Transducer Arrays for Ultrasonic Particle Manipulation

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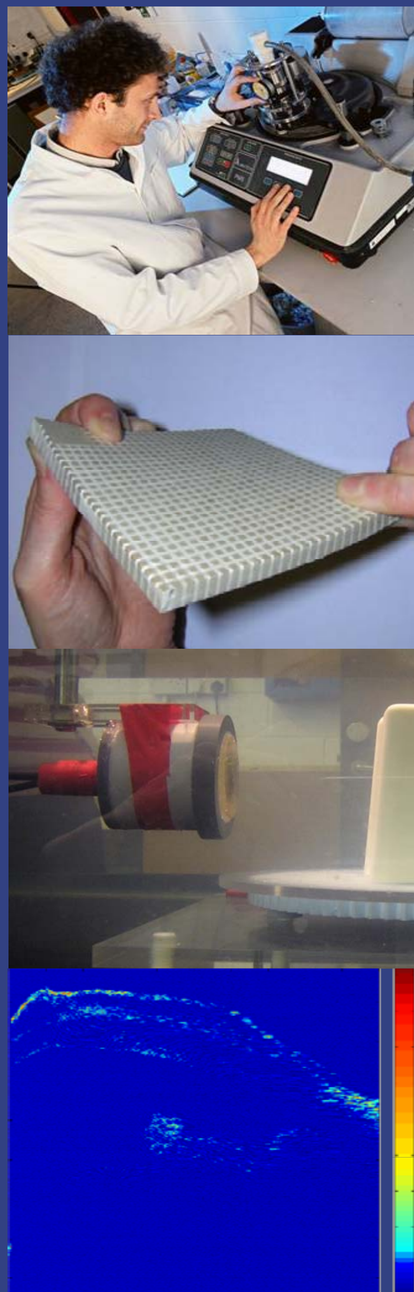


Outline

Introduction

Ultrasonic particle manipulation

Finite element modelling

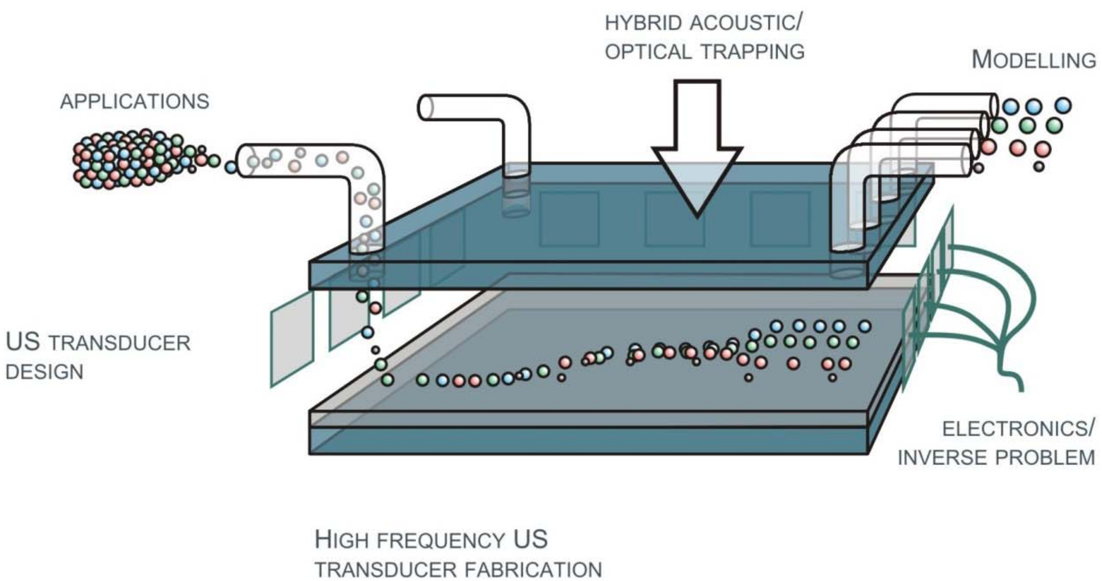
Experimental validation

Conclusions

INTRODUCTION

sono tweezers

Electronically controlled acoustic particle manipulation for life sciences research



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Electronic Sonotweezers

- Ultrasonic particle manipulation tools enable:
  - Manipulation of **larger particles**, **cells** and **groups of cells** compared to other manipulation technologies
  - Dimensions of less than 1 μm up to hundreds of microns
- Ultrasound devices are readily **integrated** with **microfluidic devices** and **electronics**
- Aim of Sonotweezers:

Dexterous acoustic manipulation

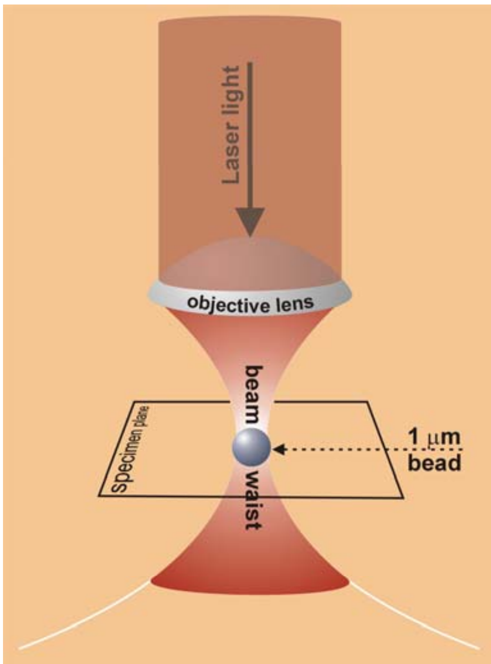
Electronic Sonotweezers

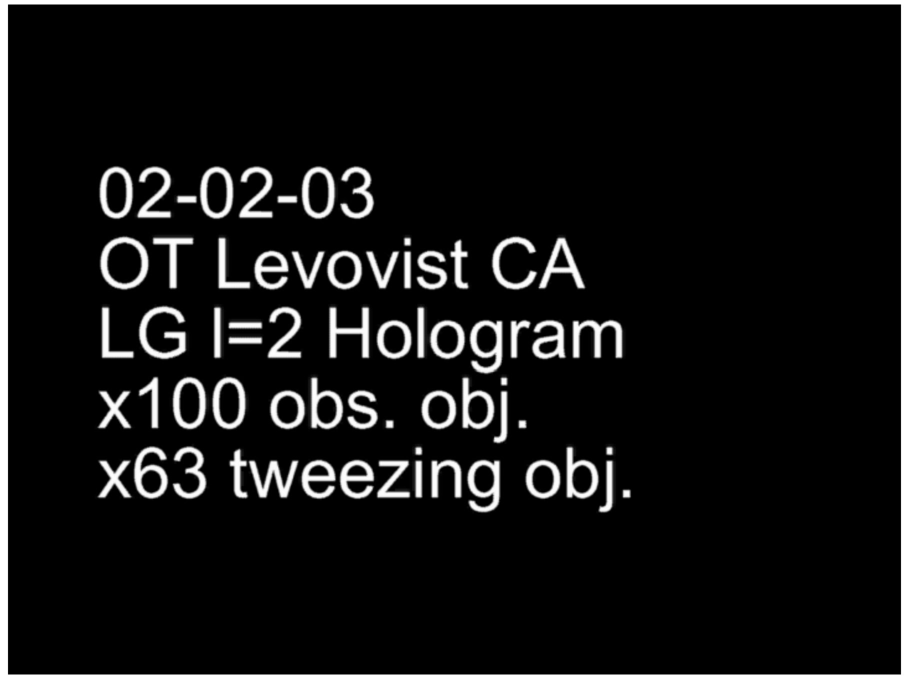
- Applications of **Sonotweezers** include:
  - Separation and sorting of cells
  - Investigation of cell characteristics
  - Measurements of cell forces
  - Tissue engineering
  - Positioning cells at sensors

- Many applications require manipulation force in more than one direction

Current Tweezing Technology

Optical Tweezing



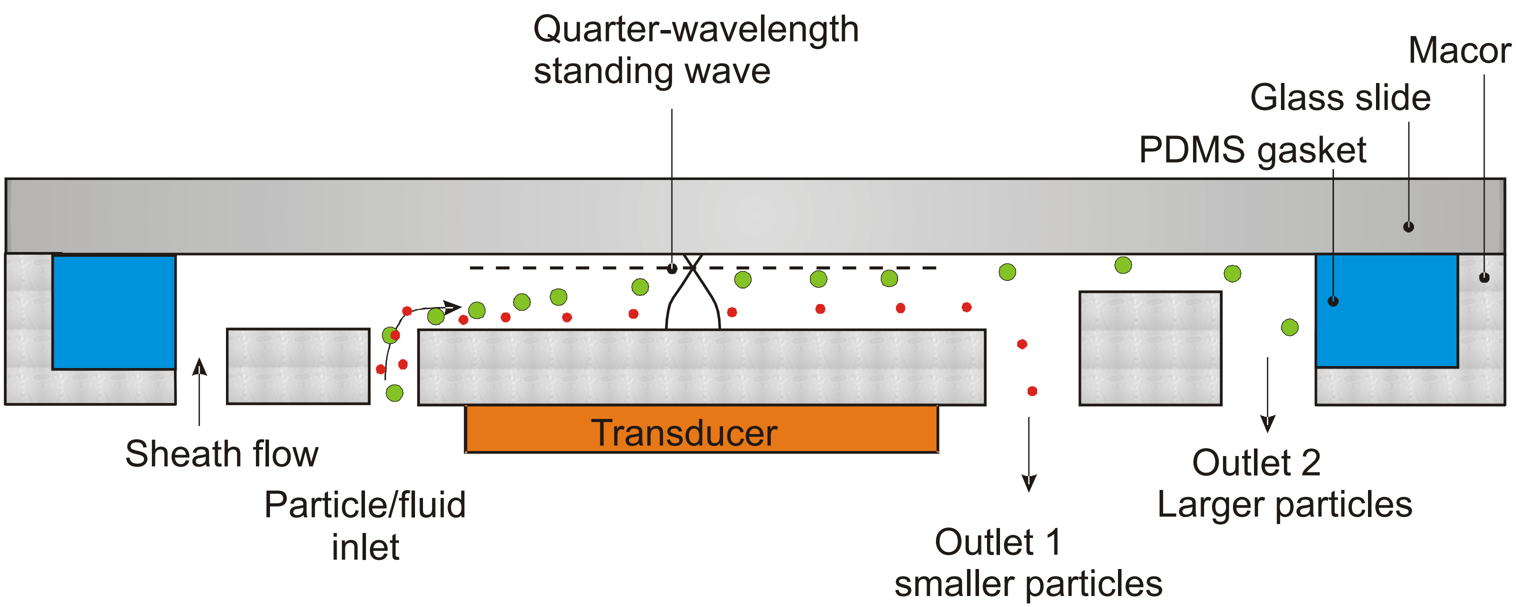


- Lateral manipulation possible by steering optical trap with mirrors

Images courtesy Mike MacDonald and Paul Prentice, IMSaT, University of Dundee

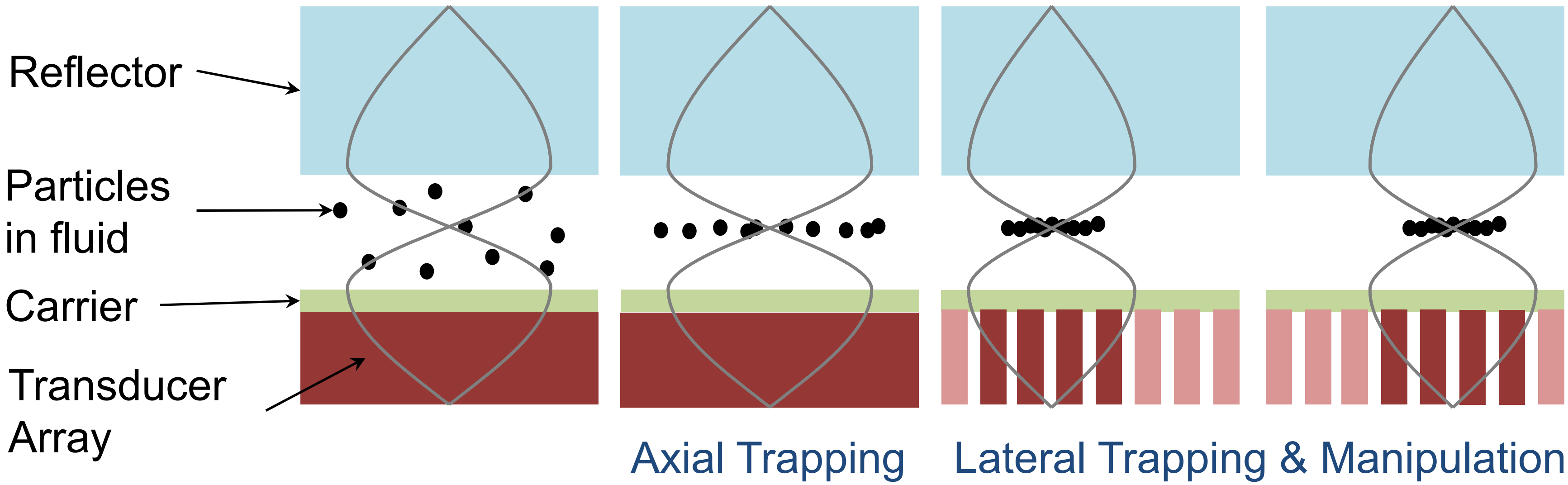
Ultrasonic Particle Manipulation

- Transducer forms ultrasound standing wave (USW) in channel
- Acoustic field is effectively constant along length of channel



P. Glynne-Jones et. al., “Ultrasonic radiation forces for cell sorting and characterisation,” UIA Symposium, Glasgow, UK, 23 May 2011.

Ultrasonic Manipulation with Arrays



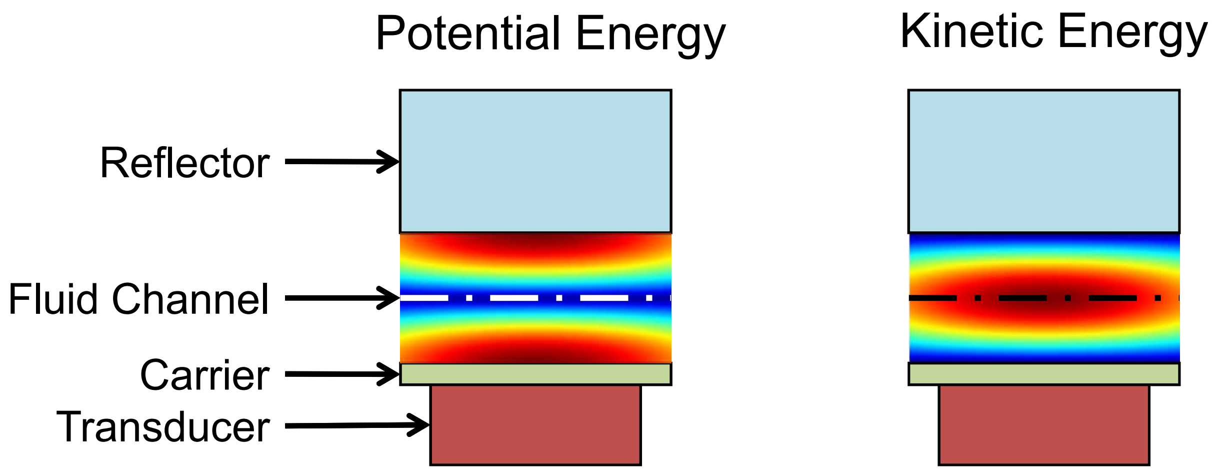
- Array replaces single transducer in USW device
- More dexterity than USW device with single element
- Can manipulate larger particles than optical tweezers

Ultrasonic Manipulation Forces

- Force on particles is towards:

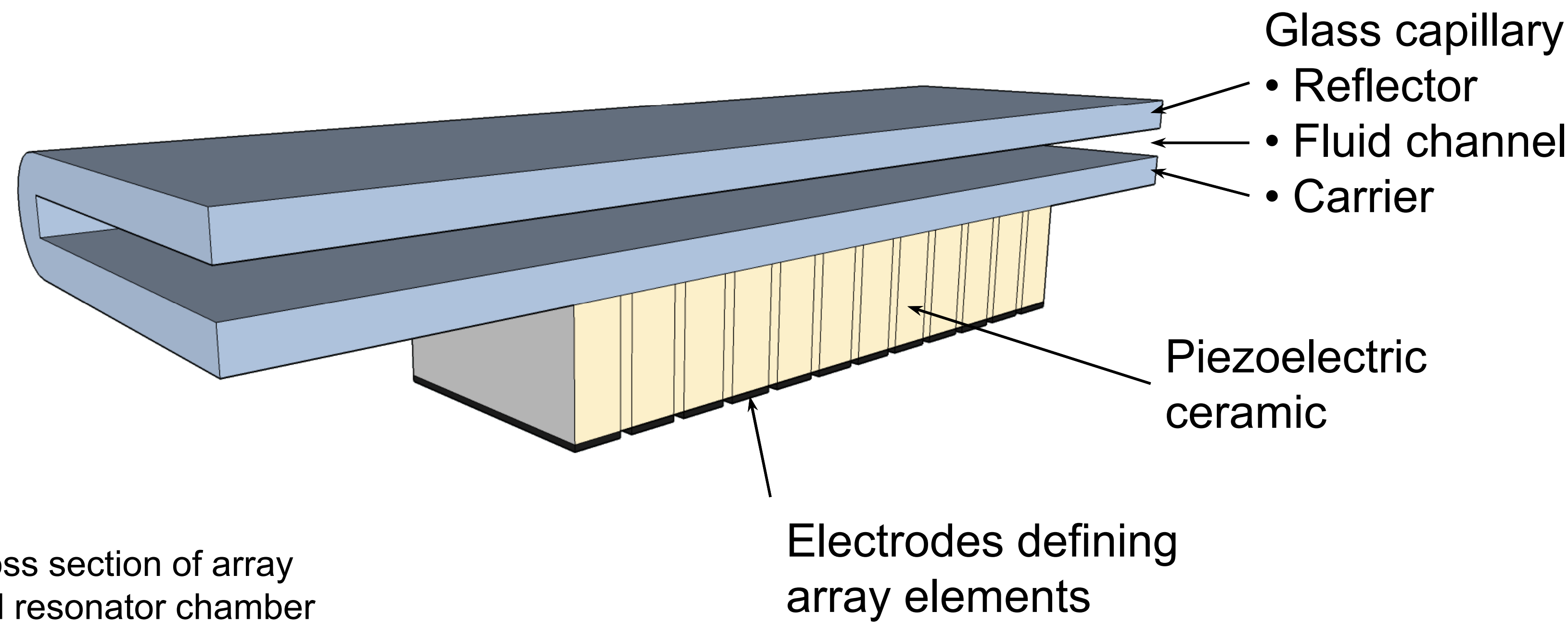
  Pressure node ↔ Potential energy minimum

  Velocity maximum ↔ Kinetic energy maximum



$$F = -\nabla(A \times E_{pot} - B \times E_{kin})$$

Resonator and Array Design



Cross section of array and resonator chamber

Resonance frequency: 2.5 MHz

Channel thickness: 300 μm

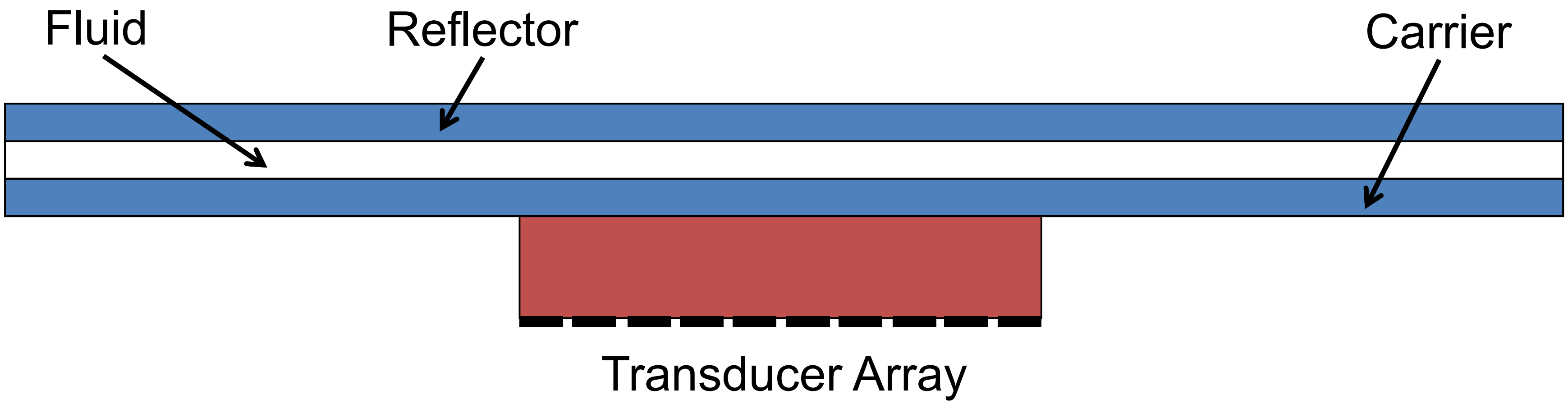
Reflector thickness: 300 μm

Transducer thickness: 1 mm

Element pitch: 500 μm

FINITE ELEMENT MODELLING

Finite Element Model

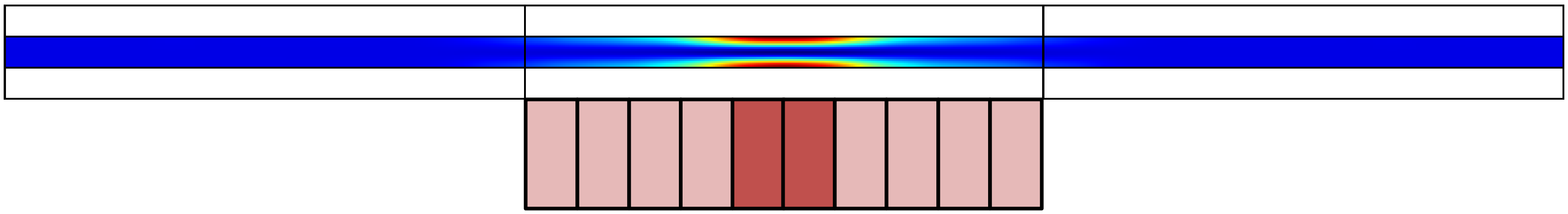


Layer	Material	Thickness
Reflector	Glass	300 µm
Fluid	Water	300 µm
Carrier	Glass	300 µm
Transducer	PZ26	1000 µm

Acoustic Energy Distributions

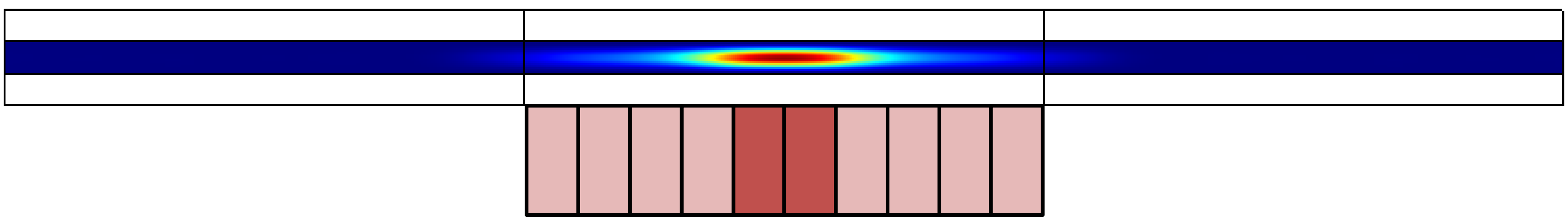
Potential Energy

Trapping position: at minimum



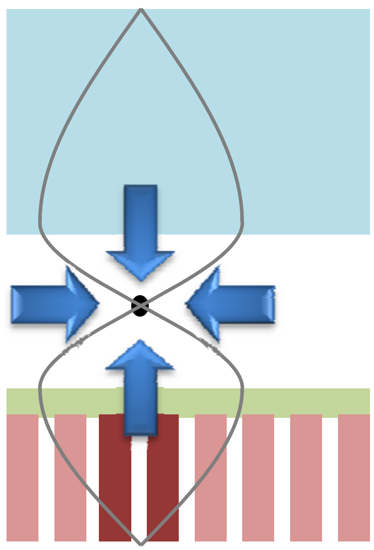
Kinetic Energy

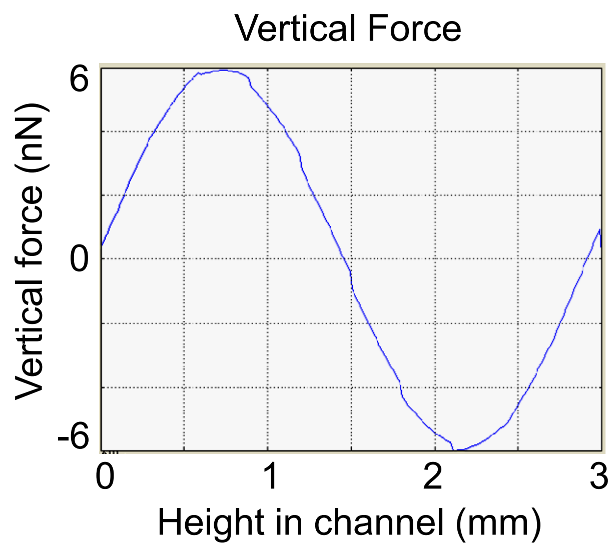
Trapping position: at maximum

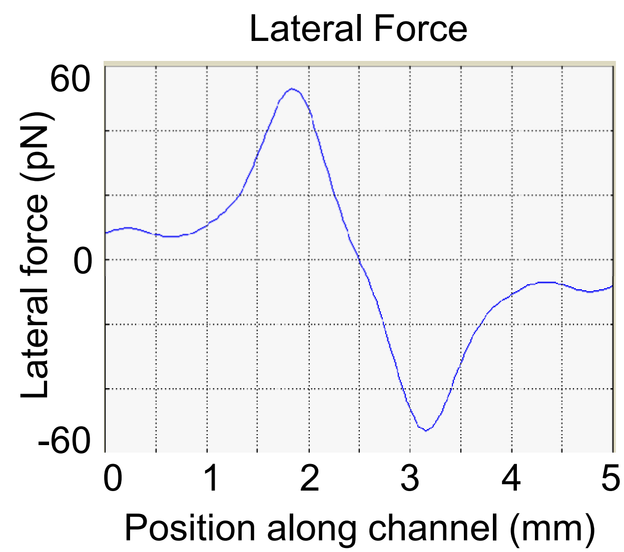


Energy Density: Min  Max

Calculated Force Distributions





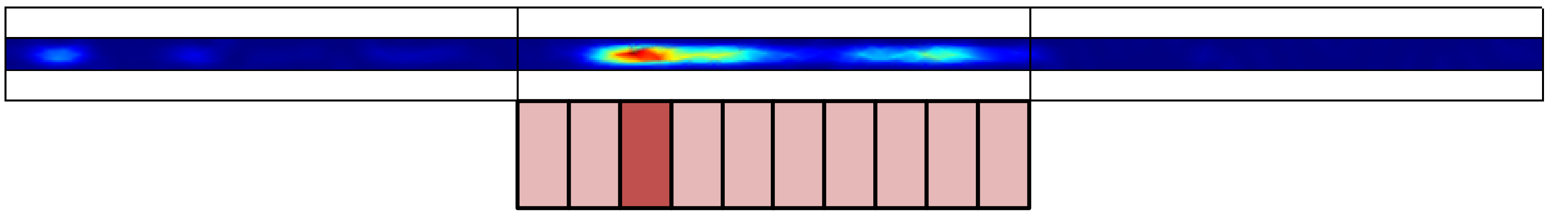


$$F = -\nabla(A \times E_{pot} - B \times E_{kin})$$

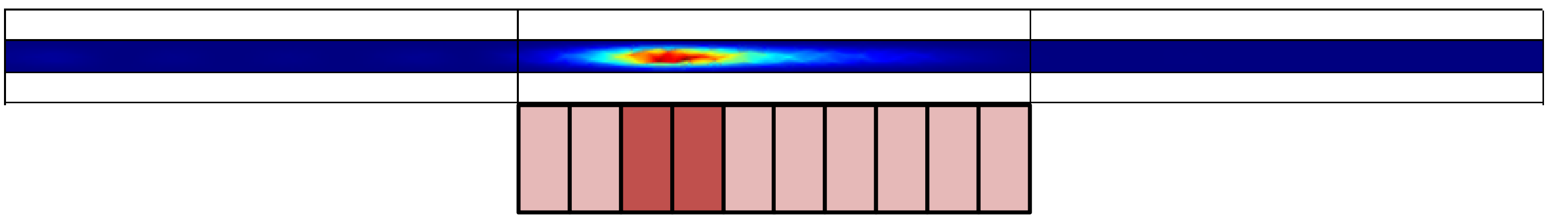
Vertical / Lateral Force: **100**

Kinetic Energy Densities

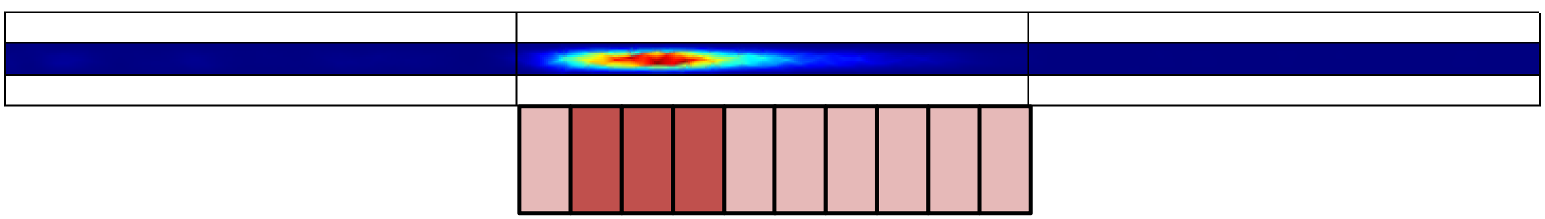
1 Element Active



2 Elements Active

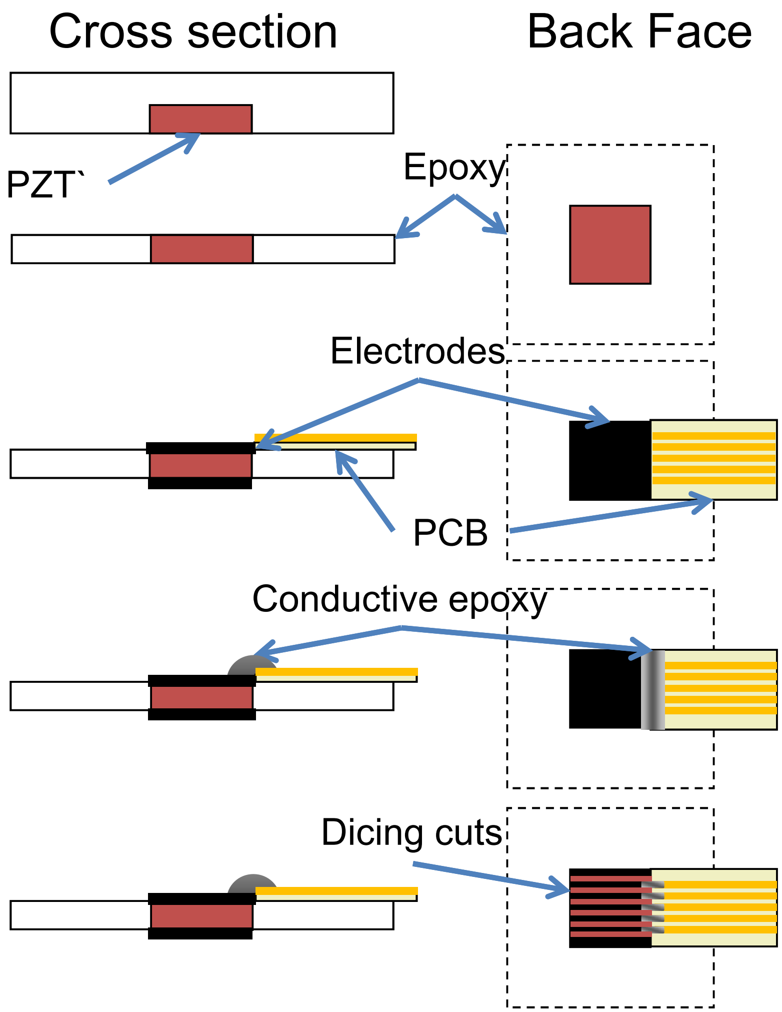


3 Elements Active



EXPERIMENTAL VALIDATION

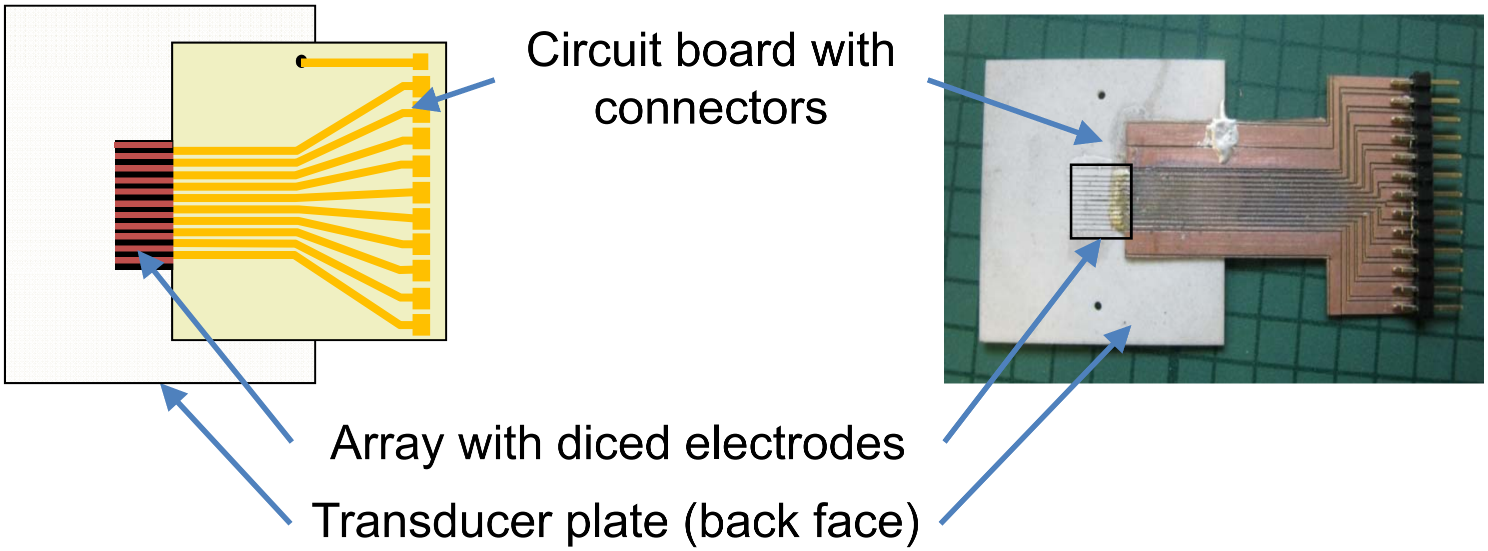
1D Array Fabrication



Fabrication Process

1. Embed piezoceramic plate in microbaloon loaded epoxy
2. Lap transducer plate
3. Deposit electrodes on surfaces of piezoceramic plate
4. Affix PCB to back face of transducer substrate
5. Connect tracks on PCB to transducer electrode with conductive epoxy
6. Dice through transducer electrode and conductive paste to separate element electrodes

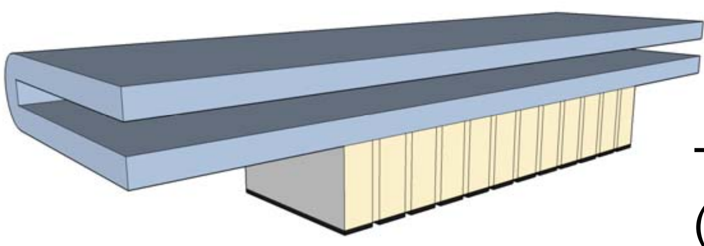
Fabricated Array

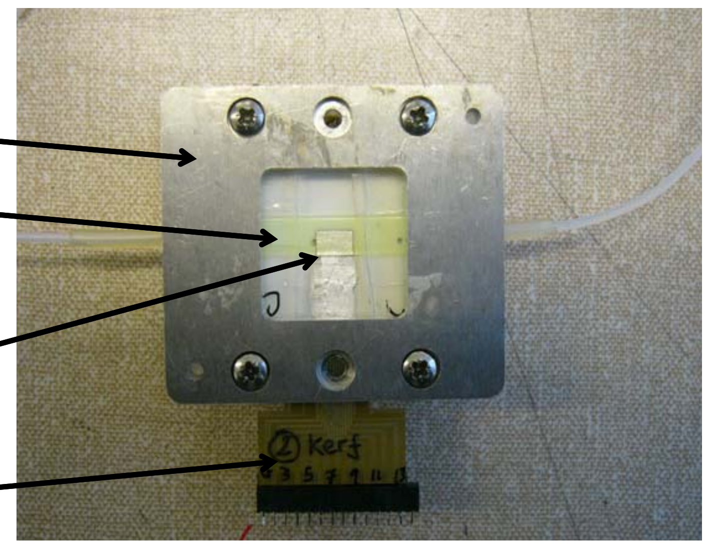


Transducer dimensions	4 mm x 6 mm
Transducer plate thickness:	1 mm
Element pitch:	500 µm
Array elements:	12

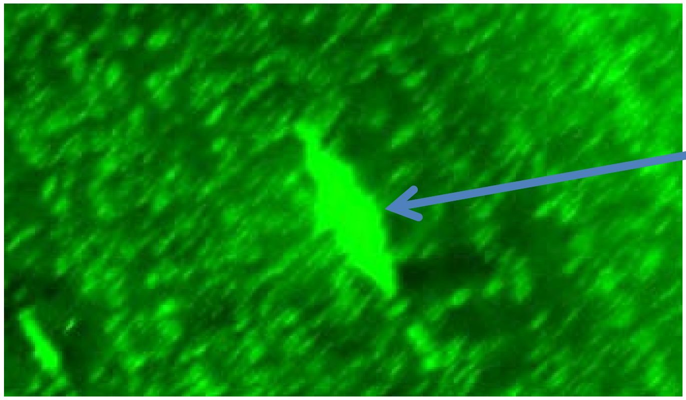
Experimental Setup

- Capillary coupled to array with glycerol
- Capillary channel filled with suspension of 10 μm fluorescent polystyrene beads in water
- Drive: 2 elements
  - 17 Volts CW @ 2.408 MHz
  - Connection switched along array





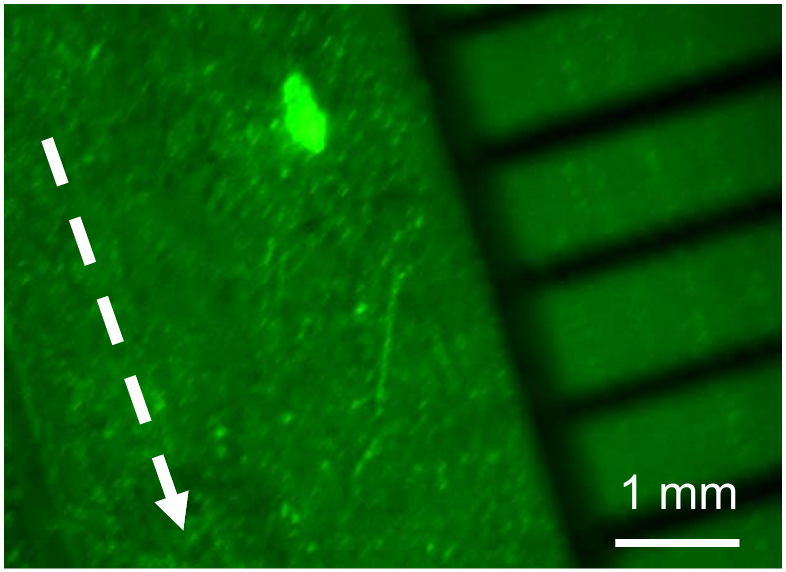
Results: Trapping Particles

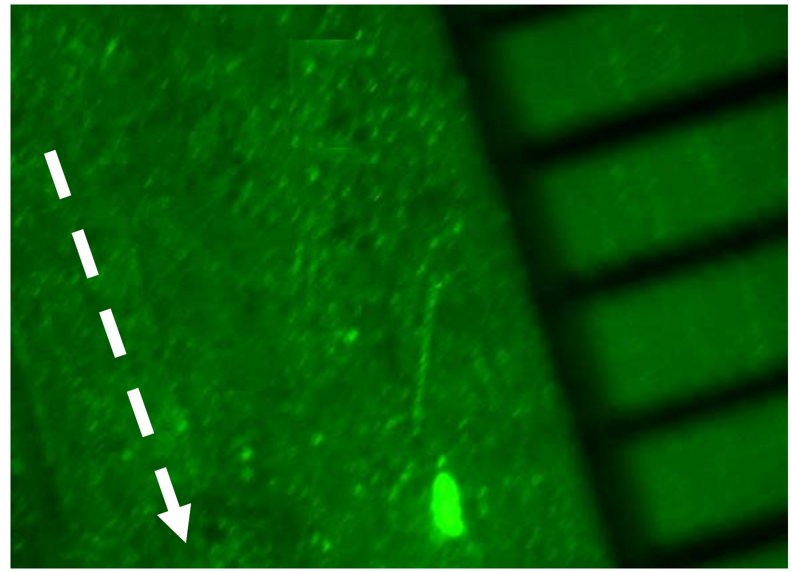


Agglomerate of
10 μm beads

Agglomerate length:	650 μm
Vertical force measurement:	180 pN
• Balance acoustic radiation force with gravity	
Lateral force measurement:	2 pN
• Determine force from drag on particle	
Vertical / Lateral force:	**90**

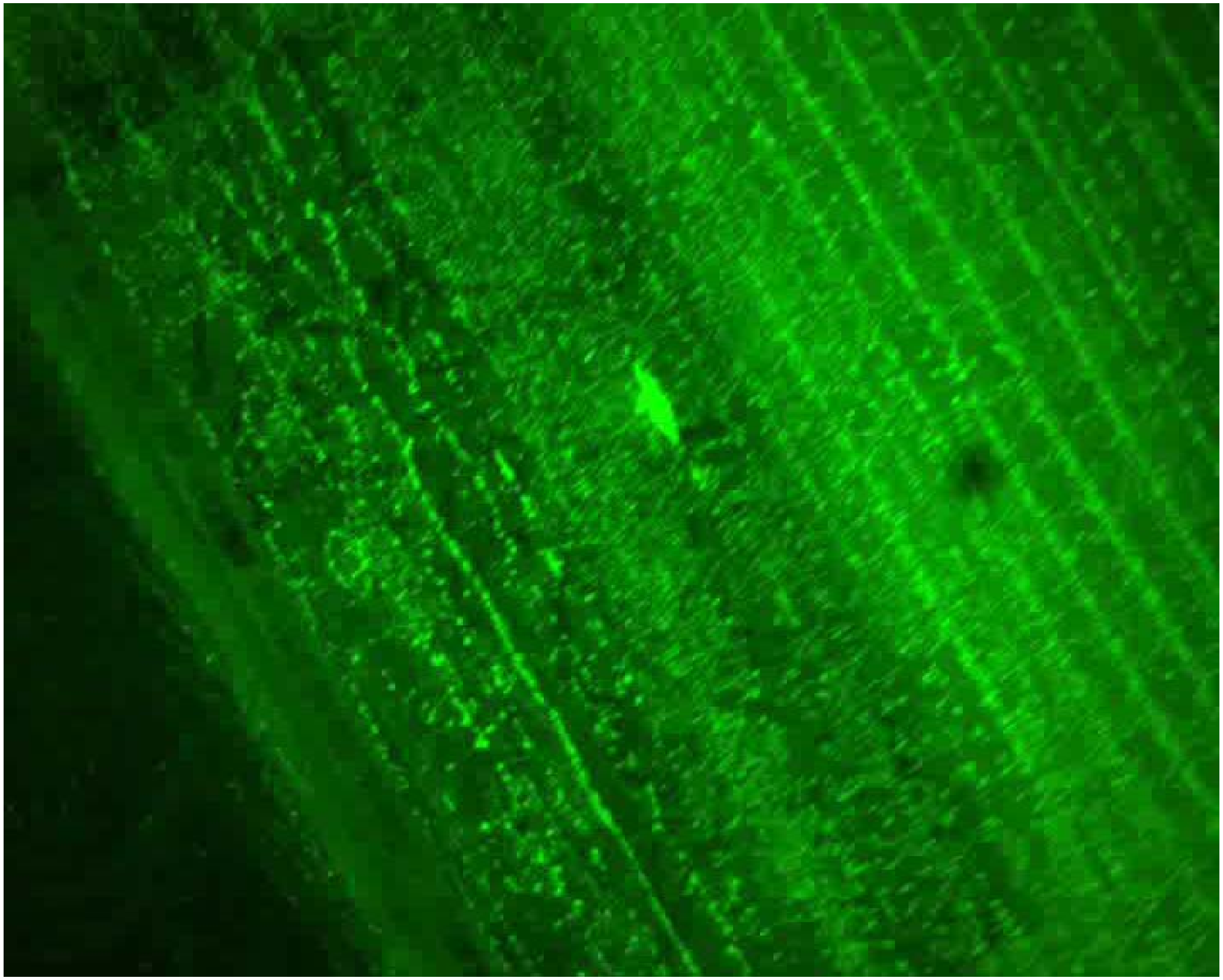
Results: Moving of Beads in Channel





- Connector switched along 6 elements
- Beads move 3 mm along channel
- Particles moved smoothly and consistently along microfluidic channel

Results: Moving beads along channel



Summary & Conclusions

- 2.5 MHz, **1-D array** in planar resonator developed for acoustic particle or cell manipulation in microfluidic device.
  - Resonator structure forces particles to centre of fluid channel
  - Switching subset of active elements forces particles to centre of active area and moves particles along channel
- Simulation confirms expected trapping points at **pressure node** and **velocity maximum**
- Experiment demonstrates feasibility of **electronically controlled lateral manipulation**

Industrial Collaborators

- Agilent Technologies
- Genetix Ltd.
- Loadpoint Ltd.
- Logitech Ltd.
- PCT Ltd.
- UK Defence Science and Technology Labs
- Weidlinger Associates, Inc.

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