Environmentally Benign Deposition of Photoresist and Low-k Dielectrics

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Outline

- Motivation & Objective
- Approach
- Micromachined ejector array fabrication
- Experimental set-up
- Experimental results
- Conclusion and future work

Motivation

- A large amount of photoresist, low-*k* and high-*k* dielectrics is wasted during spin coating.
- The same can be said for many chemicals used in IC manufacturing
  - Waste of expensive chemicals
  - Cost of disposal of hazardous waste
  - Environmental Pollution
- Our aim is to reduce this waste

Cost of Dispensed Photoresist Per Track

Photoresist	cost/gl	cost/cc	1cc/wafer	2cc/wafer	3cc/wafer	4cc/wafer
SPR 510	$560	$0.148	$69,021	$138,042	$207,064	$276,085
Apex E	$1,500	$0.396	$184,878	$369,757	$554,635	$739,513
DUV	$2,000	$0.528	$246,504	$493,009	$739,513	$986,017
DUV	$3,000	$0.793	$369,757	$739,513	$1,109,270	$1,479,026
DUV	$4,000	$1.057	$493,009	$986,017	$1,479,026	$1,972,035
DUV	$5,000	$1.321	$616,261	$1,232,522	$1,848,783	$2,465,043

Calculated for a wafer throughput per year for one track of (60 wafers/hr) (360 days/year)(0.90 track utilization)=466,560 wafers/year.

Photoresist	Viscosity (cSt)	Volume dispensed (cc)	Thickness (μm)	Final volume (cc)	Waste (%)
TOK	7.0	1.3	0.80	0.0251	98.1
AZ7511	10.1	2.1	1.08	0.0339	98.4
SPR505	8.2	1.4	0.60	0.0188	98.7
SPR507	12.3	1.9	0.84	0.0264	98.6
SPR508	13.9	2.1	1.00	0.0314	98.5
SPR510	18.6	2.1	1.20	0.0377	98.2
JSR061	18.0	2.1	1.06	0.0333	98.4
JSR300	55.0	2.4	3.20	0.1005	95.8

Rrom "How to minimize resist usage during spin coating," B. Lorefice *et al.*, SVG Photo Process Division, Semiconductor Intl., June 1998.

Objective

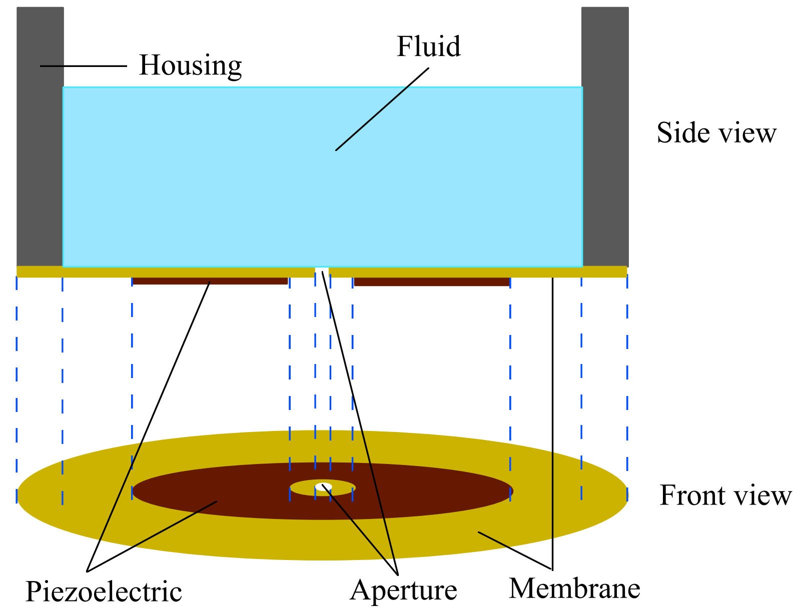
- Develop a fluid ejection system capable of depositing fluids with minimum or zero waste
- Drop on demand and continuous ejection
- Develop a coating system to demonstrate waste reduction with full coverage of wafers
- Demonstrate photoresist and low-*k* dielectric coating of 20 cm and 30 cm silicon wafers

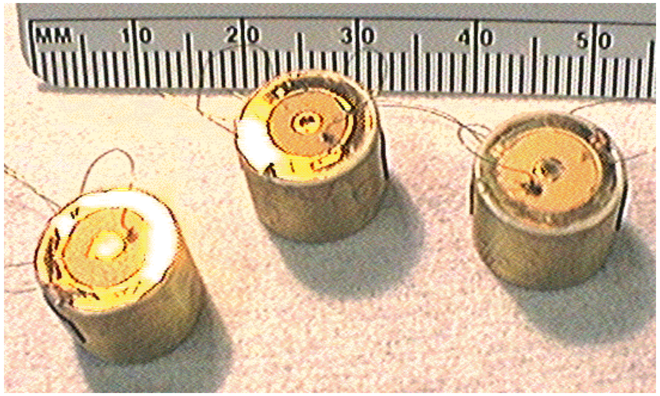
Approach

- Use flex-tensional ejectors for deposition
  - Design and implement micro-machined version with a single and multiple piezoelectric drivers
- Ejector requirements
  - Deposit low and high viscosity fluids
  - High flow rate
  - Compatible with most chemicals
  - Can be made using IC process technology

Large Scale Prototype

- Dimensions of demonstration device:
  - Diameter = 9 mm
  - Membrane thickness = 25 μm
  - Piezoelectric thickness = 15-25 μm
  - Piezoelectric inner diameter = 2 mm
  - Piezoelectric outer diameter = 6-7 mm
  - Orifice size = 50-200 μm
  - Operating frequencies: 9.5 kHz, 16.4 kHz, 19.0 kHz
  - Membrane material: brass, steel, silicon
  - Piezoelectric material: Murata SWM, Motorola PZT 3203HD, and lithium niobate
- Drop-on-demand and continuous modes of operation

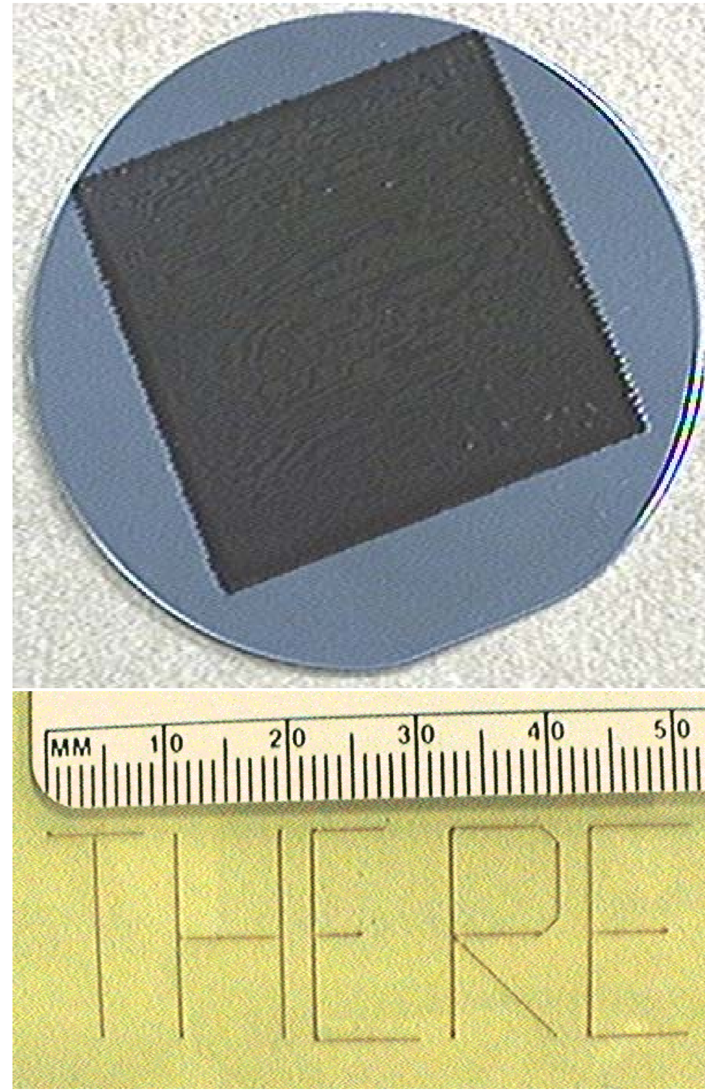




* G. Percin Ph.D. thesis, Stanford University, Dec. 2001

Photoresist Coverage of A Wafer

- Shipley Microposit® 1805, 1813, 1400-21, and 1400-27 photoresists with dynamic viscosities of 5, 20, 8, and 18 cSt, respectively.
- Thickness = 3.5 μm ± 0.15 μm
- Nonuniformity due to dust and dry lab environment
- Better results expected in solvent saturated chamber
- Direct write applications for MEMS
- Quick spinning after ejection may increase uniformity

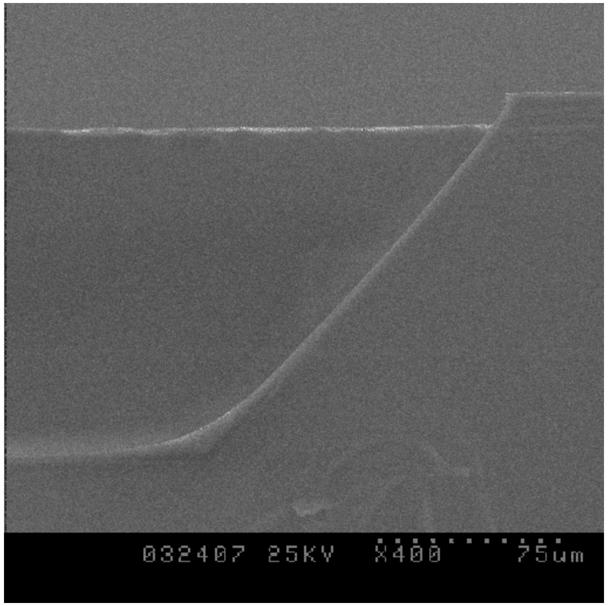


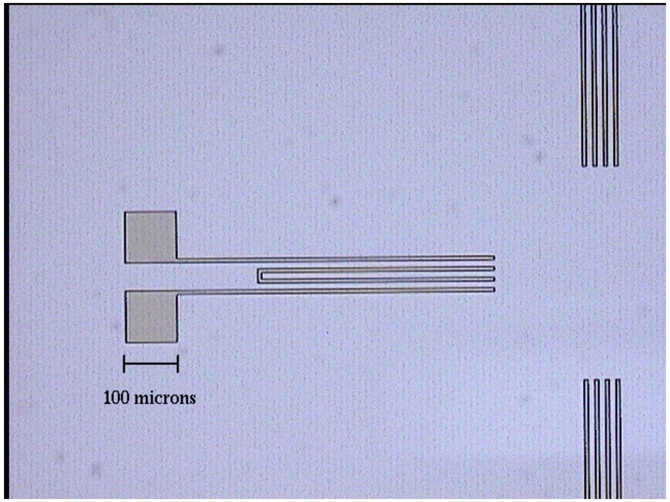
Direct write with photoresist, 350 μm-wide lines

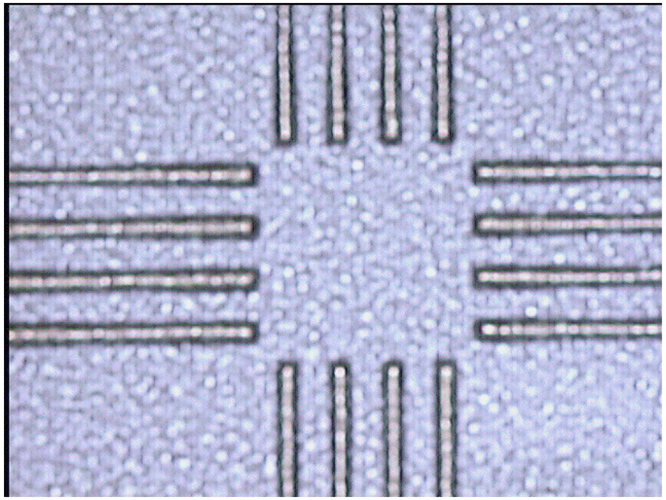
* G. Percin Ph.D. thesis, Stanford University, Dec. 2001

Deposited and Patterned Photoresist

- Shipley Microposit® 1813 photoresist (20 cSt)
- 10 µm wide lines & 10 µm spacing.
- Photoresist coverage of deep silicon trenches
- 2.5 µm thick photoresist



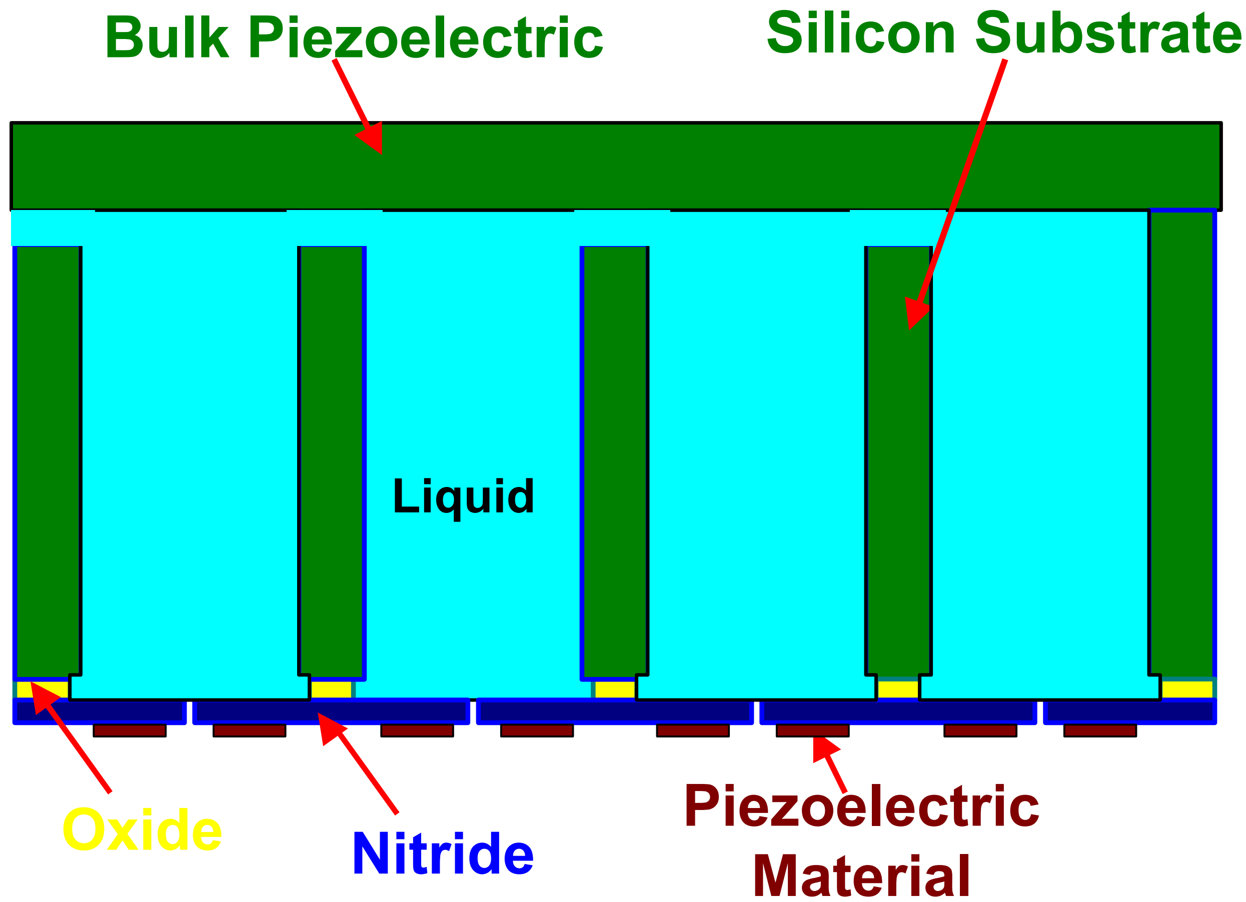




* G. Percin PhD thesis, Stanford University, Dec. 2001

Patterned resist at 150 µm deep Silicon trench

Previous Device Configuration



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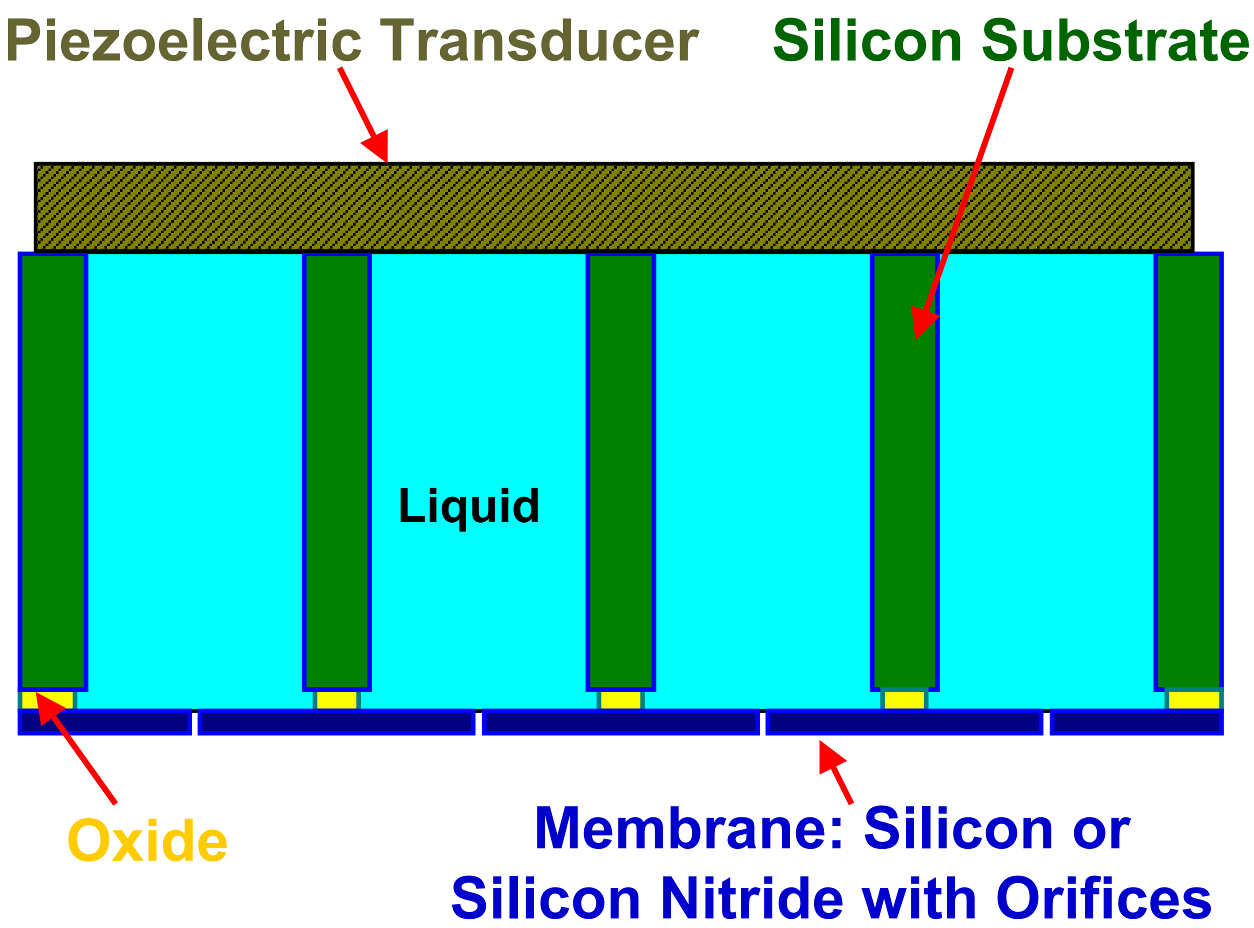
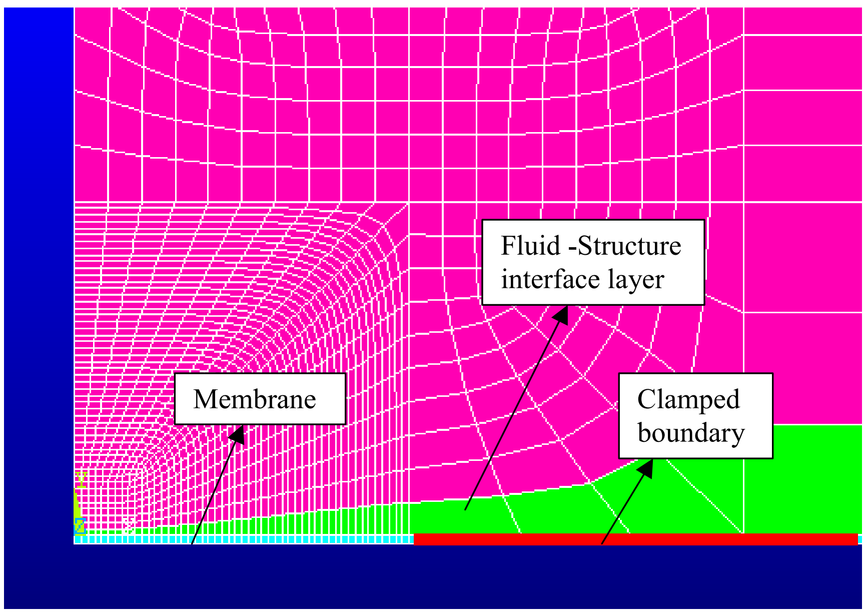
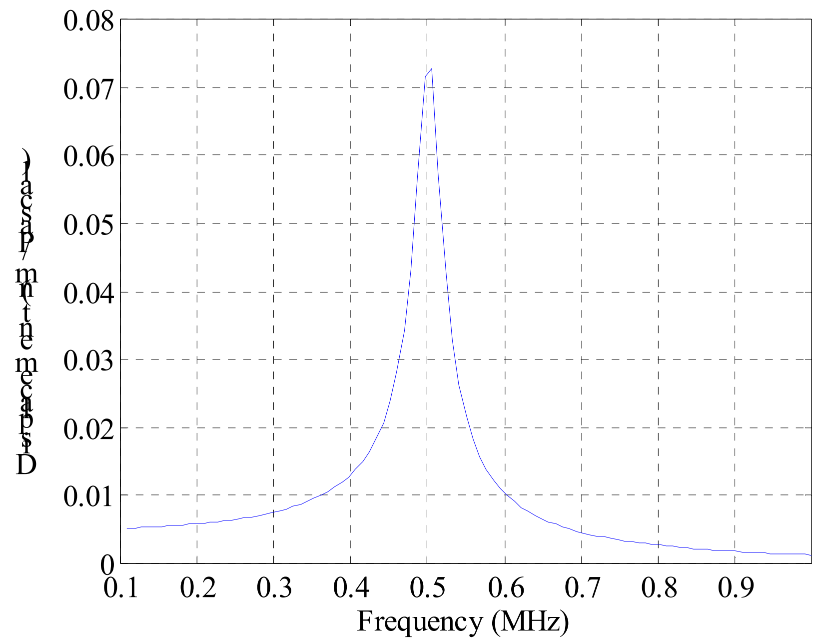
Micromachined Device Configuration



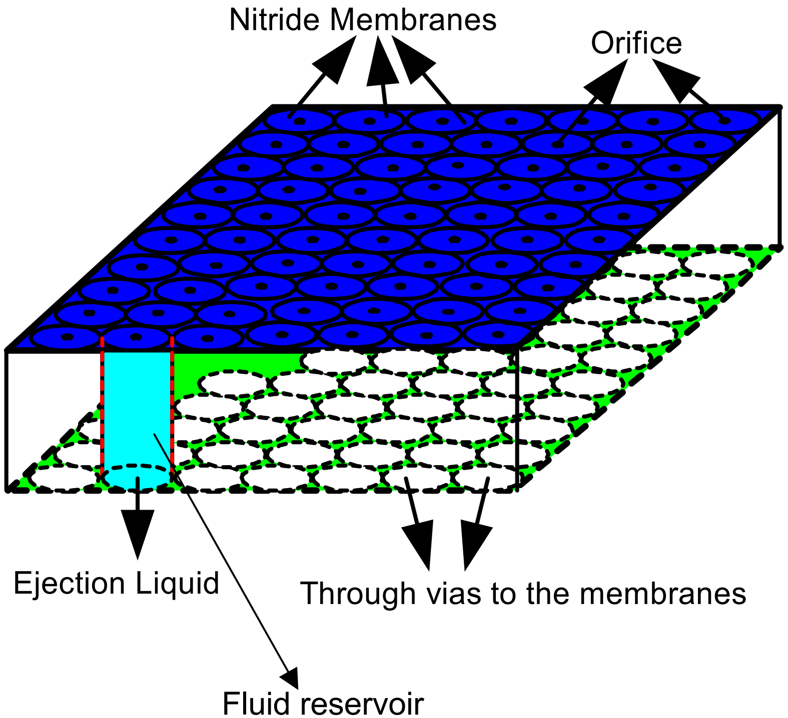
Finite Element Modeling of Ejector

FEM modeling of Si_3N_4 membrane that is 2 µm thick and 160 µm in diameter. Membrane and cavity resonance dictate operation at around 0.5 MHz for ejection.



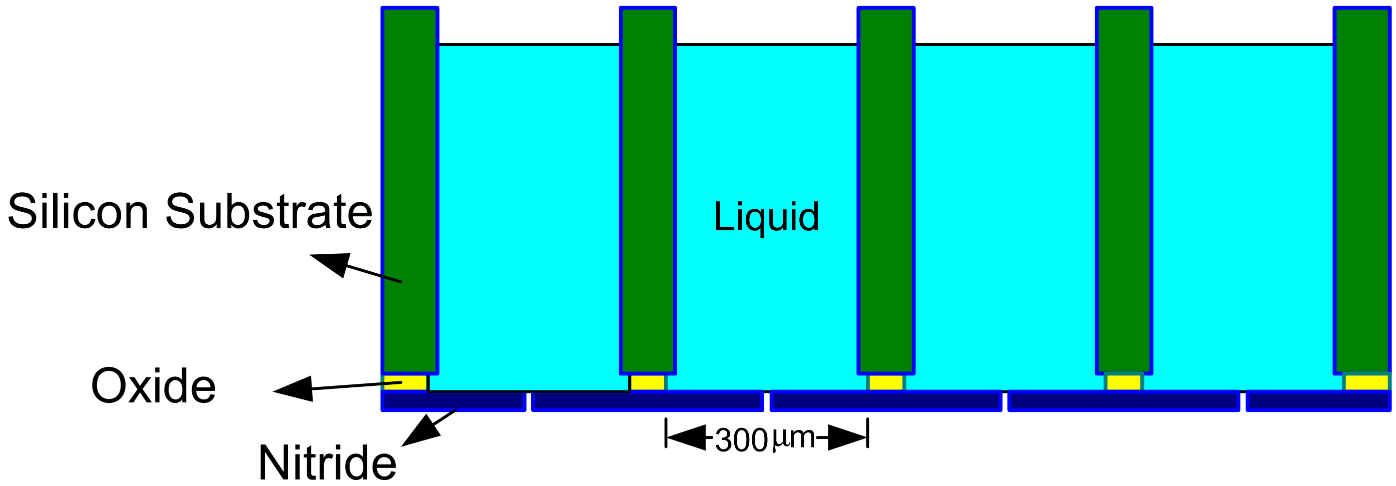


2D Micro-machined Array



- 2D array of ejectors
- Actuation by a transducer from behind the device
- Thin silicon nitride membrane
- Deep reactive ion etched reservoir
- High frequency operation for high flow rate (MHz)
- Drop-on-demand and continuous modes of operation

2D Micro-machined Array: Dimensions



Device Dimensions

Membrane Diameter : 300 µm
Membrane thickness : 2.1 µm
Orifice diameter : 10 µm
Operating frequencies: 470 kHz, 1.24 MHz, 2.26 MHz
Membrane material : $Si_3 N_4$

Fabrication Process

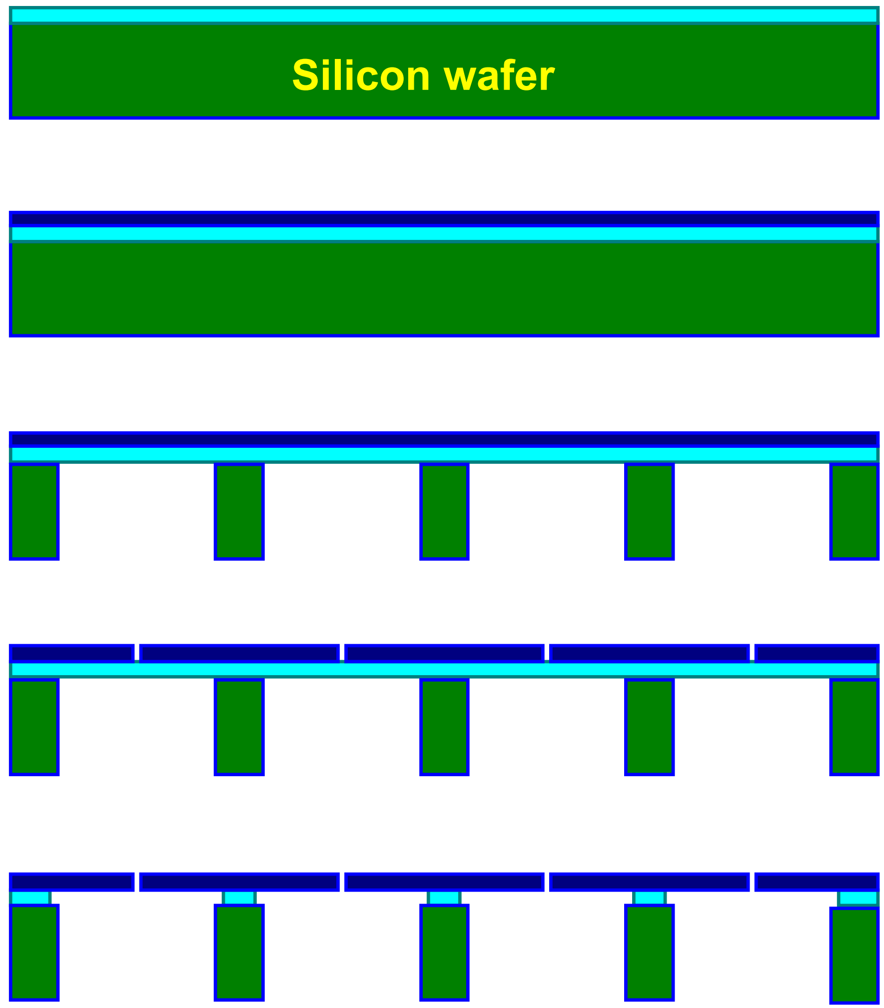
Oxide film deposition

Nitride film deposition

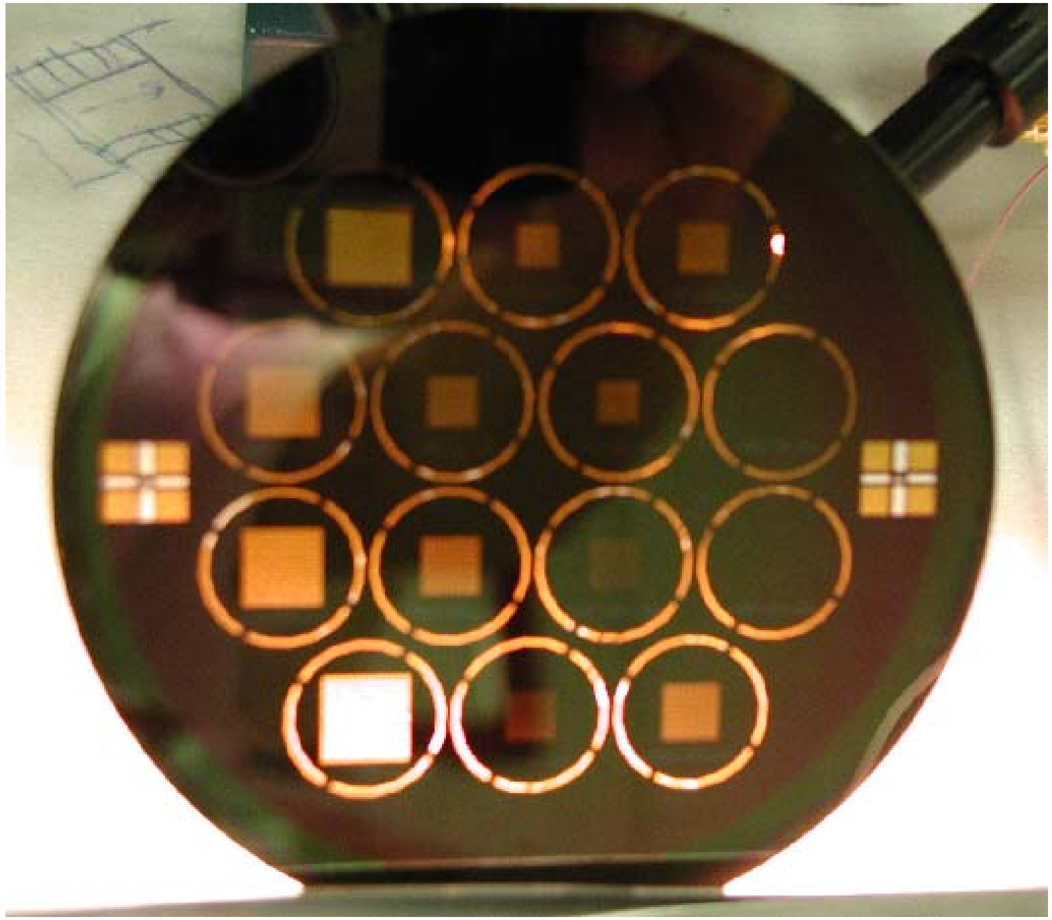
Silicon bulk etch

Orifice formation with dry etching

Oxide etching

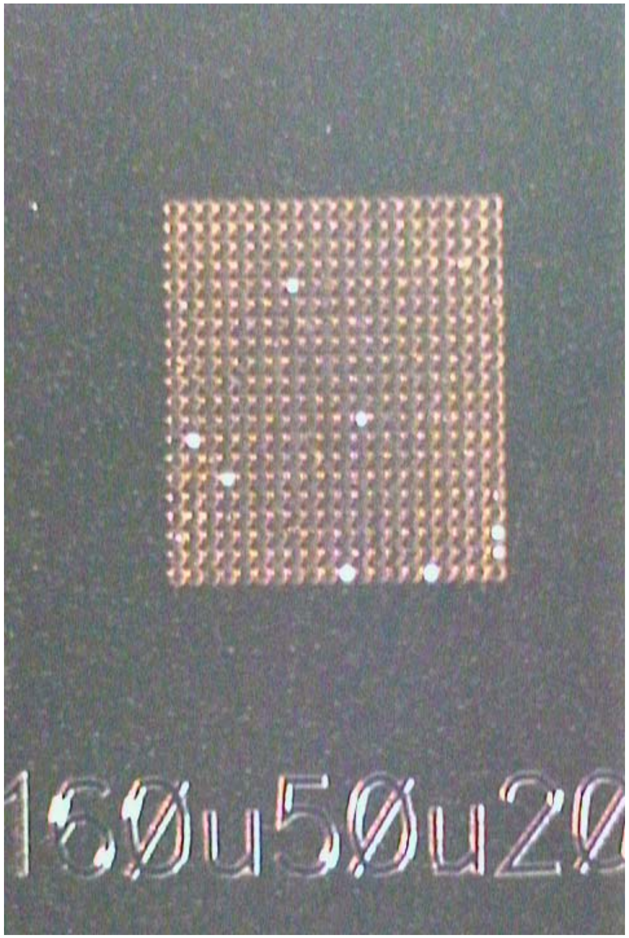


2D Micro-machined Array: Actual Devices



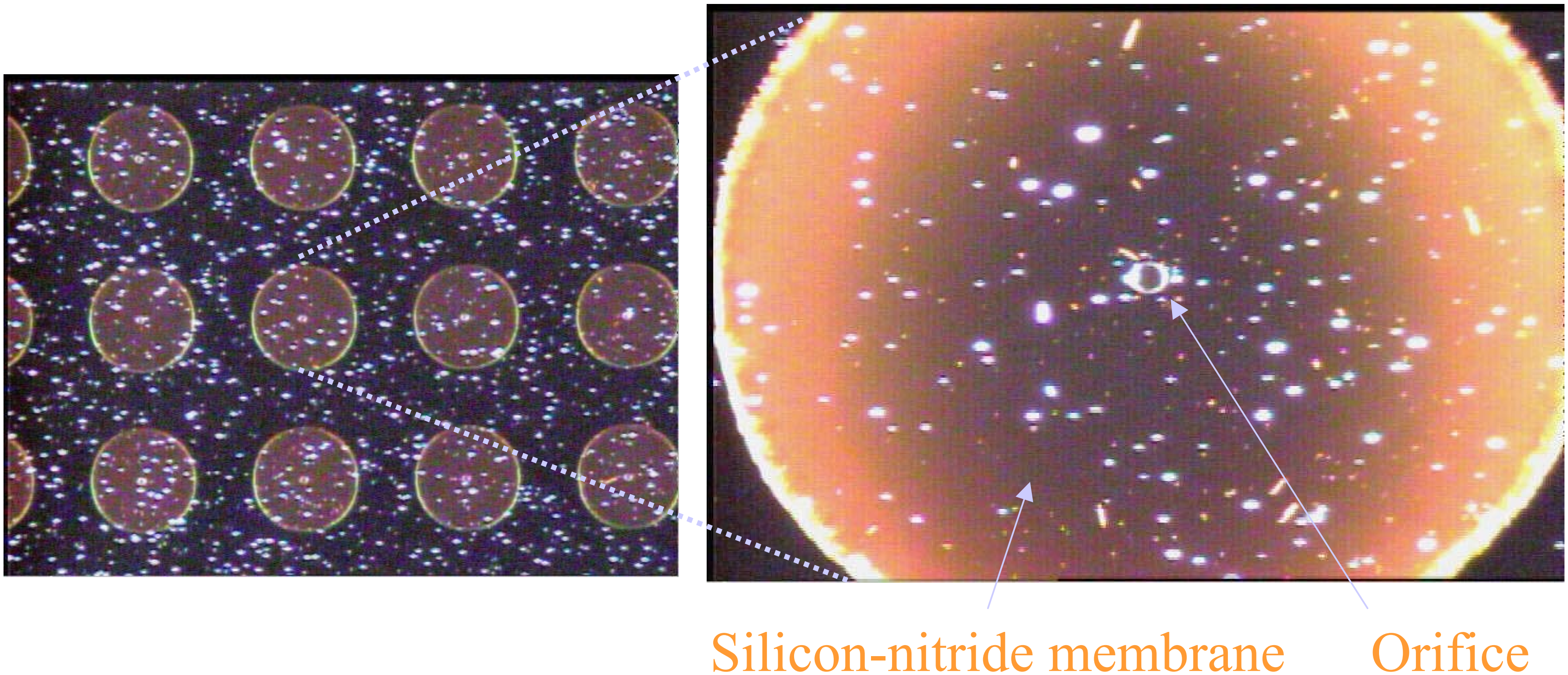
Various membrane radii and device sizes on a Silicon wafer

2D Micro-machined Array: Actual Device



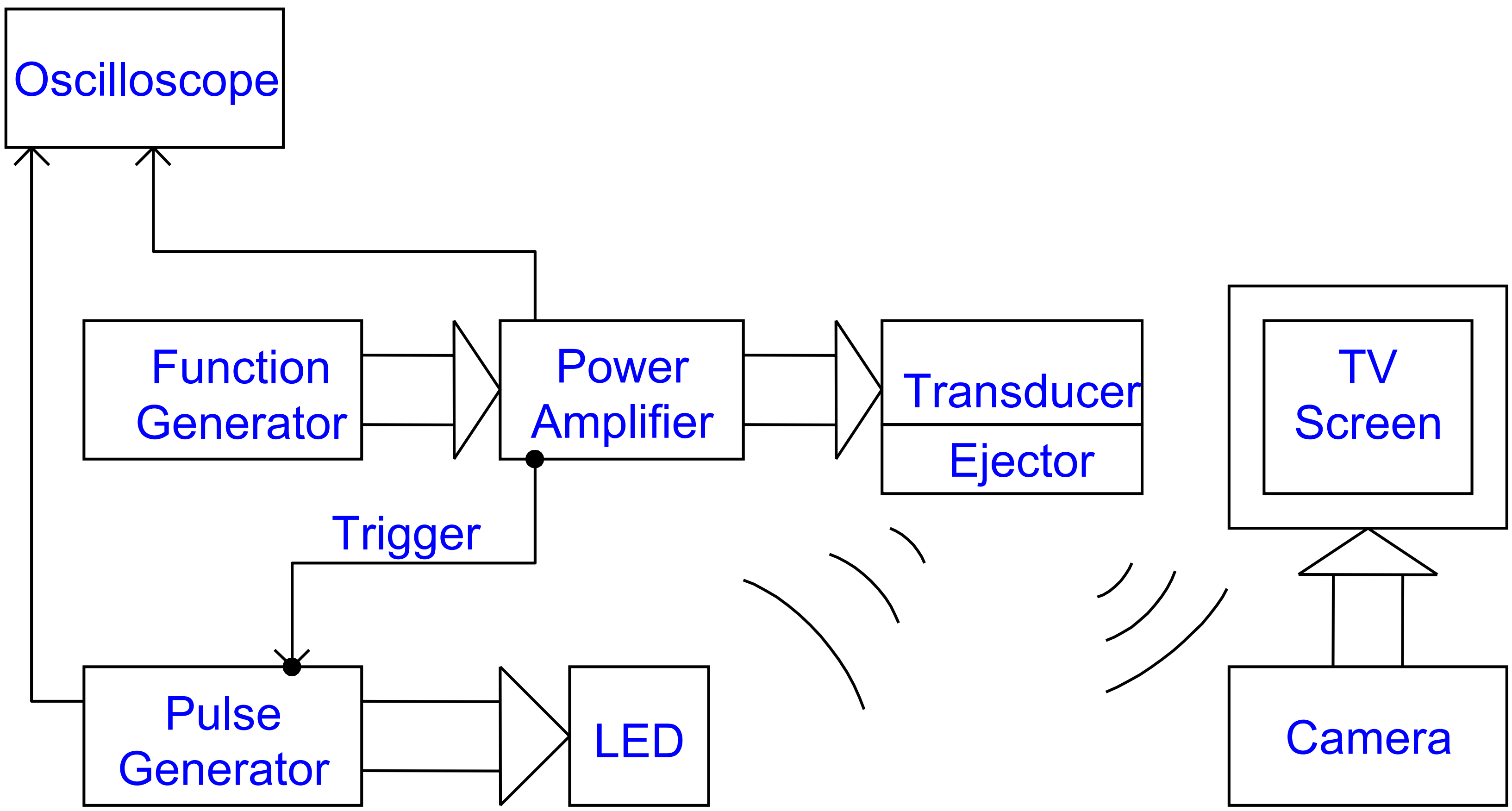
- 2D array of ejectors (20x20)
- The membrane diameter is 160 µm
- Orifice size is 10 µm
- Thin silicon nitride membrane
- Deep reactive ion etched reservoir

Membranes

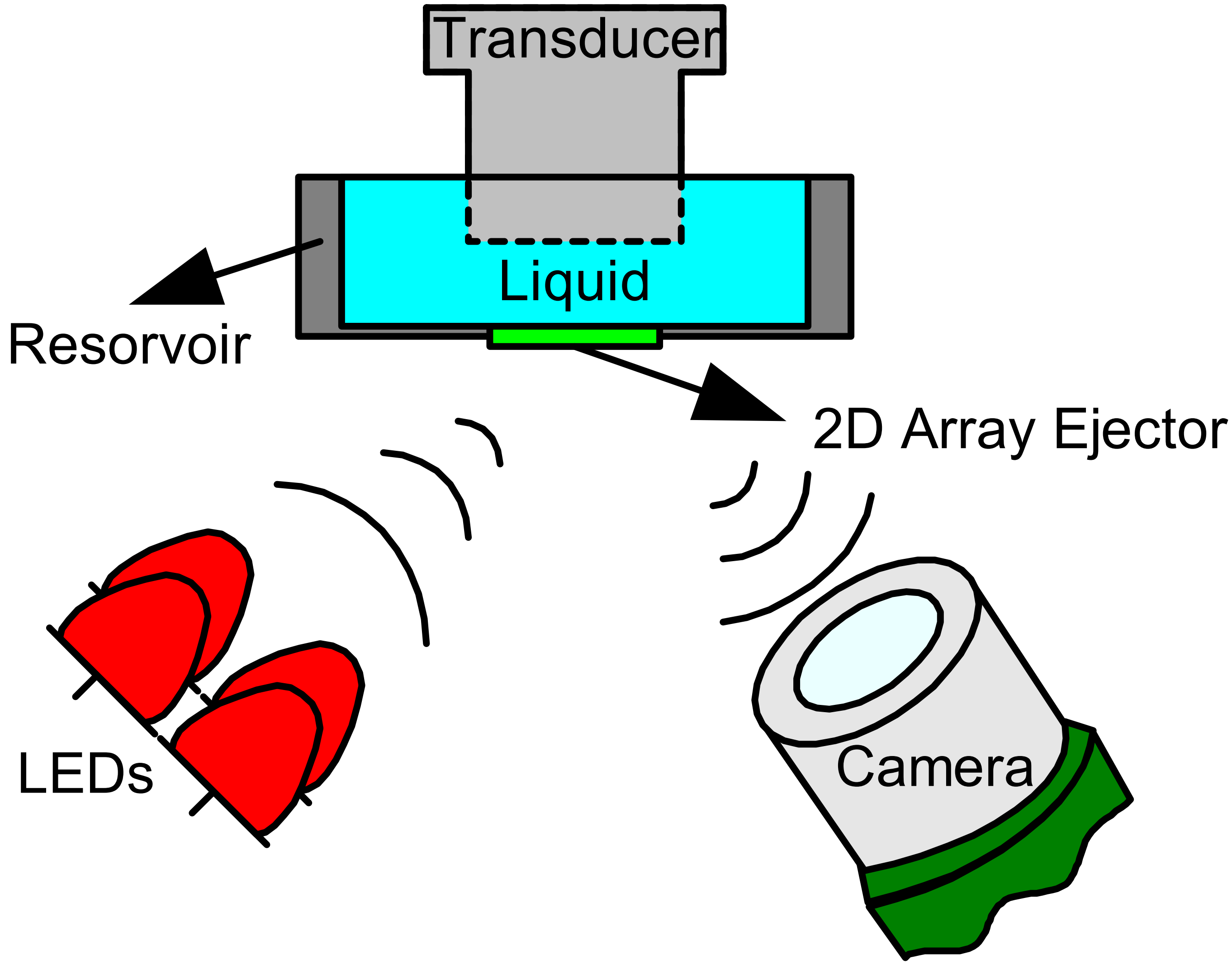


Membrane diameter : 160 µm
Orifice diameter : 10 µm

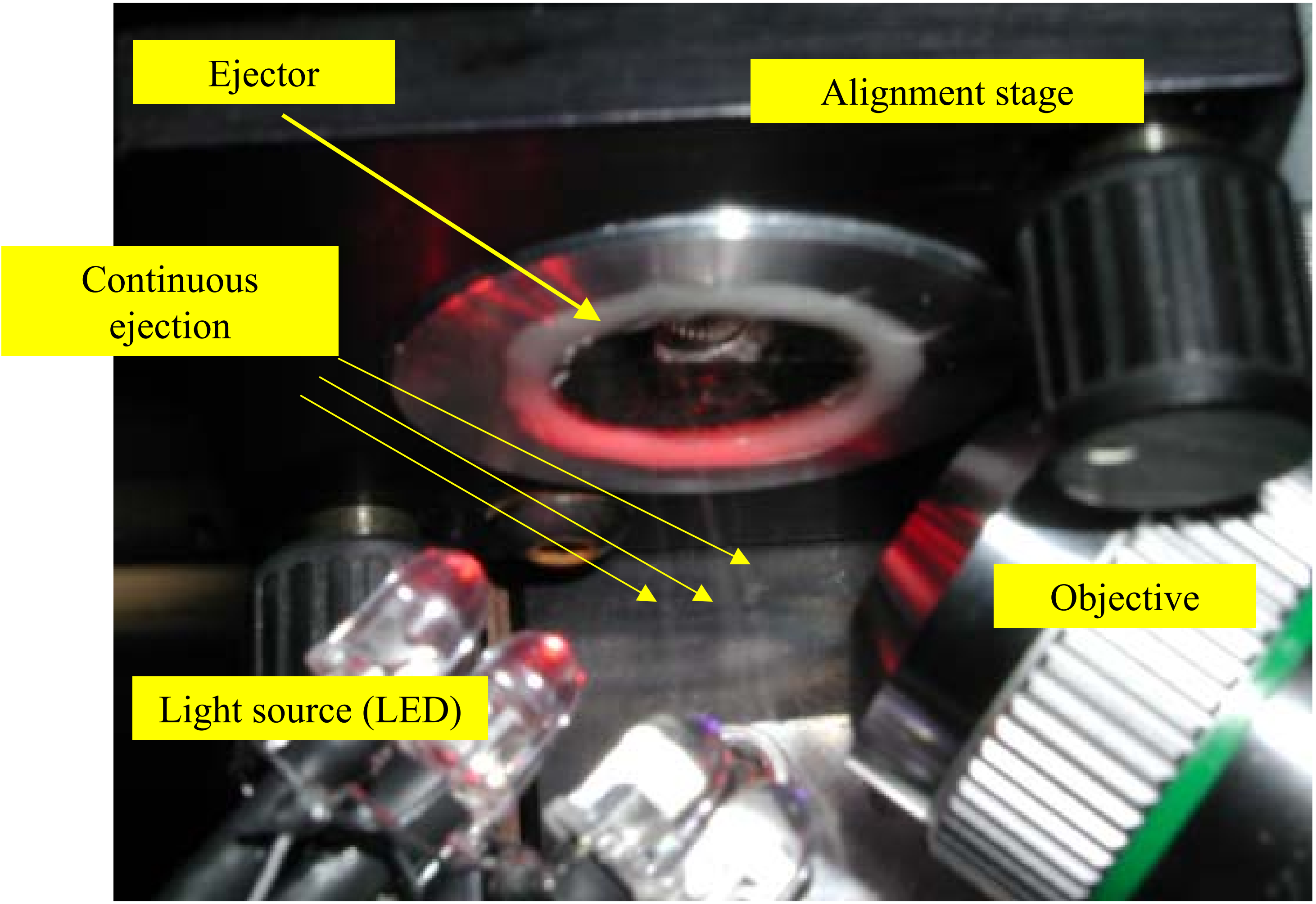
Experimental Setup: Block Diagram



Experimental Setup: Drawing

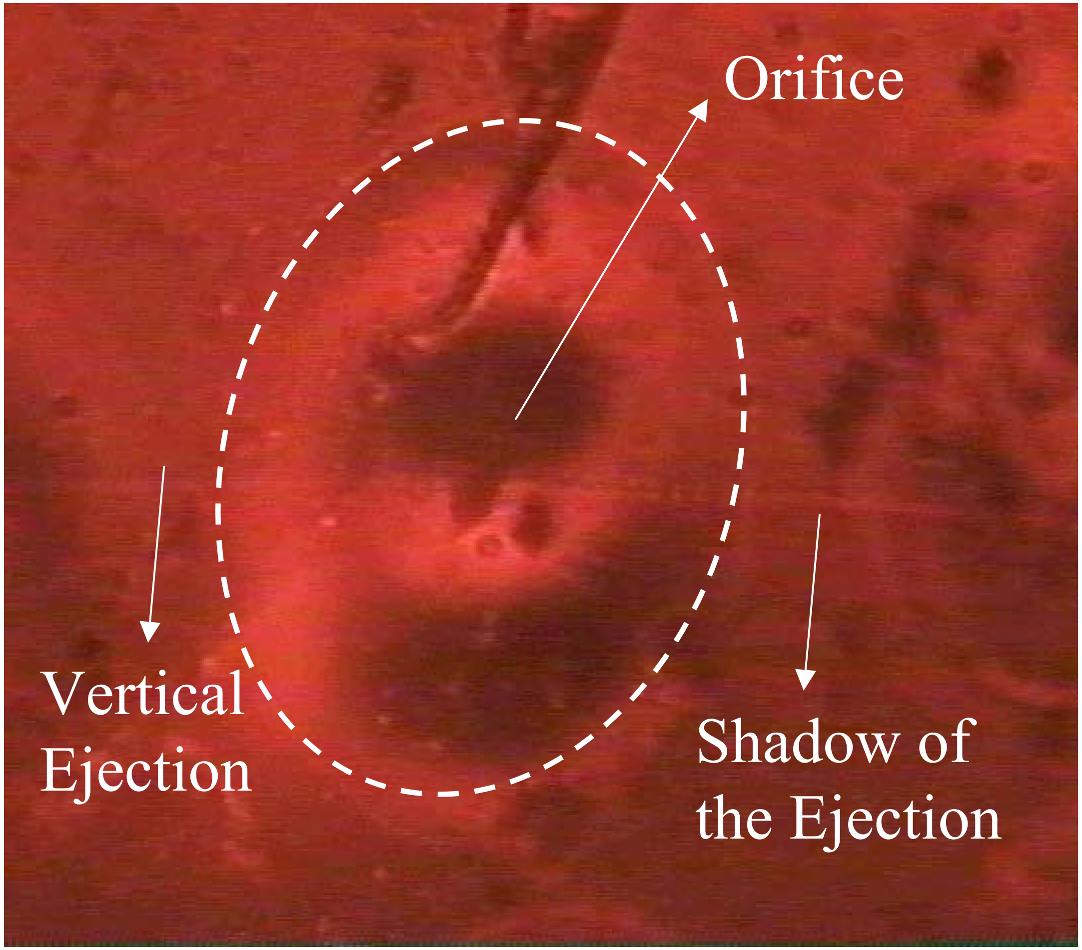


Experimental Setup: Ejecting Device



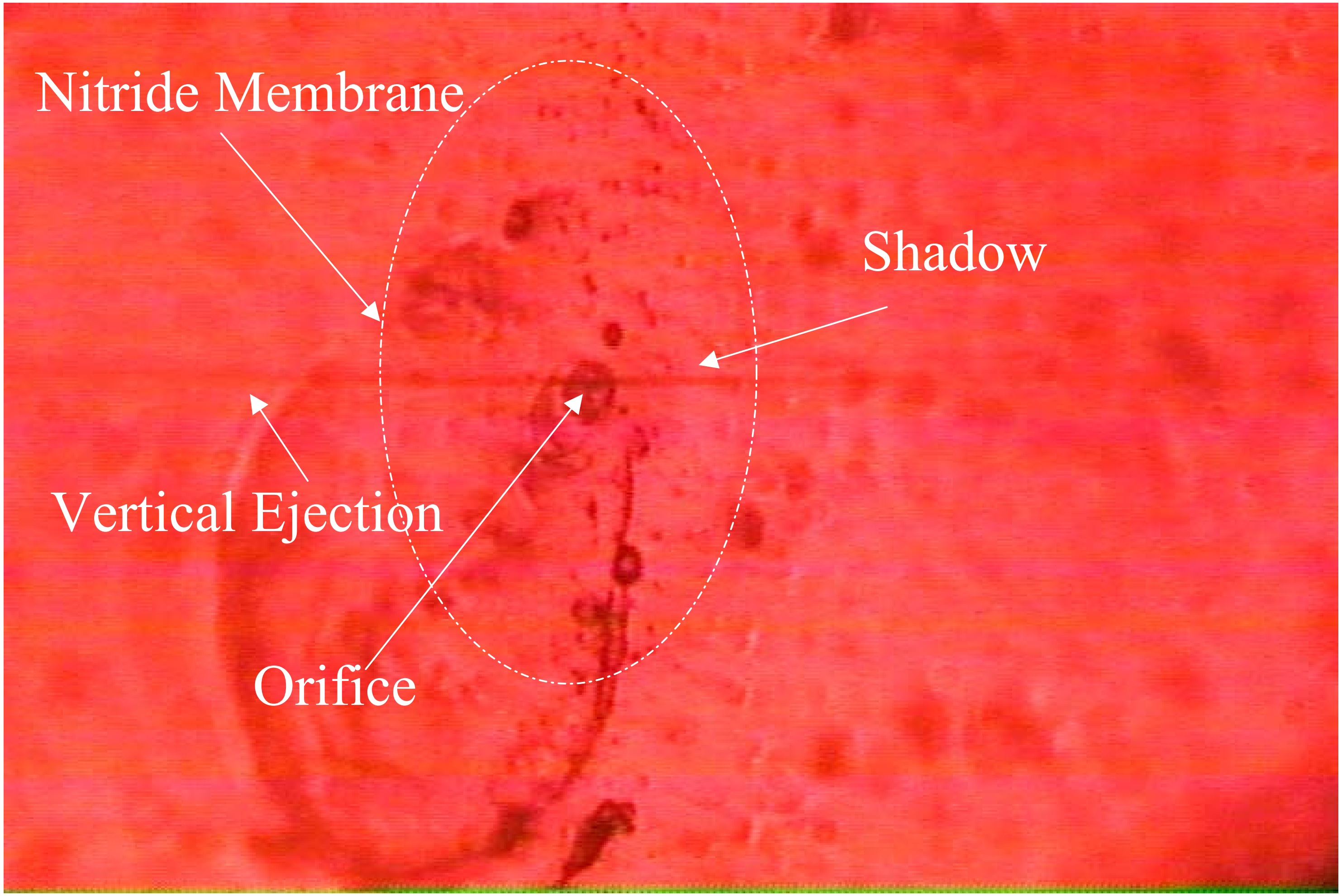
- Ejection is difficult to see due to very small sizes of droplets

Membrane Mode Shape at 1.24 MHz

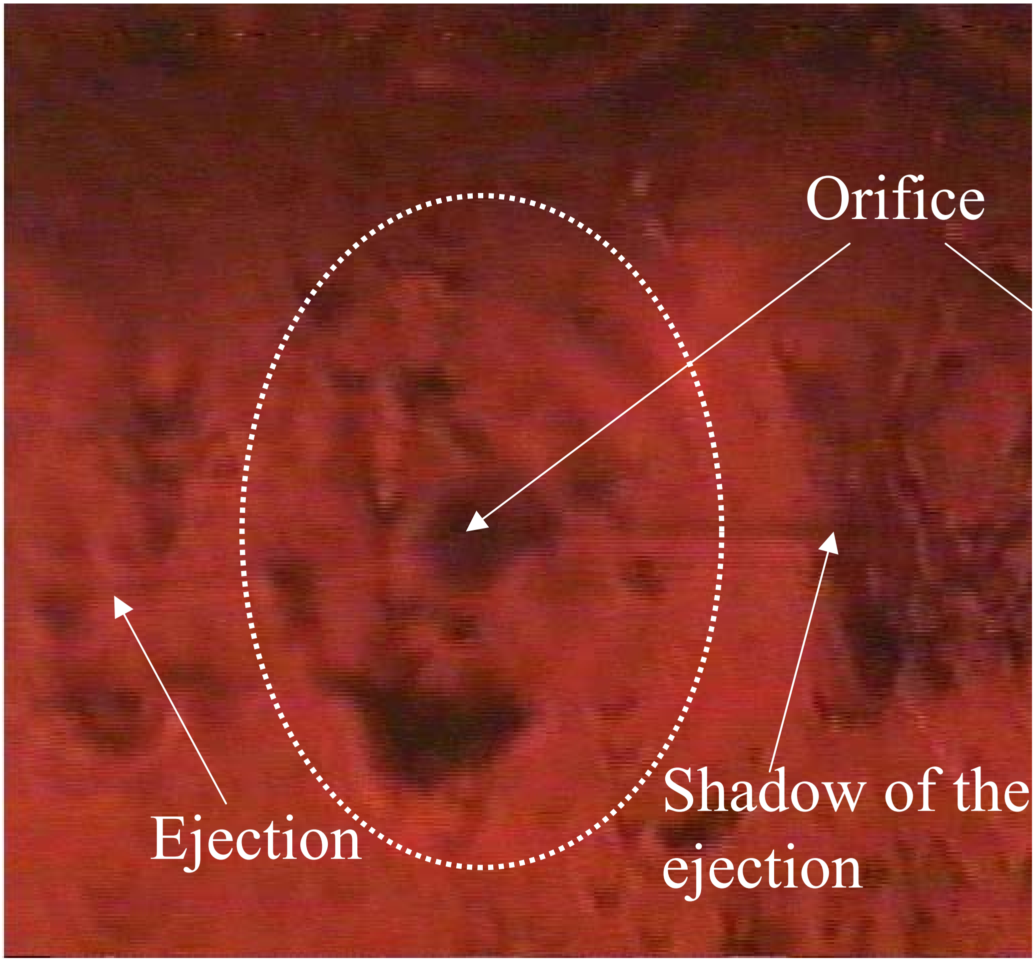


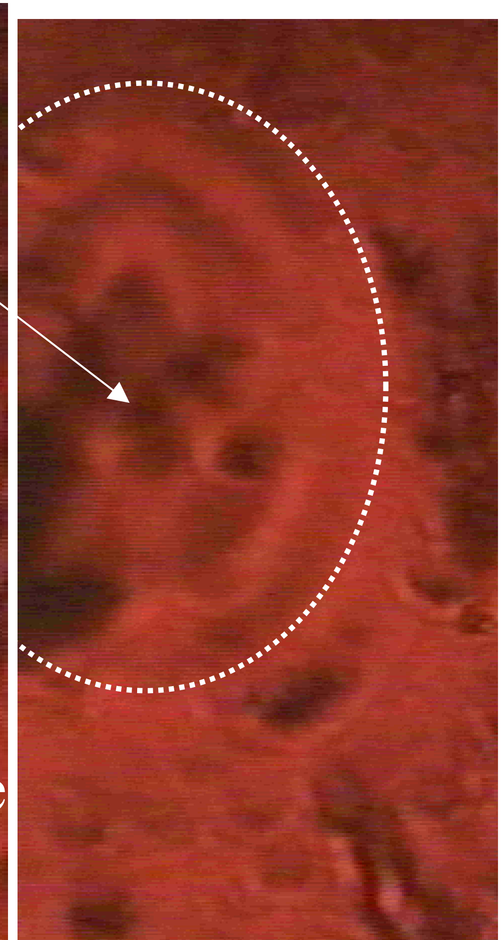
Water Ejection at 1.24 MHz

Ejection at 2.26 MHz

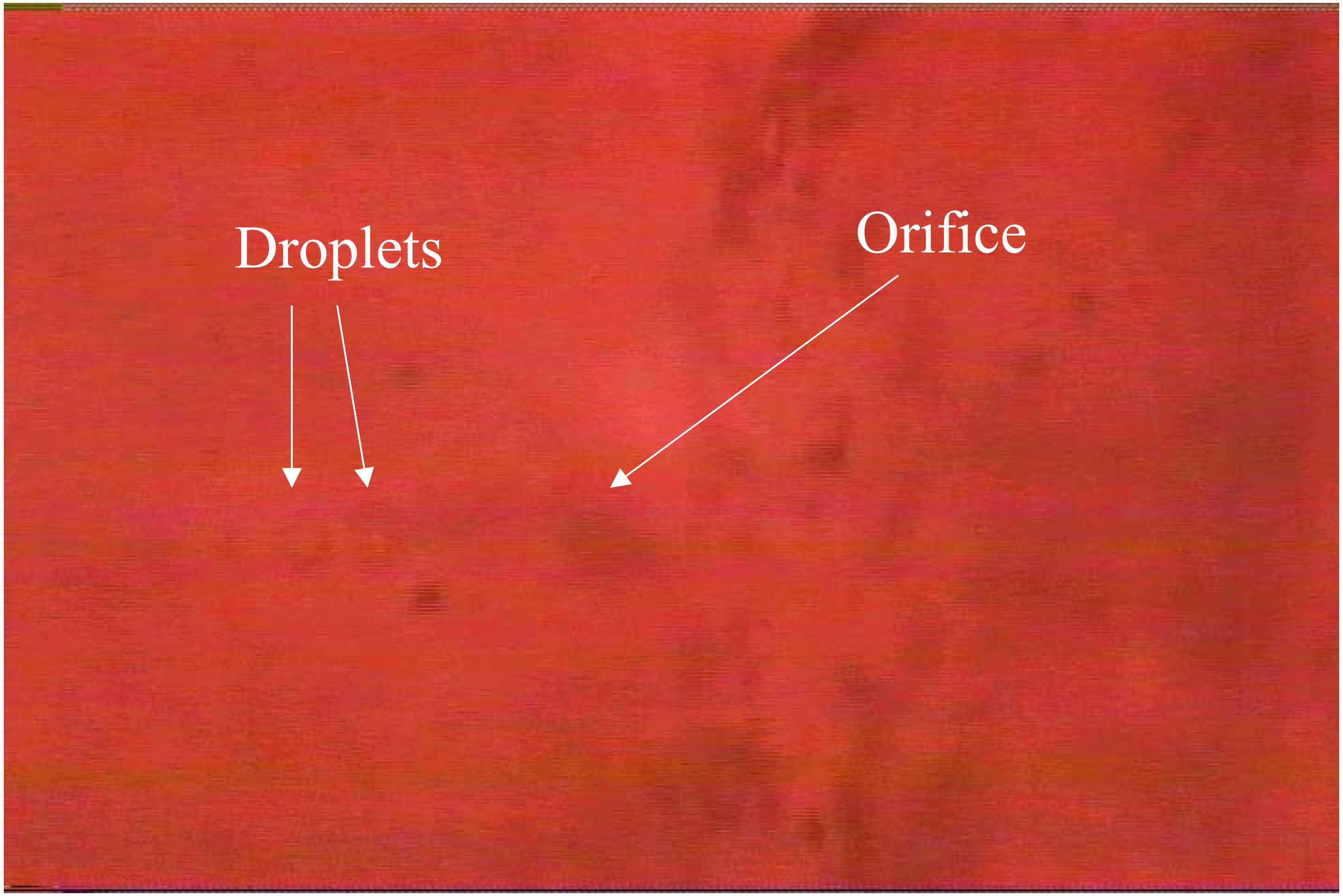


Membrane Mode Shape at 2.26 MHz



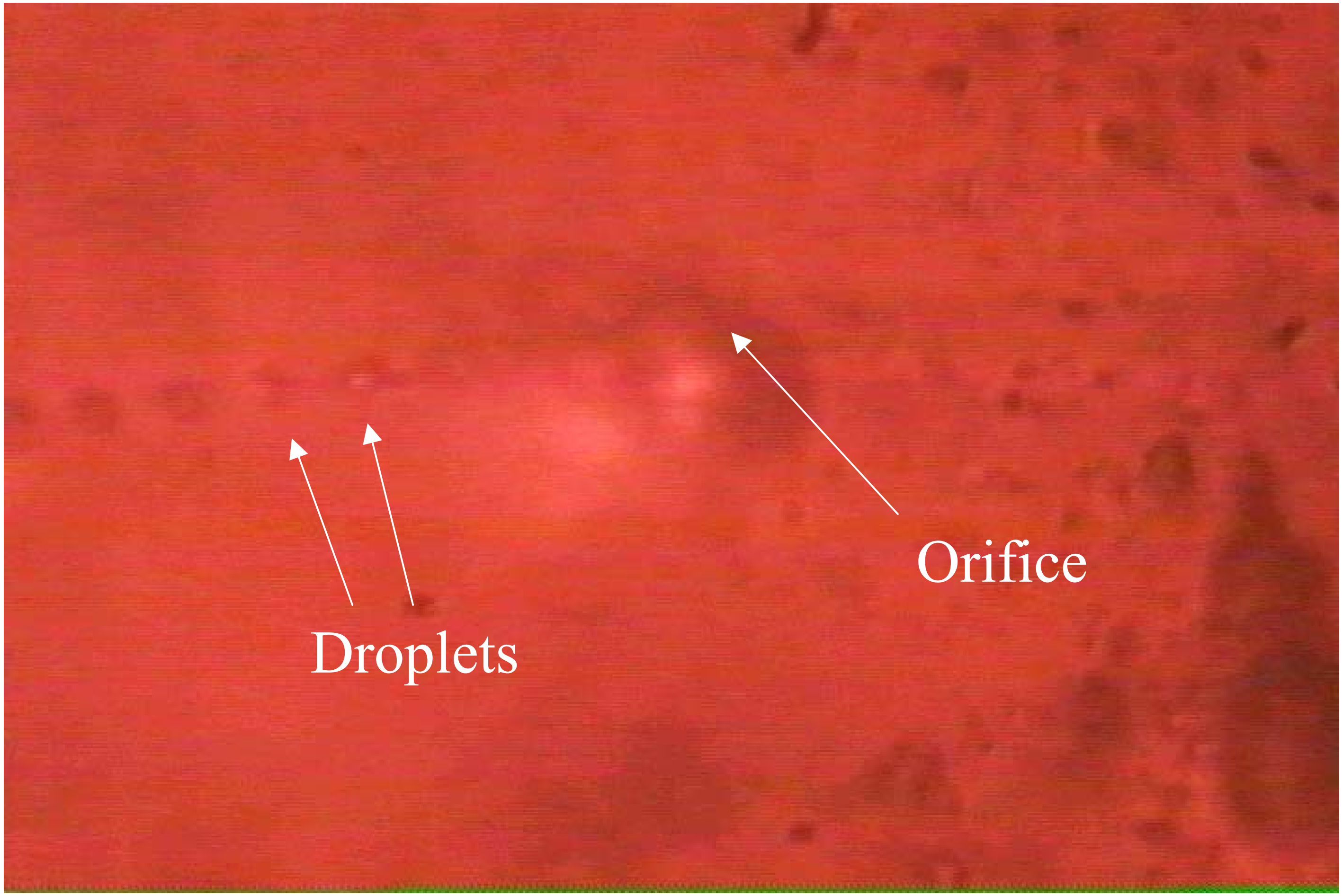


470 kHz Droplet Ejection



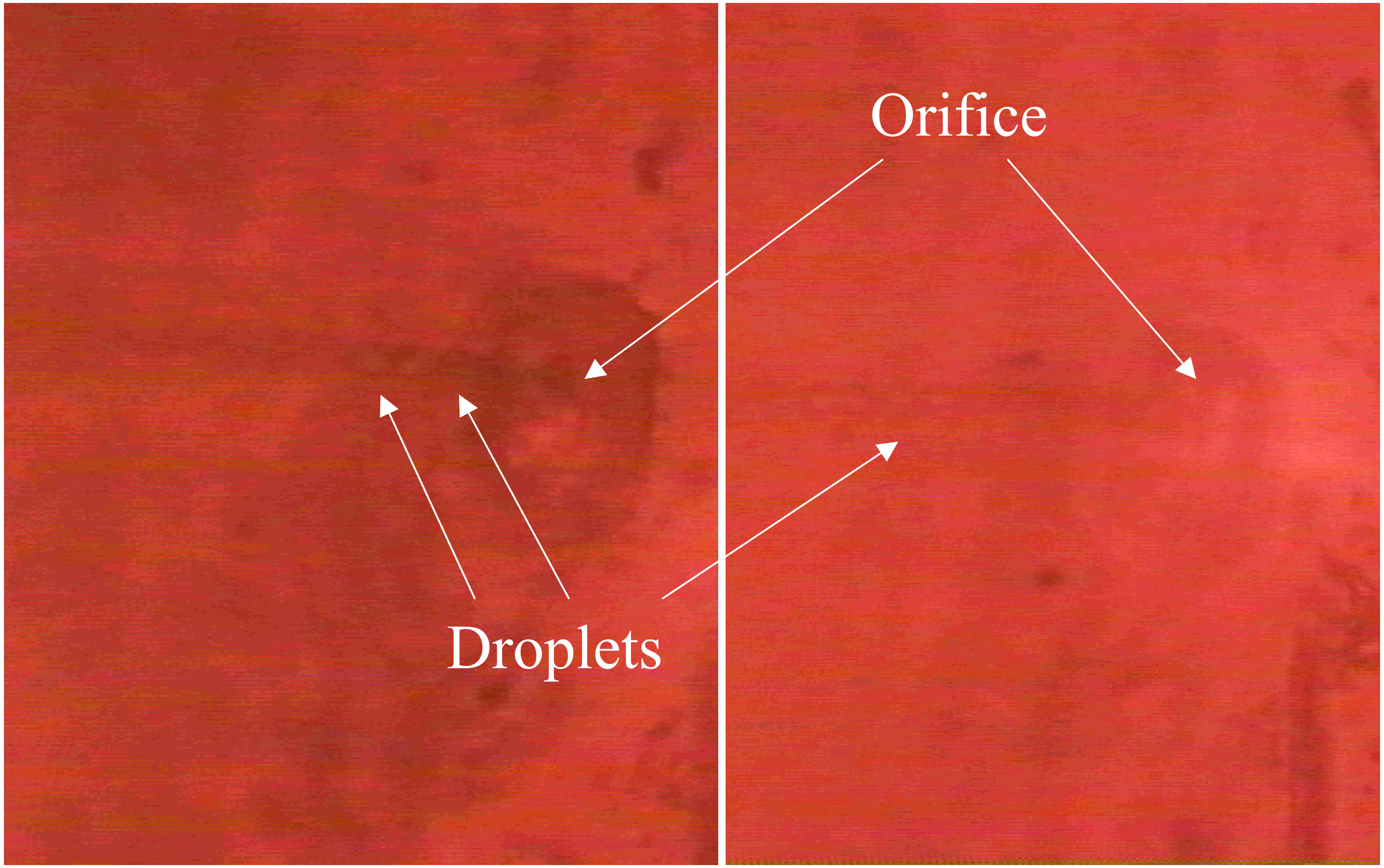
Water Ejection at 470 kHz

1. 24 MHz Droplet Ejection



Water Ejection at 1.24 MHz

2.26 MHz Droplet Ejection

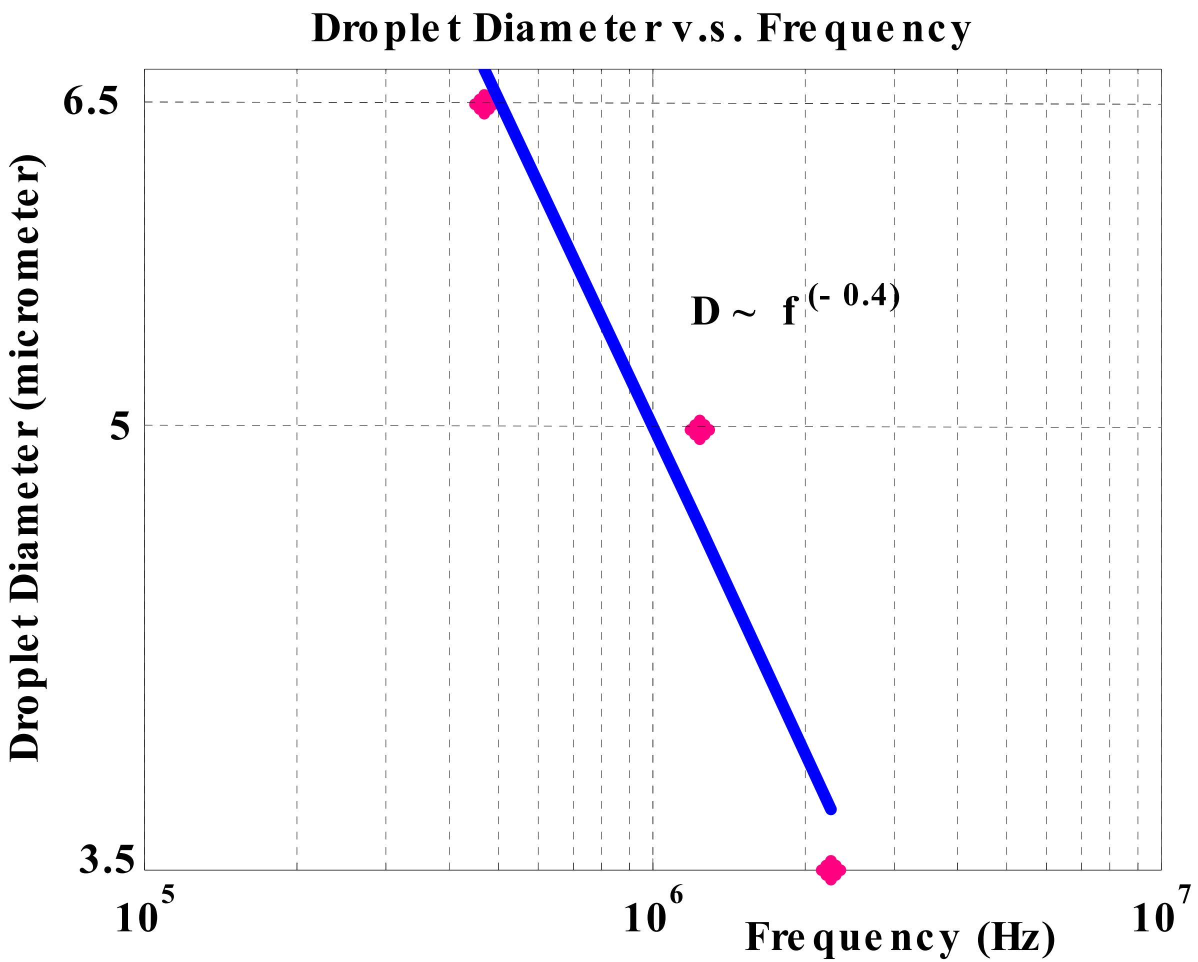


Water ejection at 2.26 MHz

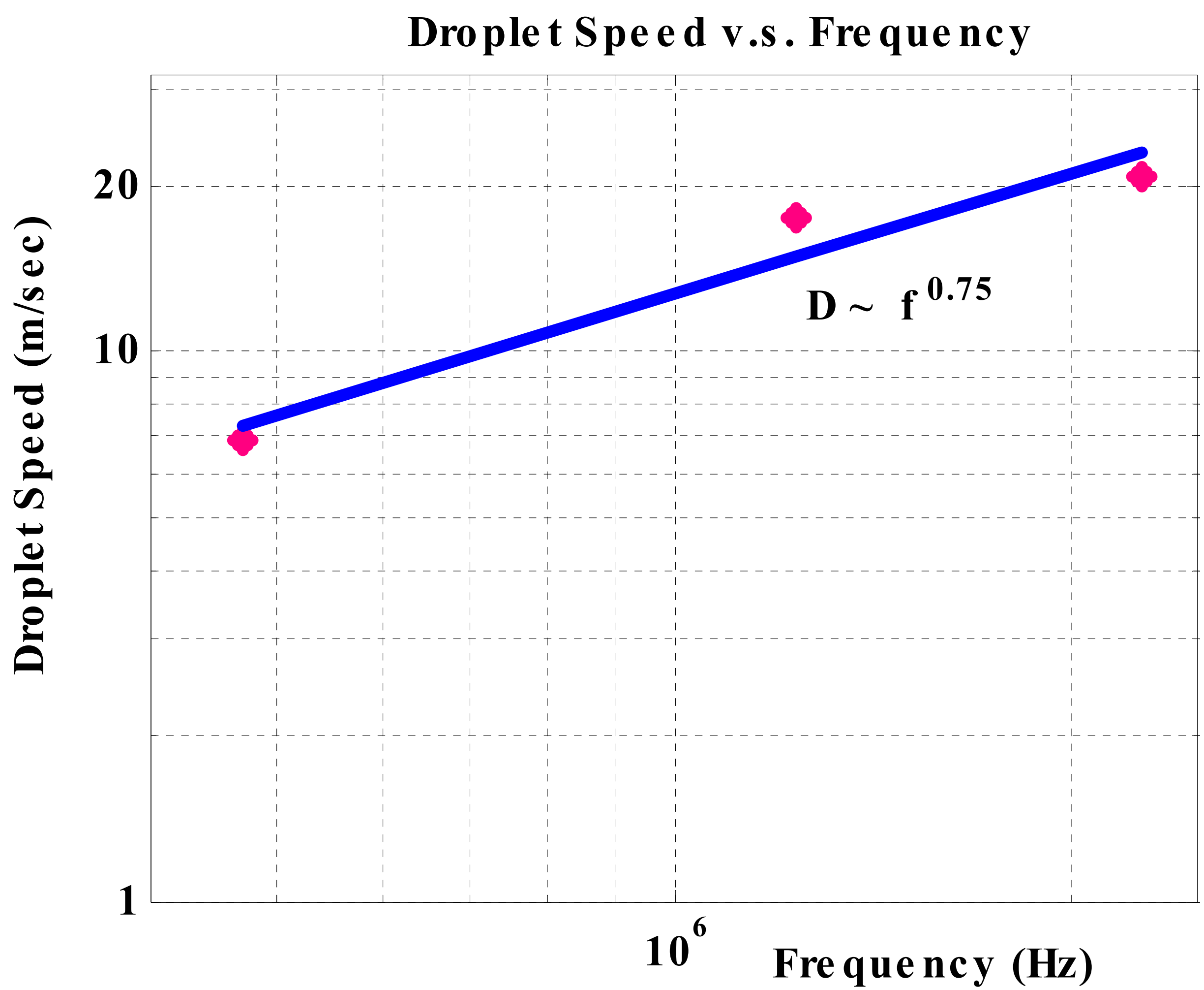
Ejection Summary

	470 KHz	1.24 MHz	2.26 MHz
Droplet Diameter	6.5 um	5 um	3.5 um
Center to Center Distance	14.8 um	14.1 um	9.2 um
Droplet Speed	6.9 m/sec	17.5 m/sec	20.8 m/sec

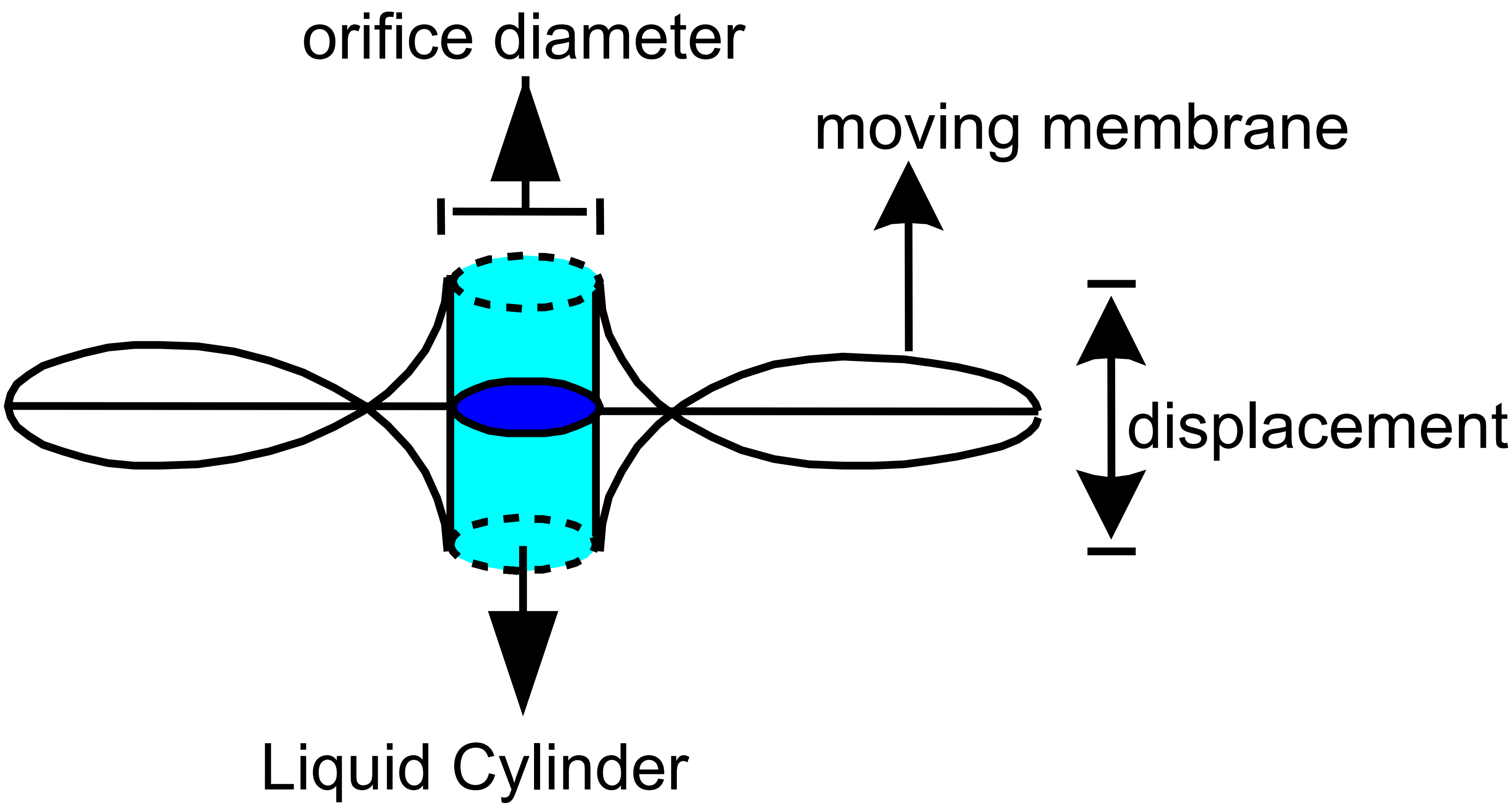
Droplet Diameter vs. Frequency



Droplet Speed vs. Frequency



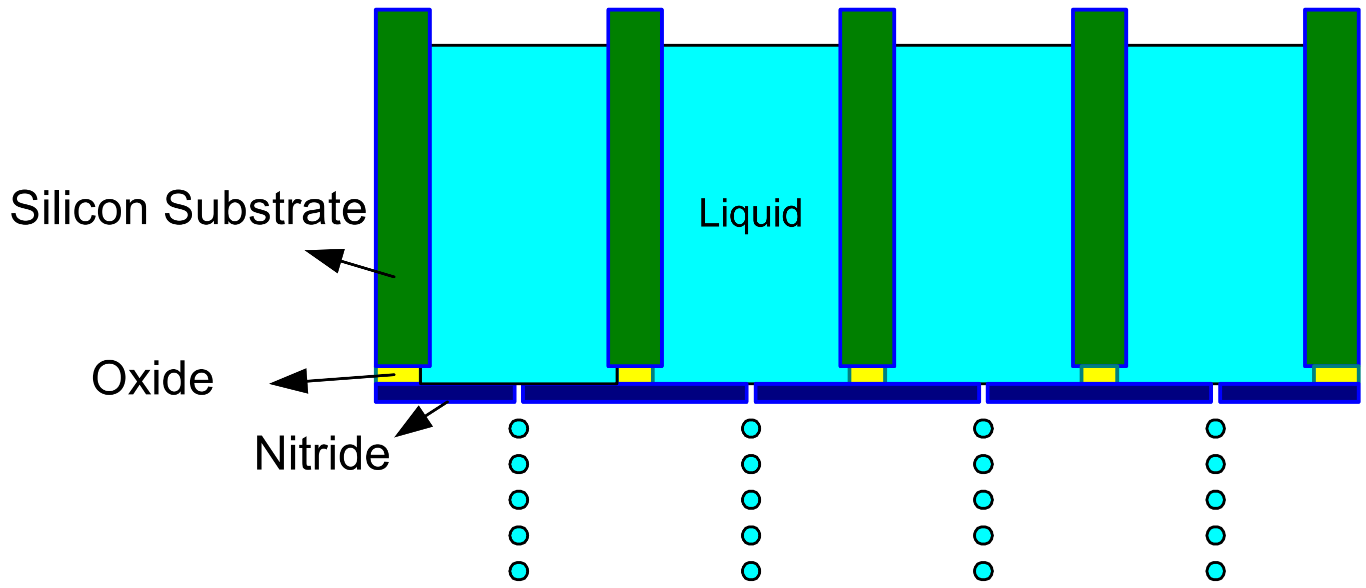
Basic Approach



Desired Good Ejection by 2D Arrays

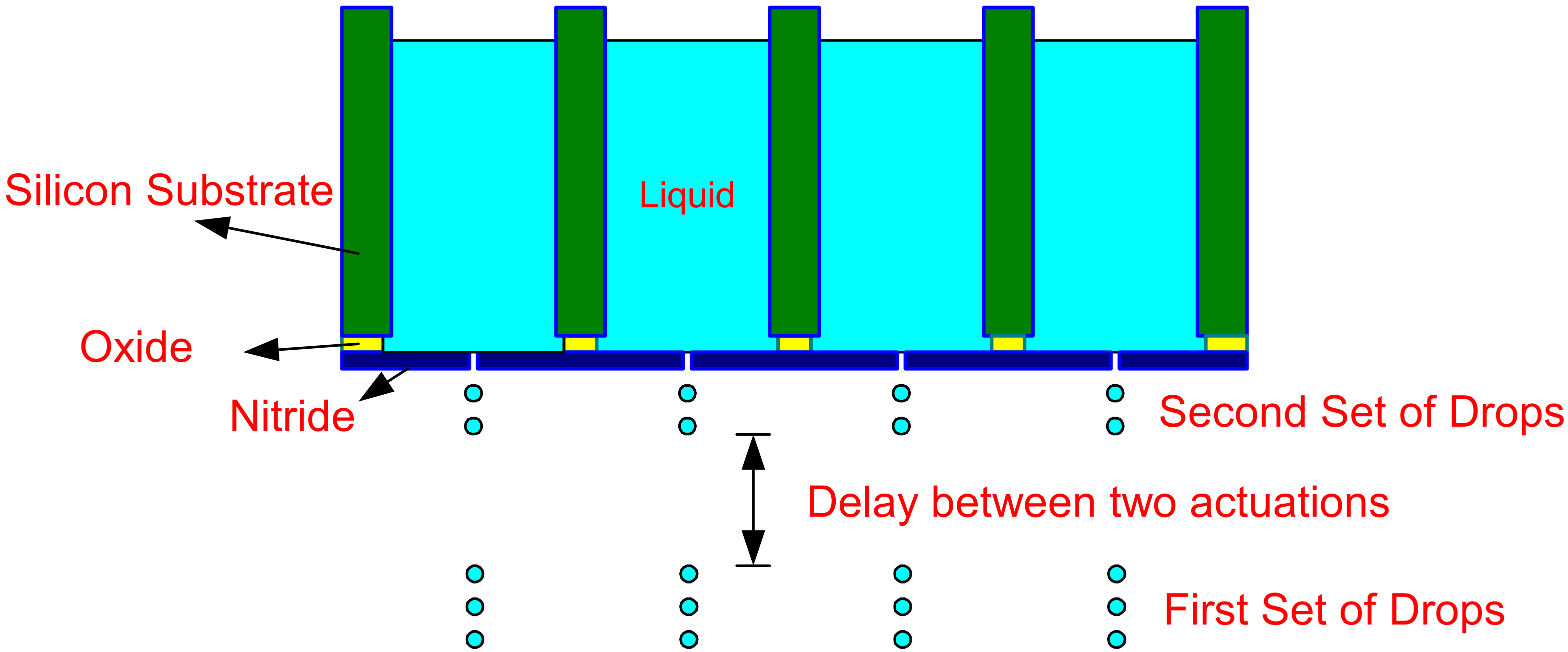
- All membranes should be ejecting simultaneously
- All should be ejecting vertical to the device surface
- Drop on Demand Ejection
- Controllable drop size and speed

Simultaneous Ejection



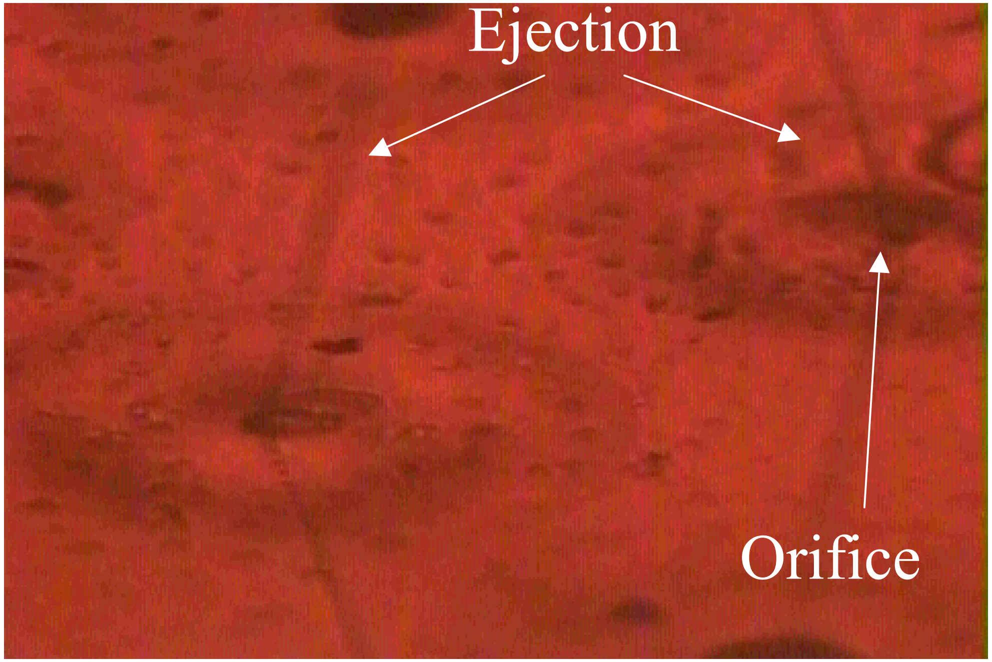
- **Continuous Wave actuation**
- **All membranes eject simultaneously**
- **The droplets are vertical to the surface of the device**

Drop on Demand Ejection



- The aim is to be able eject
  - desired number of droplets
  - at the desired time

Two Membrane Ejection at 1.24 MHz



Two neighboring membranes ejecting simultaneously

– Observed 20 ejecting membranes out of 400

Conclusions

- 2D Array of a micromachined ejector (multiple nozzles) with single driver was fabricated and tested.
- Demonstrated the droplet ejection at 470 kHz , 1.24 MHz, 2.26 MHz for water.
- Demonstrated multiple droplet ejection at 470 kHz , 1.24 MHz, 2.26 MHz for water.
- Demonstrated potential for zero waste or near-zero waste of fluids.

Future Work

- New fabrication process to improve device performance.
- Single crystal silicon membranes, where the orifice is formed by wet etching.
- FEM simulations to understand cross-talk issues.
- Better control on ejection
  - On demand ejection
  - All membranes active at a given time