Environmentally Benign Deposition of Photoresist and Low-k Dielectrics

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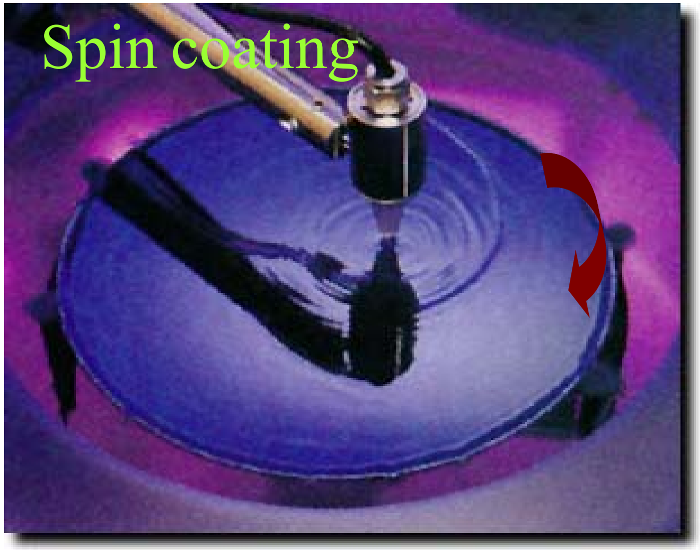
Outline

- Motivation
- Objective
- Approach
- FEM Analysis of the micro-machined ejector
- Previous research
  - *Experimental setup*
  - *Ejection*
- New experimental & simulation results
  - *Ejection with Single Crystal Silicon*
- FEM Simulation Results and Verification
  - *Membranes Micromachined Acoustic Band Gap Arrays (MAPGA)*
- Conclusions
- Future Research

Motivation: Waste



Inefficient use of Expensive Chemicals

Cost of disposal of Hazardous Waste

WASTE
Over 95%
of the spinned resist

Environmental Pollution

Spin Coating Technology

Resist on the wafer
5%

Objective

- Since a large amount of photoresist, low-*k* and high-*k* dielectrics is wasted during spin coating,

  our aim is to **minimize the waste.**

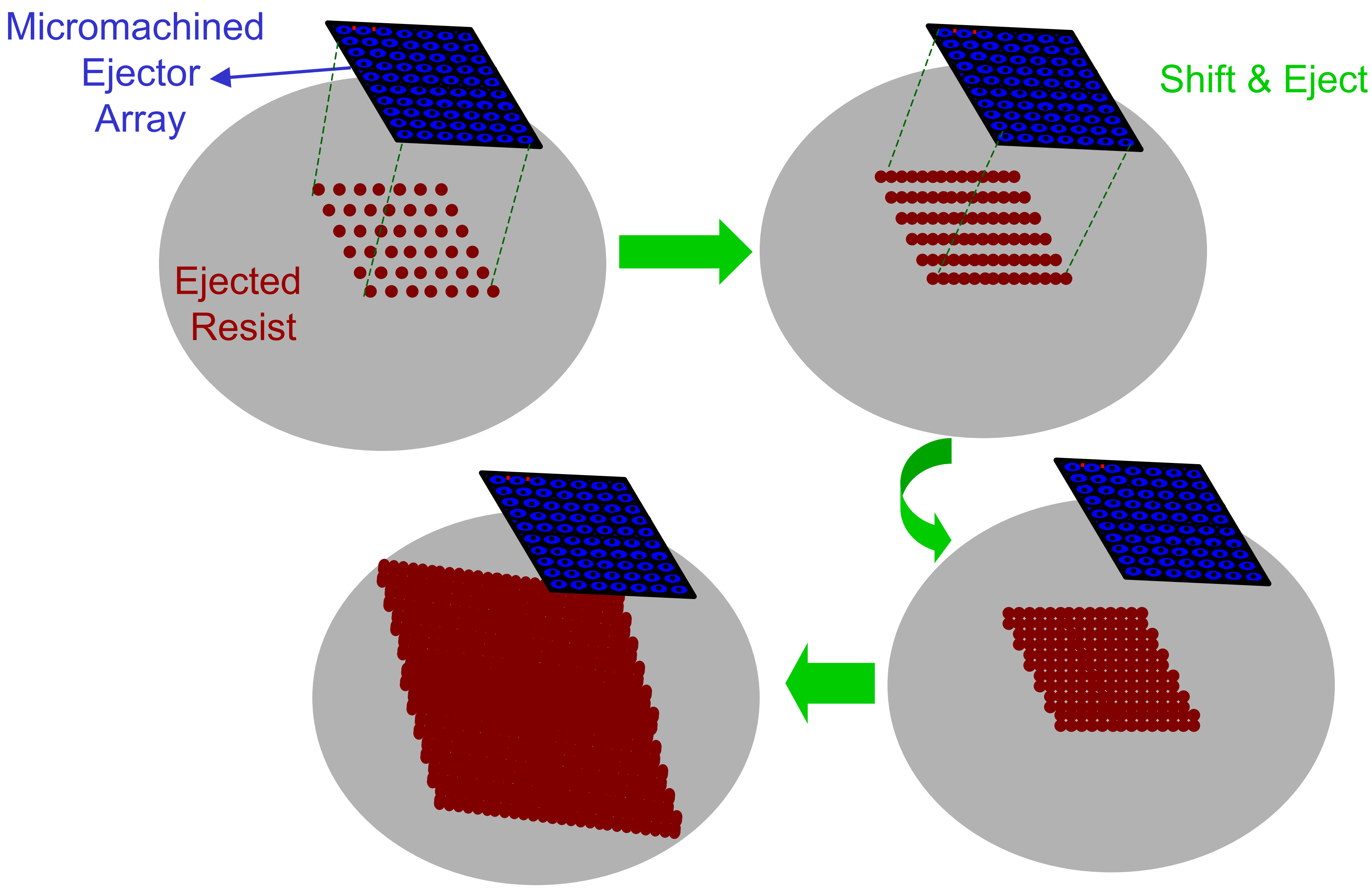
  – Develop a fluid ejection system capable of depositing fluids with a minimum of waste.

  – Develop a system capable of drop on demand and continuous ejection.

  – Develop a coating system to demonstrate waste reduction with full coverage of wafers.

  – Demonstrate photoresist and low-*k* and high-*k* dielectric coating of 20 cm and 30 cm silicon wafers.

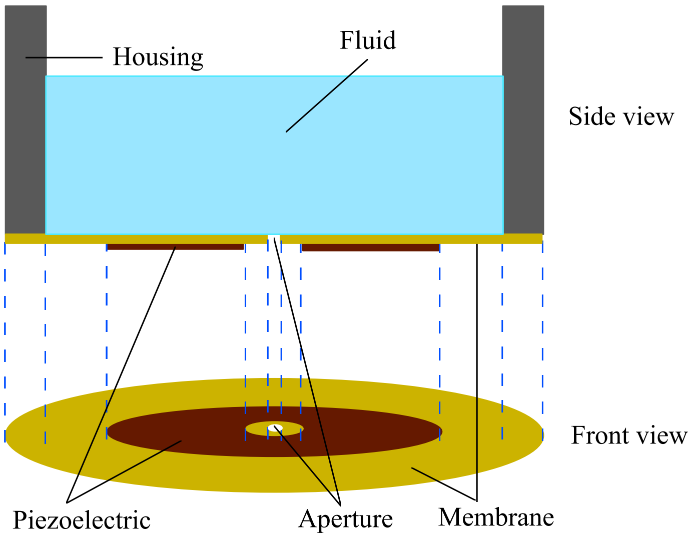
Approach: Full Device

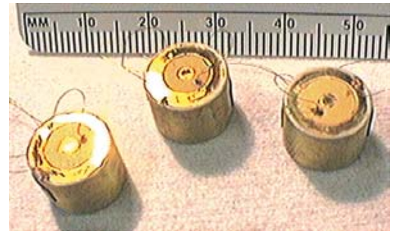


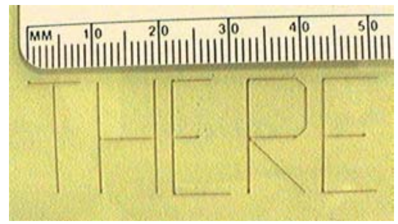
Approach: Design Requirements

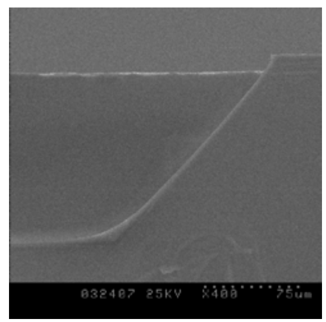
- Use flex-tensional ejectors for deposition
  - Design and implement micro-machined ejector arrays with either single or multiple piezoelectric drivers
- Ejector requirements
  - Able to deposit low and high viscosity fluids
  - No damage caused to the ejected fluids
  - High flow rate
  - Compatible with most chemicals
  - Can be made using IC process technology

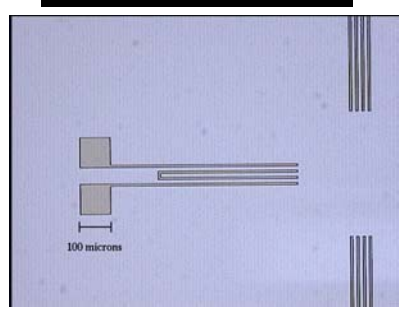
Large Scale Single Ejector

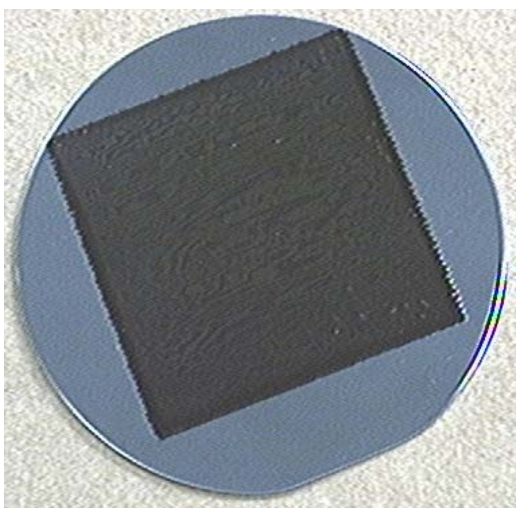












Membrane : brass, steel

Diameter : 9 mm

Membrane thickness : 25 μm

Orifice size : 50-200 μm

Operating frequencies:

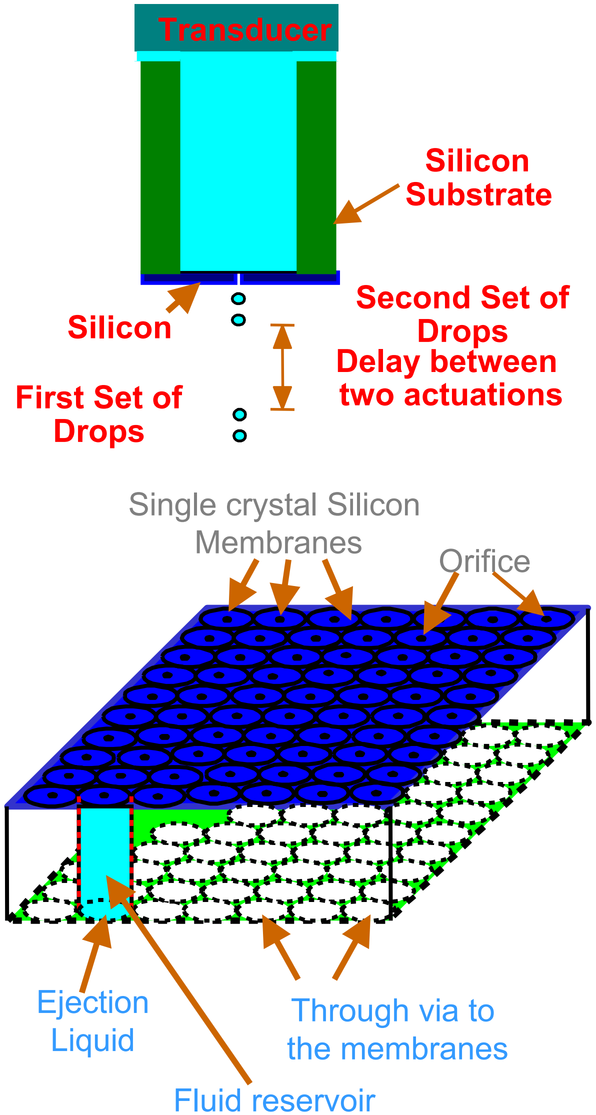
9.5 kHz, 16.4 kHz, 19.0 kHz

- Photoresist covered deep trench
- Deposited Photoresist Thickness :

  3.5 μm ± 0.15 μm
- Direct write with resist:

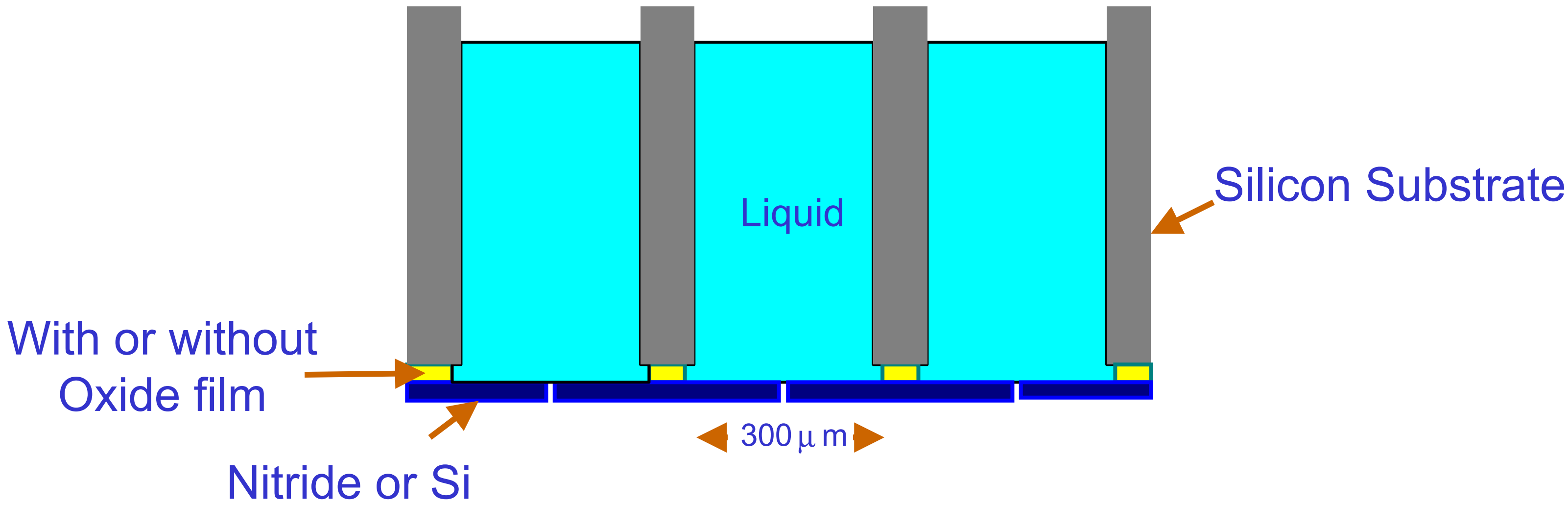
  350 μm-wide lines

2D Micro-machined Ejector Array



- 2D array of ejectors
- Membrane actuation by a transducer through the fluid reservoir
- Thin single crystal silicon uniform membrane
- Deep reactive ion etched reservoir
- High frequency operation for high flow rate (MHz)
- Drop-on-demand and continuous modes of operation

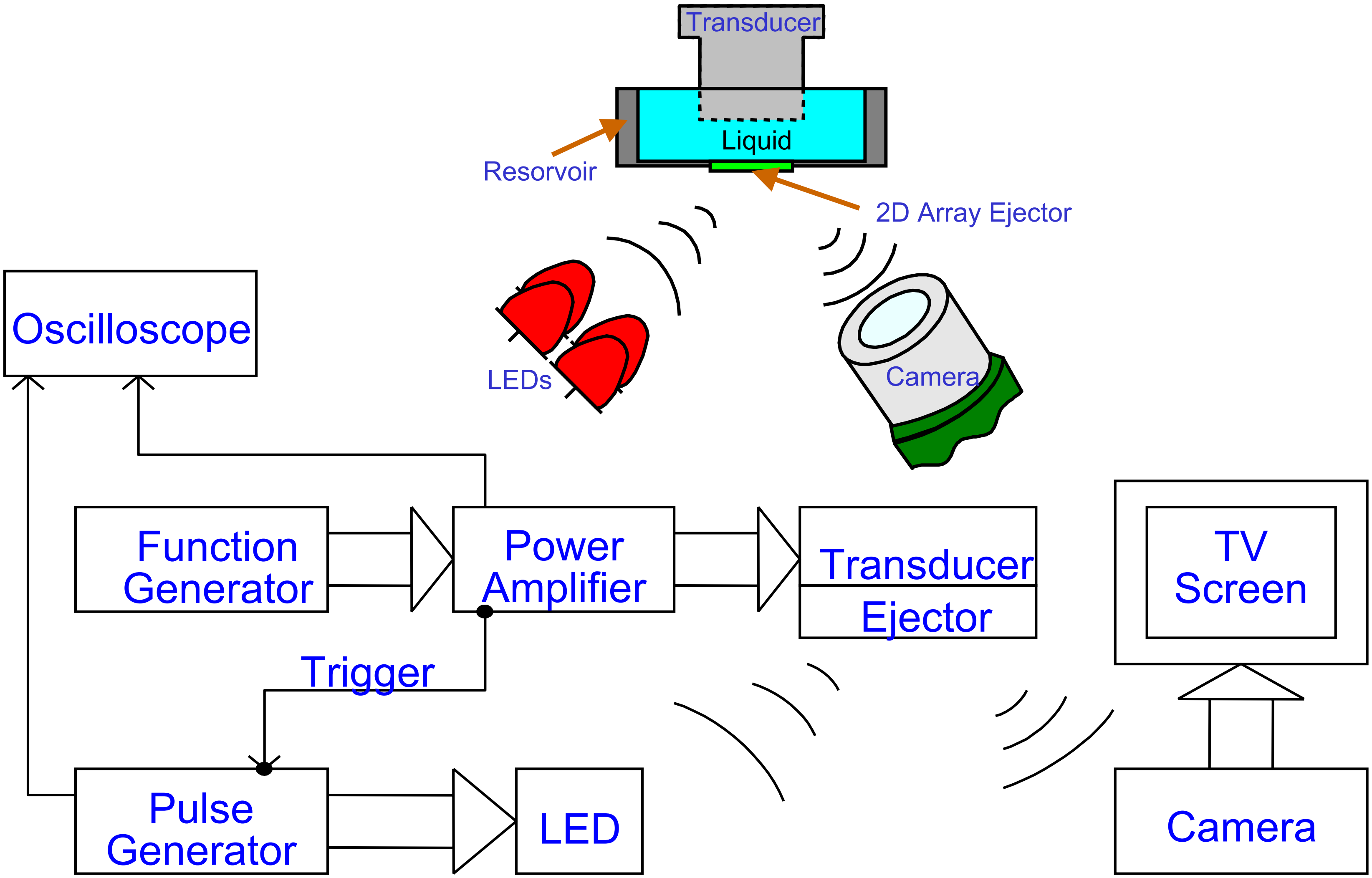
Fabricated 2D Micro-machined Array: Dimensions



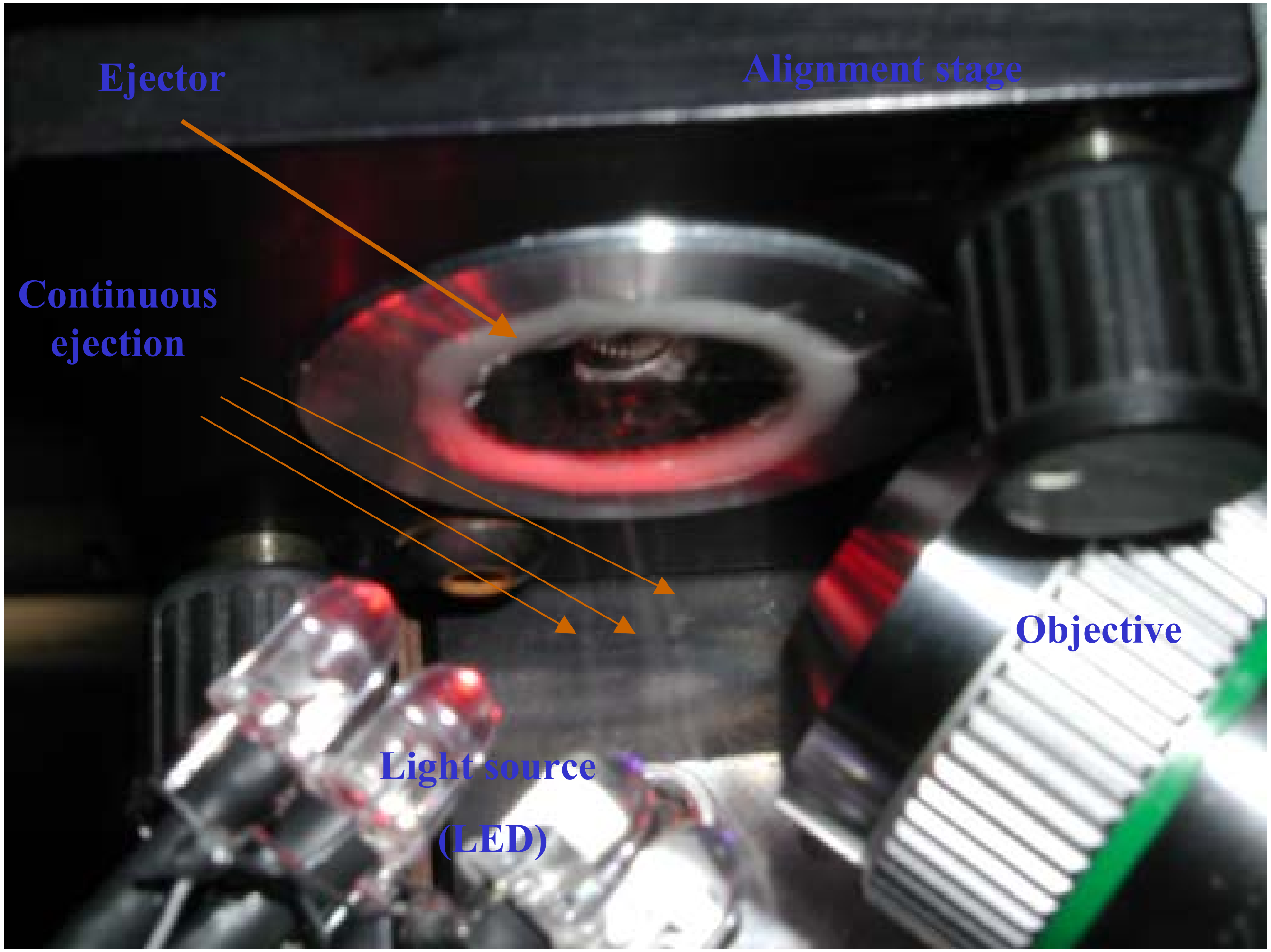
Device Properties

Membrane material	:	Single crystal silicon, Si_3N_4
Membrane Diameter	:	100 µm, 200 µm, 300 µm, 500µm, 1 mm
Membrane thickness	:	1 µm for Si, 2.1 µm for Si_3N_4
Orifice diameter	:	4 µm, 10 µm, 14 µm
Operating frequencies:		470 kHz, 1.24 MHz, 2.26 MHz for Si_3N_4

Experimental Setup

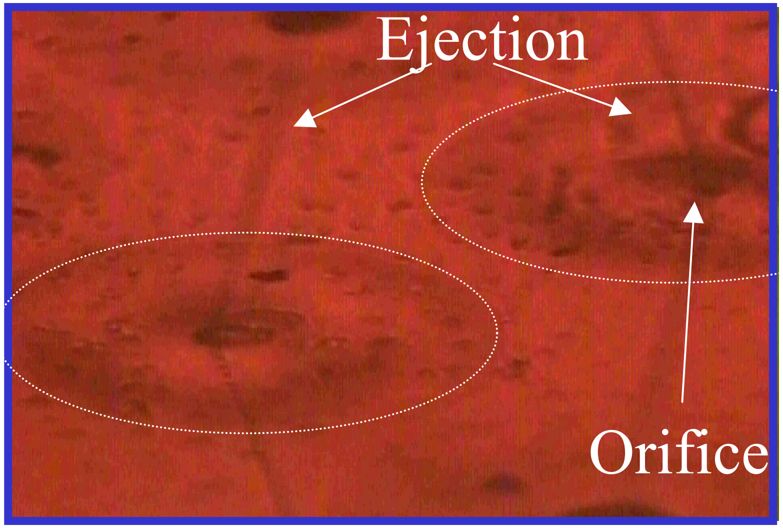


Experimental Setup: Ejecting Device



- Ejection is difficult to see due to very small droplets

Si_xN_y Membrane (previously fabricated device)



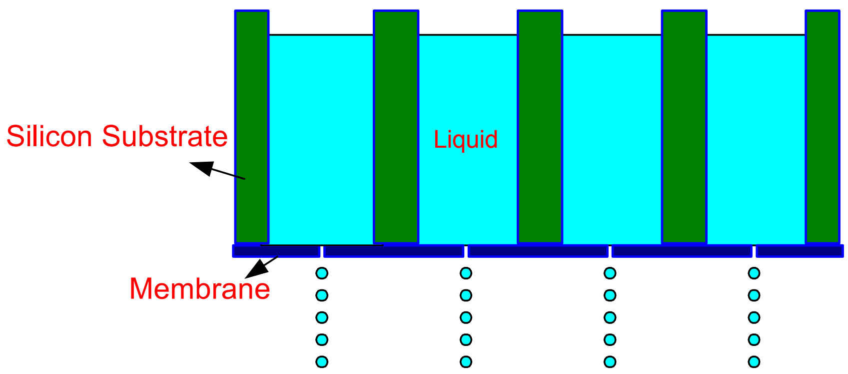
*Two neighboring membranes ejecting at 1.24 MHz simultaneously.
*Observed 20 ejecting membranes out of 400.

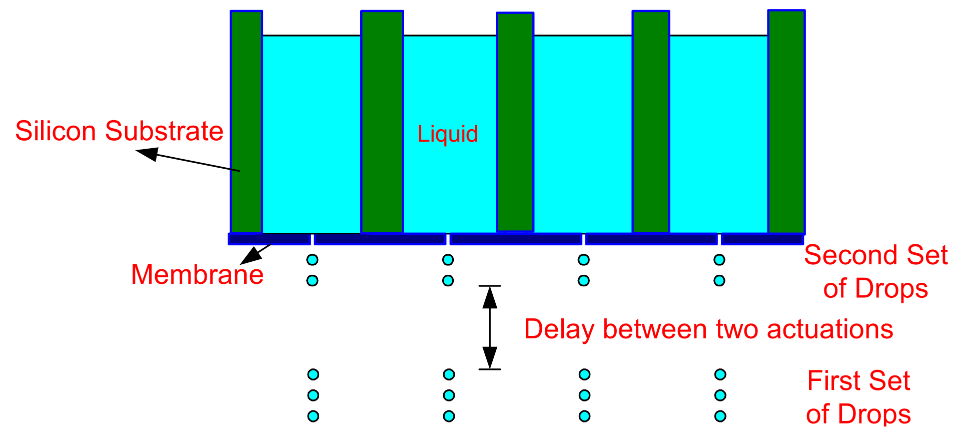
Ejection Summary	470 KHz	1.24 MHz	2.26 MHz
Droplet Diameter	6.5 um	5 um	3.5 um
Center to Center Distance	14.8 um	14.1 um	9.2 um
Droplet Speed	6.9 m/sec	17.5 m/sec	20.8 m/sec

Desired Good Ejection by 2D Arrays

- All membranes should be ejecting simultaneously
- Ejection should be perpendicular to the device surface
- Drop on Demand Ejection should be possible
- Droplet size and ejection speed should be controllable

Good Ejection

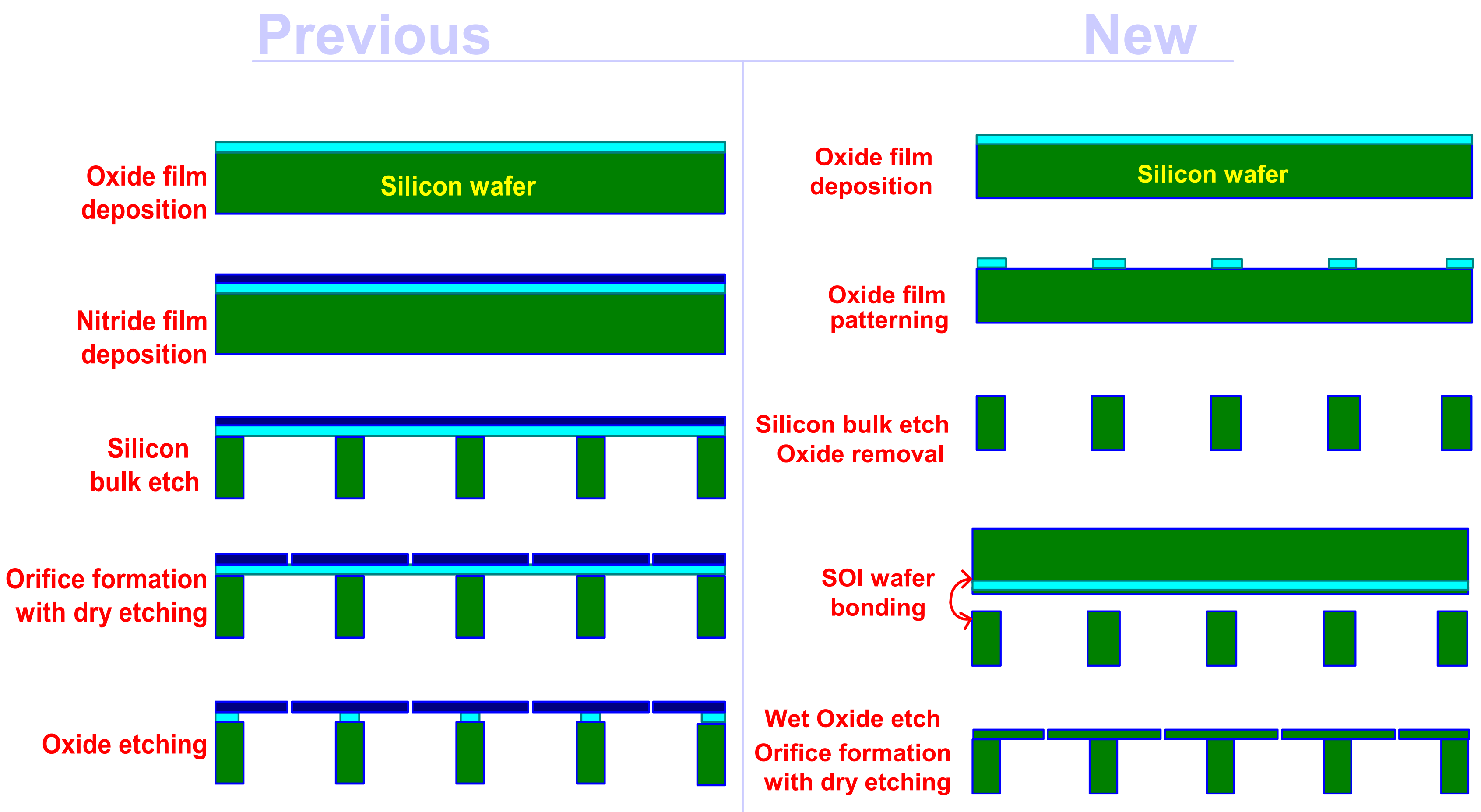




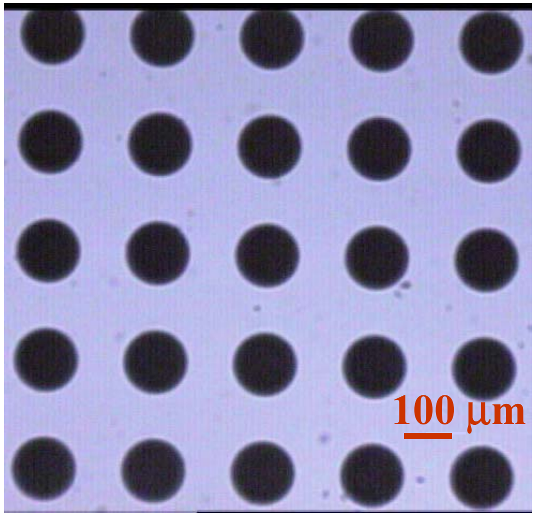
- Continuous Wave actuation
- All membranes eject simultaneously
- The droplets eject perpendicularly to the device surface

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

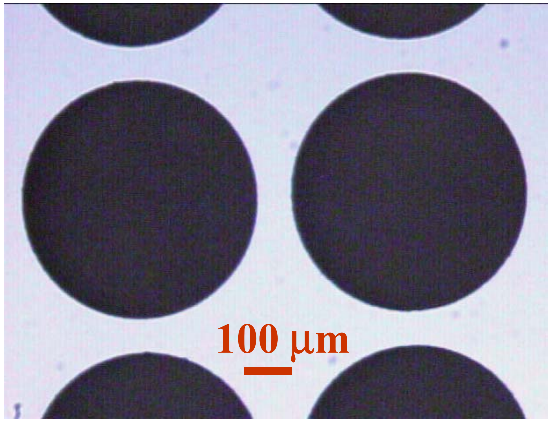
Fabrication Process: SOI Wafer Bonding



DRIE of the Reservoirs



100 μm wide etched holes in silicon wafer.



500 μm wide etched holes in silicon wafer.

Device

5x5 STS etched silicon wafer ready to be bonded to a SOI wafer for membrane formation.

Benefits

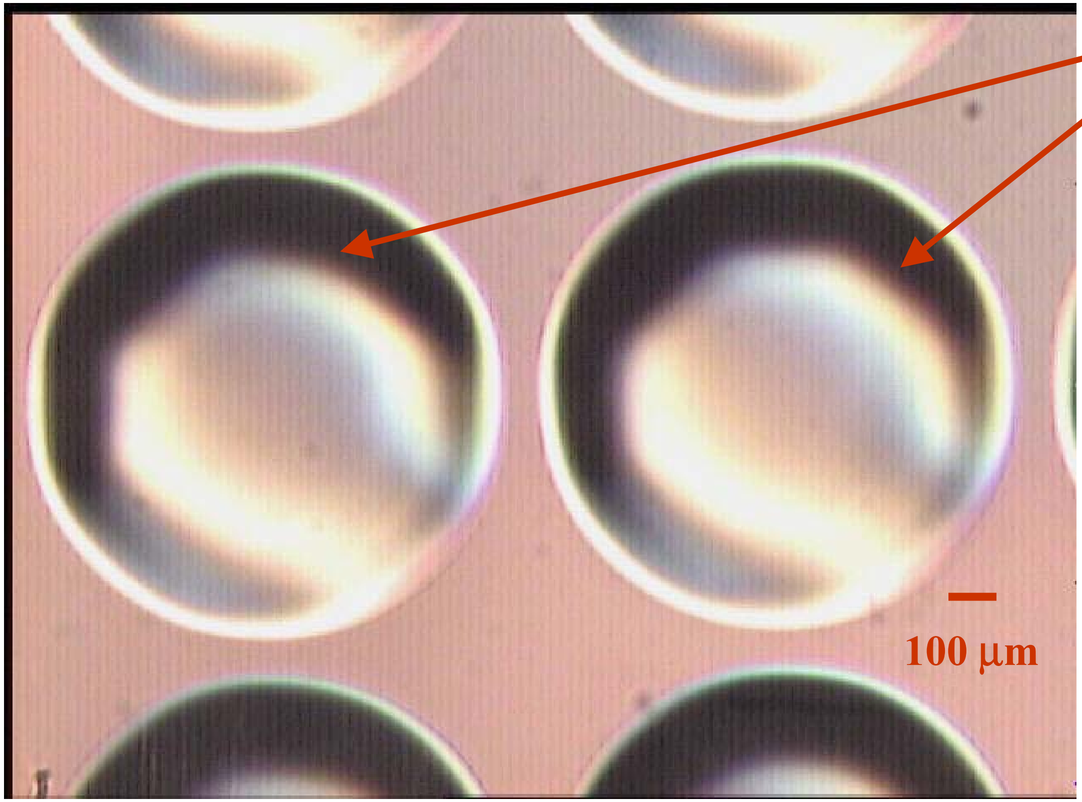
•Uniform 1 μm thick single crystal silicon membrane.

•Membrane radius does not depend on the wet oxide etch rate.

•Uniform membrane radius with Deep Reactive Ion Etching (DRIE).

•Uniform membrane orifice with dry etching.

Wet SiO_2 Release

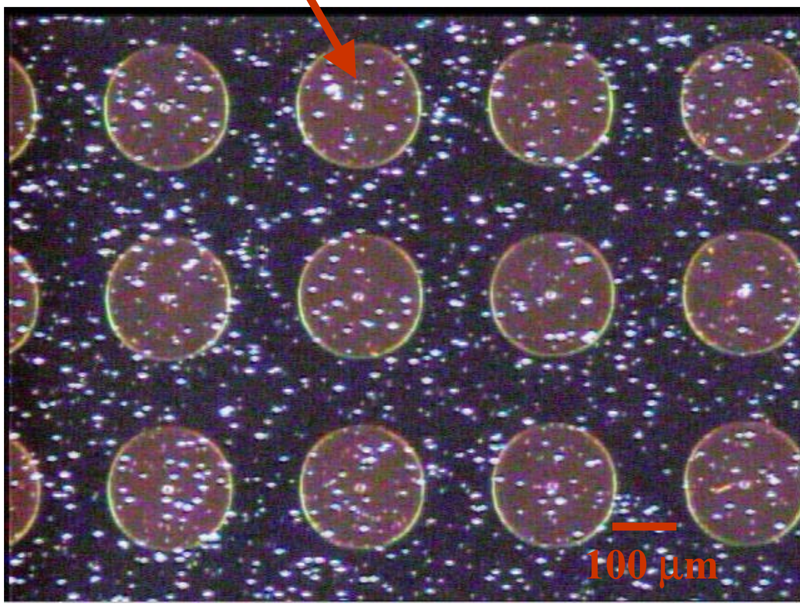


Single crystal Si membrane release with wet-etch is completed.

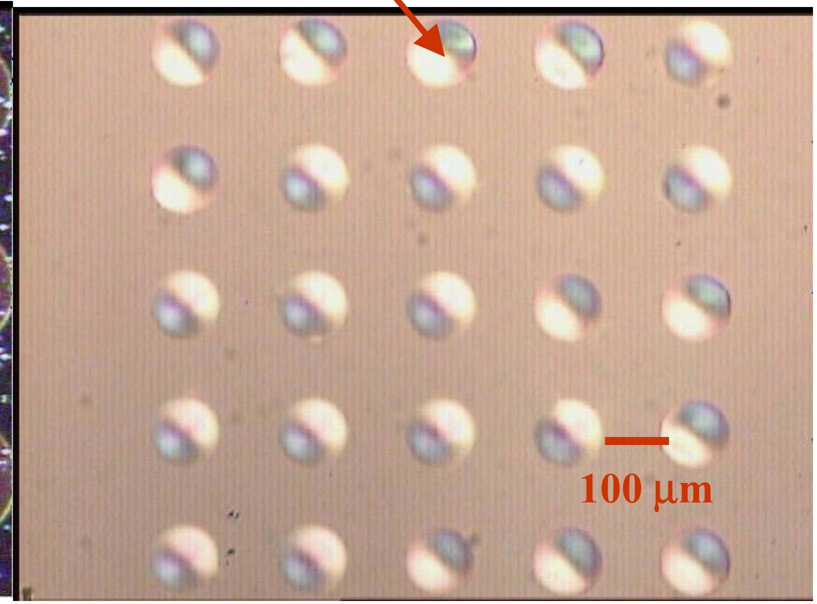
- 1 µm thick uniform Single Crystal Silicon membranes.
- The ripples on the membranes have disappeared.
- Very clean membrane formation.
- No polymers are left on the single crystal silicon .

Old Process vs. New Process
Si_3N_4 vs. Single Crystal Si Arrays

Silicon nitride membrane



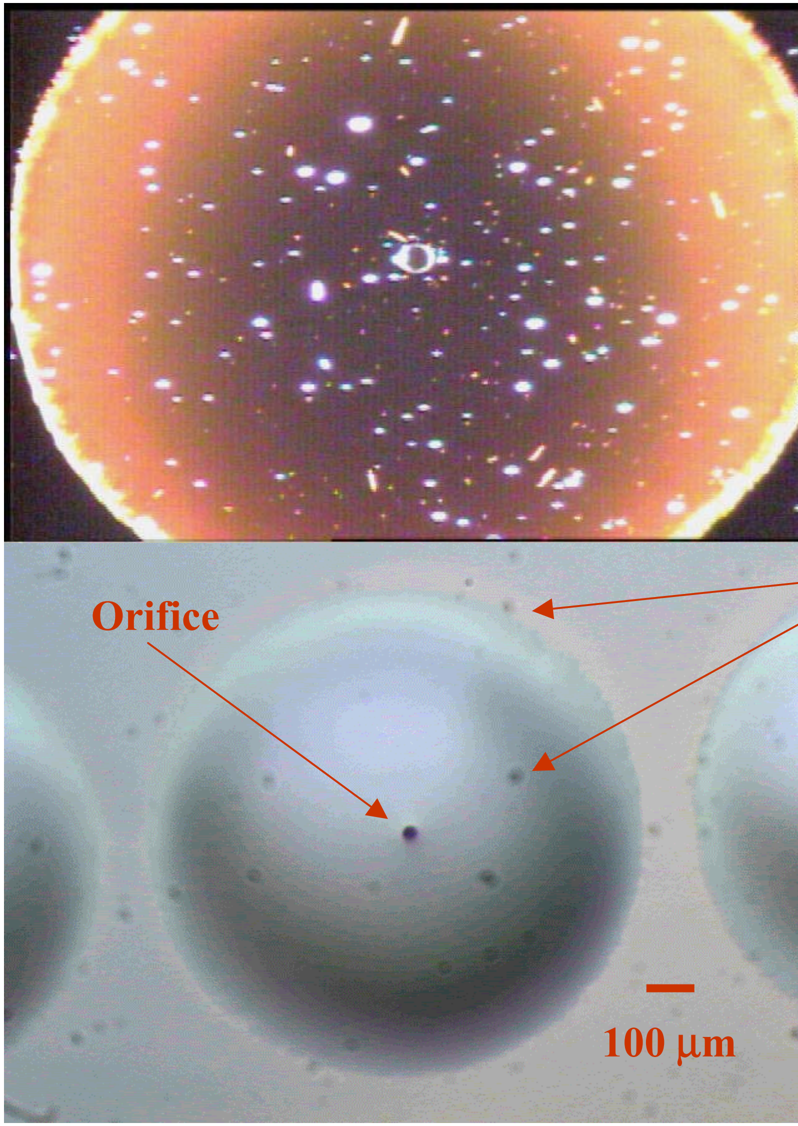
Single Crystal Si membrane



Membrane diameter : 160 µm
Orifice diameter : 10 µm

Membrane diameter : 100 µm
Orifice diameter : 14 µm

Old Process vs. New Process: Si_3N_4 vs. Single Crystal Membrane



Silicon-nitride membrane:

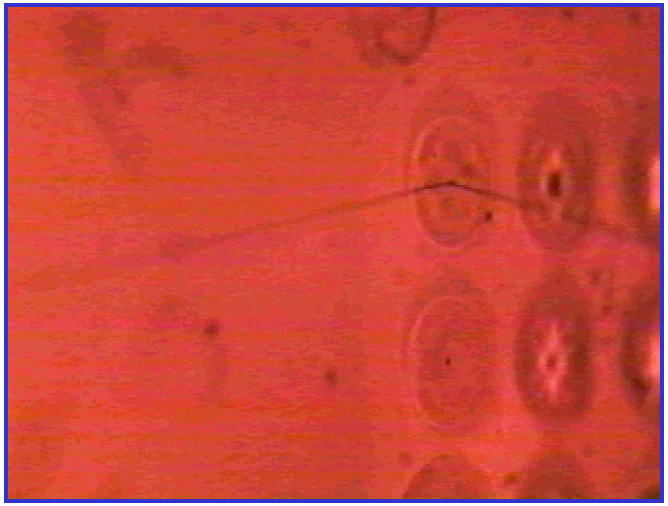
Membrane diameter : 160 µm
Orifice diameter : 10 µm

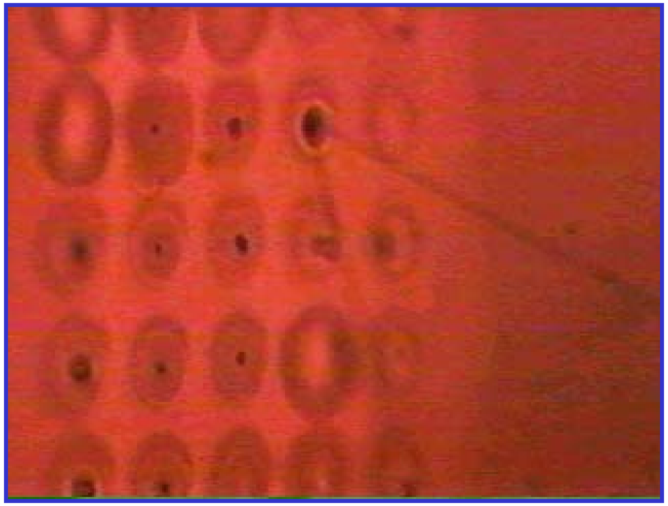
The black marks are on the camera lens **not** on the membrane surface.

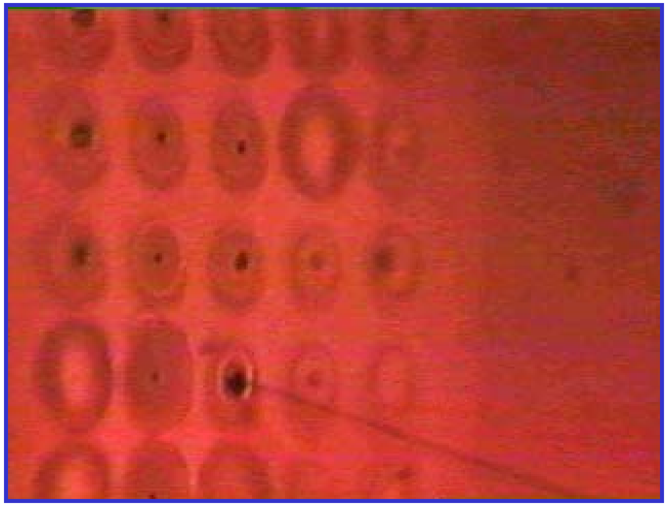
Single Crystal Si membrane:

Membrane diameter : 100 µm
Orifice diameter : 14 µm

Single Crystal Si Membrane Uniformity Check: Ejection at 1.2 MHz







- The yield is normally 100 % on an array.
- A special case is chosen to show uniformity .
- All the 100 μm diameter membranes can eject at 1.2 MHz indicating the uniformity of the device.
- The other membranes are at the edge of ejection.
- The ones that do not eject at this frequency are bigger size membranes due to bad bonding.

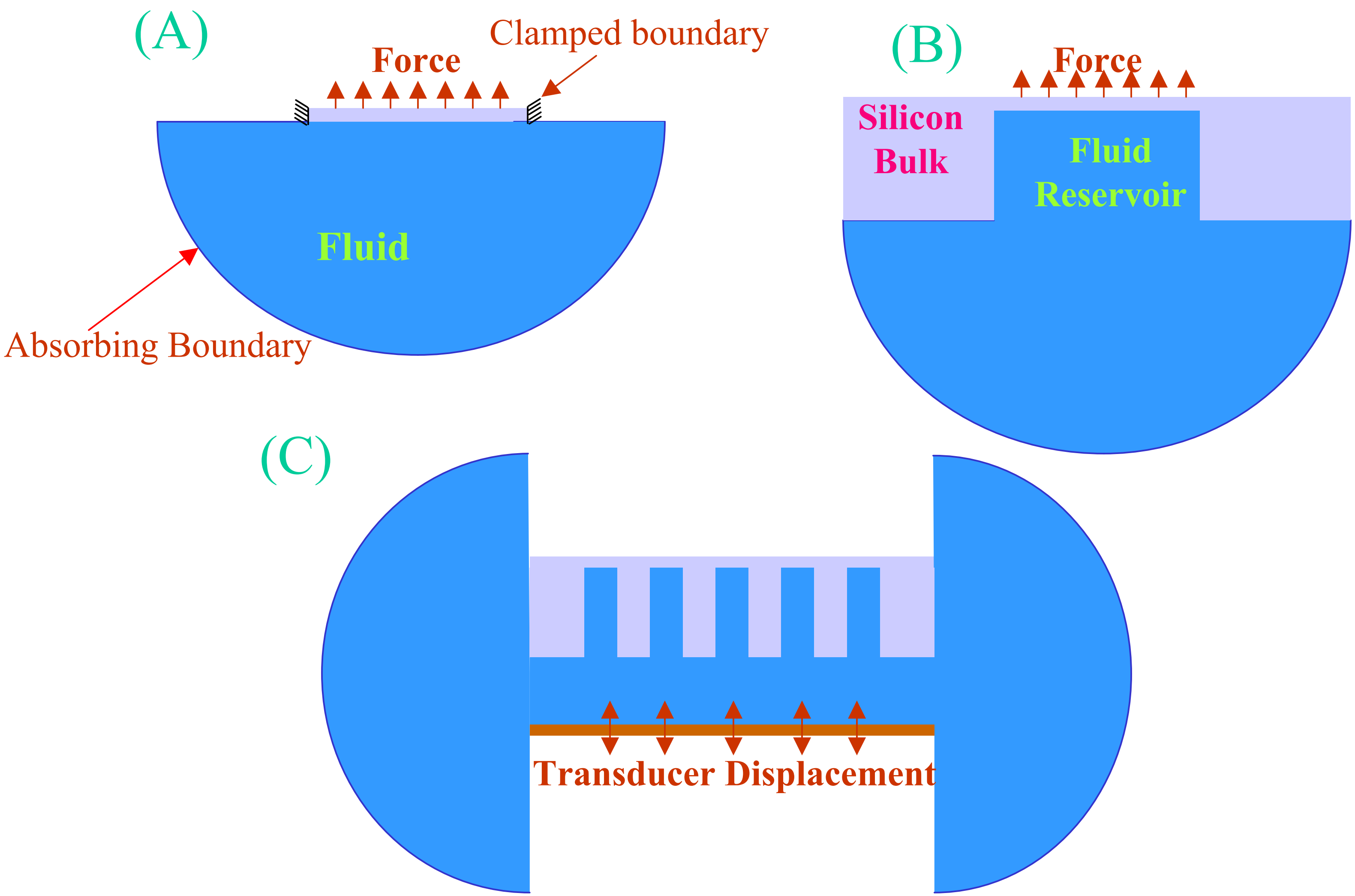
Finite Element Modeling of Ejector

FEM modeling of a Silicon membrane that is 1 µm thick and 100 µm in diameter. Membrane and cavity resonance govern operation at resonance for ejection.

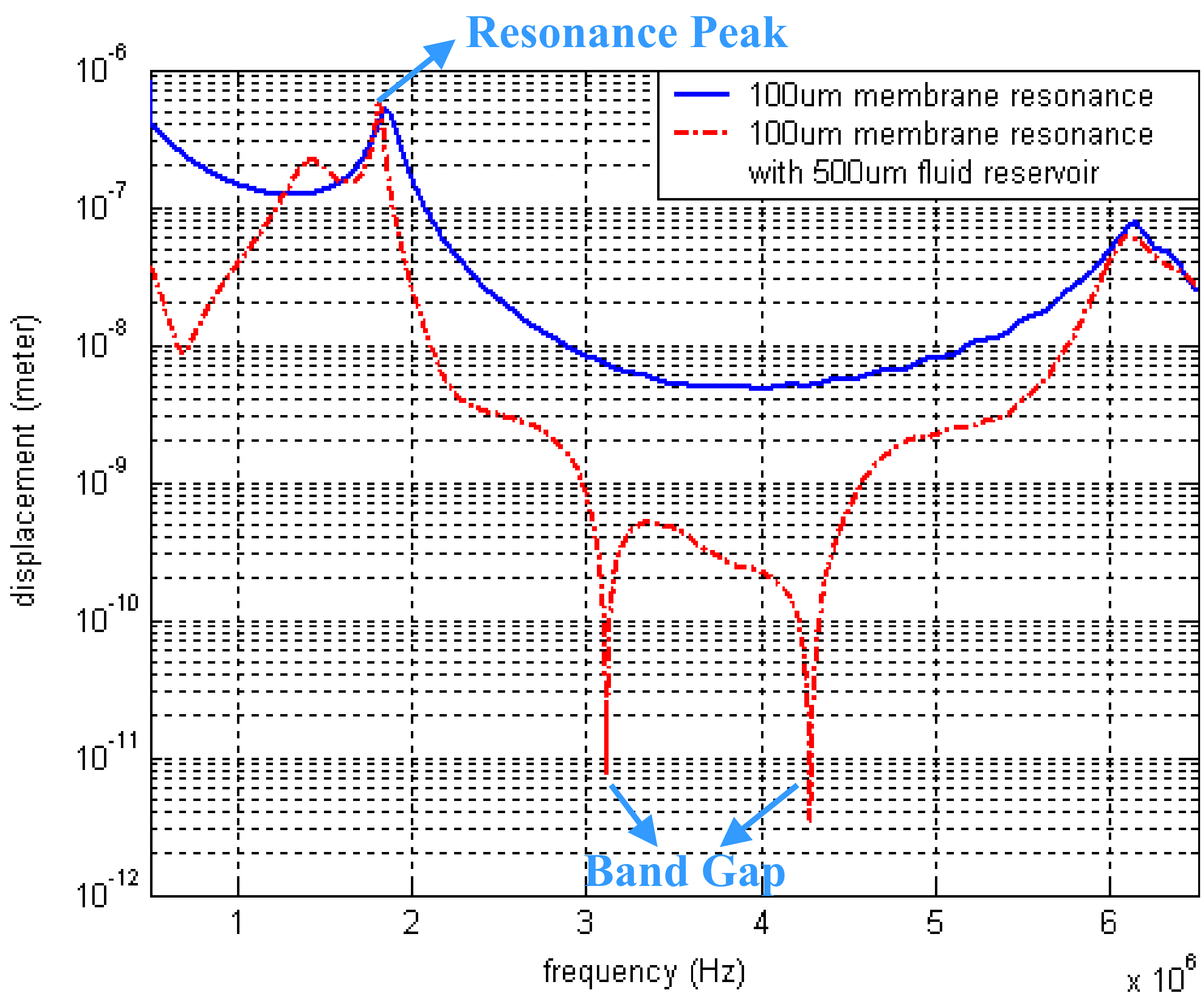
Membrane diameter		Resonance Number 0	1	2	3	4
200 µm	Vacuum	382 kHz	1.49 MHz	3.34 MHz	5.91 MHz	
	Water	78 kHz	480 kHz	1.33 MHz	2.72 MHz	
500 µm	Vacuum	61.26 kHz	238.3 kHz	533.5 kHz	946.9 kHz	1.479 MHz
	Water	11.4 kHz	66.4 kHz	187.6 kHz	388.1 kHz	677.1 kHz

Vacuum
Water

Recent FEM Work: 100 µm Si Membrane

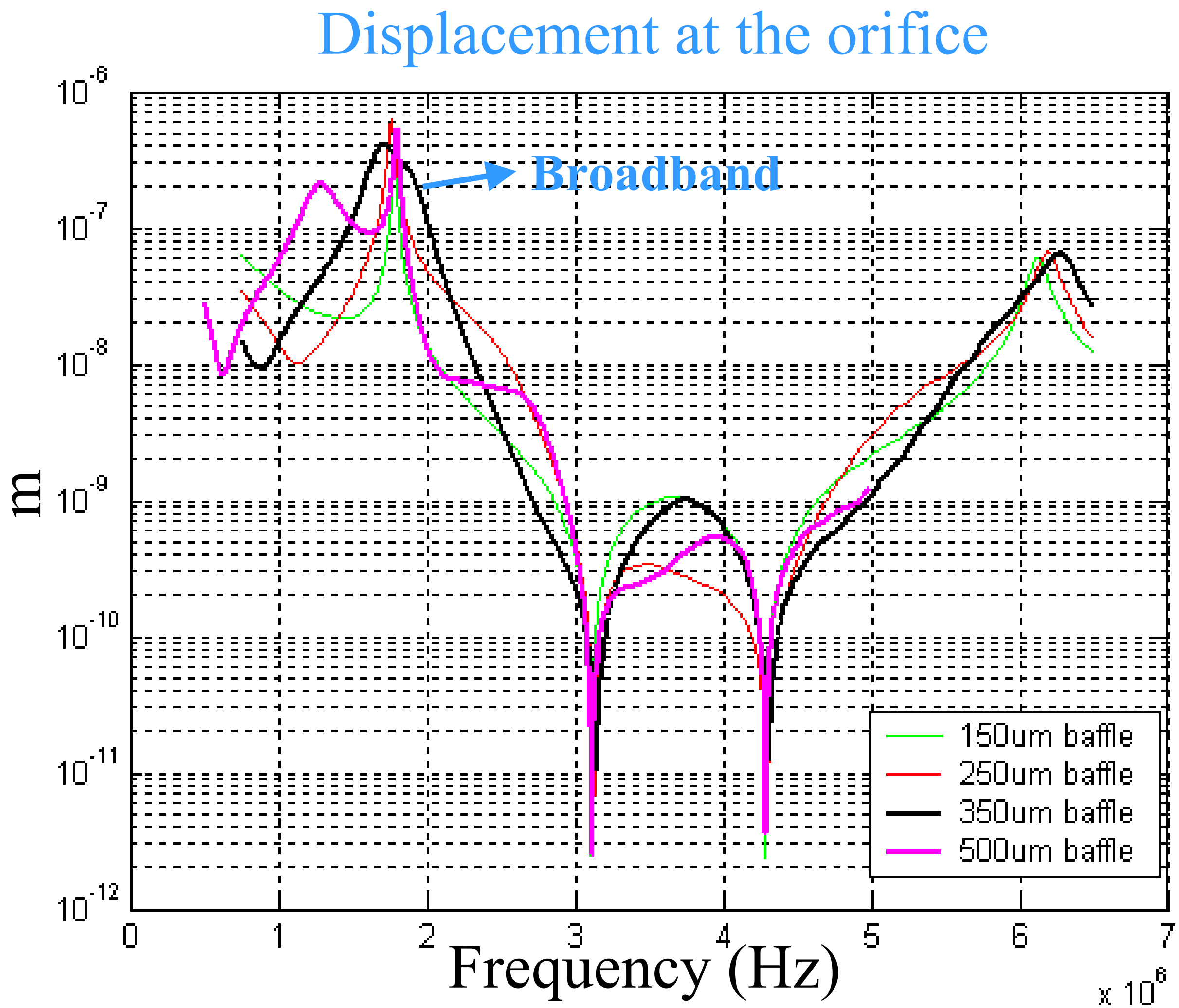


FEM Work: (A) &(B)



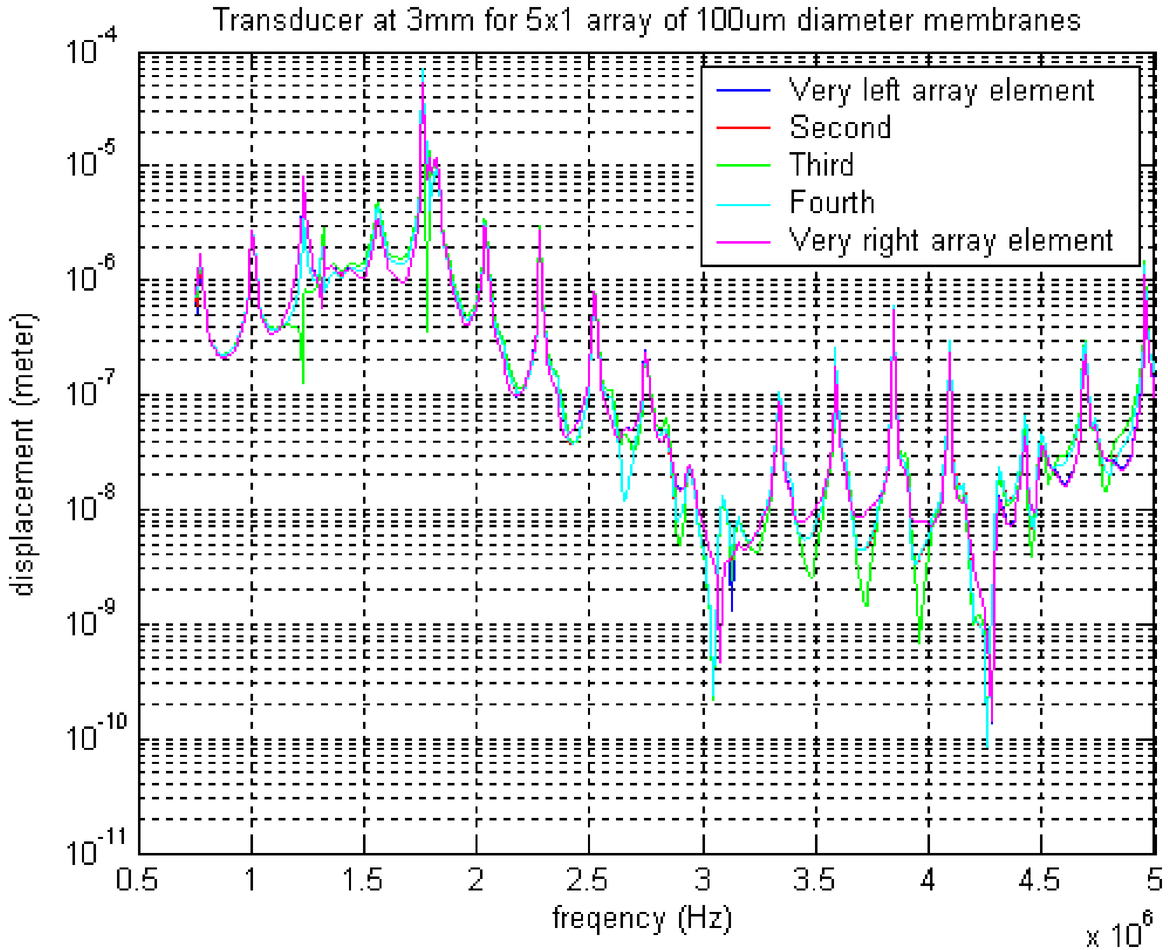
100 µm diameter membrane displacement with and without fluid reservoir.

FEM Work: (B) Fluid Reservoir Height



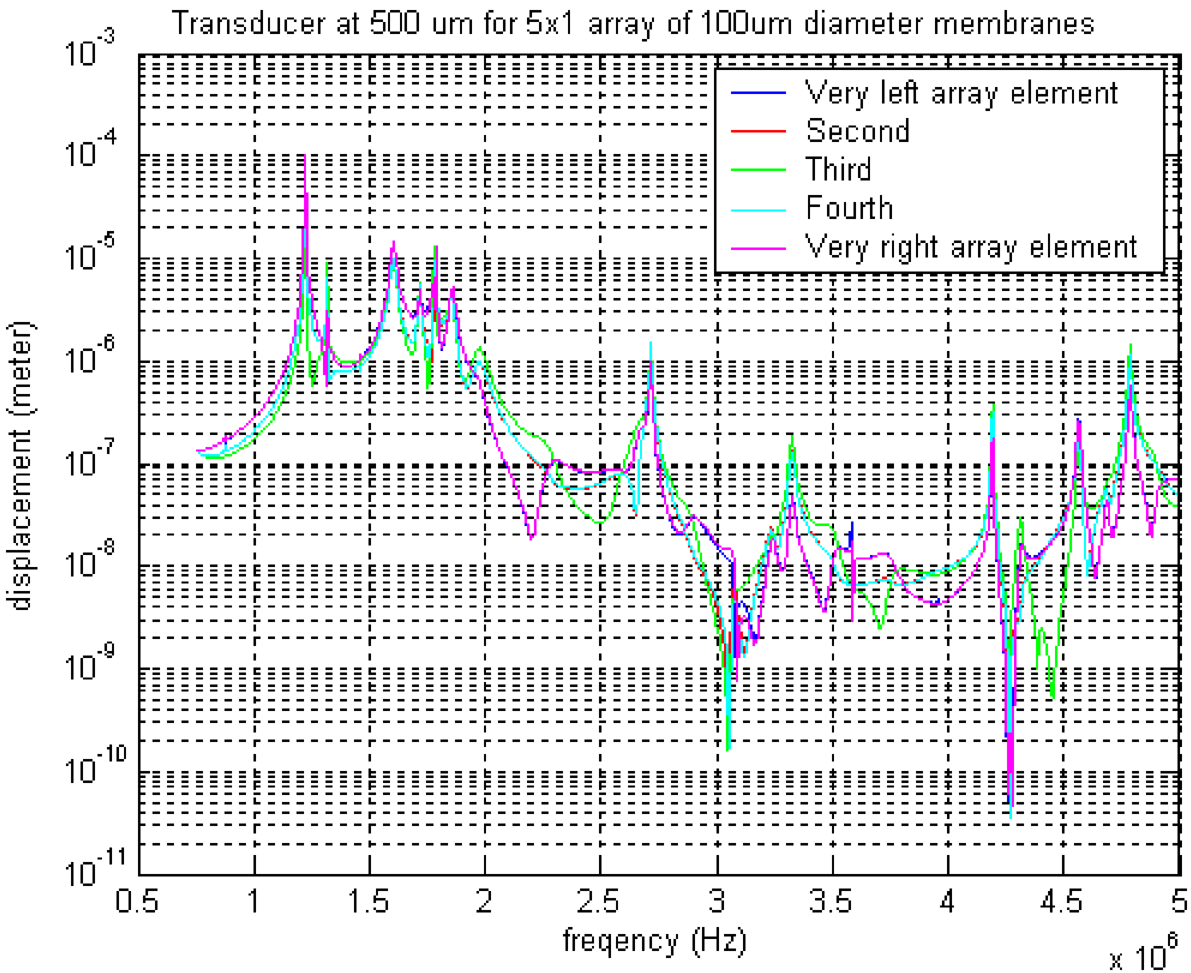
100 µm diameter membrane displacement with *various fluid reservoir heights.*

FEM Work: (C) Transducer @ 3 mm



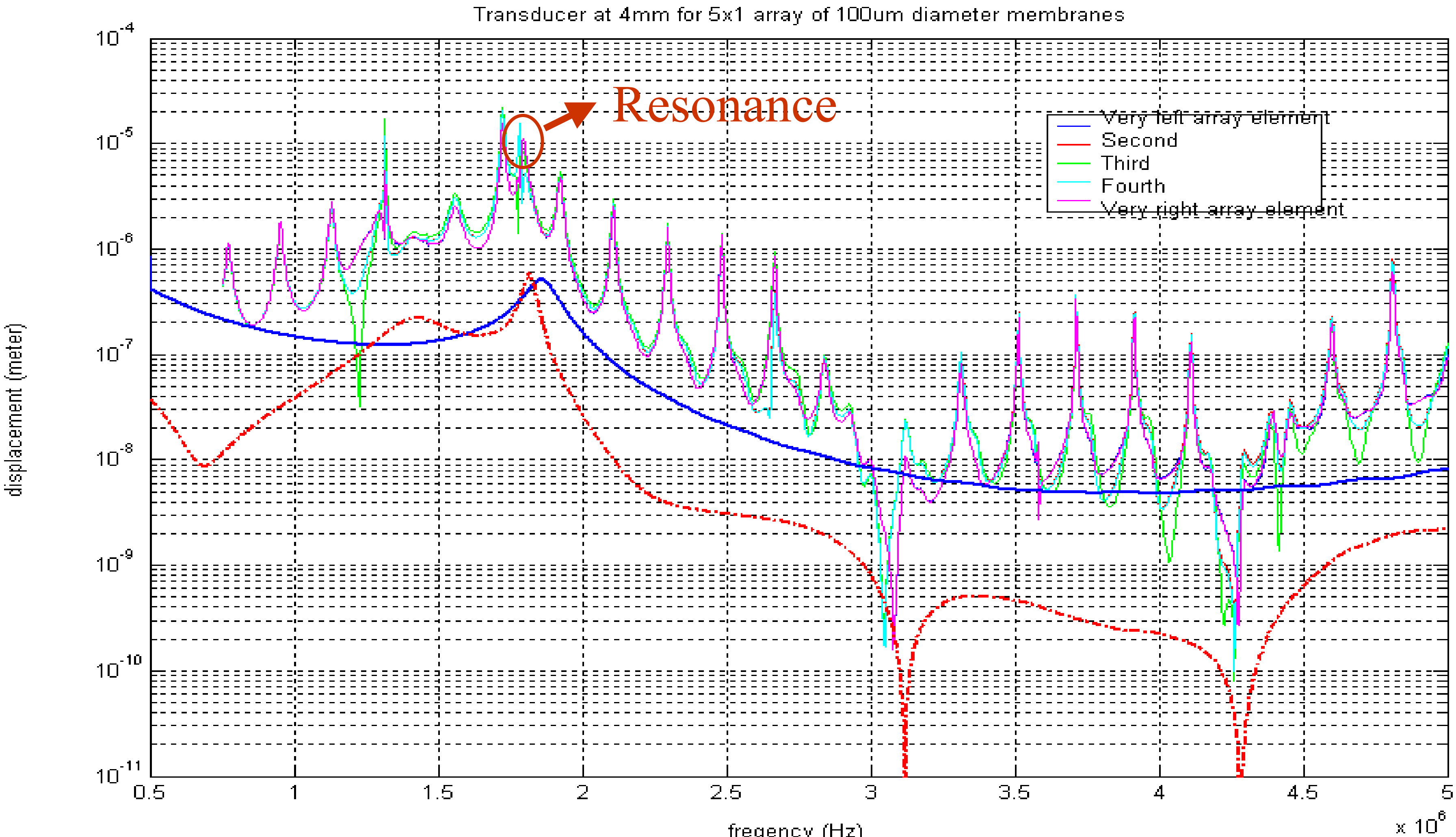
- Transducer in the far field, good uniformity of displacement of array elements.
- The Standing wave resonance between the device and the transducer

FEM Work: (C) Transducer @ 500 μm



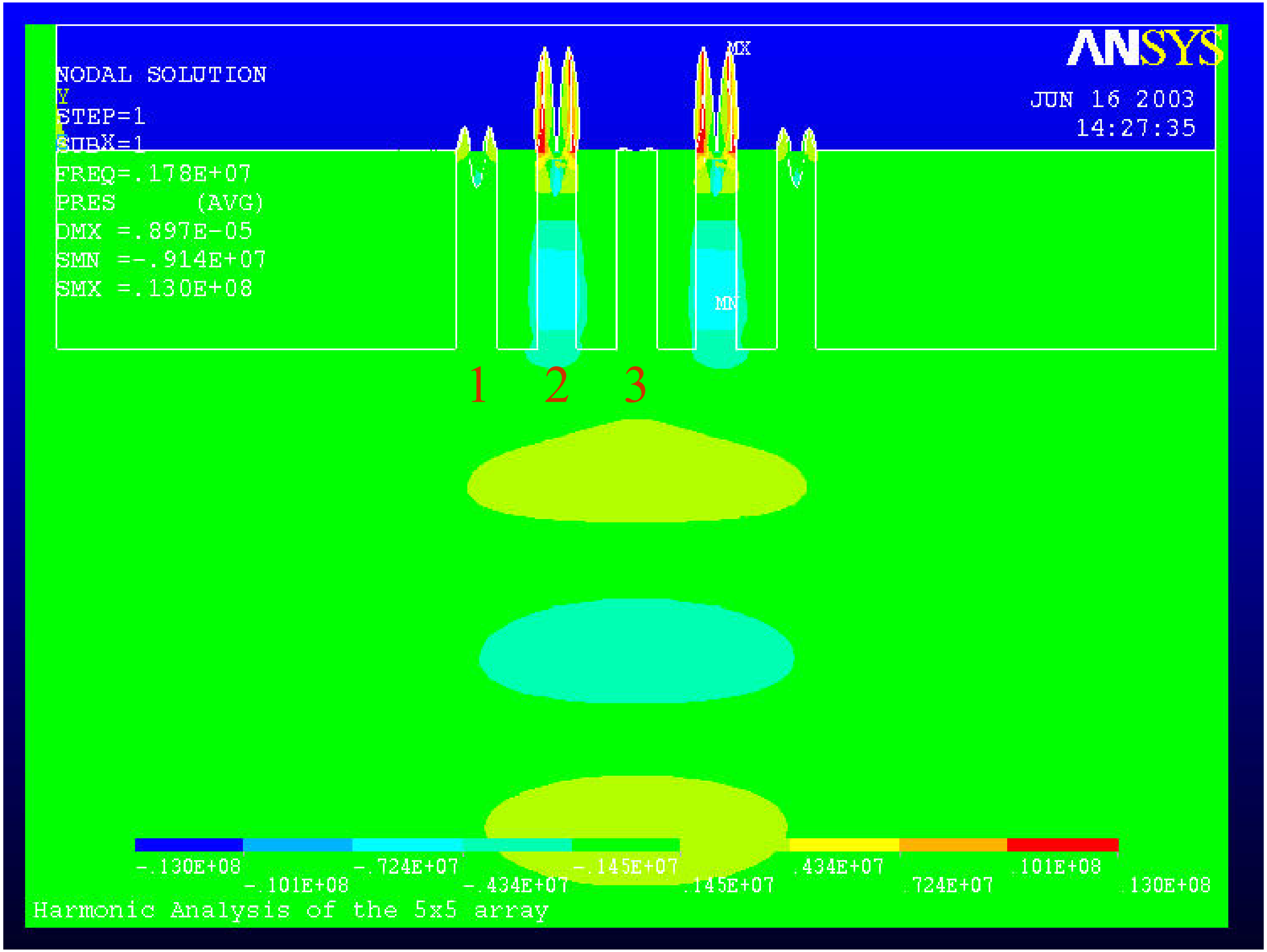
Transducer in the near field, bad uniformity of displacement of array elements..

FEM Work: (C) Transducer @ 4 mm

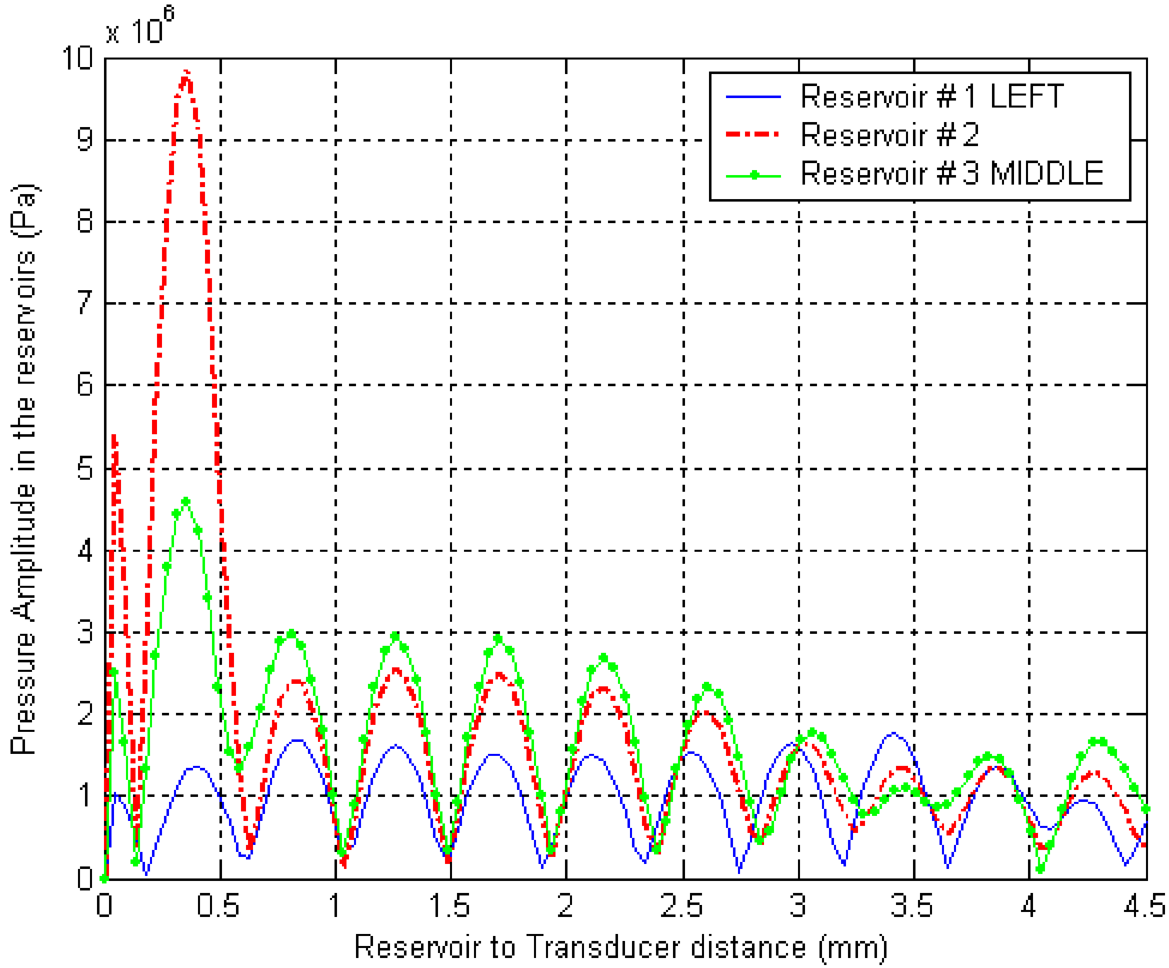


Membrane, cavity, and standing wave resonances should overlap for maximum displacement.

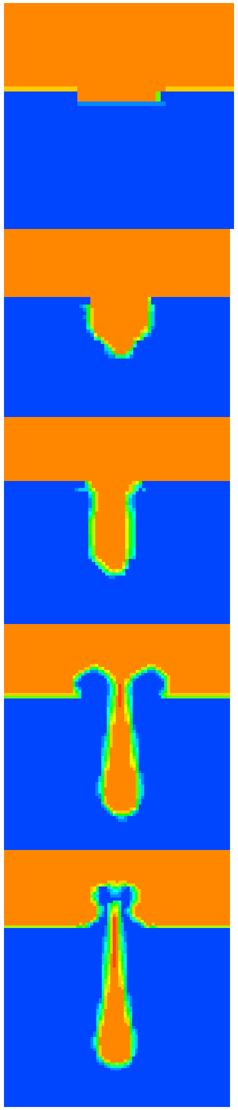
FEM Work: A Design



FEM Work: Pressure Amplitude in Reservoirs

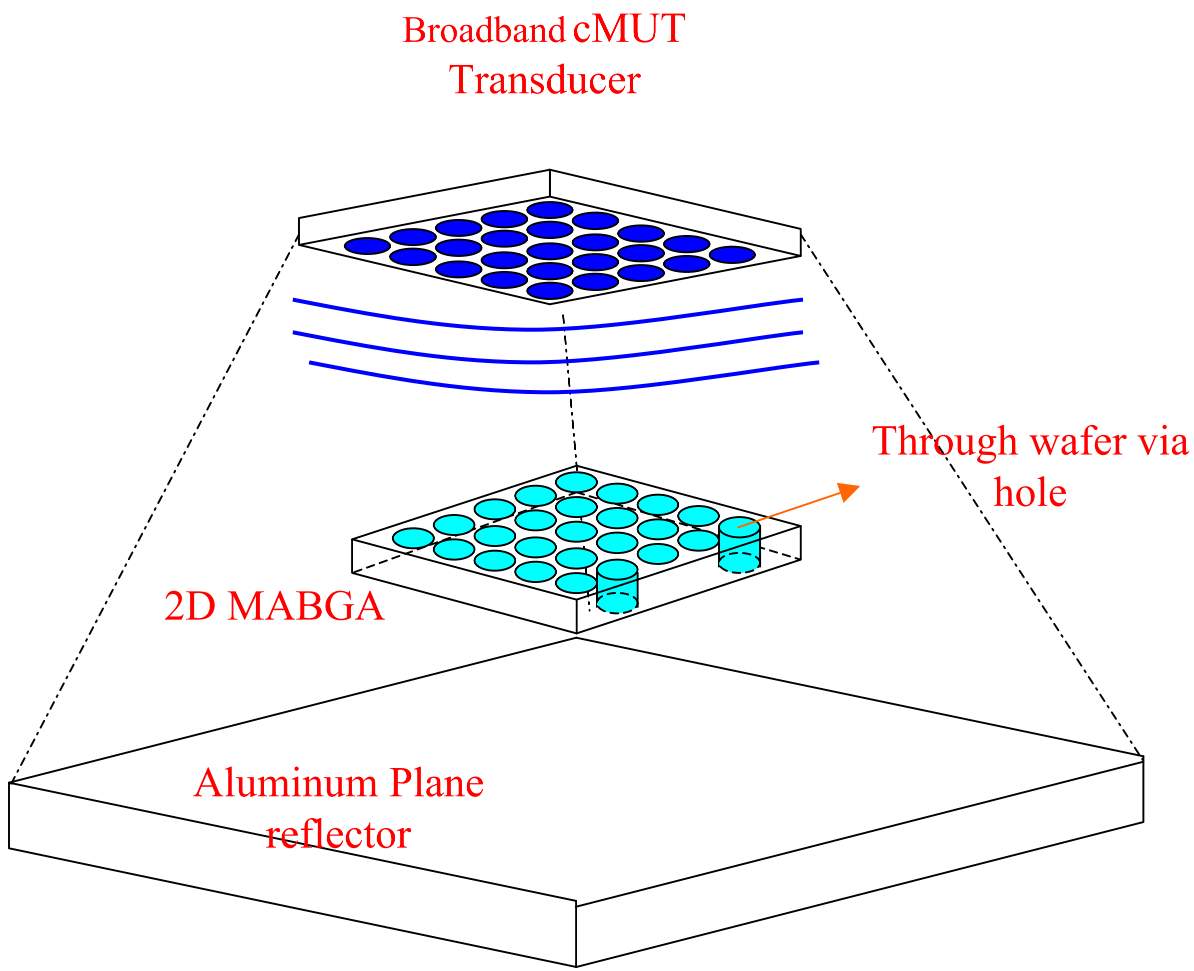


FEM Work: Droplet Generation @ the orifice



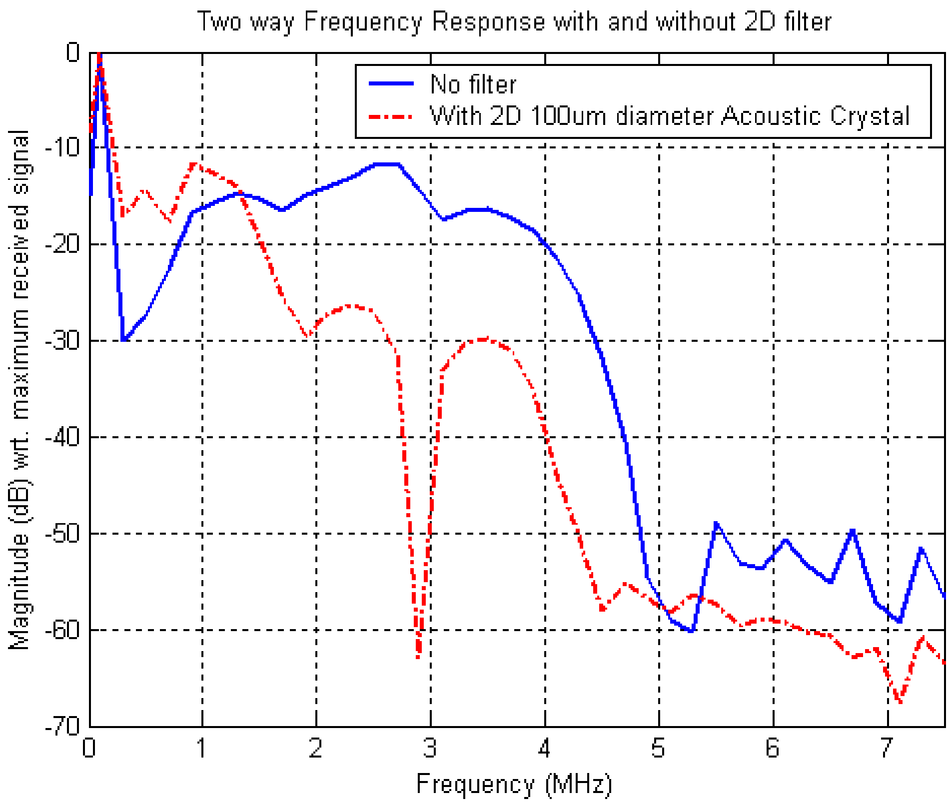
- The membrane displacement is determined by ANSYS FEM.
- The displacements are applied to the membrane loaded with fluid on one side using COVENTORWARE FEM.
- Droplet Evolution from the orifice is demonstrated.
- Droplet size and velocity can be determined.

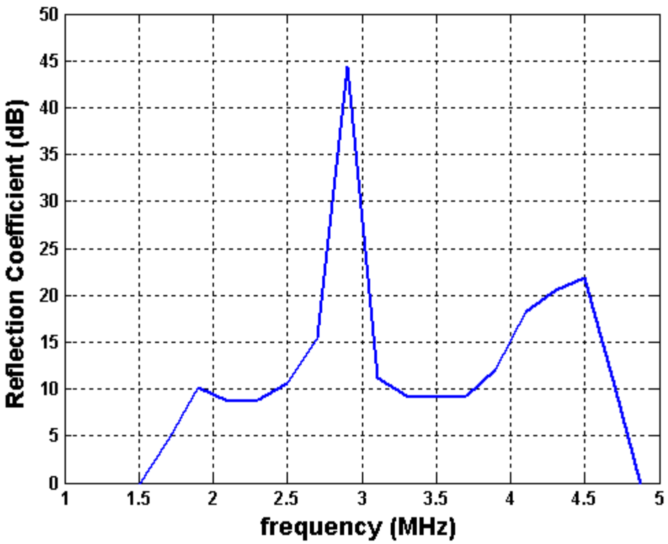
FEM Work: Experimental Understanding of the Band Gap



These experiments are carried on in oil to experimentally search the existence of the band gap predicted by the simulations.

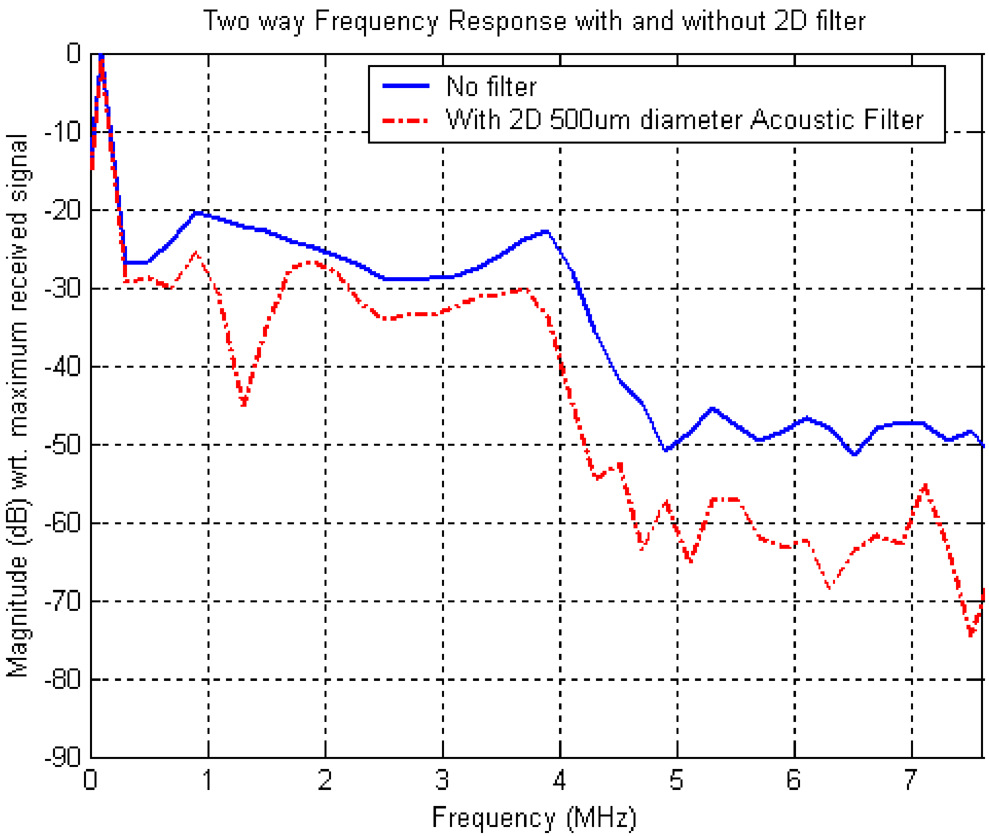
2D Micromachined Acoustic Band Gap Arrays: MABGA in vegetable oil

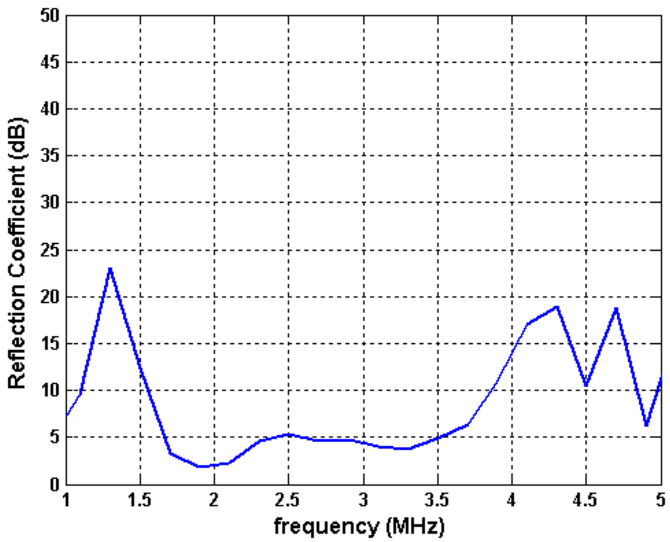




300 µm membranes diameter and 400 µm periodicity.
50dB Band Gap at 2.9MHz and the reflection coefficient over frequency range.

2D MABGA in vegetable oil





500 µm membranes diameter and 600 µm periodicity.
23dB Band Gap at 1.3 MHz and the reflection coefficient over frequency range.

Conclusions

- A new ejector fabrication process has been developed that provides
  - Uniform membranes
  - More control on material properties
  - Stress free membranes (no membrane buckling)
- Demonstrated that all **single crystal silicon** membranes in a 2D Array of micromachined ejectors are uniform and capable of ejection at 1.2 MHz.

Conclusions

- Finite Element Simulations are demonstrated.
  - Operate at the far field.
  - The fluid reservoir height should be designed for broad band operation.
  - Membrane, cavity, standing wave resonance's should match for ejection.
- Demonstrated the first 2D Micromachined Acoustic Band Gap Array spectral response.

Future Work

- Perform further FEM simulations to understand cross-talk issues and model the devices.
- Utilize the understanding of device operation to improve the design of 2D Micromachined Ejector Arrays .
- Using the new fabrication process to build ejectors capable of better controlled ejection
  - Drop on Demand ejection
  - All array membranes active at a given time
- Demonstrate full photoresist coverage of a wafer using micro-machined 2D ejector arrays.