The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization
IAEA
International Atomic Energy Agency

2037-20

Introduction to Optofluidics

1 - 5 June 2009

Fabrication of Optofluidic Devices

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Fabrication of Optofluidic Devices

Massimo Tormen

PART I

Lilit group

advanced technology and nanoscience
TASC national laboratory
tecnologie avanzate e nanoscienza

Main area of activity:

- Nanofabrication technologies
- Applications of nanotechnology to biology
- Optical manipulation
- Photovoltaics
- Microfluidics
- Plasmonics

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Lilit Nanotech Facility

advanced technology and nanoscience
TASC national laboratory
tecnologie avanzate e nanoscienza

Lithography:

- Electron and ion beam dual system
- Soft and Deep X-Ray Lithography
- Nanoimprint & Soft Lithography
- UV (365 nm) mask aligners
- UV (250 nm) flood exposure system
- Spin coaters, hot plates.
- 200 mq cleanroom

Etching:

- Inductive Coupled Plasma (ICP) systems for Si.
- Riective Ion Etcher (RIE)
- Hoods for wet chemical etching

Optical manipulation:

- Different optical tweezers setups for dynamic trapping, force measurements

Deposition:

- HV evaporators
- Sputtering (6” target, 4” wafer)
- PECVD (silicon based materials)
- Electroplating
- Glove box (SAM’s in moisture free atmosphere)

Characterization:

- SEM with microanalisys (EDX)
- Optical microscopes
- Raman microspectrometer
- Semiconductor parameter analyzer IV and CV measur., 1 fA , 1 µV res.)
- Sun simulator
- Monocromateor (200-1100 nm)
- AFM

Outline

- Introduction
- Examples of optofluidic microdevices and components
  - Microchannels/waveguides, valves, mixers, dye lasers.
- Lithographic technologies:
  - Soft Lithography
  - Nanoimprinting, Hot embossing
  - UV, EBL, FIB, XRL, hybrid approaches.
- Examples
- Conclusions

Example of "optofluidics": Parabolic mercury mirror

Rotating liquid mirror telescope

Atomic scale roughness. ☺

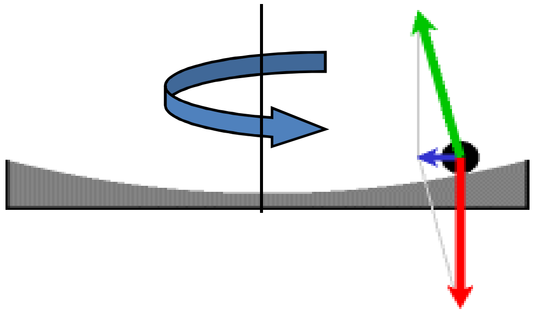
Perfect parabolic shape obtained with the laws of nature. ☺

Can be actuated (vary the focal length). ☺

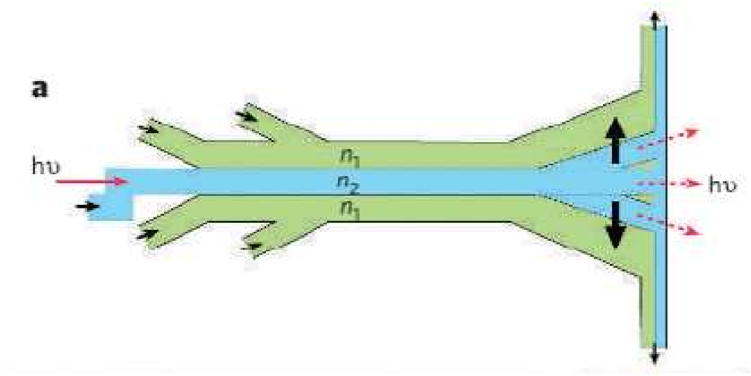
Low cost telescope (500 k$ against 25 M$). ☺

The mirror can only point straight up. ☹

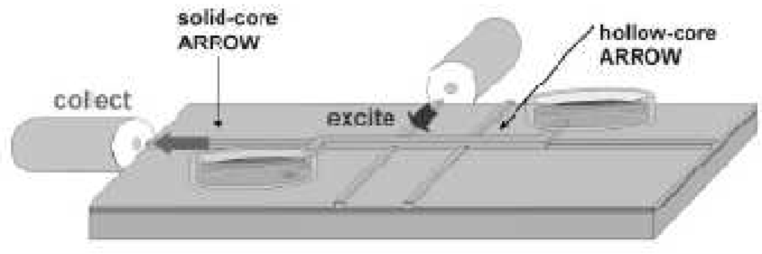
Large Zenith Telescope near Vancouver, Canada. It is a 6-meter telescope with a surface of liquid mercury



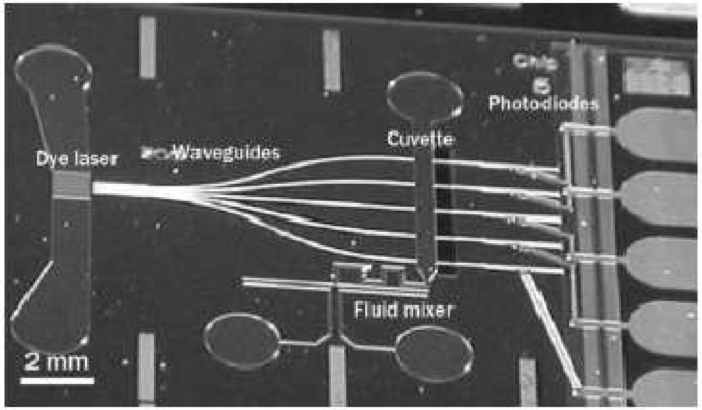
Optofluidics in microsystems



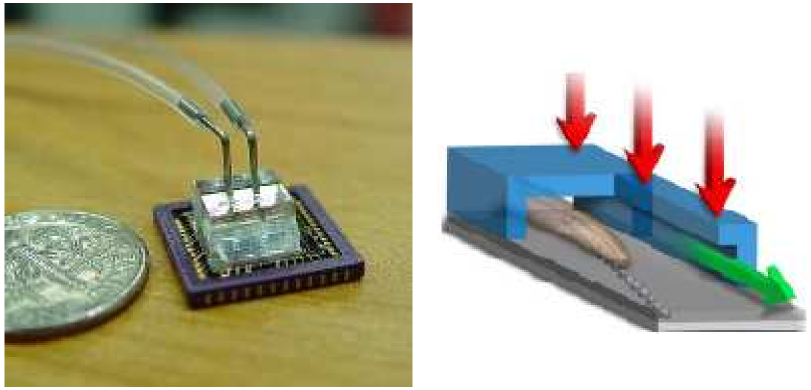
Tunable waveguides



Detection of analytes on chip



Tunable lasers



Imaging

Lab-on-a-Chip.

Objectives:

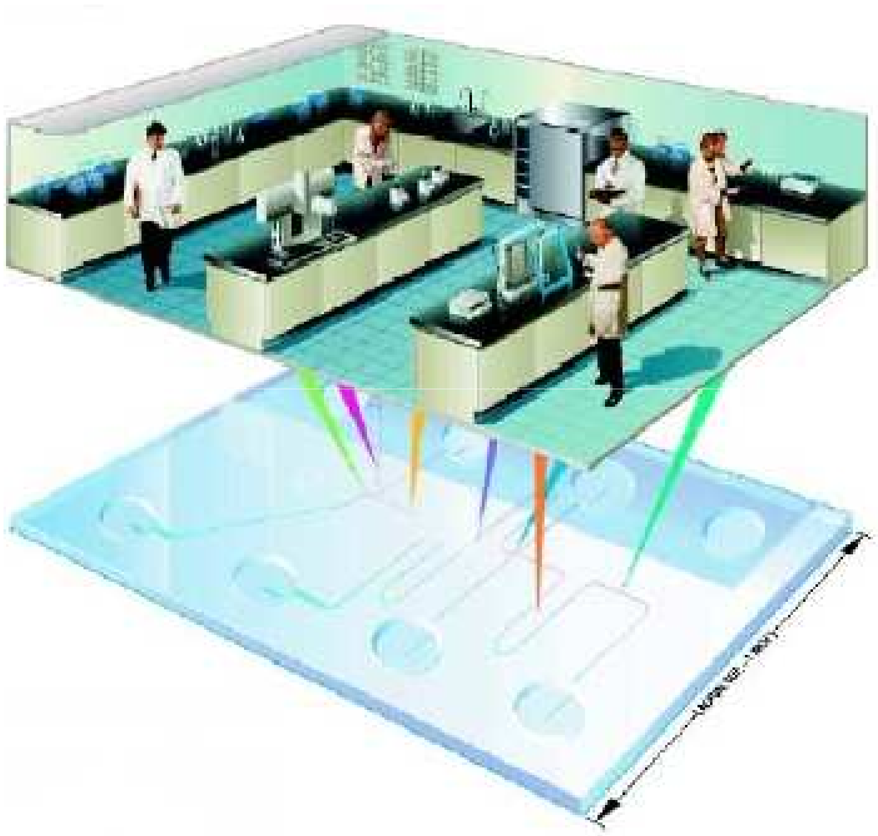
- Replace an entire chemical/biological laboratory
- High level of integration, by miniaturization
- Perform a large number of experiments in parallel. Explore space of parameters combinatorially (Multiplexing).
- Reduce: time, space, material, cost.
- Increase: automation, speed, reliability.
- Portable, simple to use, disposable devices.

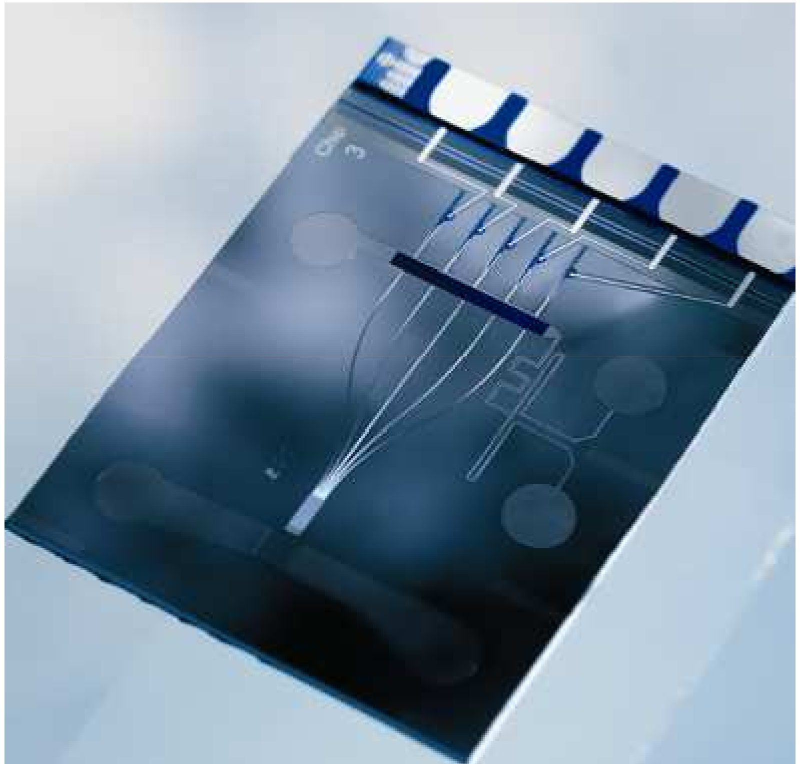
Lab-on-a-Chip.

<u>**Functionalities:**</u>

- **Sample manipulation (cells, chemicals, biochemicals, liquids)**
- **Set conditions (temperatures, Ph, relative concentration of reagents in reaction chambers)**
- **Act (cultivate and sort cells, purify molecules, proteins, nucleic acids, amplify DNA, RNA by PCR).**
- **Analyse (detect chemicals, measure concentrations, identify type of cells).**

Lab-on-a-Chip is based on Microfluidics





S. Balslev et al., Lab Chip, Vol. 6, pp. 213-217 (2006)

Courtesy: Anders Kristensen
DTU Nanotech, Technical University of Denmark

Optofluidics vs. Microfluidics

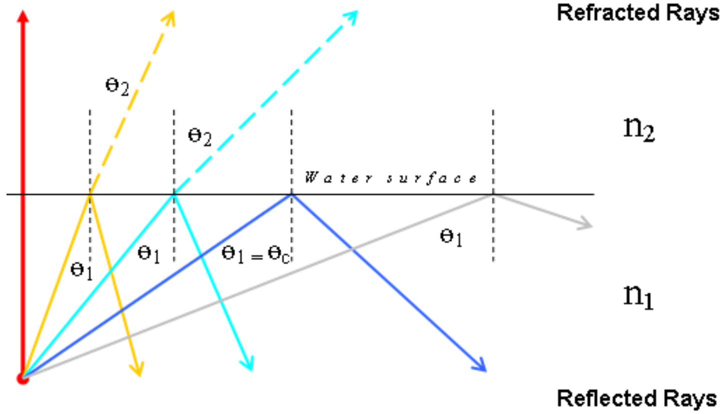
Addition of optical functionalities to a microfluidic Chip

- Waveguides
- Coherent light sources (dye lasers)
- Optical switches actuated by fluids
- Optical manipulation inside liquids
- Reconfigurable optics (tunable lenses)
- Integrated optical detection:
  - Absorption
  - Fluorescence
  - Surface Plasmon Resonance (SPR)
  - Raman

Some optofluidic components

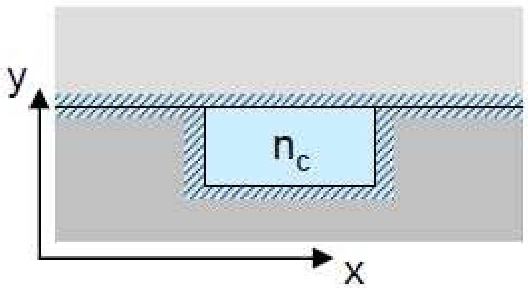
- Waveguides
- Microfluidic lenses
- Mixers
- Valves
- Microfluidic dye laser

Liquid-core Solid-cladding waveguides



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Total Internal Reflection (TIR)

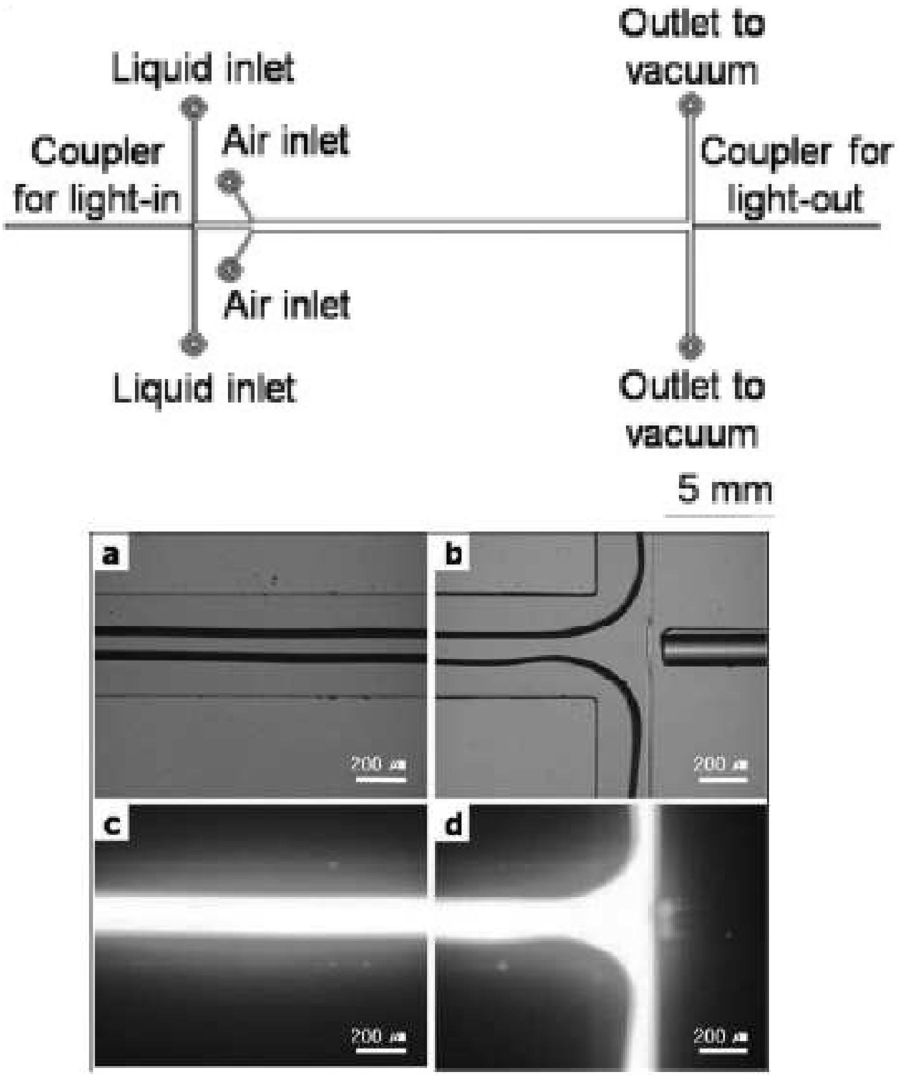


Liquid-core waveguides

Material	Refractive index
Air	1
Water	1.33
2-Propanol	1.375
Hexane	1.49
$CaCl_2$ in w. 5 M	1.44
Teflon AF	1.29
PDMS	1.40
PMMA	1.49
PC	1.58
SU-8	1.59
SiO_2	1.46
SiN	2.05
Si	3.5

Waveguiding by TIR requires liquid core of higher refractive index (RI) than cladding (= microfluidic channel walls). However, RI of liquids are typically smaller than for polymers and solids.

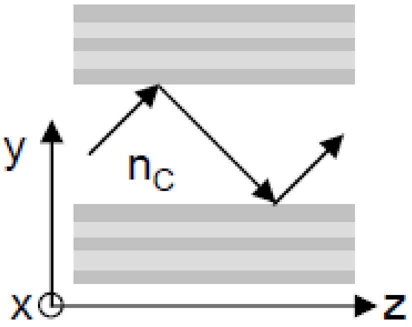
L^2 or Liquid-core Air-cladding waveguides



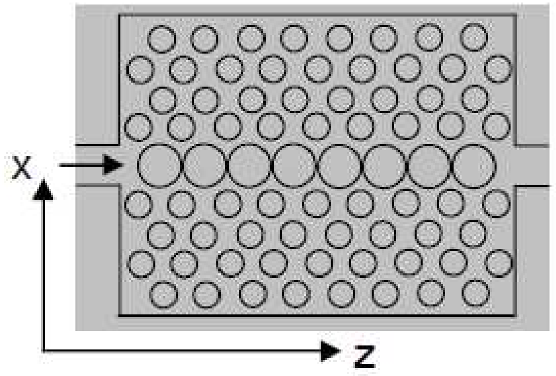
- **Large structures (l,h,w >>10 µm)**
- **Fabrication by UV photolithography on photoresists + <u>Soft Lithography</u> for the microfluidic channels.**
- **<u>PDMS elastomers</u> (RI=1.406) for microchannels, Ethylene Glycol (1.432) as core, air cladding.**
- **PDMS and glass treated with oxygen plasma before <u>bonding</u>.**
- **<u>Surface treatment</u> of the inner channel surface to prevent the complete wetting by EG. Use of fuorinated trichlorosilanes on PDMS.**

J.-M. Lim *Lab Chip*, 8, 1580 (2008).

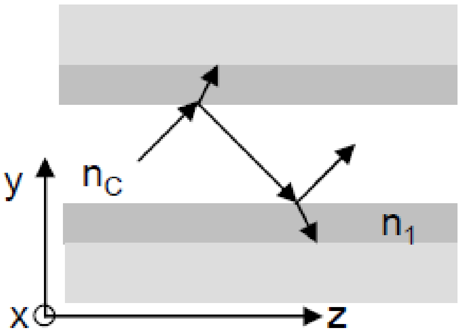
Waveguides based on interference



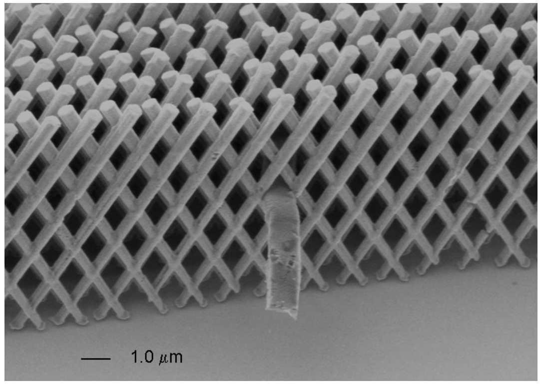
multilayer reflection



Photonic crystal waveguide



ARROW waveguides

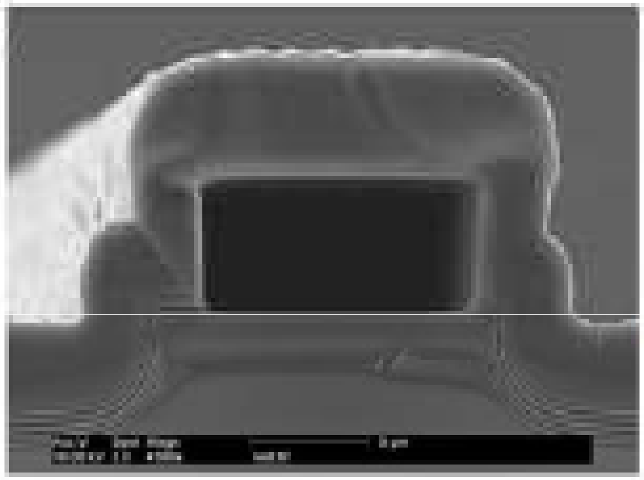


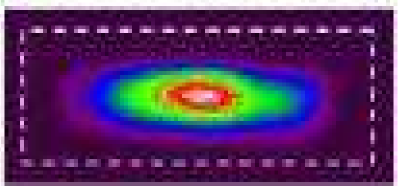
F. Romanato et al. 3D PC with embedded waveguide

H. Schmidt & A. R. Hawkins Microfluid Nanofluid (2008)

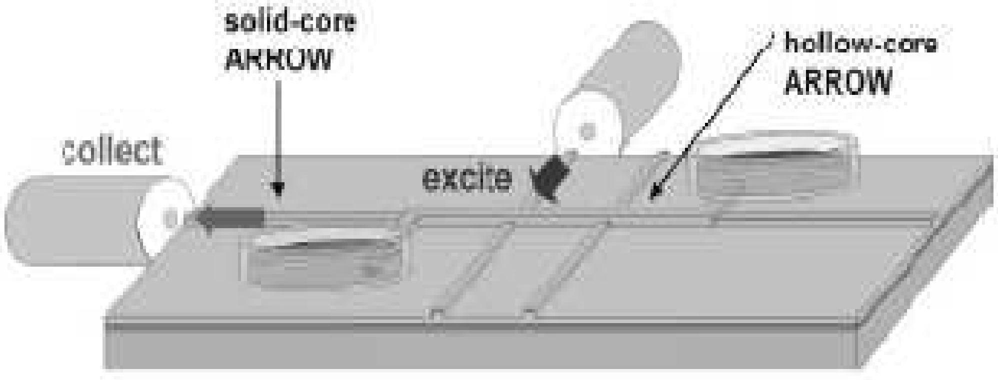
Liquid-core waveguides

Planar optofluidic chip for single particle detection, manipulation, and analysis





Antiresonant Reflecting Optical Waveguides (ARROW)

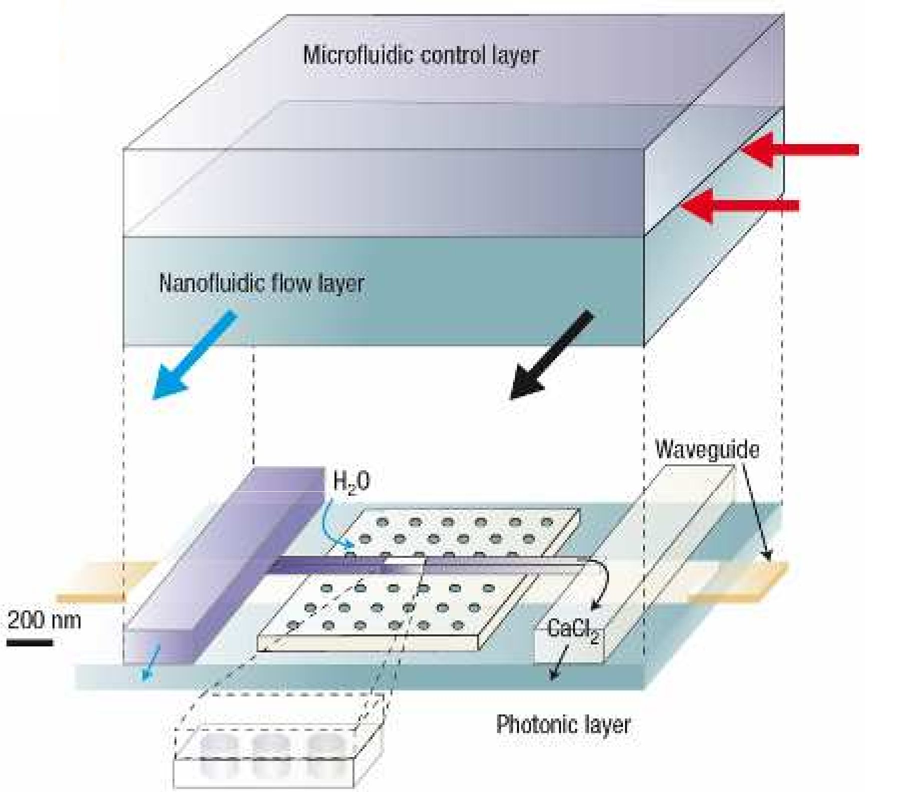


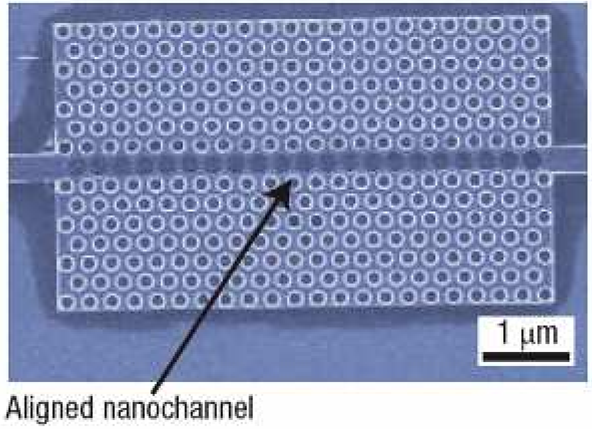
Liquid-core optical waveguides guide both light and fluids in the same volume.

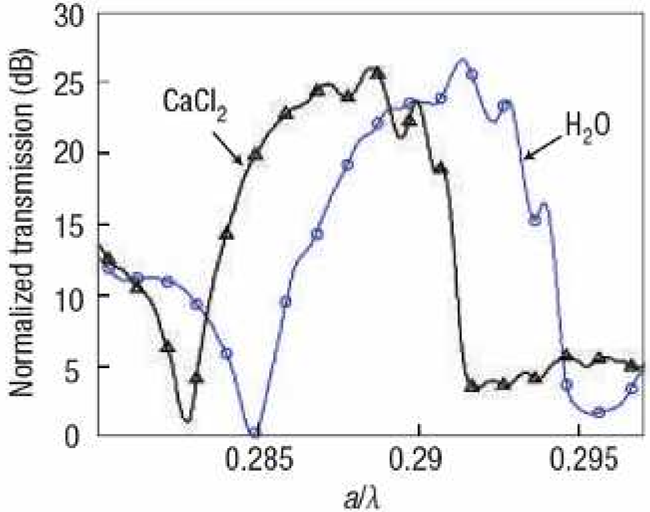
H.Schmidt & A. R. HawkinsMicrofluid Nanofluid (2008)

D. Yin et al., Lab Chip, 2007, 7, 1171

Photonic-crystal based waveguides



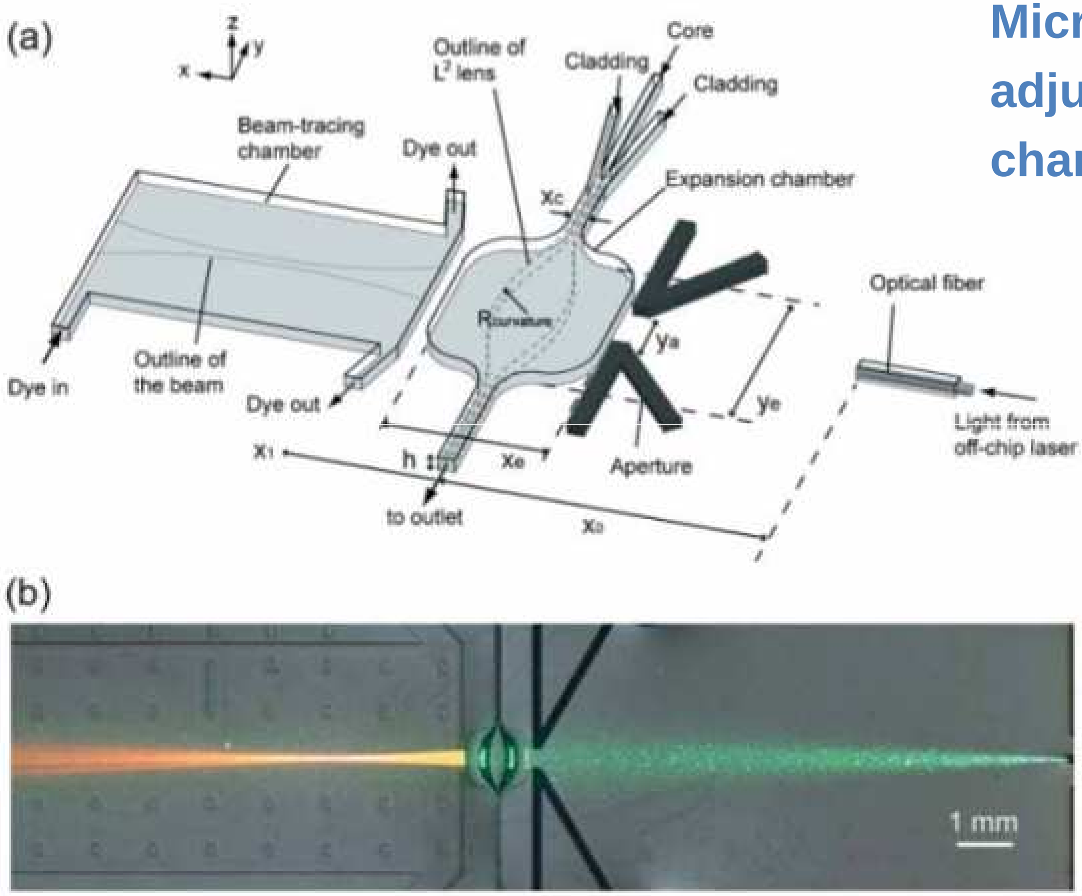




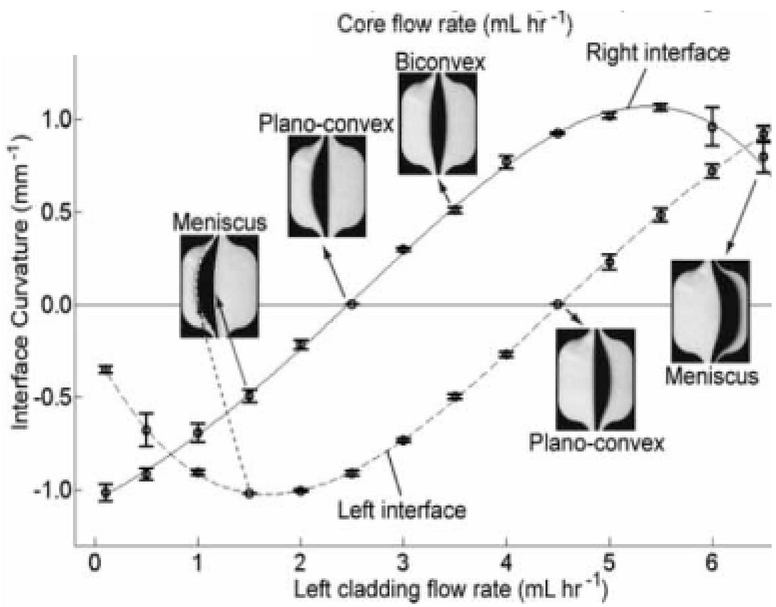
- Photonic crystal controlled by the filling of voids with different liquids.

- Tuning the wavelength dependent attenuation of a waveguide.

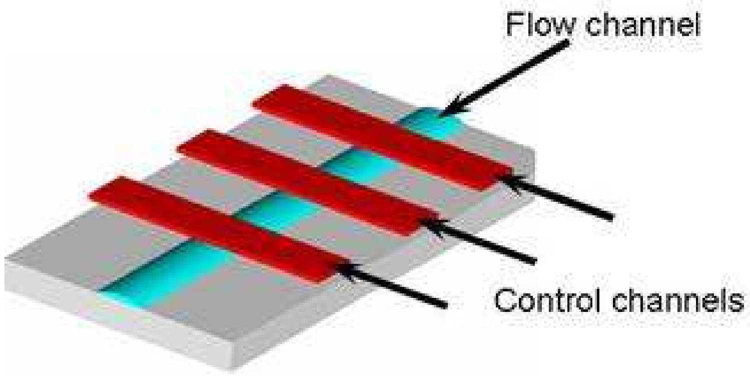
Tunable microlenses (in plane)

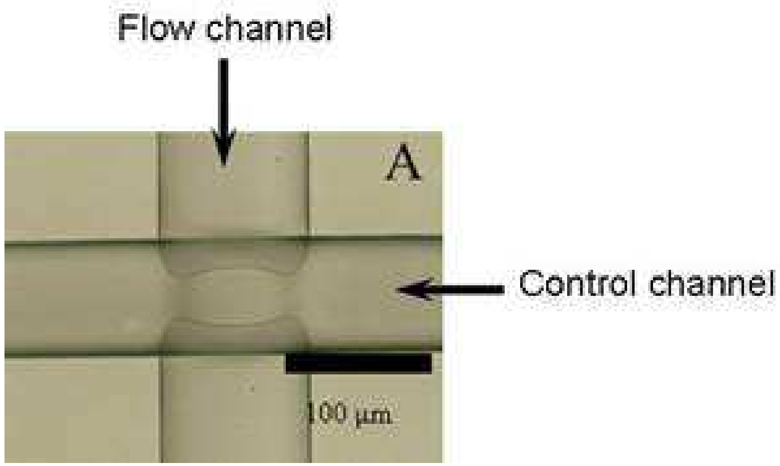


Microlenses are reconfigured by adjusting the flux in the three channels.

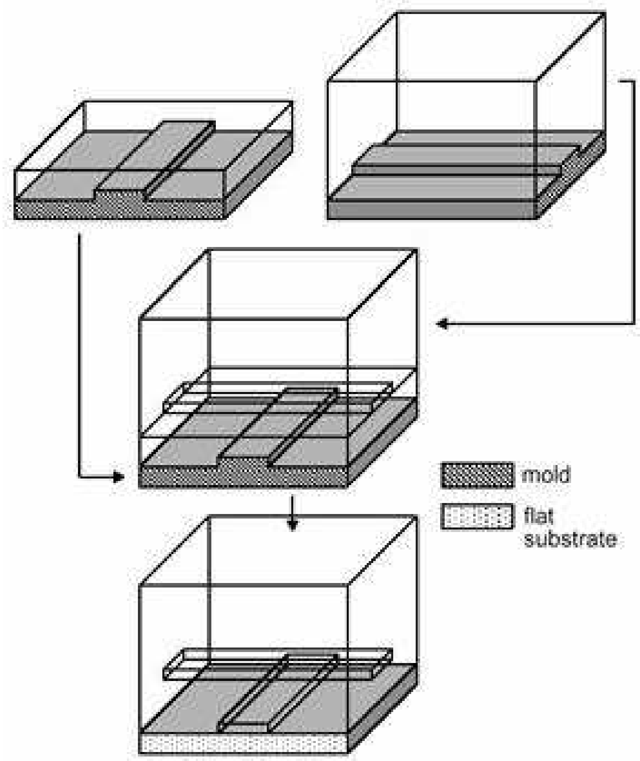


Microfluidic valves





Fabrication by casting liquid precursor of elastomers and thermal curing.

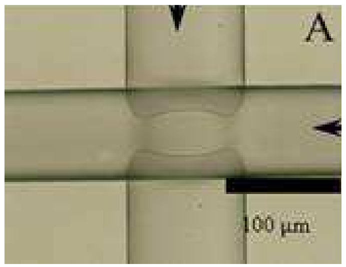


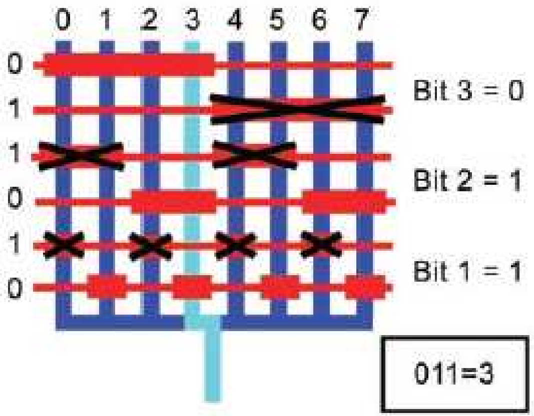
Source: Stanford Microfluidics Foundry

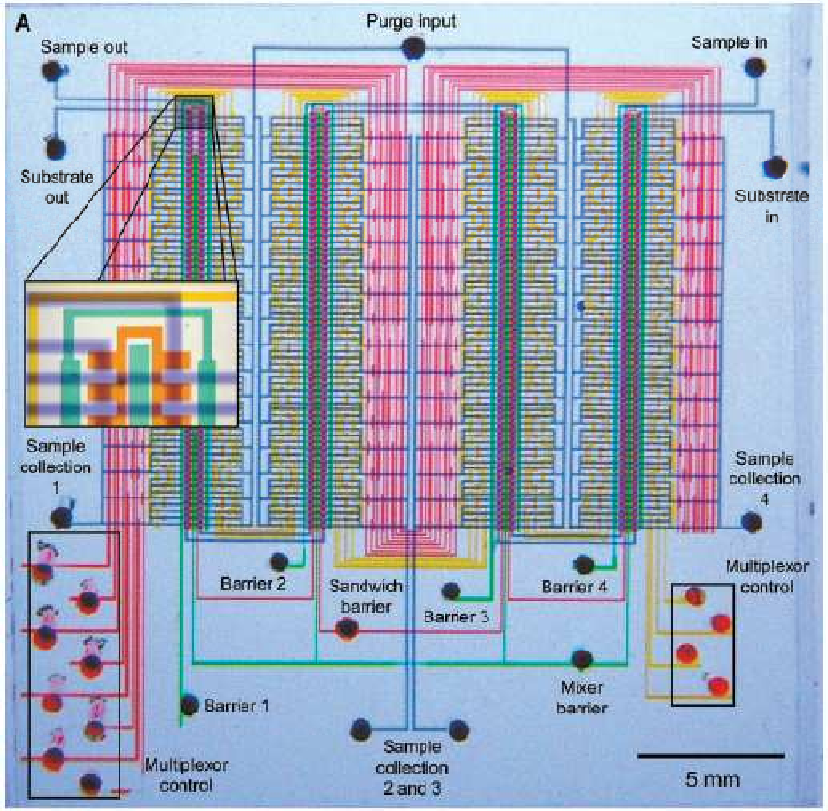
http://thebigone.stanford.edu/foundry/technology/valve.html

Microfluidics Large Scale Integration

- **Controlling 2^N fluidic channels with N input valves (multiplexing). Binary logic.**
- **Microfluidic channels and control layer made in transparen elastomer (PDMS).**
- **Microfluidic valves actuated by air pressure (20-50 kPa).**



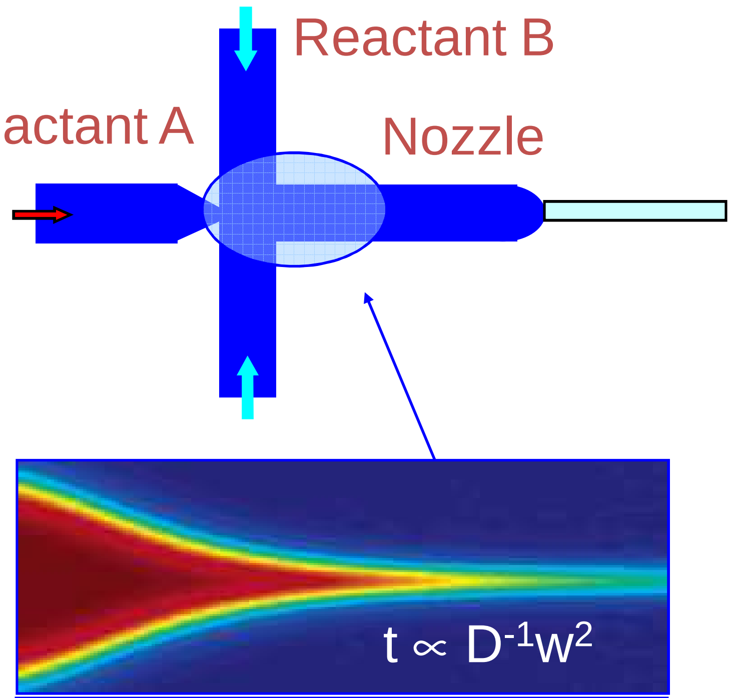




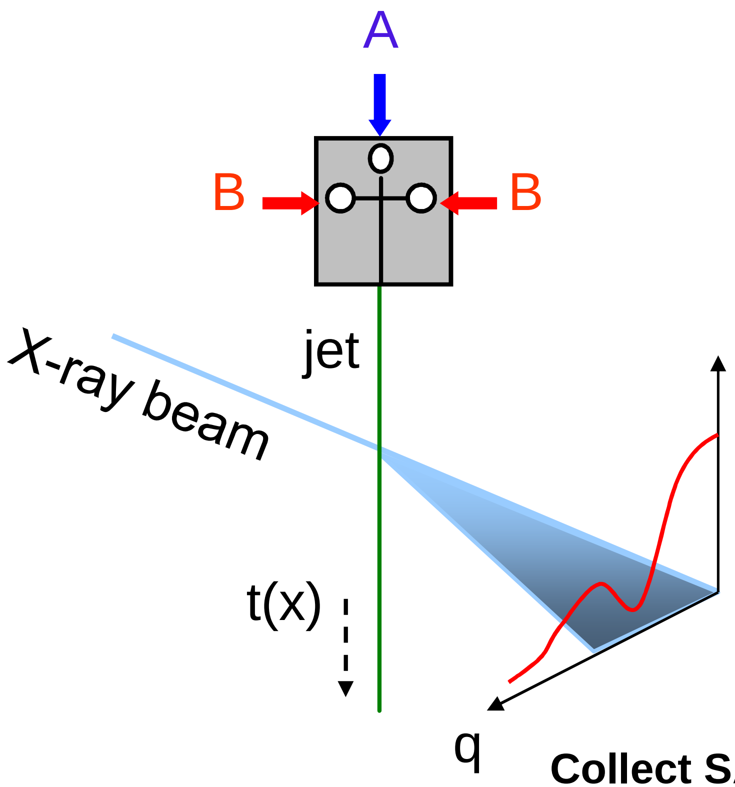
Thorsen *et al.*, Science **298,** 580, (2002)

Melin *et al.* Annu. Rev. Biophys. Biomol. Struct. **36,** 213 **(**2007).

Optical detection of reaction kinetics



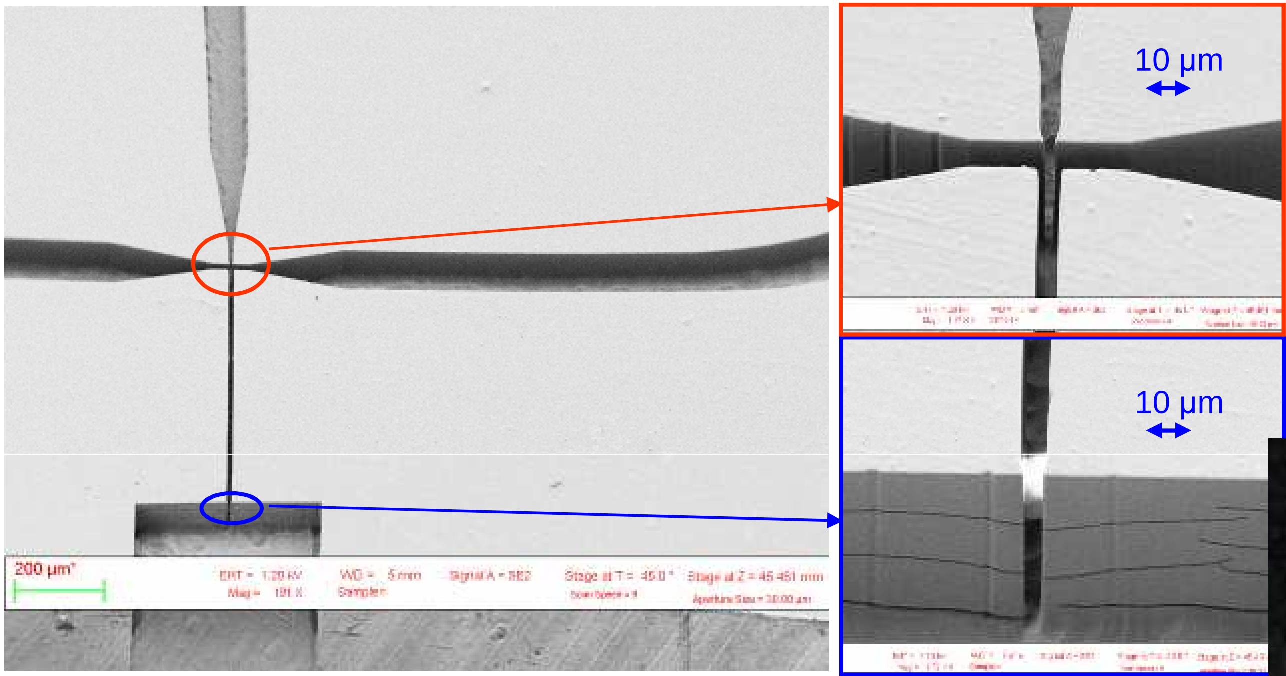
Mixing by hydrodynamic focusing

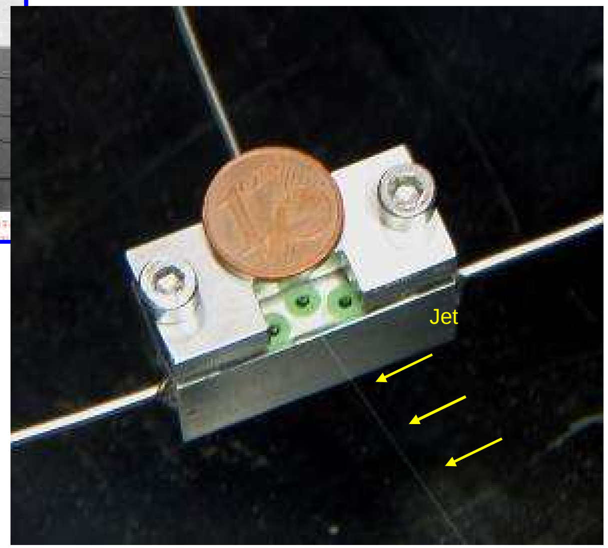


Collect SAXS signal

B. Marmiroli, G. Grenci et al. Lab Chip, 2009, DOI: 10.1039/b904296b

Microfluidic mixer



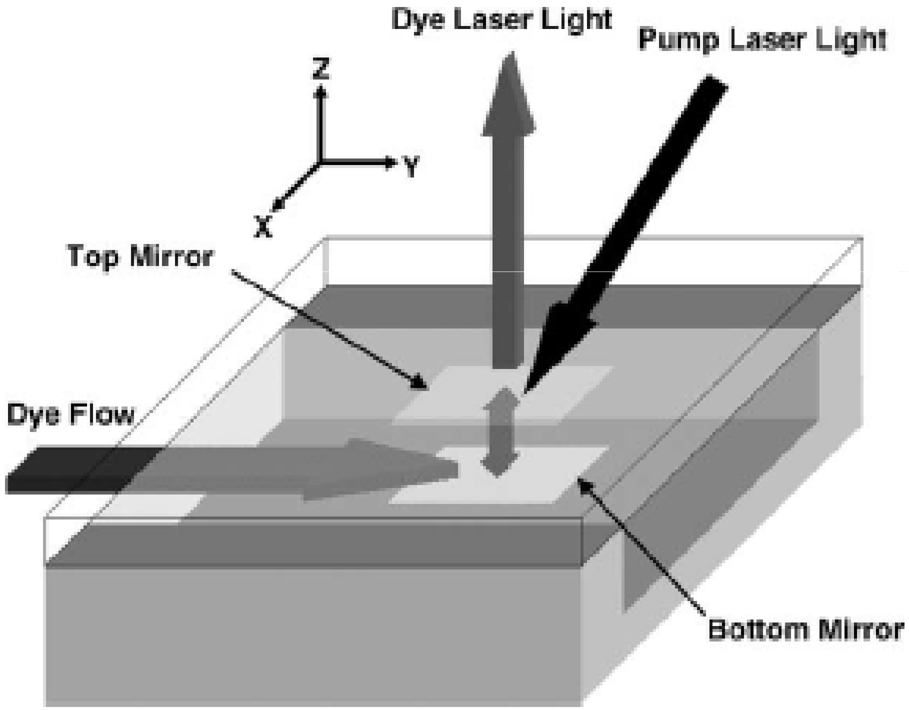


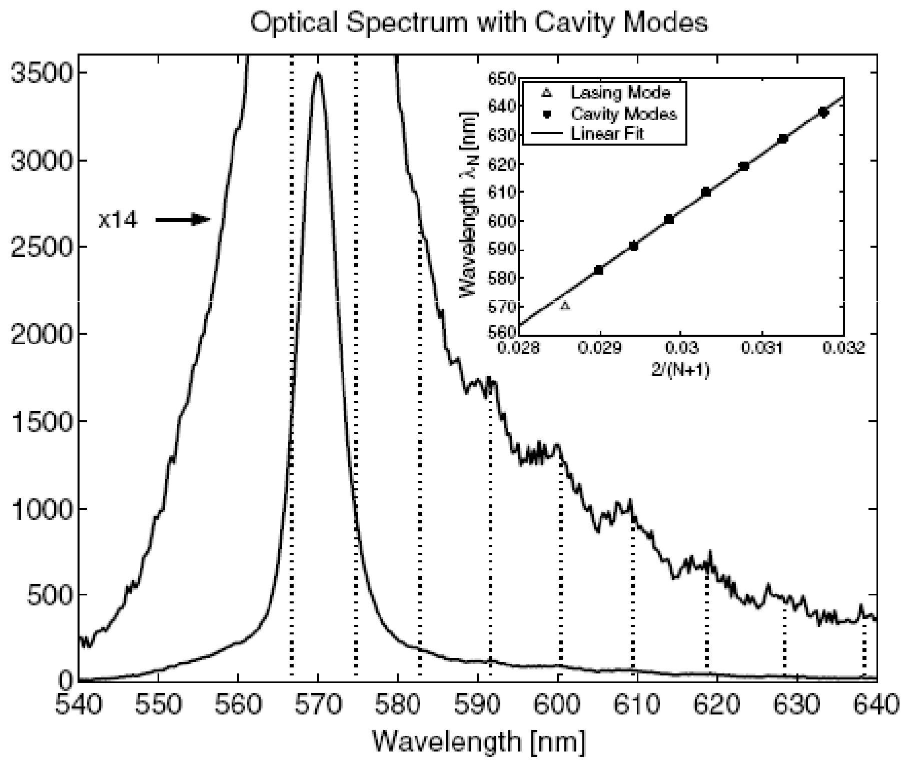
Device in PMMA:

- 60 µm deep channels
- inlet nozzle 5 µm wide
- outlet nozzle 8 µm wide

Deep X-ray lithography

First Microfluidic Dye Laser (2003)

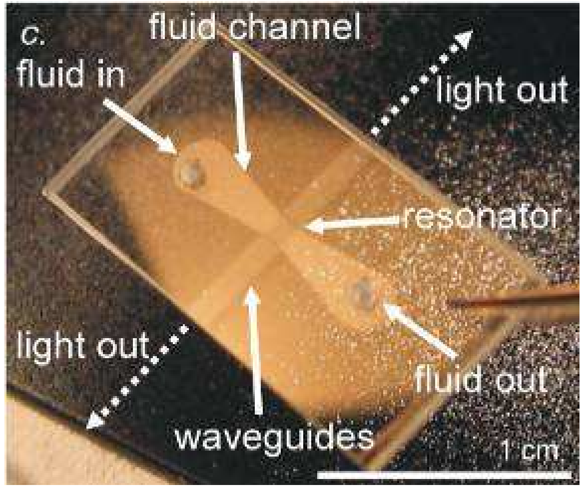


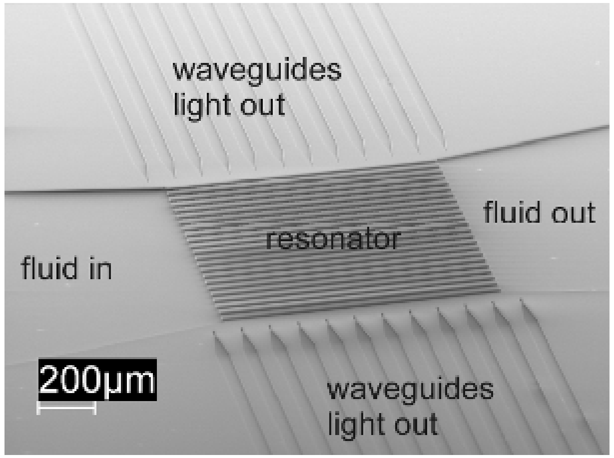


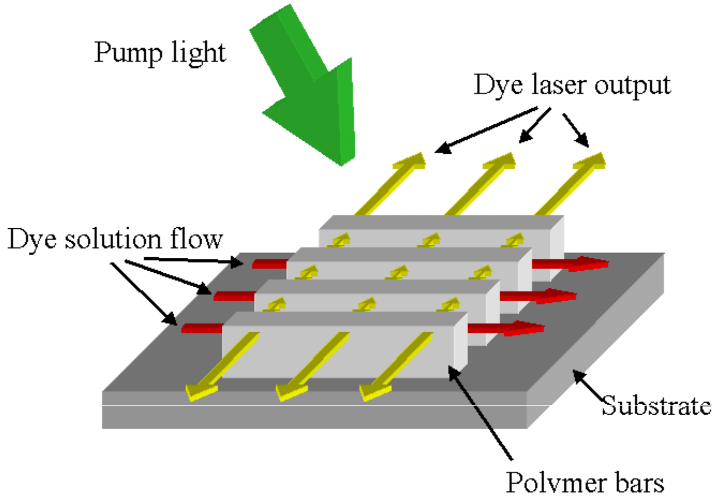
B. Helbo et al., IEEE MEMS 2003, J. Micromech. Microeng., Vol. 13, 307 (2003)

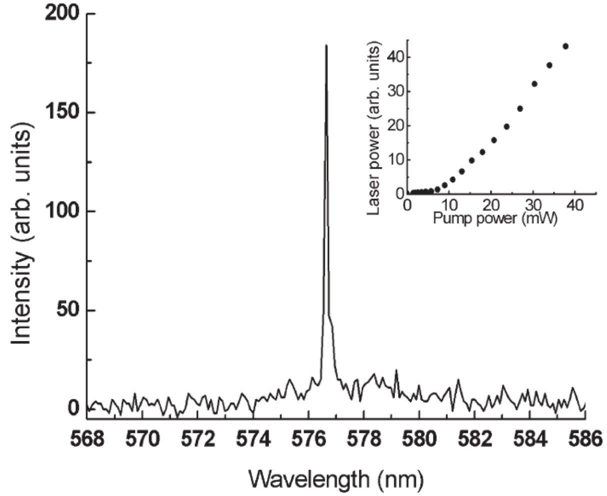
Courtesy: Anders Kristensen
DTU Nanotech, Technical University of Denmark

Optofluidic DFB Laser (2005)









S. Balslev and A. Kristensen, Optics Express, Vol. 13, pp. 344-351 (2005)

Courtesy: Anders Kristensen
DTU Nanotech, Technical University of Denmark