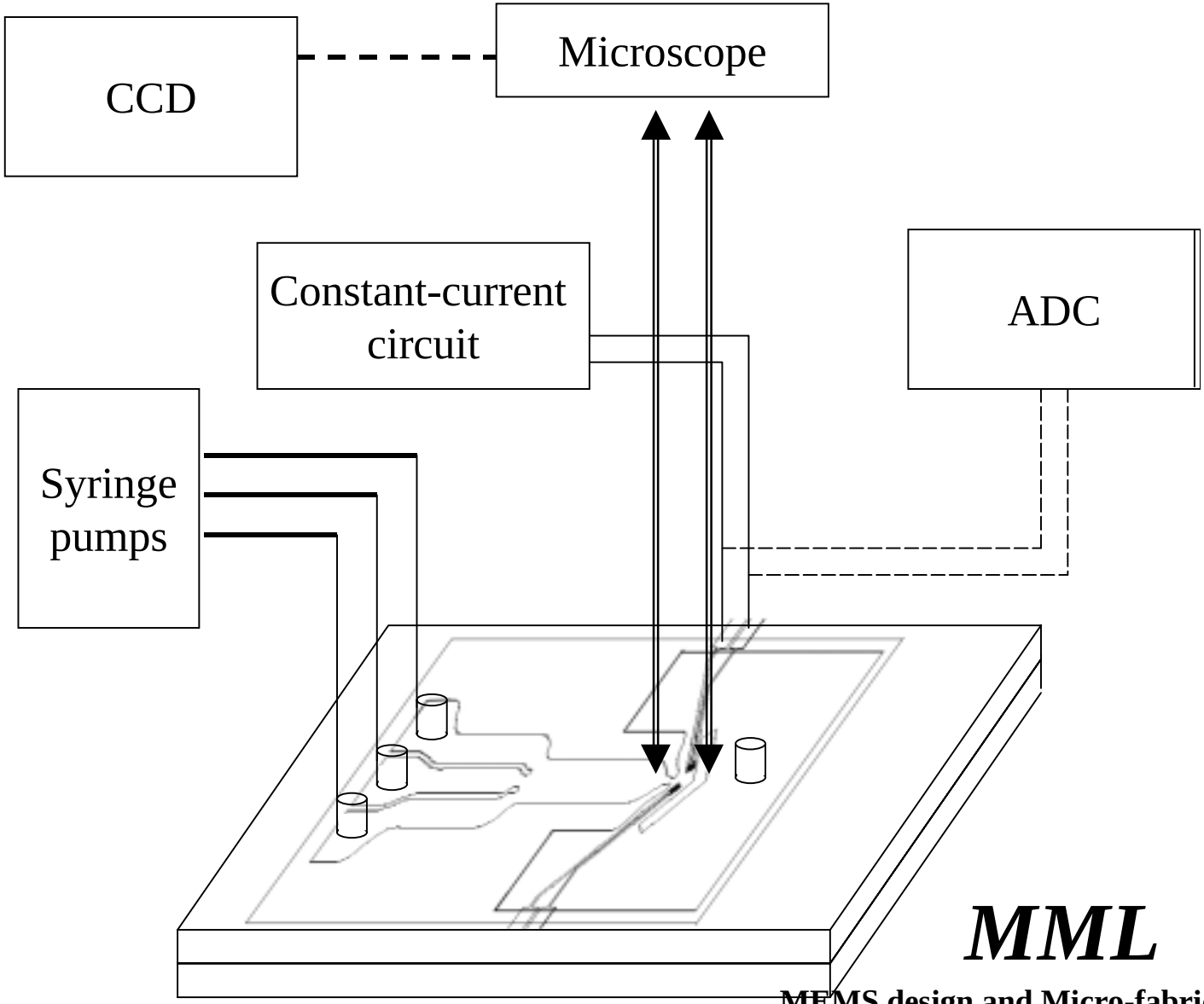
(a) sensing resistors



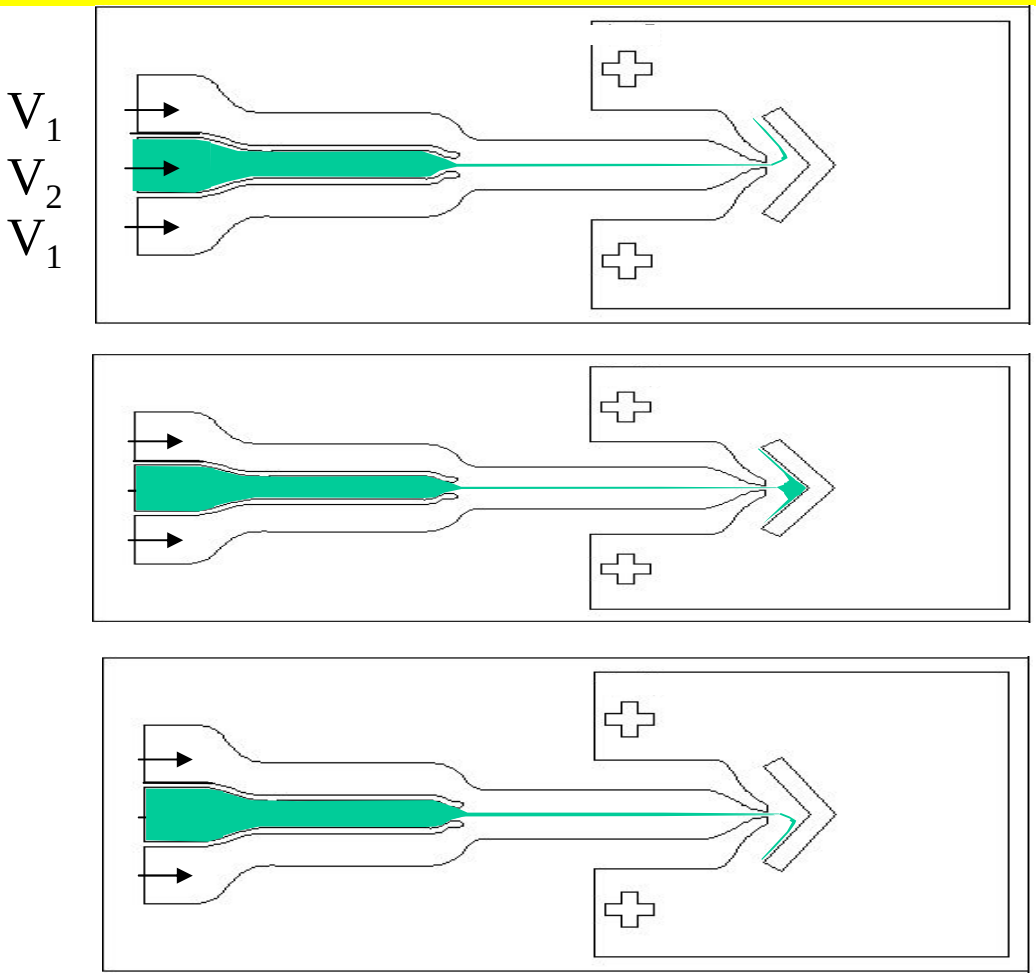


(b) convergent nozzles

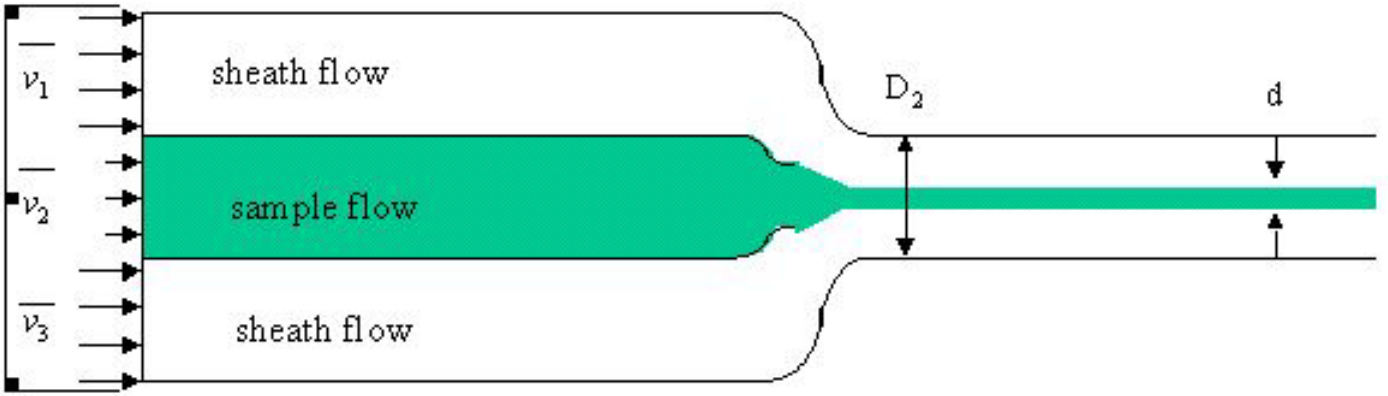
# Experimental setup



# Schematic representation of typical oscillograms of the jet-column flapping motion



# *Hydrodynamic focusing inside a flow cytometer*




- Center sample stream constrained by two surrounding sheath flows.

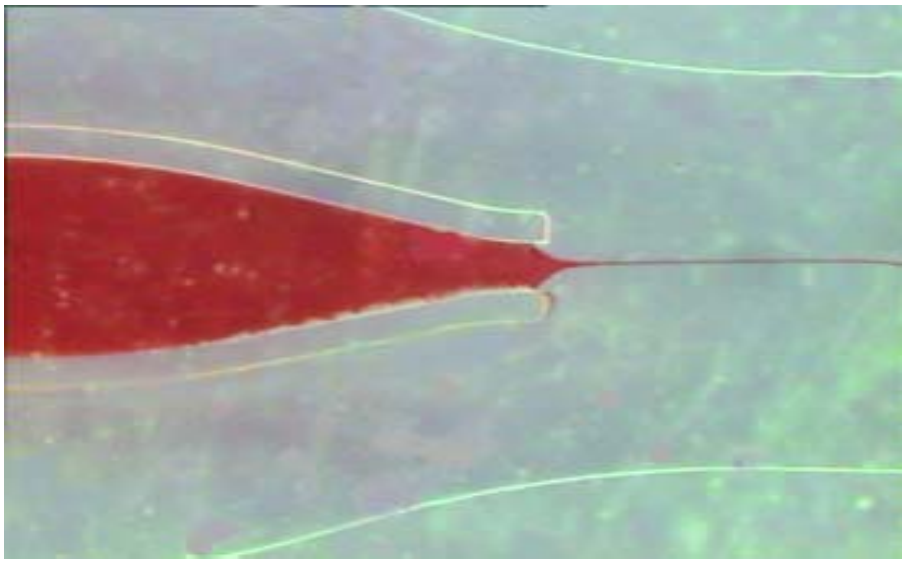
- Focused width can be predicted by the following formula.

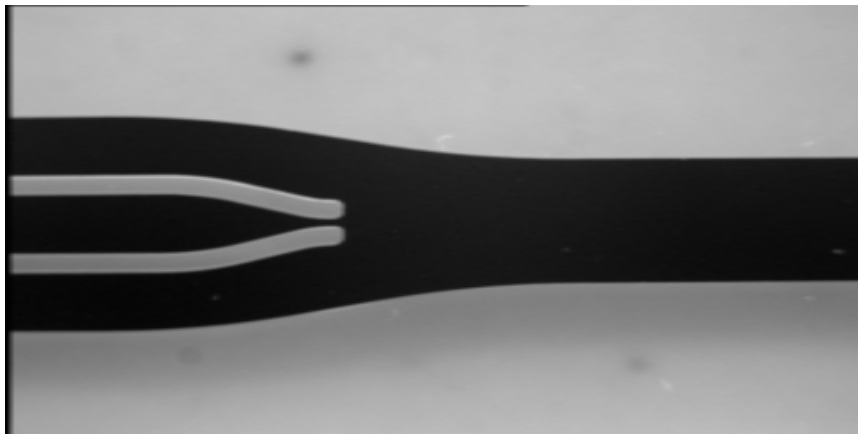
$$d = \frac{\rho_a D_a}{1.5\left(\rho_1 \frac{\bar{v}_1}{\bar{v}_2}\frac{D_1}{D_2} + \rho_2 + \rho_3 \frac{\bar{v}_3}{\bar{v}_2}\frac{D_{31}}{D_2}\right)}$$

*(Lee et al. 2001, ASME)*

# *Hydrodynamic focusing*

*Micro chip*



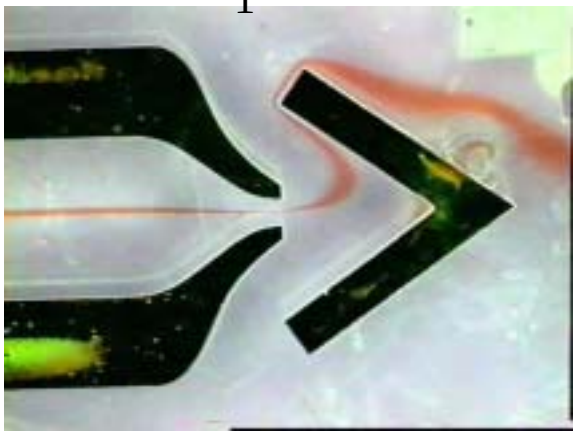
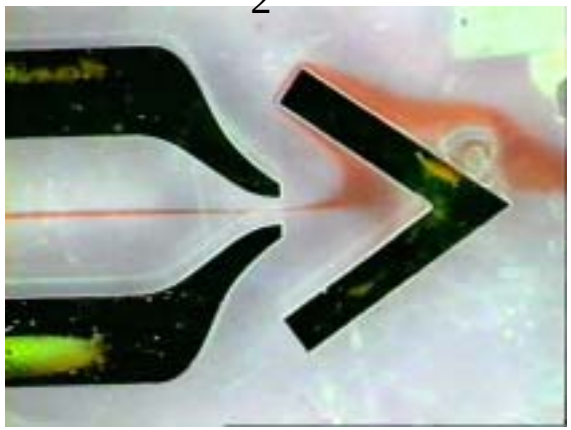
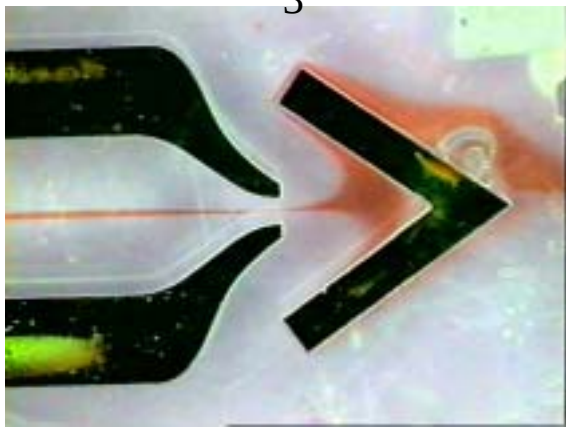


•the size of focused sample stream can be reduced to about 3 μm

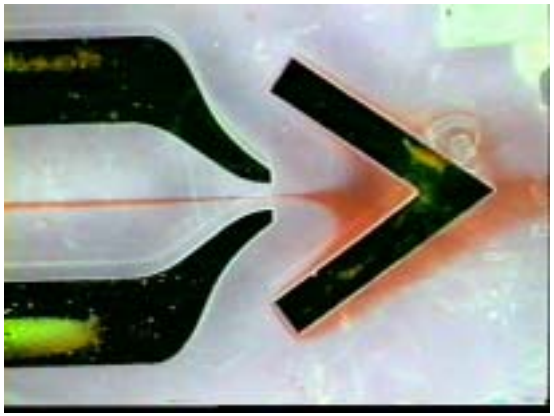
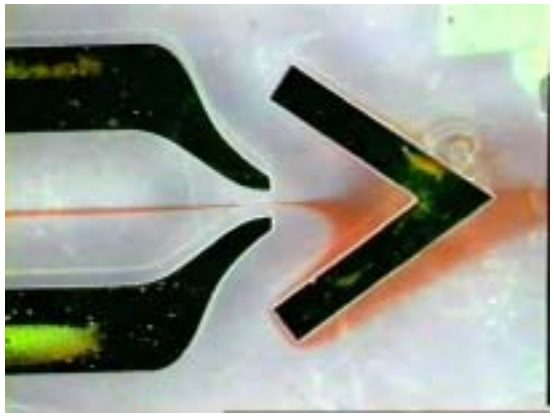
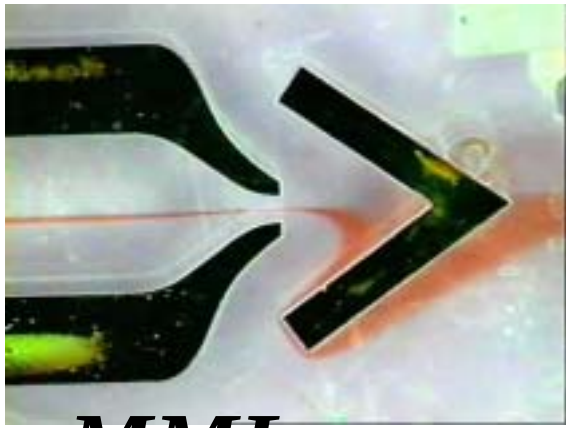
# Flapping motion of an impinging jet

## Sensor #1

$t_1$ $t_2$ $t_3$

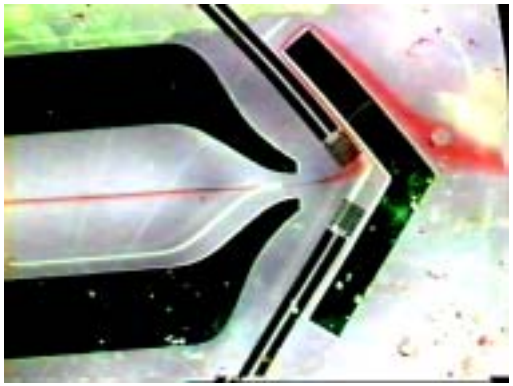




$t_4$ $t_5$ $t_6$

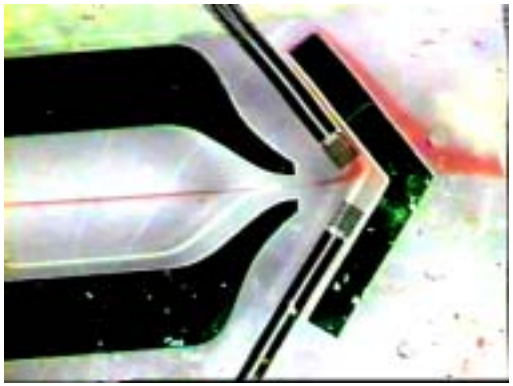




# Flapping motion of an impinging jet

## Sensor #2

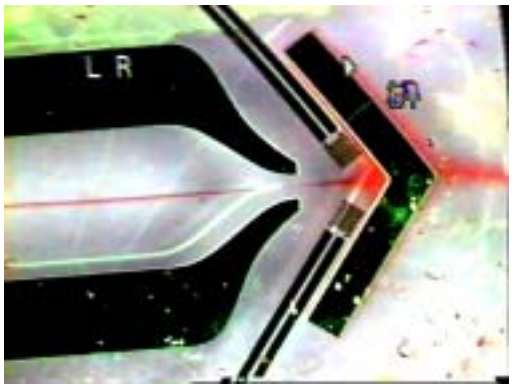


t1



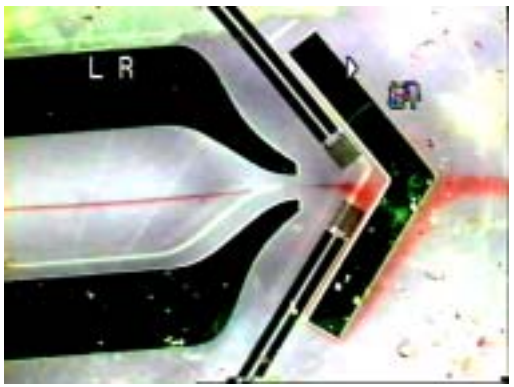
t2


t3




t4


t5




t6

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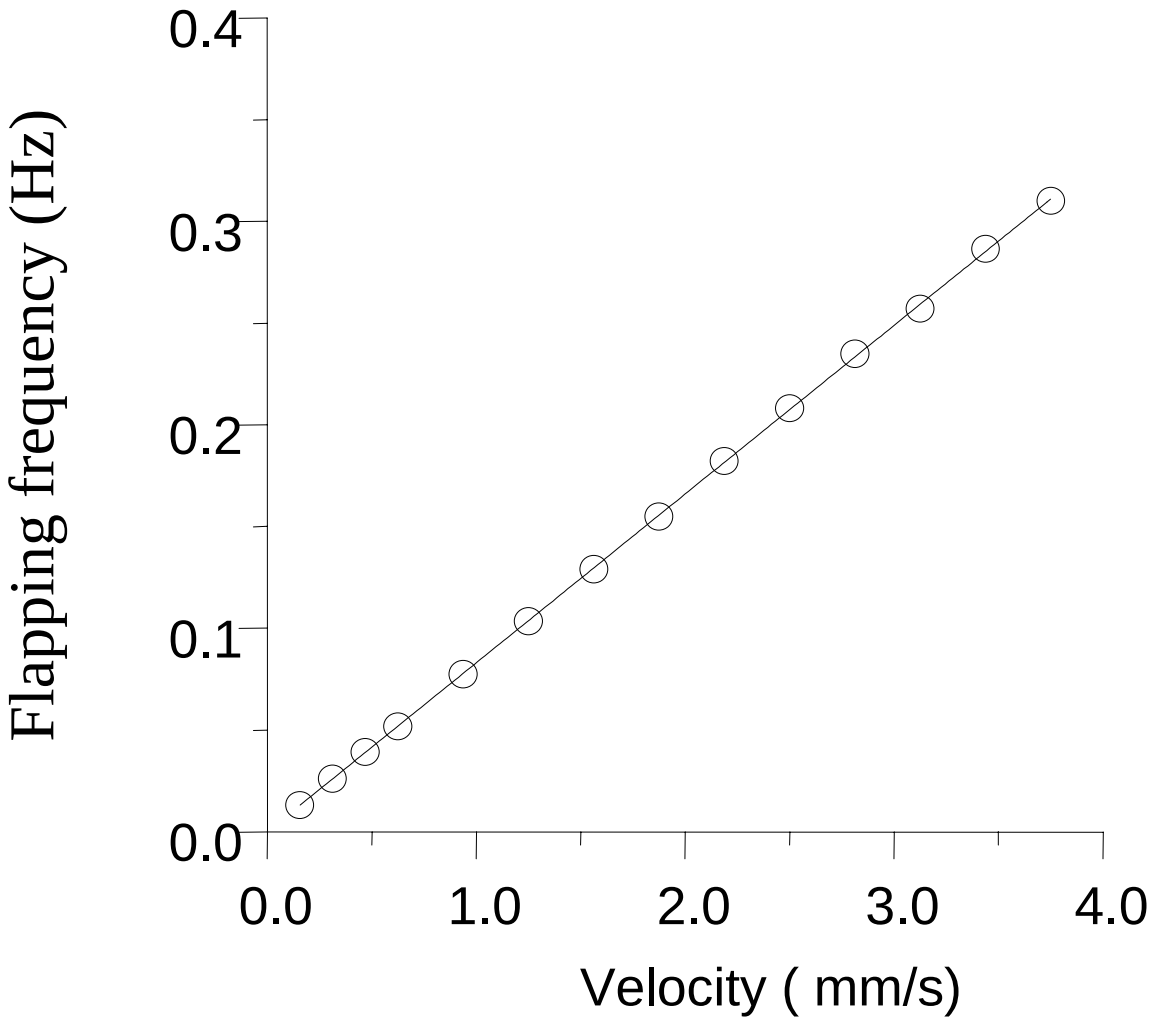
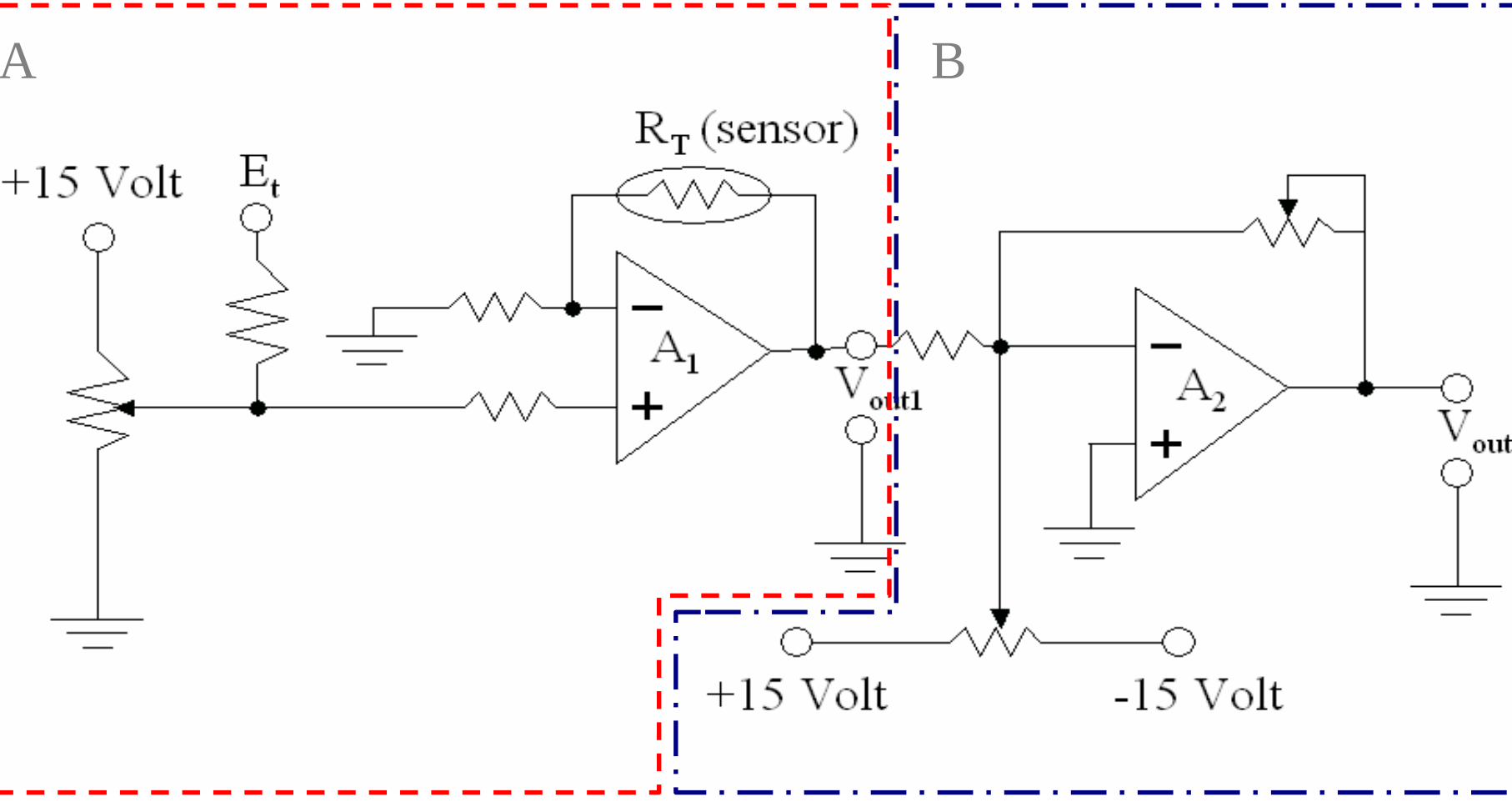
# Experimental Data

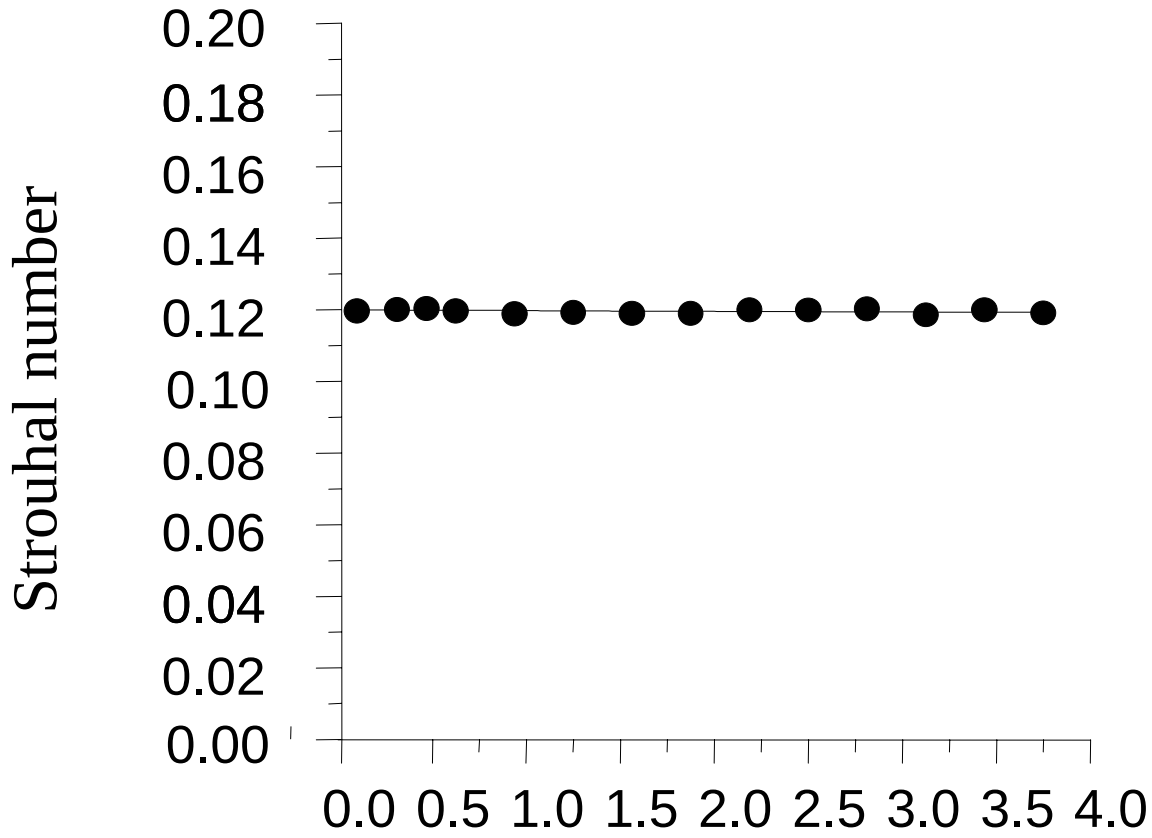



- Frequency is linearly proportional to velocity

# Constant-current Driving Current



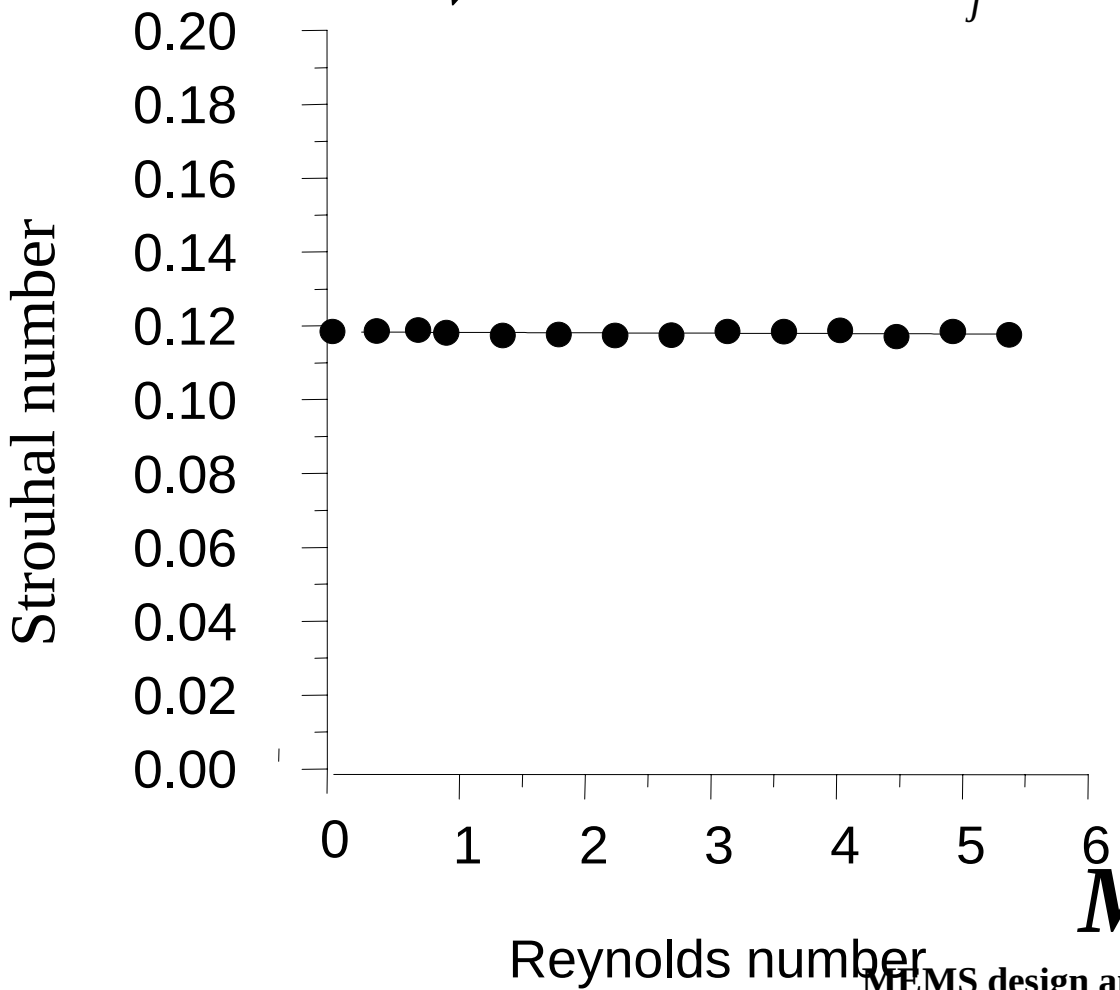
# Velocity vs. Strouhal number




Strouhal number= constant

# Reynolds number vs. Strouhal number

$$\mathrm{Re} = \frac{U_j L}{\nu} \qquad S_t = \frac{f_F L}{U_j}$$



# Conclusions

- Flapping motion of an planar jet impinging on a V-shaped plate, was used for flow sensing.
- A pair of sensing resistors were integrated with a convergent nozzle and a V-shaped plate downstream.
- Two methods were used to verified the performance of the sensor.
  - (a) Flow visualization
  - (b) Electronic sensing
- Flow velocity is still linearly proportional to the frequency of the jet flapping motion in microfluidic device.
- It is the first time that low-Reynolds-number flow is reported with a flapping motion for flow impinging on a V-shaped plate.