Environmentally Benign Deposition of Photoresist, Low-k and High-k Dielectrics

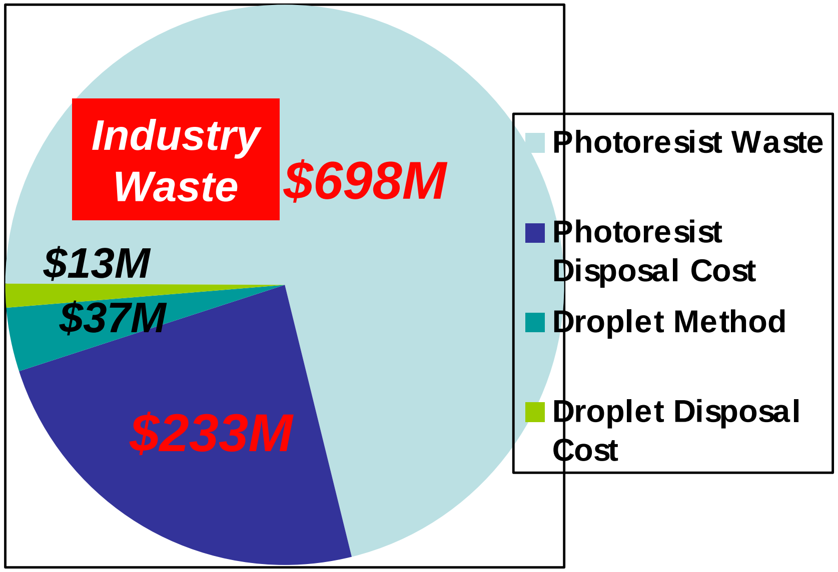
Utkan Demirci, G. G. Yaralioglu,
Prof. B.T. Khuri-Yakub

*Stanford University, E. L. Ginzton Laboratory,
Stanford, CA, 94305-4088*

Opportunity

Spin Coating

Photoresist Market ($1B+ Yearly)



Over 95% WASTED

$930M Potential Market Cost Savings Yearly

Huge Photoresist Waste

- Huge amounts of photoresist waste ($735M sold in 2003, 95% wasted)

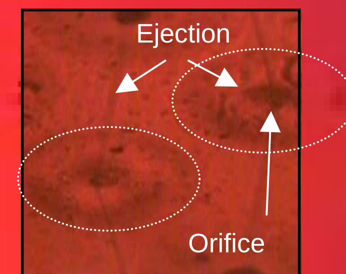
Enviromental Regulations

- Growing hazardous waste disposal costs ($245M costs 2003)
- Strengthening environmental regulations

Process Limitations

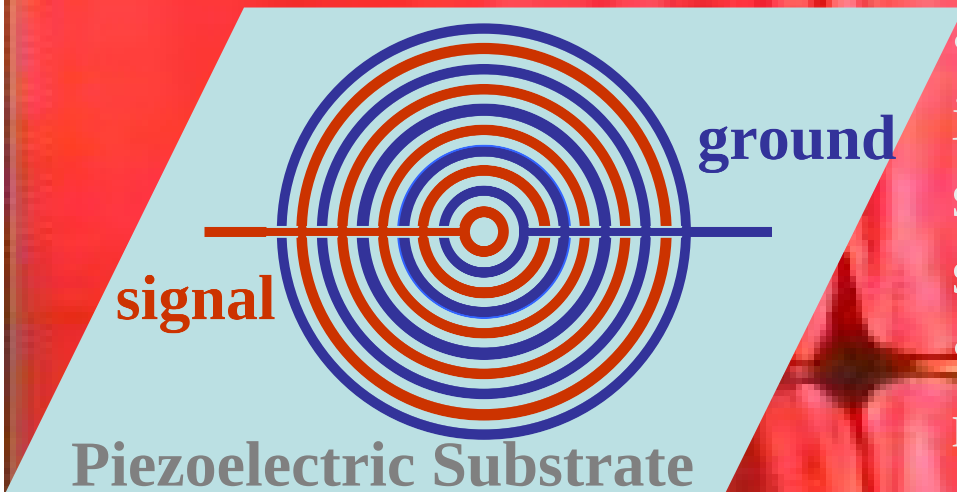
- Fundamental chip fab challenges as photo-mask technologies shrink
- 3D Lithography

Competing Technologies

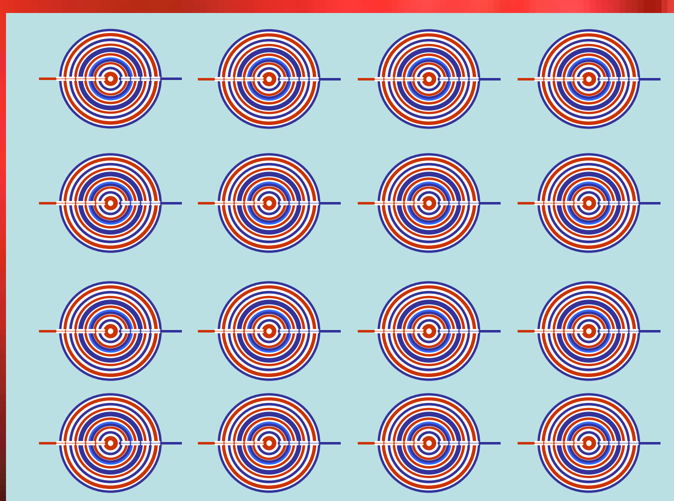


	Spin Coating	Spray Coating	Chemical Vapor Deposition	Micro-droplet Approach
Waste	95%	30%	N/A	<5%
Droplet Size	N/A	20µm	Vapor	3-20µm
Complexity	Low	Low	Very High	Low
Edge Bead	Prominent	Minimal	None	None
Liquid Limits	Current Resist	Pressurized	Special Resists	No heat or pressure

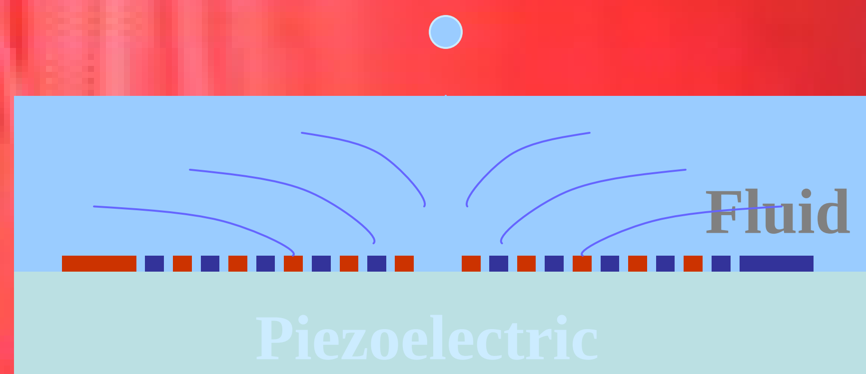
Interdigital Ring Ejectors



Top View

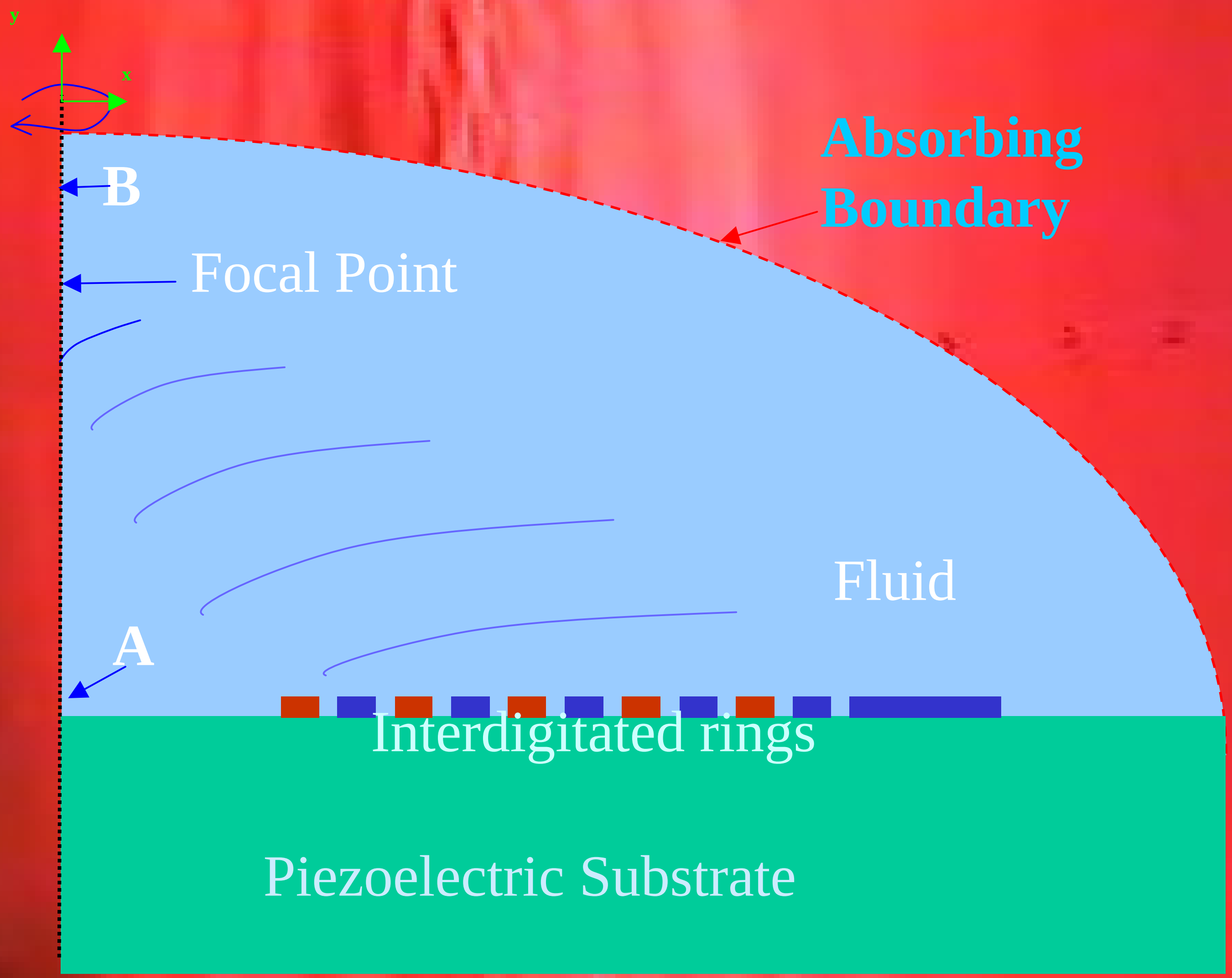


- Sinusoidal voltage on the interdigital electrodes generates surface waves on the piezoelectric substrate.
- These waves couple to the fluid medium and focus at the fluid surface.
- Radiation pressure breaks a droplet off the fluid surface.

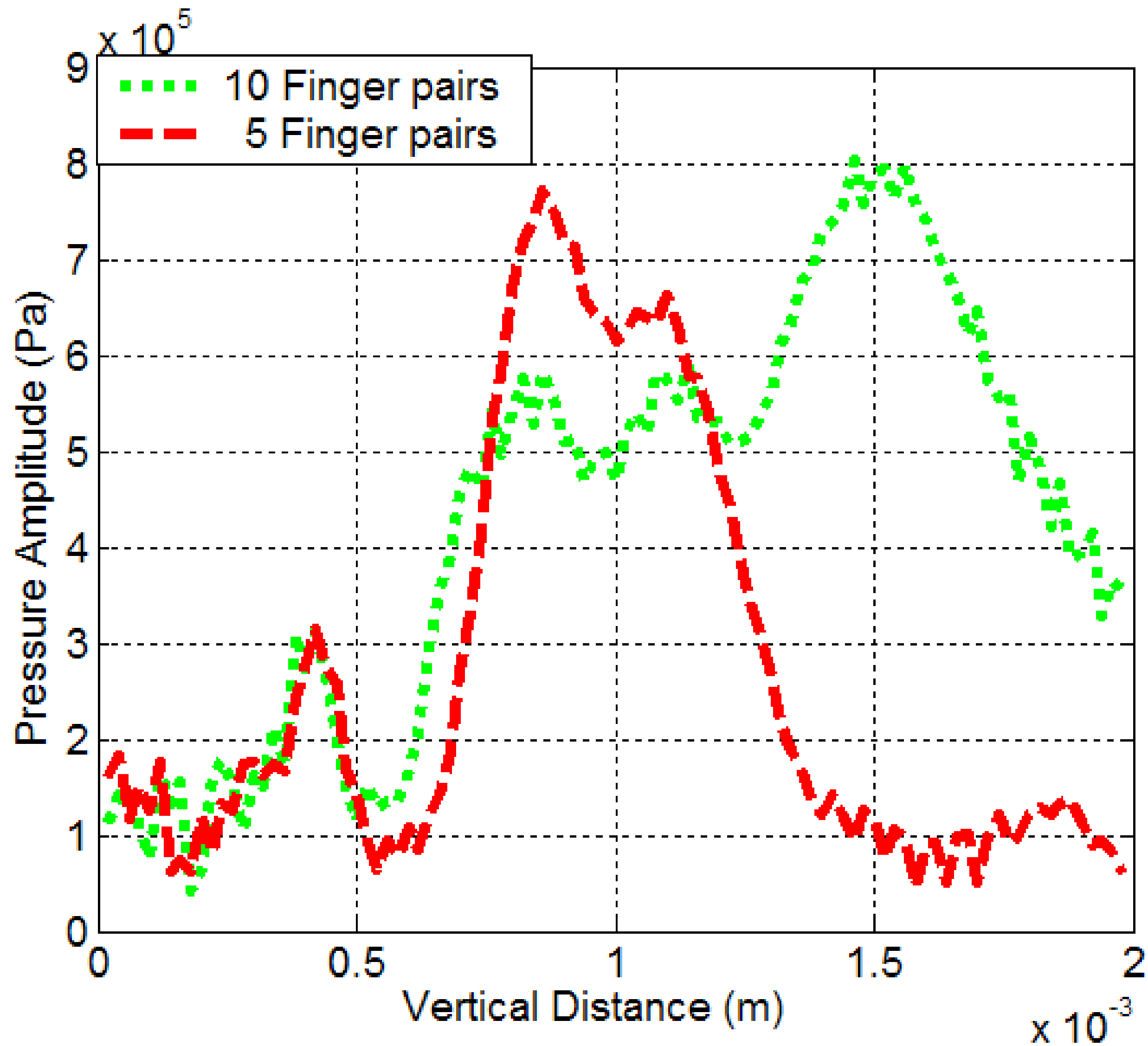


Side View

Finite Element Analysis (FEA)

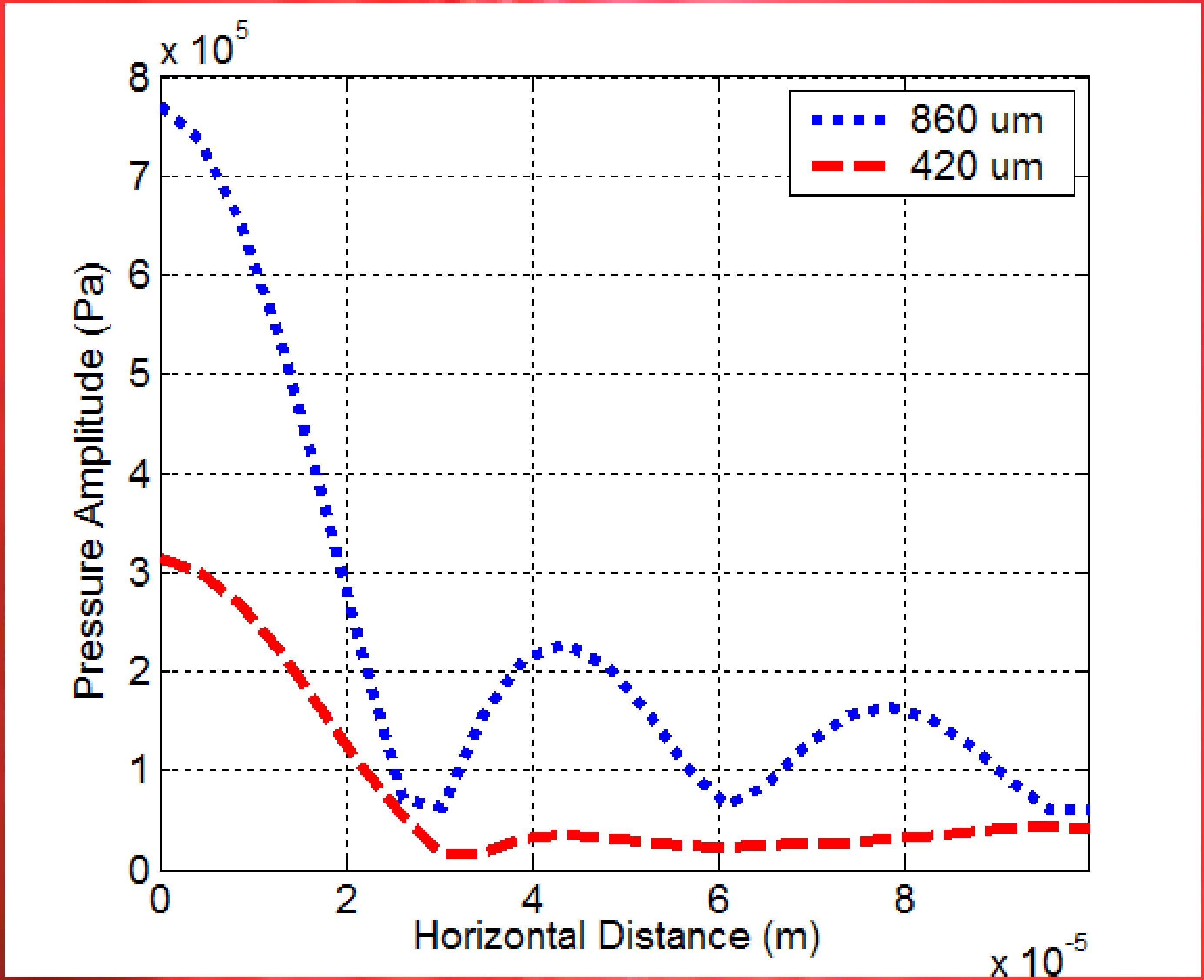


FEA: Number of Rings



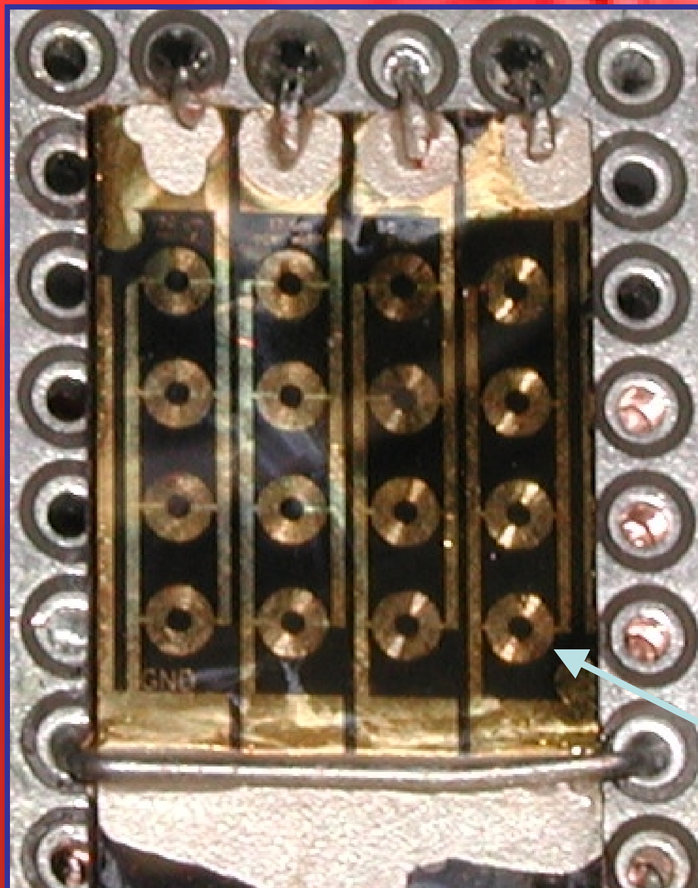
Pressure on the axisymmetry line from ‘A’ to ‘B’ in the fluid medium.

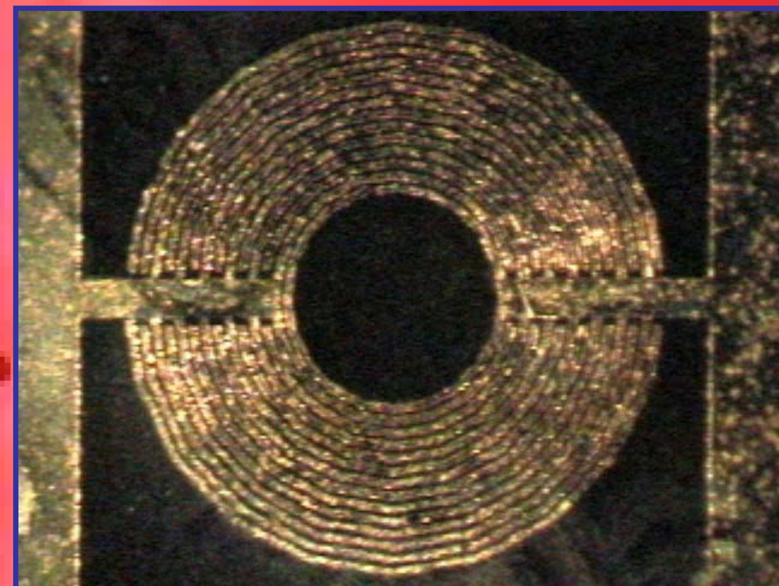
FEA: Focal Point



Lateral pressure distribution at the focal point of 860 µm and at 420 µm.

Fabricated Devices



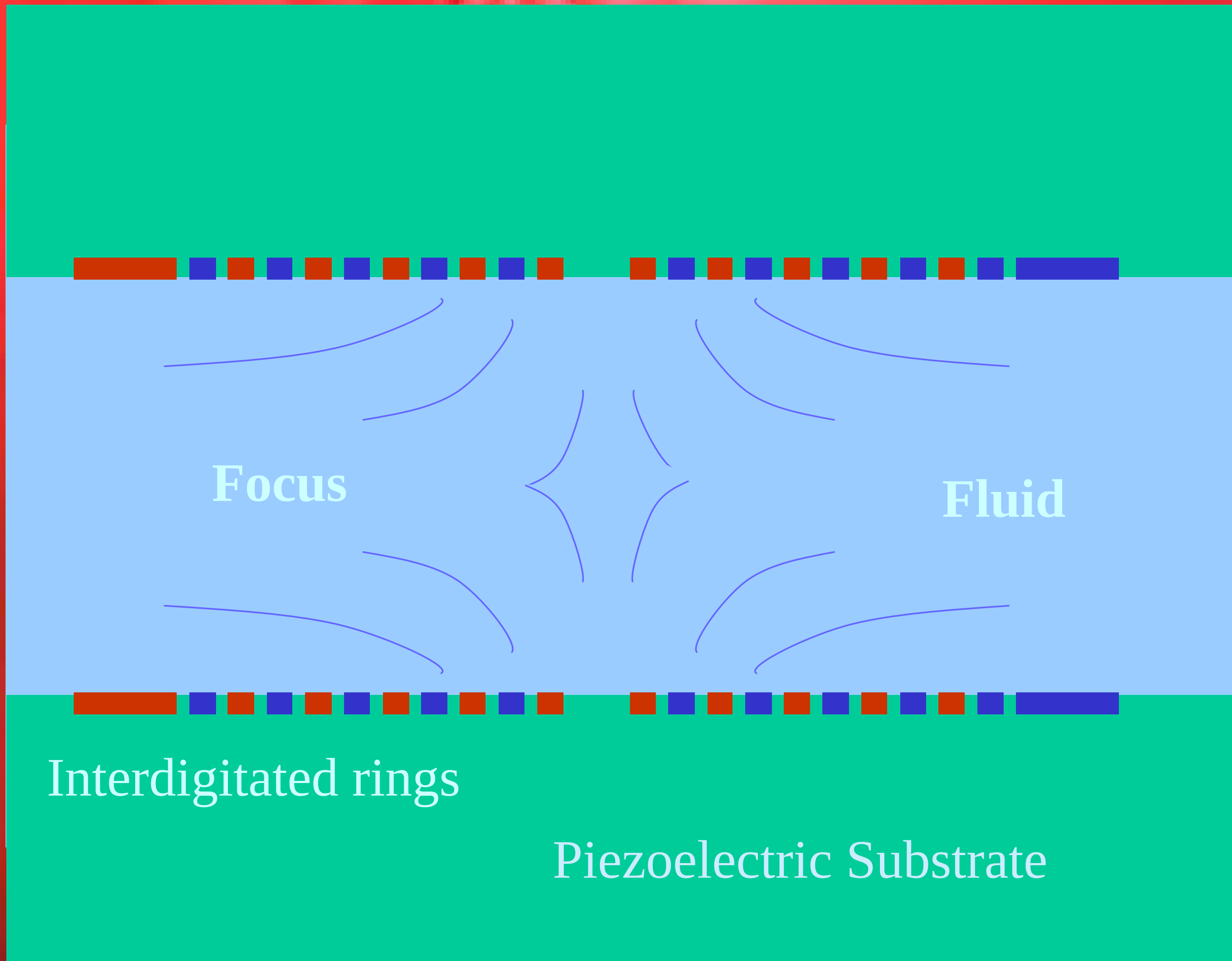


OD=1.5mm
ID=0.5mm

4x4 2D ejector array

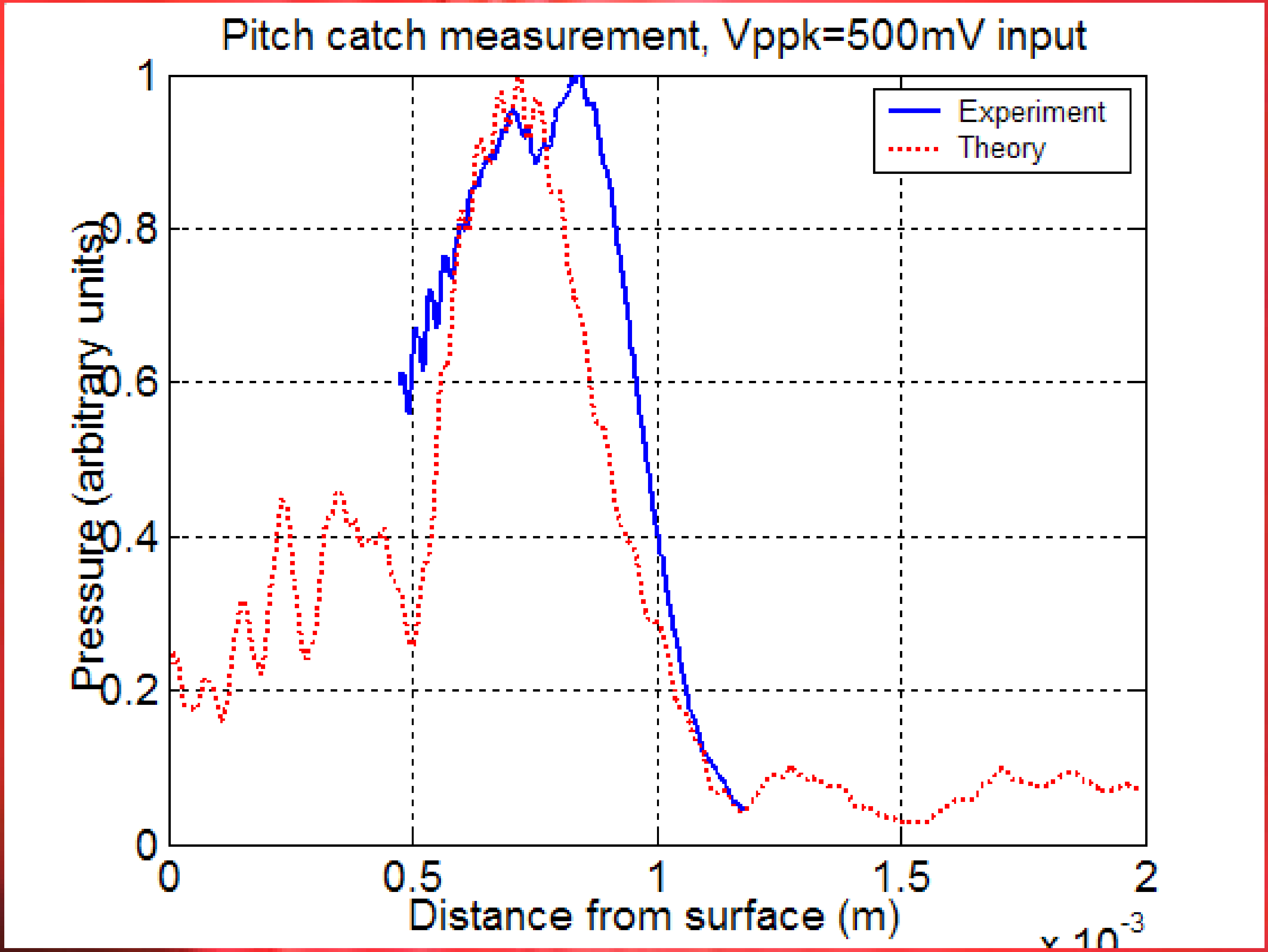
- SAW velocity on PZT= 2312 m/s , f_0=34 MHz ➔ ID w=17 μm
- Leak angle, asin(1500/2312) = 40º

Pitch Catch Experiments with Single Devices

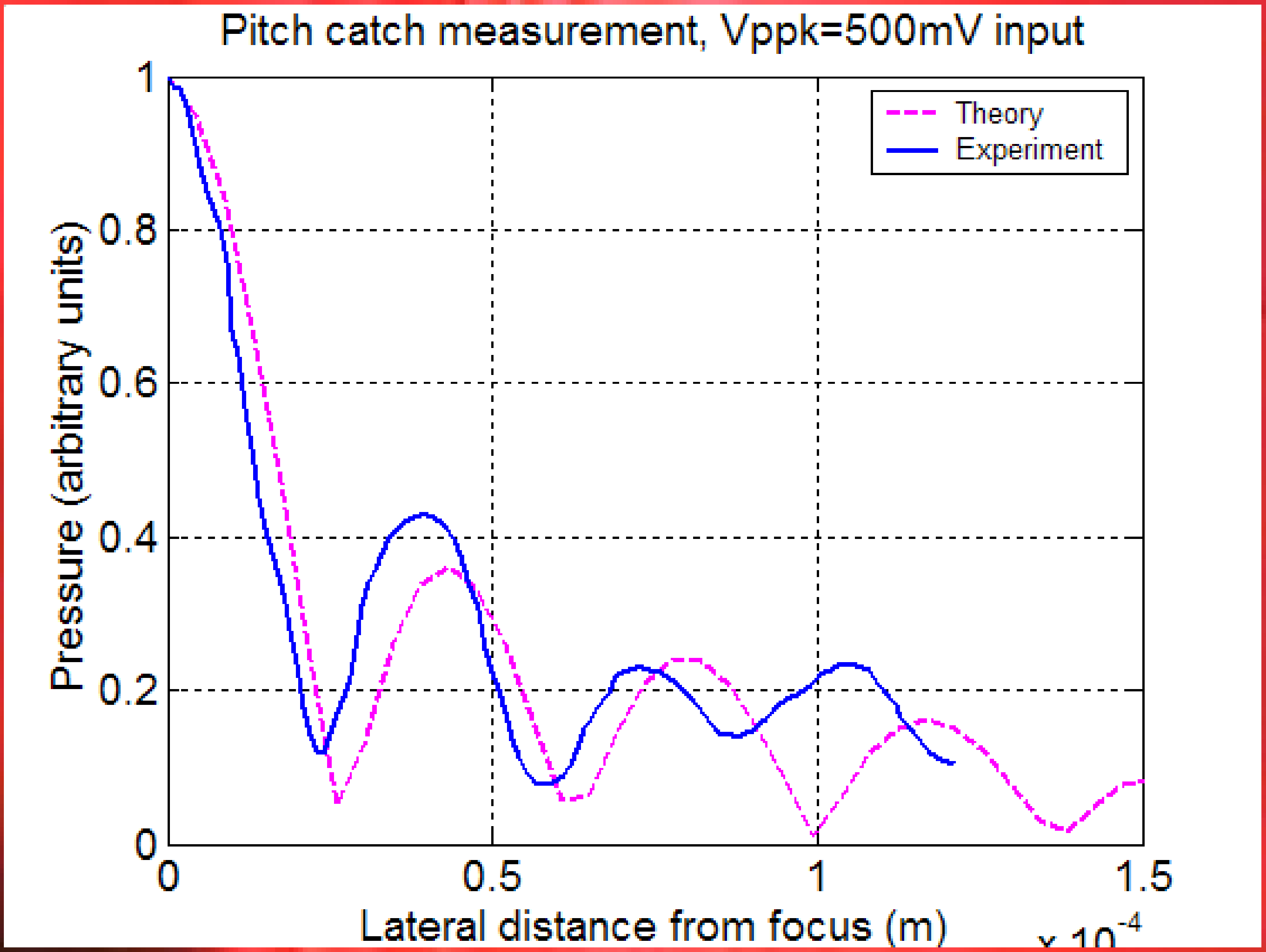


We have two micromachined ejectors facing each other.

Focus Location



Focus Pressure Distribution

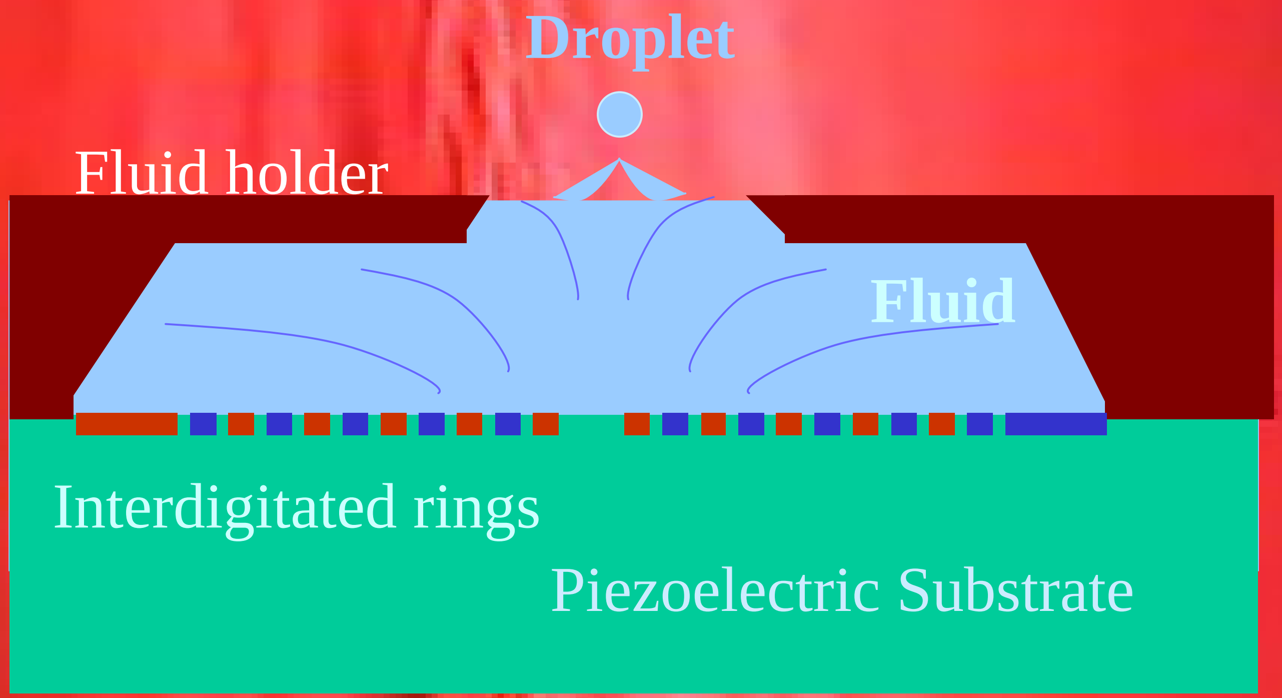


Open Pool Ejection from Ring Ejector Arrays

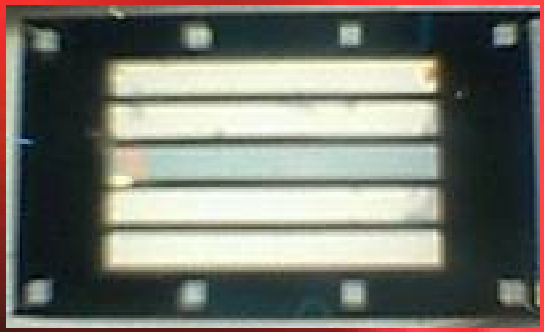
Droplet size: 28 μm, Repetition frequency: 1 kHz

RF frequency: 34 MHz, Pulse width: 10 μs

Fabricated Spacers



We have two micromachined spacers aligned on top of each other.
300 µm and 500 µm thick wafers; 50,100,200 µm wide ejection pools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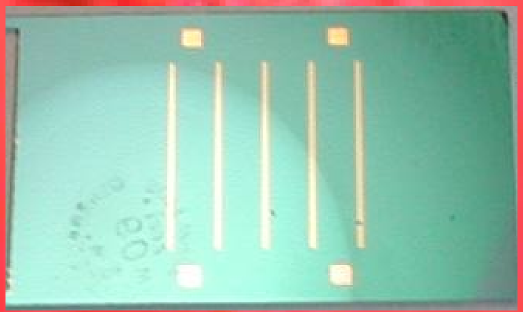
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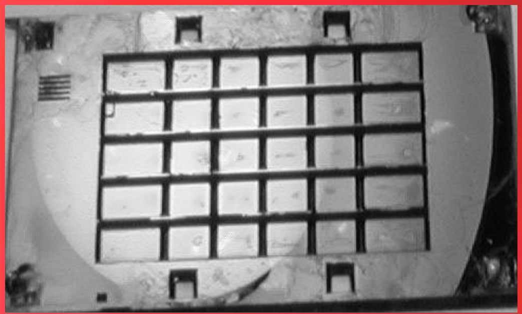
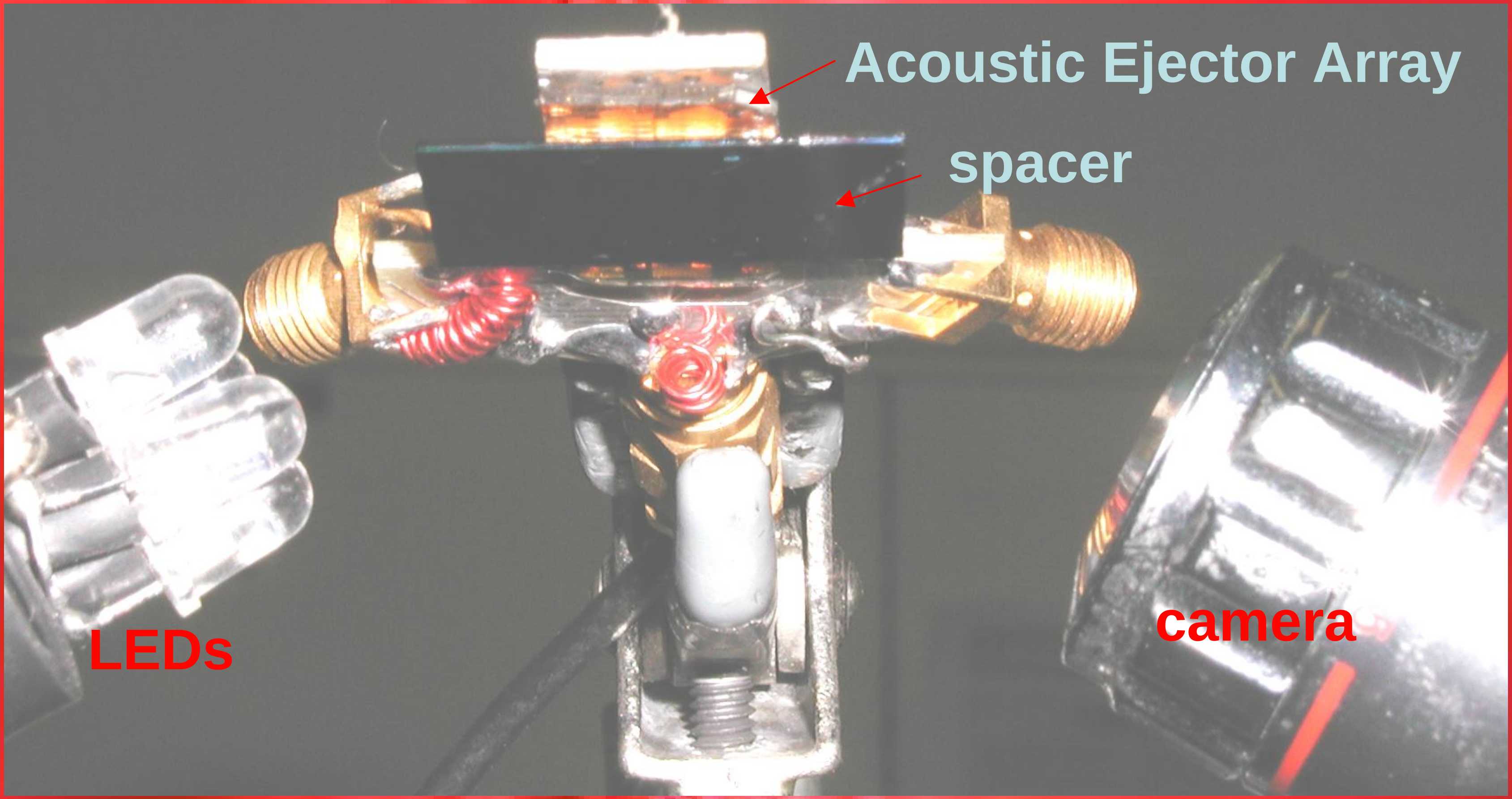
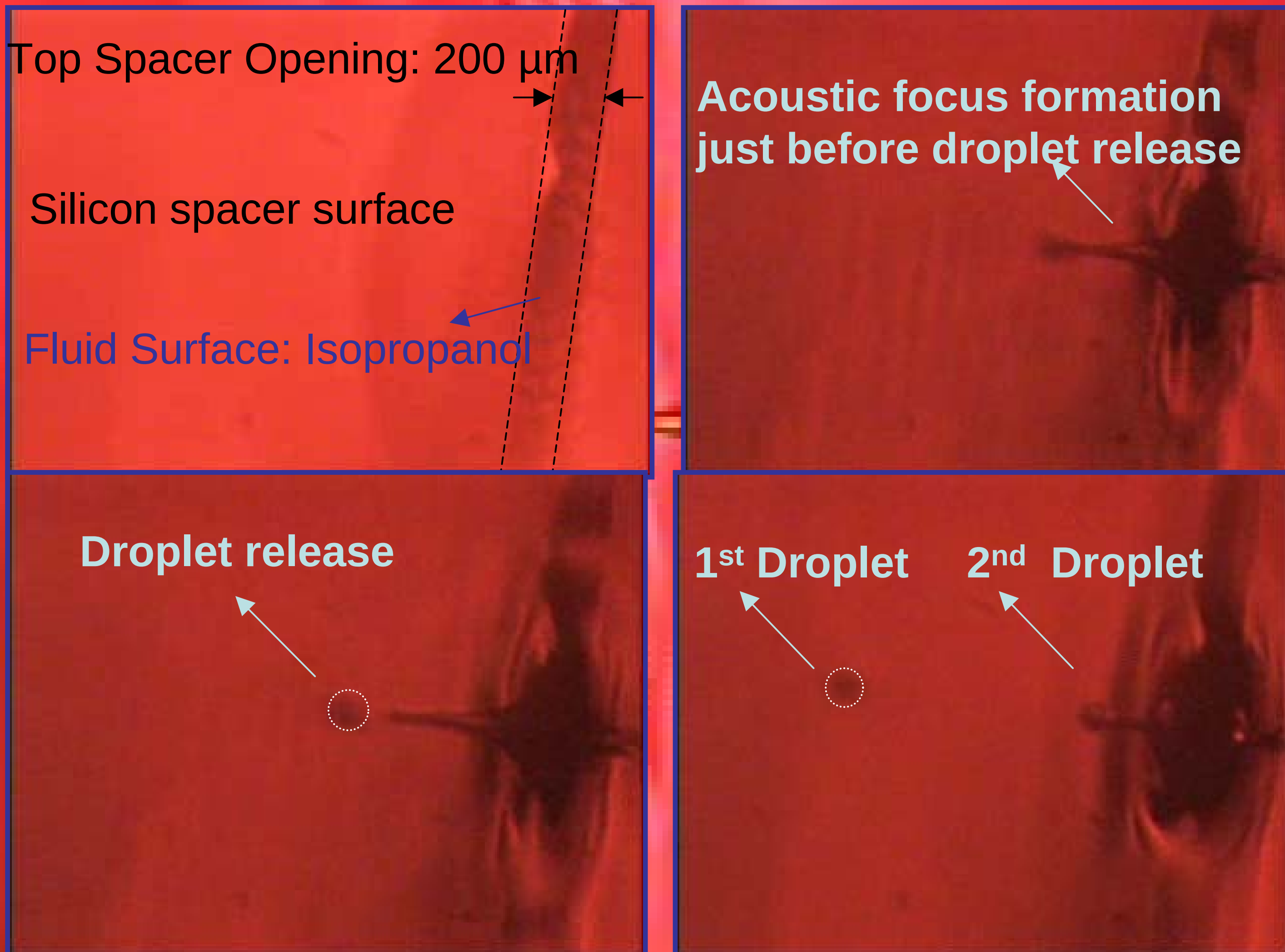


Open Pool Downwards Ejection Setup



The stroboscopic imaging setup for a 3x3 Droplet Ejector Array.
Spacers are aligned on top of the ejectors.
This spacer design allows ejection in all directions.
The picture shows ejection downwards to the ground.
The fluid holds with surface tension at the spacer edges.

Step by Step Droplet Ejection with Spacers



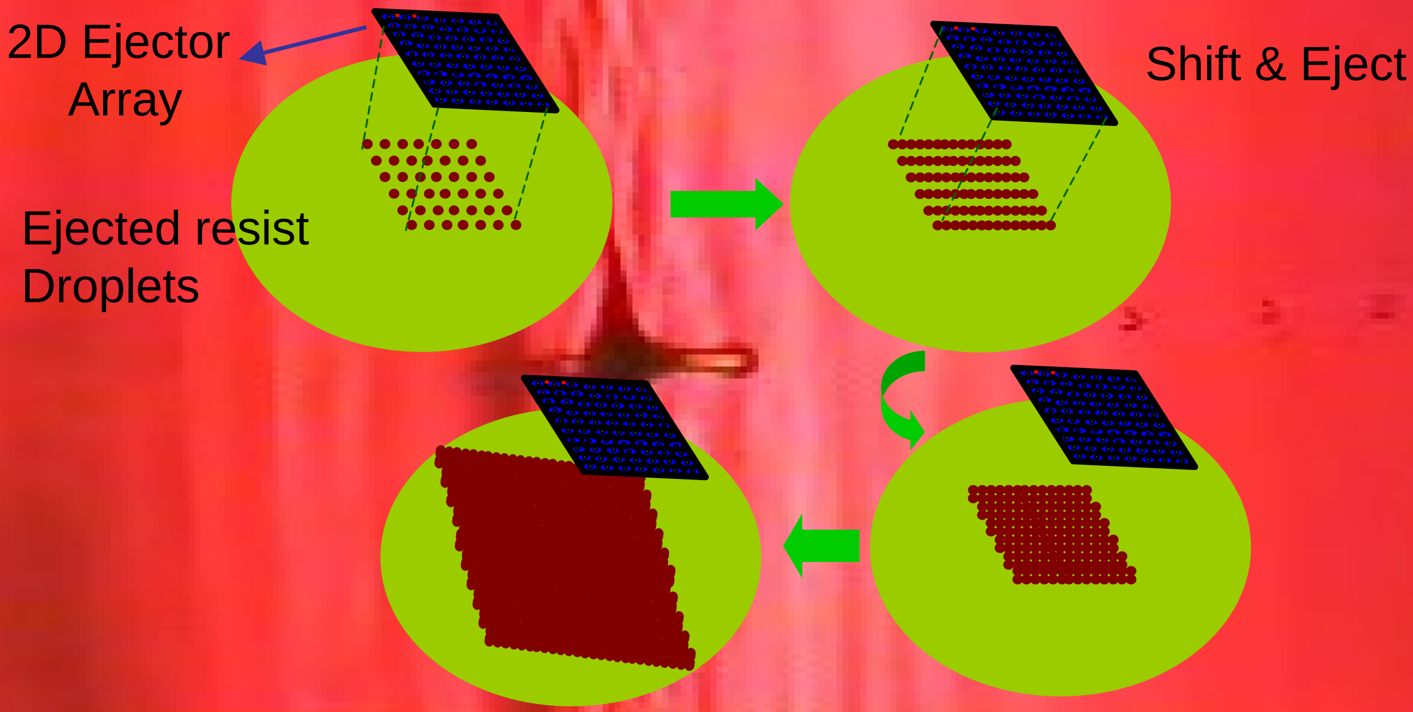
-Droplet sizes and directionality are uniform.

-Drop on Demand and Continuous modes of operation are easy to control.

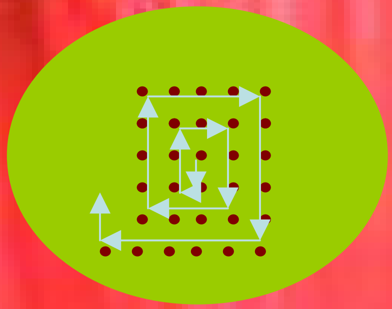
-All the array elements eject, addressing can be done.

Coverage Theory : Simulation

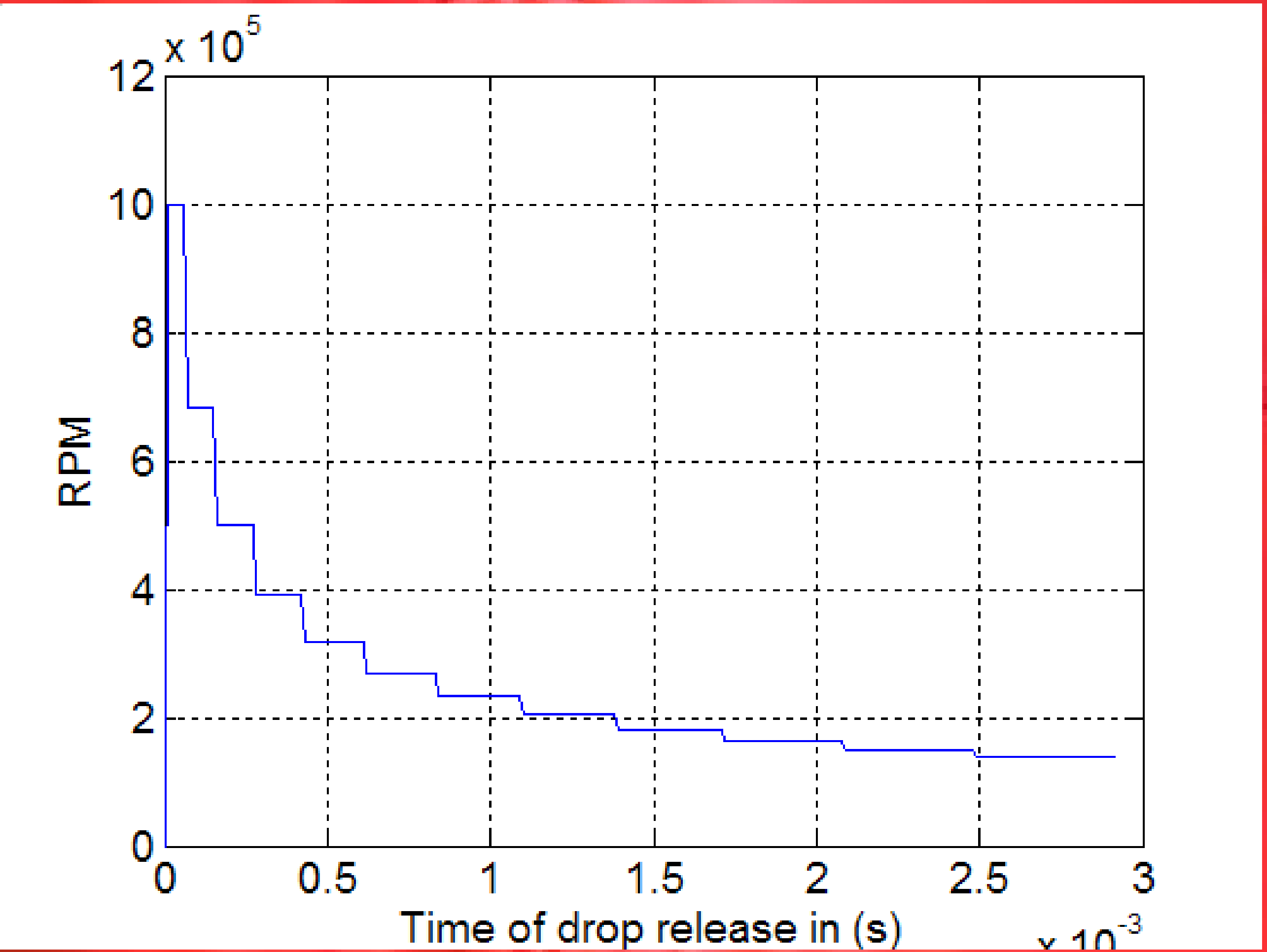
(i) X-Y stepping coverage approach



(ii) Spiral Approach: a single droplet ejector



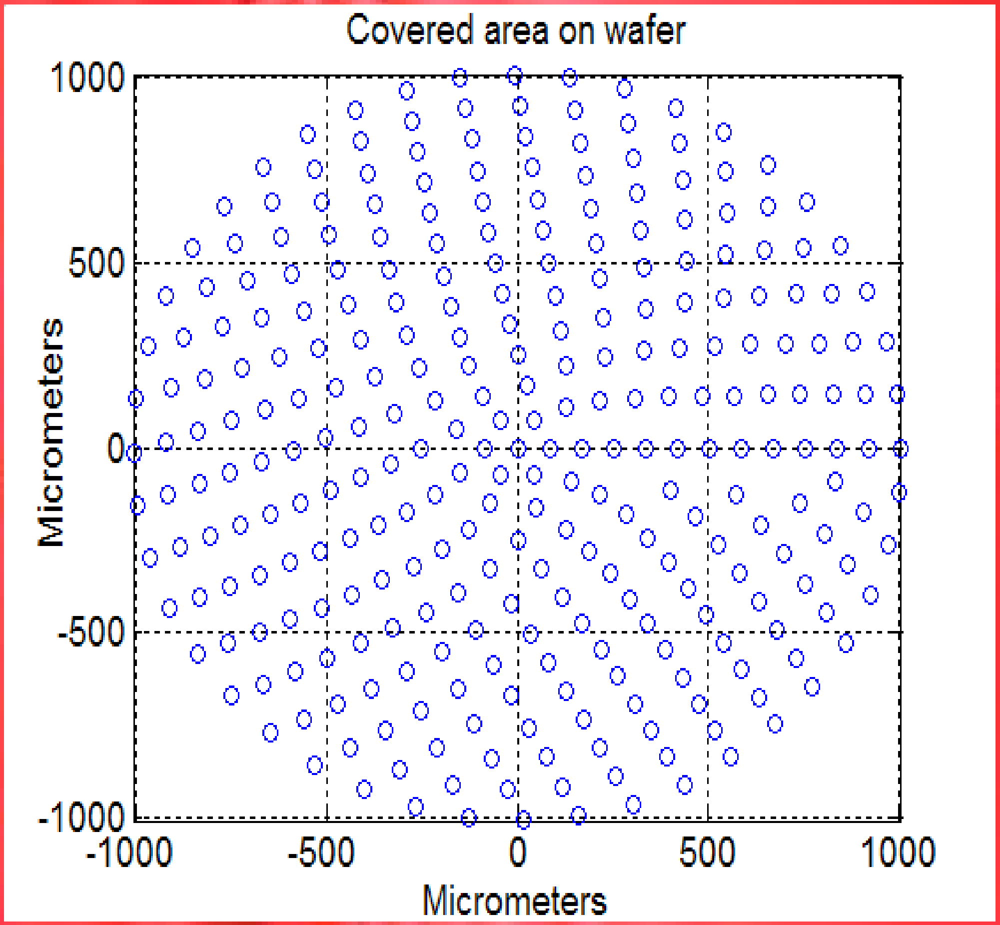
Initial Coverage Theory: Time of Coverage



Using the experimental data: Droplet size: 28 micrometers, Repetition frequency: 100 kHz.

Our simulation predicts: Time of coverage &Drop locations for uniform thickness coverage for a single ejector.

Drop Locations on the Wafer



Using the circles show where the mid point of the droplets should land after ejection.
The simulation assumes a spiral path coverage for a single ejector.

2D Array coverage considerations

The algorithm will be different as we have a 2D array of ejectors.
The theoretical coverage time decreases due to increased number ejectors.

Summary

• Ejected high viscosity fluids.

Ejected Fluids	Water	Isopropanol	Photoresist	Ethylene glycol
Viscosity (cP)	1	5	5-8	16

• Drop on demand and Continuous mode of operation.
• Each element is easily addressable.
• Easily cover surfaces with fluids and reduce waste.
• Single lithography step. Easy to fabricate as arrays.
• Easy to make the each array element eject.
• Cross-talk is no longer a serious problem, does not impede ejection.
• FEA predicts device characteristics, but there is room for improvement.
•All the 2D array elements ejected droplets.

Conclusions and Future Work

Conclusions

FEM Simulations and experiments show that

- We need to determine the location of the focal point for each type of fluid (especially for photoresist).
- We have a wide vertical range focal point, which is helpful in spacer design.
- The spacers hold fluid by surface tension, and will allow us to eject in any angle.
- We could eject from all the elements of 2D ejector arrays.

Future Work

- Perform FEM simulations to determine a better fit to the location of the focus.
- Place spacers smaller than the focus to understand ejection by radiation pressure and generate smaller droplets.
- Demonstrate coverage of an area with photoresist using 2D Ring Ejector Arrays.