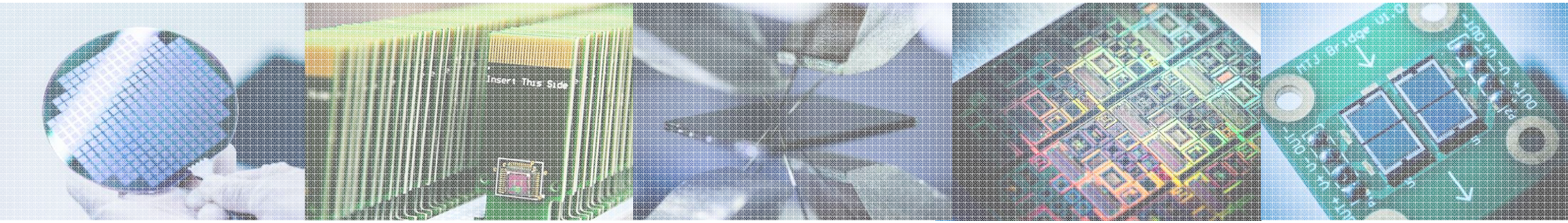

Microfluidics

the science and technology for miniaturized laboratories on-chip

vania.silverio@tecnico.ulisboa.pt

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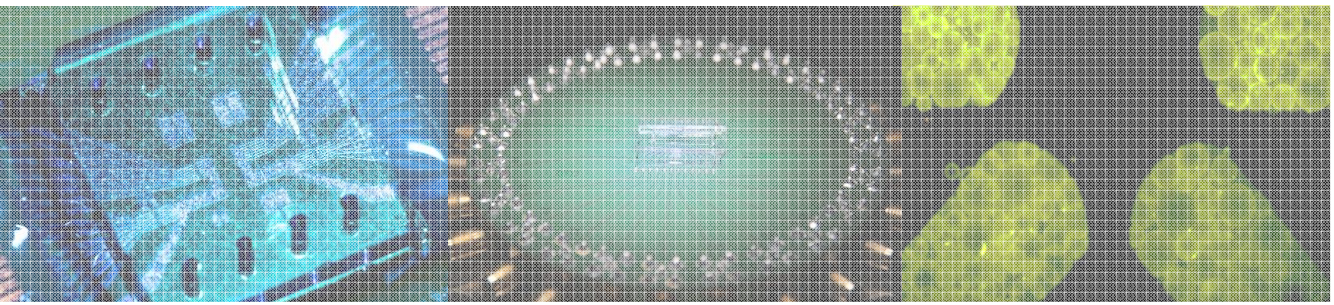
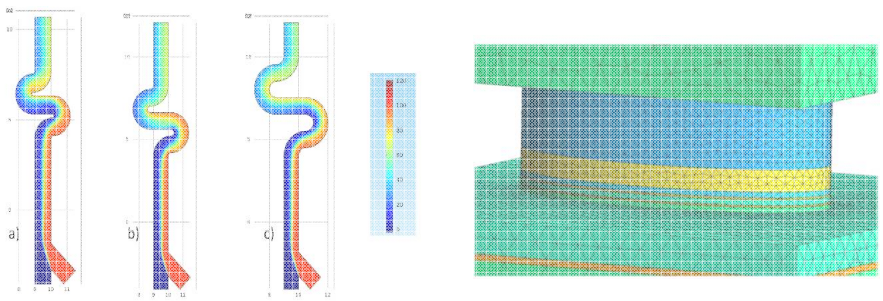
Microsystems and Nanotechnologies

- Spintronics and Biosensors
- MEMS and BioMEMS
- Magnetic Nanostructures and Nanodevices
- Bioanalytical Engineering
- Wide Bandgap Semiconductors
- Materials Simulations

Training, service providing, protocols for regular user access

FLOMEKO2019
18th International Flow Measurement Conference
Portugal | Lisbon | LNEC | 26-28 june 2019





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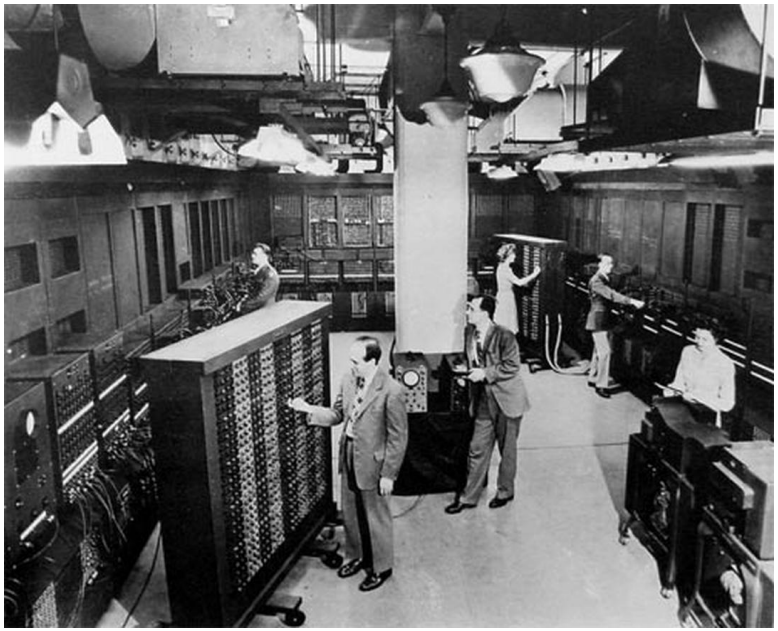
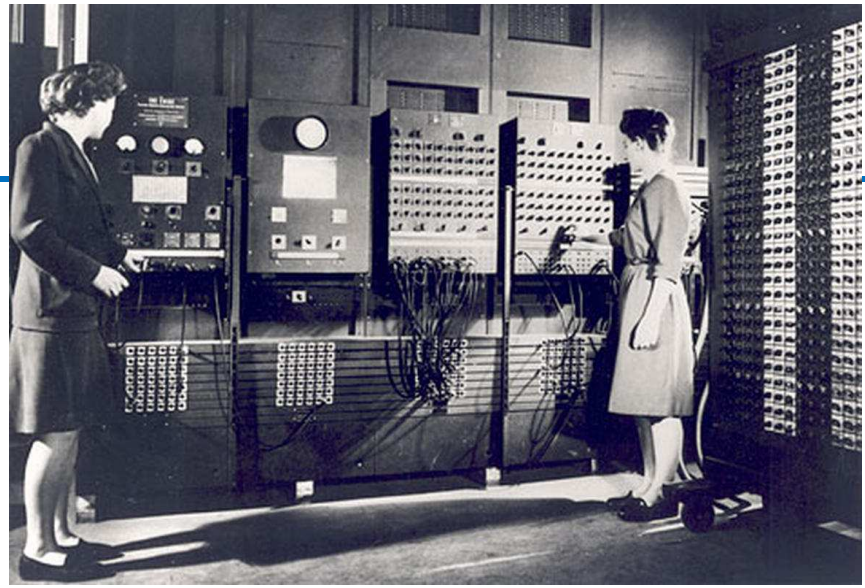


Fine-tuning ENIAC
J. Presper Eckert (the man in the foreground turning a knob) served and John Mauchly (center) designed ENIAC to calculate the trajectory of artillery shells. The machine didn't debut until February 1946, after the end of World War II, but it did launch the computer revolution.

http://www.zdnet.com/pictures/images-birth-of-the-first-computer



trajectory exam
Frances Blias and Elizabeth Jennings with ENIAC. Women performed many of the mathematical calculations and developed the programming techniques. Although they didn't get credit at the time, their role has recently become better acknowledged. "The audience was absolutely astounded. ENIAC ran the trajectory faster than it took the bullet to trace it. People got, as a souvenir, a printout of the trajectory we ran," said Jean Bartik, one of the surviving programmers, about the first demonstration of ENIAC to the military and other scientists.

Eckert-Mauchly Computer
Mauchly and one of ENIAC's programmers. After a disagreement with the University of Pennsylvania over patents, Mauchly and Eckert left to form the Eckert-Mauchly Computer, which was bought a few years later by Sperry Rand and later became Unisys. Although Eckert stayed on, Mauchly left and was nearly broke when he died in 1980.

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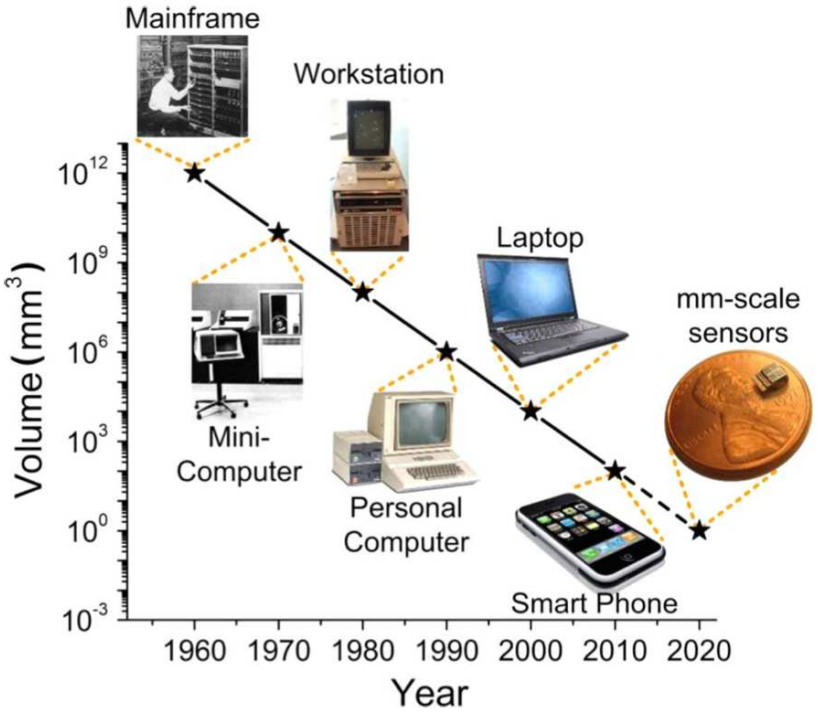
The World's Smallest Computer

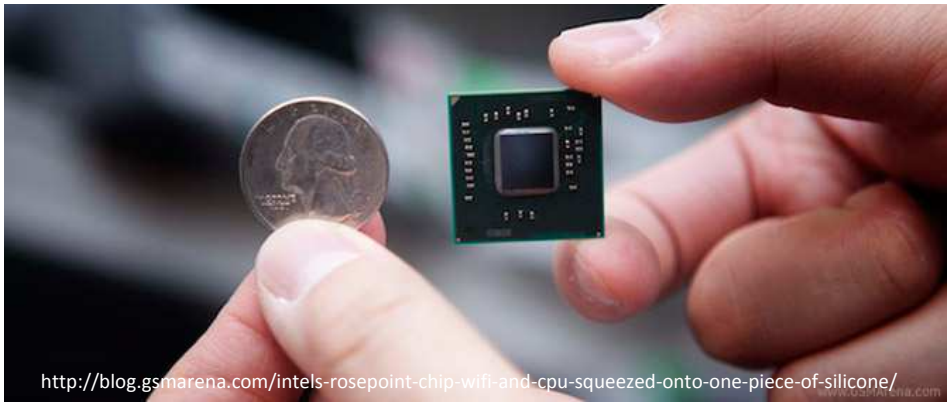
Dag Spicer March 26, 2015 Curatorial Insight, From the Collection



http://www.computerhistory.org/atchm/the-worlds-smallest-computer/

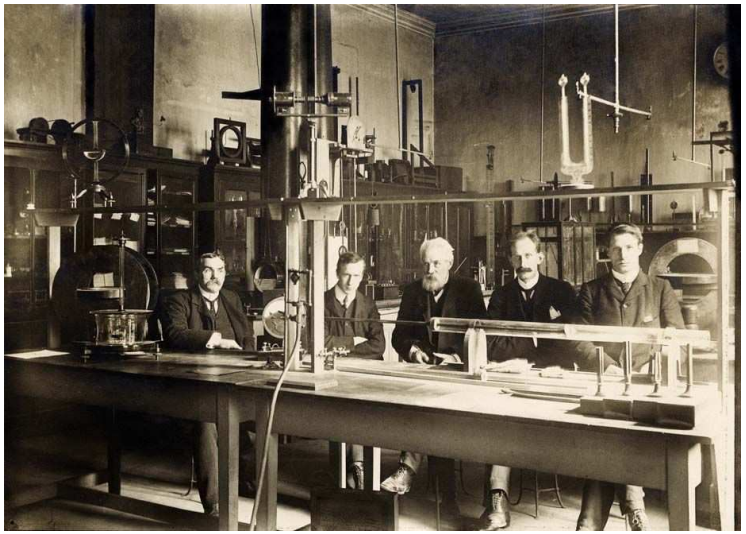
Intel's Rosepoint chip: WiFi and CPU squeezed onto one piece of silicone

February 21st, 2012, 04:19 by Alex



ZOTAC Reveals Next-Gen Pico Mini PCs With Latest CPUs From Intel And AMD

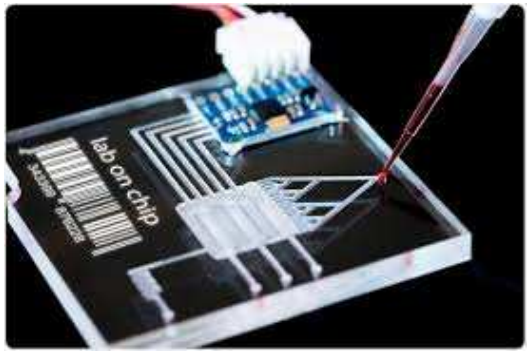
by Microsoft News @@msftnws
Jan 10, 2015 at 1:47 GMT

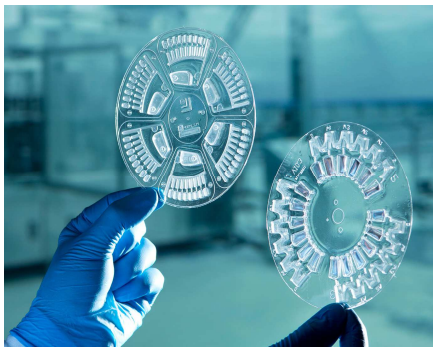


CHEMICAL LABORATORY IN THE 30'S

LIFE SCIENCES LABORATORY IN ~ 2000

LABORATORIES OF THE FUTURE





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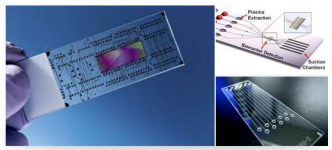
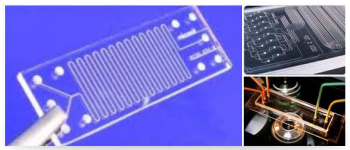
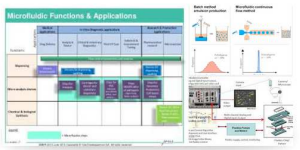
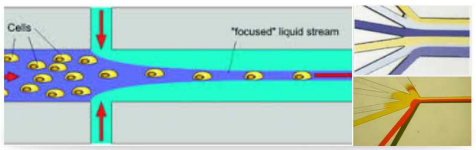
MICROFLUIDICS


Lab on A Chip

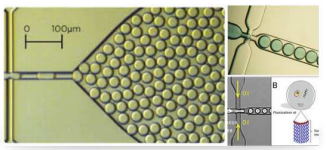

Device



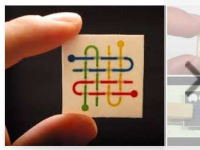
Applications

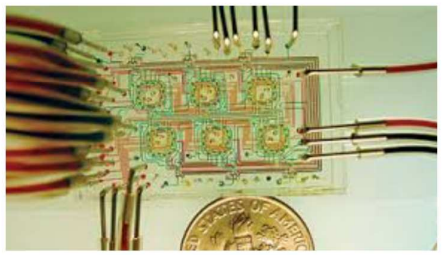


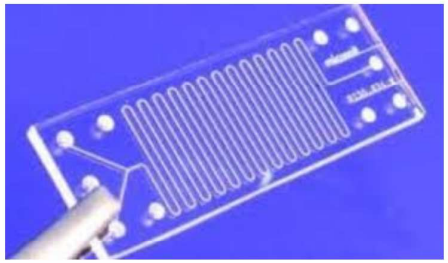
Laminar Flow

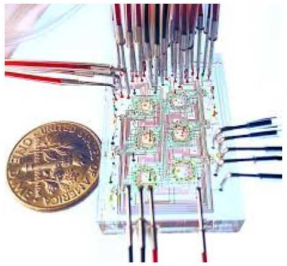


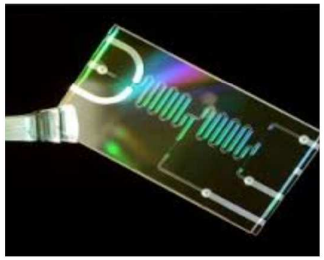
Droplet

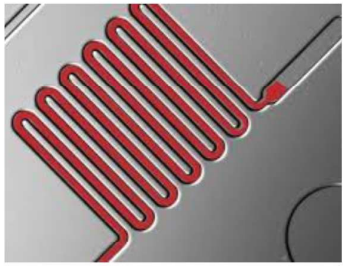

Paper

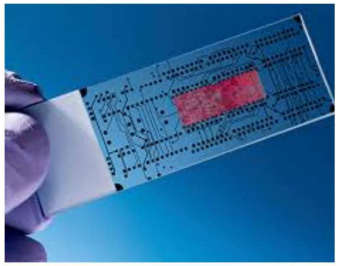


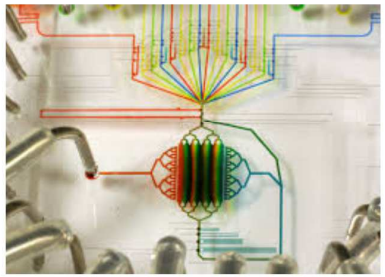


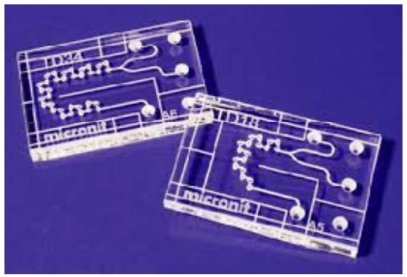


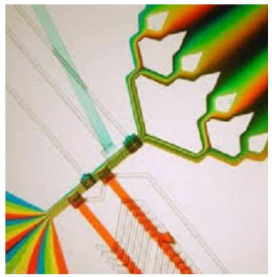


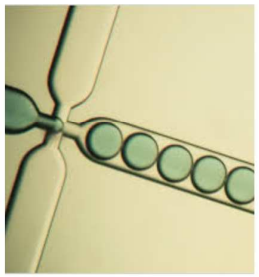


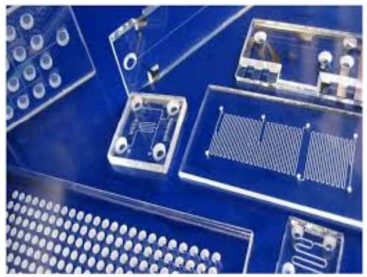


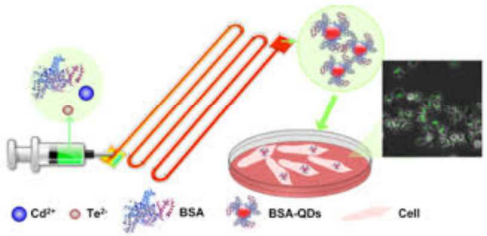












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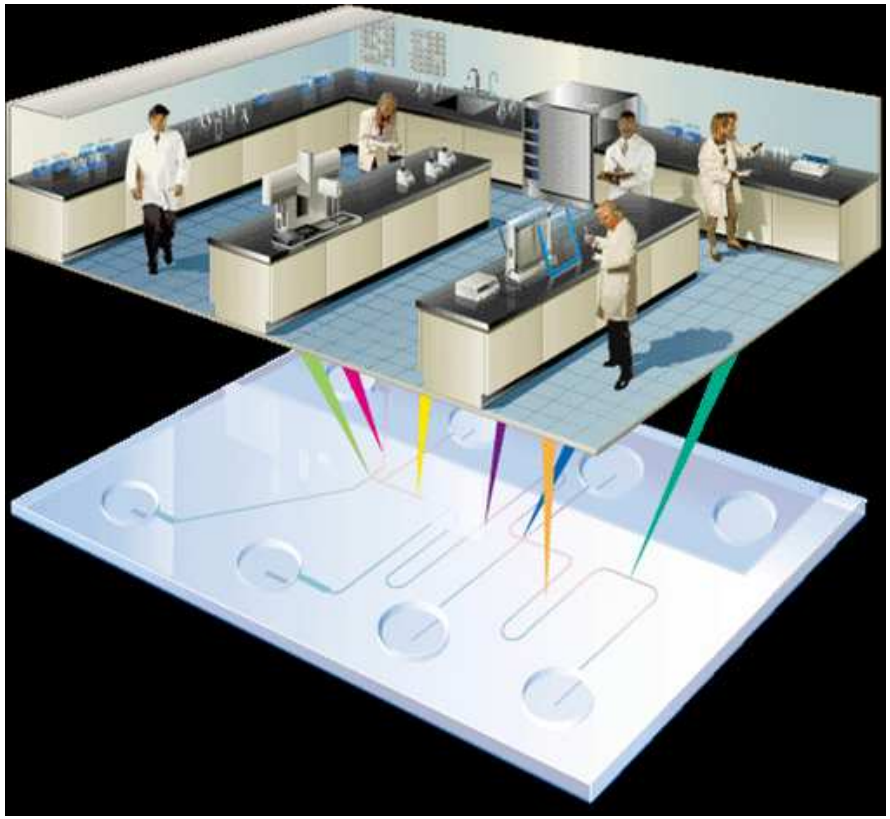
Microsystems and Nanotechnologies

MINIATURIZATION

mi · cro · flu · id · ics *(mī′krō flōo id′iks)*

"It is the science and technology of systems that process or manipulate small amounts of fluids, using channels with dimensions of tens to hundreds of micrometres."

GM Whitesides, The origins and the future of microfluidics, Nature 442(2006)368-373



dominated by
- **Surface tension**
- **Energy dissipation**
- **Fluidic resistance**

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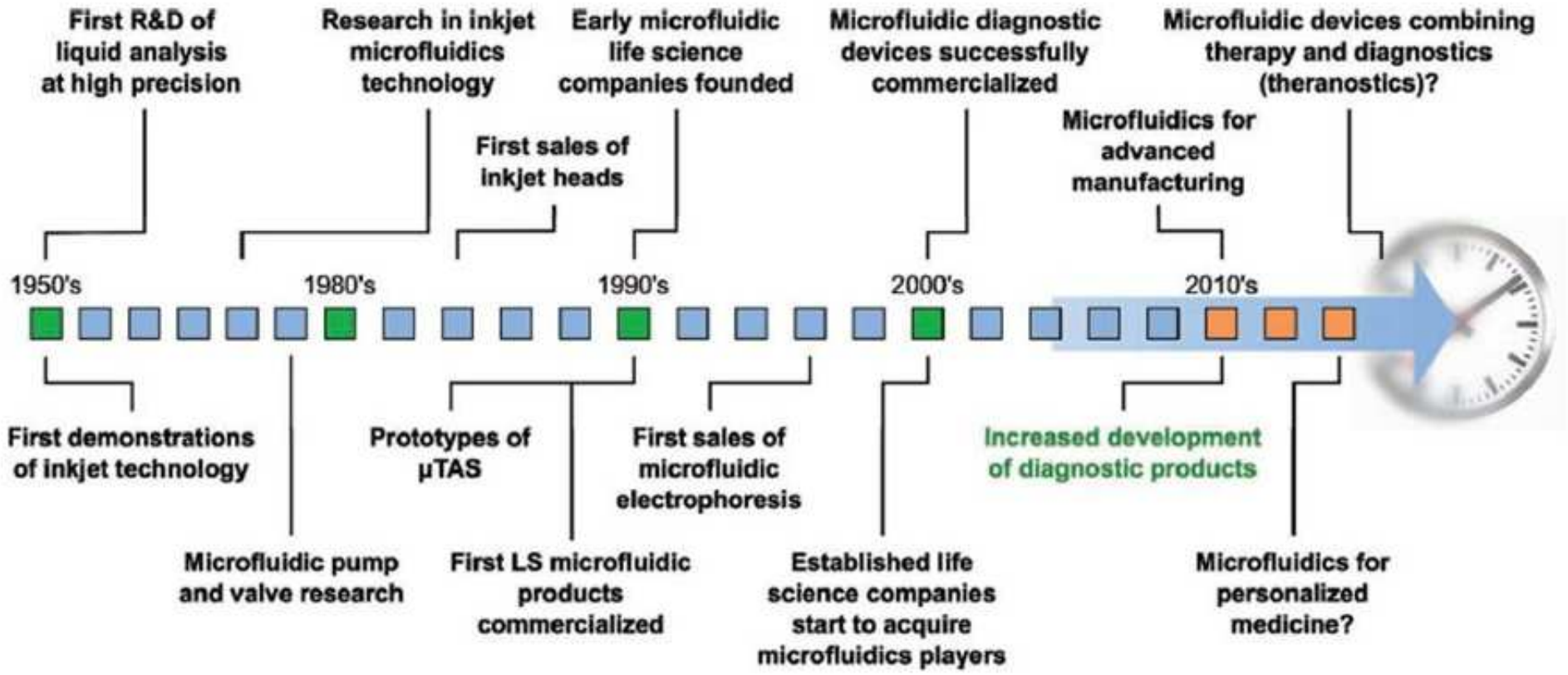
Microsystems and Nanotechnologies

EVOLUTION OF MICROFLUIDICS TECHNOLOGY



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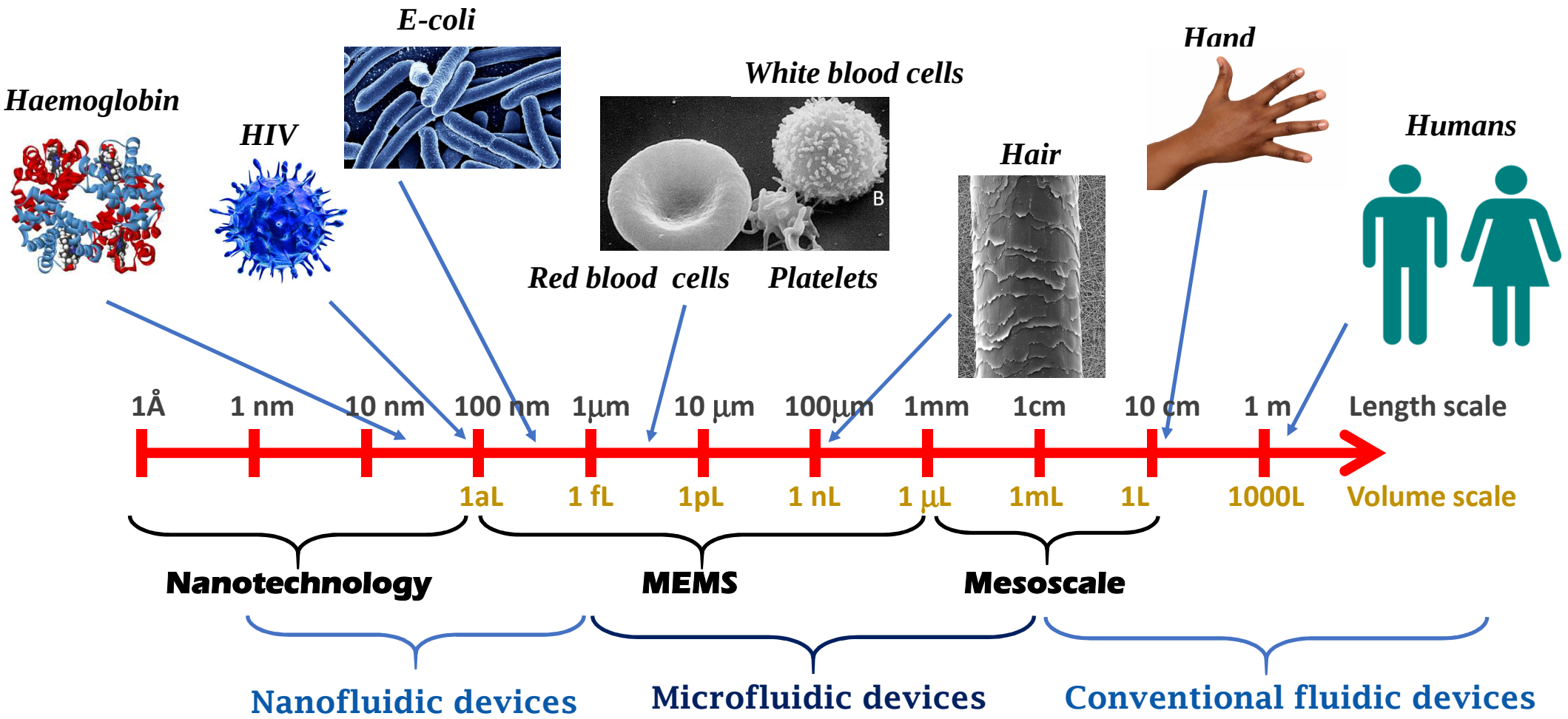
Microsystems and Nanotechnologies

LENGTH SCALES



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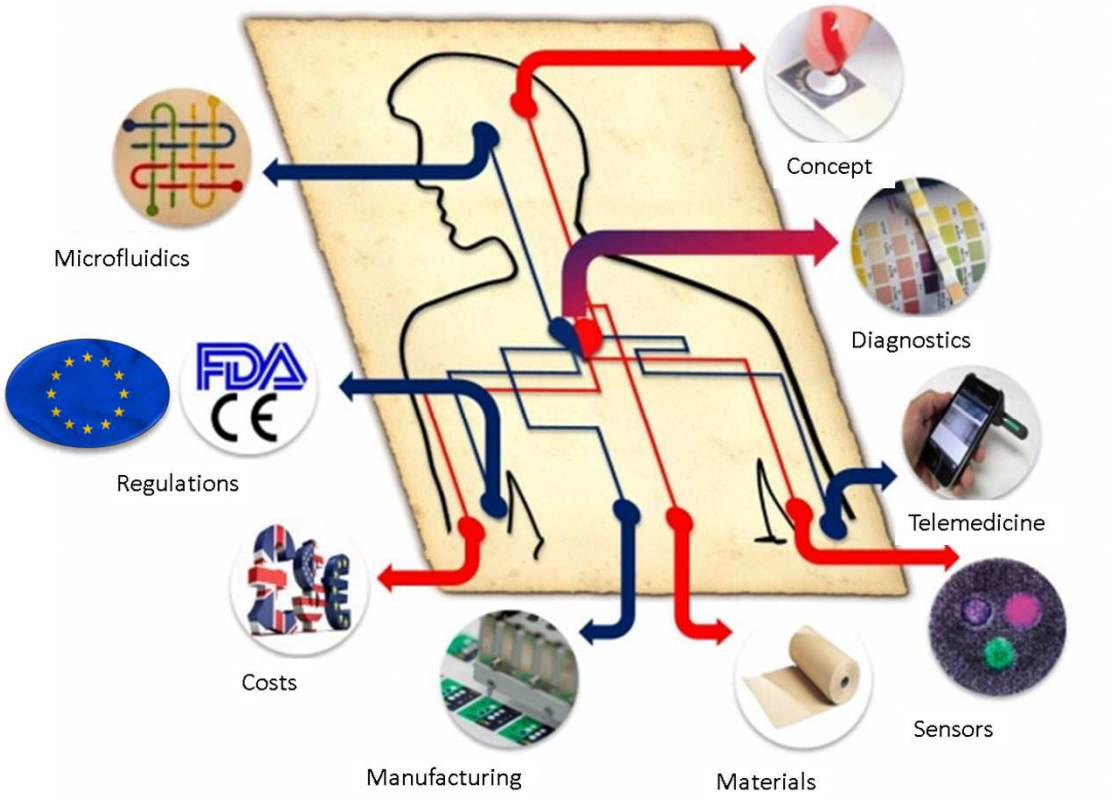
Microsystems and Nanotechnologies

WHY MICROFLUIDICS ?

- Required when the application demands handling of **very small liquid volumes** (ex: inkjet printers, drug administration, chemical microanalytical systems, …)

- Advantages of scaling down
  - **Decreased** sample and reagent volumes
  - **Faster** response : shorter diffusion distances
  - Paralell, multitarget and **multiplex** detection
  - **Portable**
  - **Small economic footprint**
  - Efficient **automation** and **integration**: several functions at the same chip – lab-on-a-chip, µTAS, organ-on-chip, lab-on-a-CD, …

- Disadvantages of scaling down
  - Increased surface tension influence



https://scholar.harvard.edu/yetisen/paper-based-microfluidics

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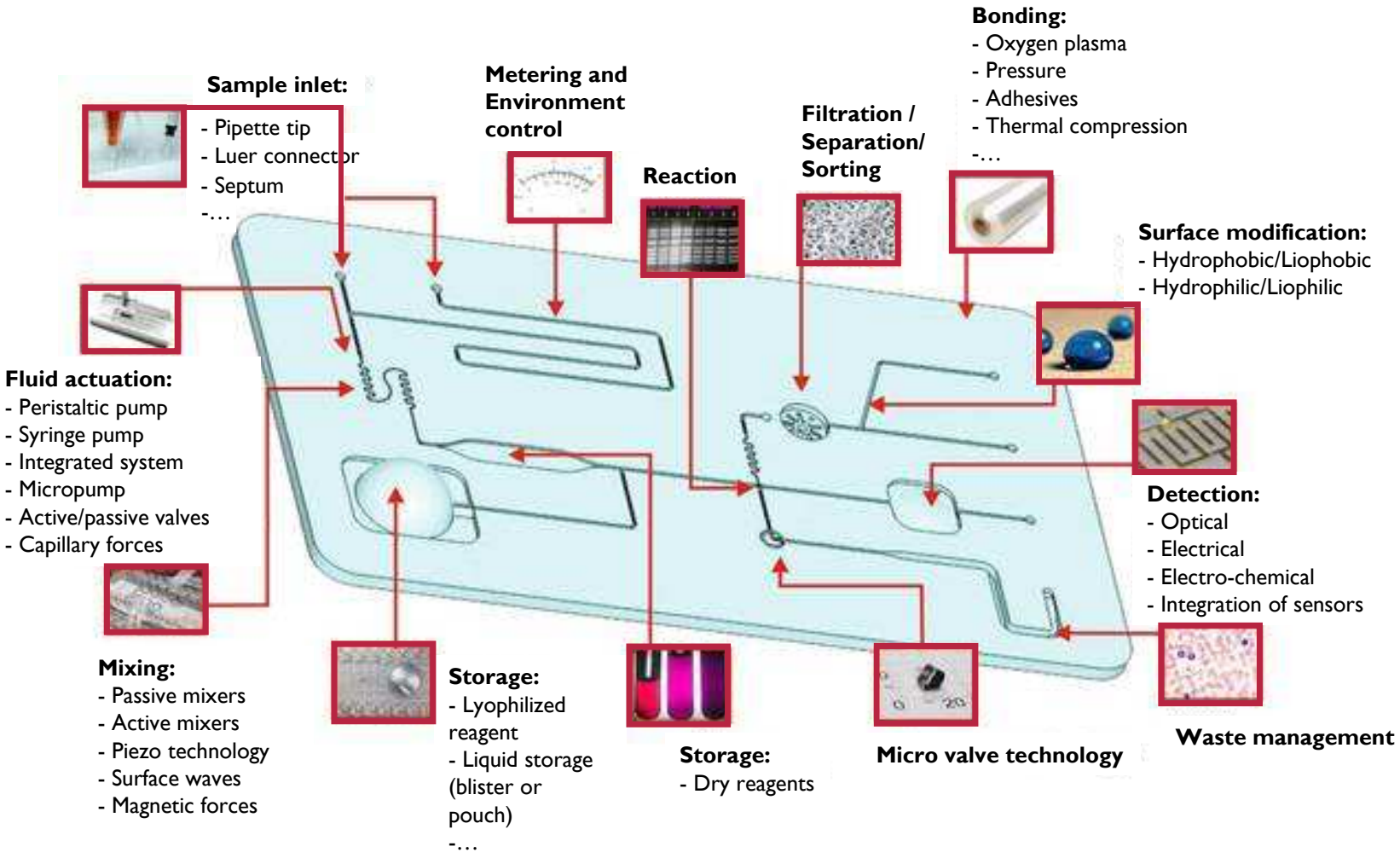
MICROFLUIDICS INTEGRATION



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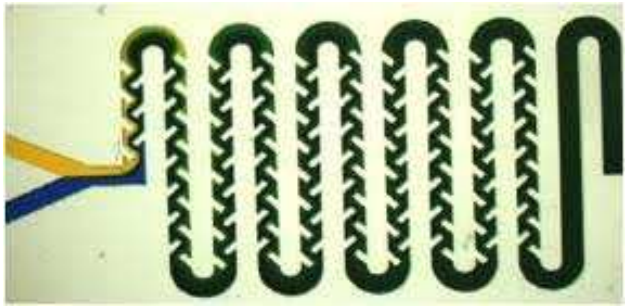
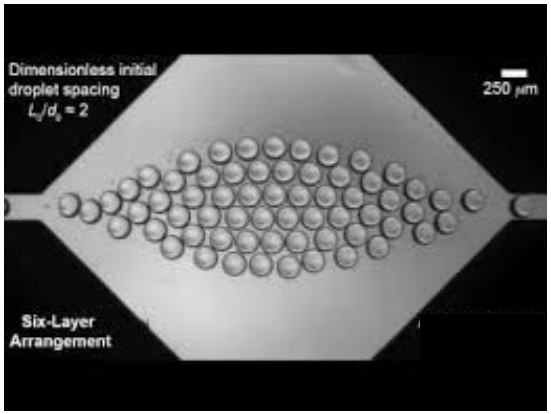
MICROFLUIDICS FEATURES

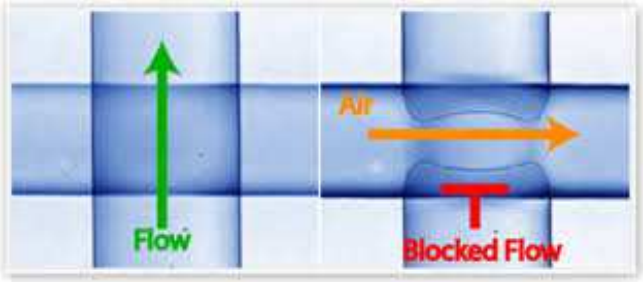
Mixers



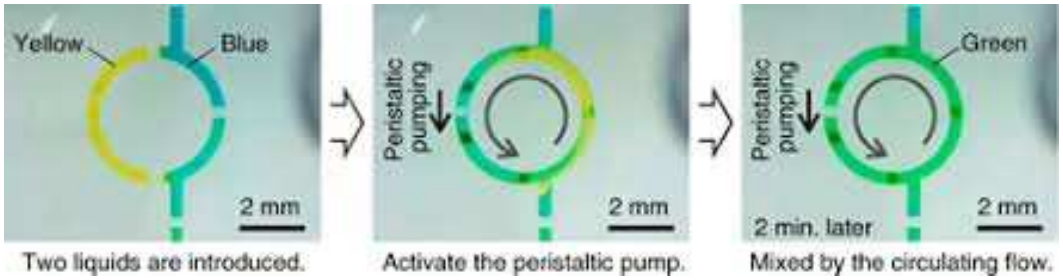
Chambers



Valves

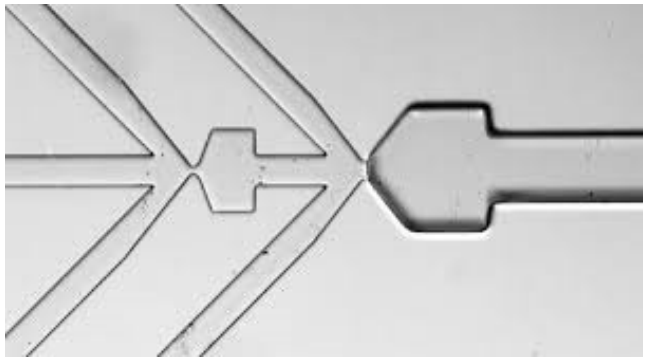


Pumps



Two liquids are introduced. Activate the peristaltic pump. Mixed by the circulating flow.

Nozzles



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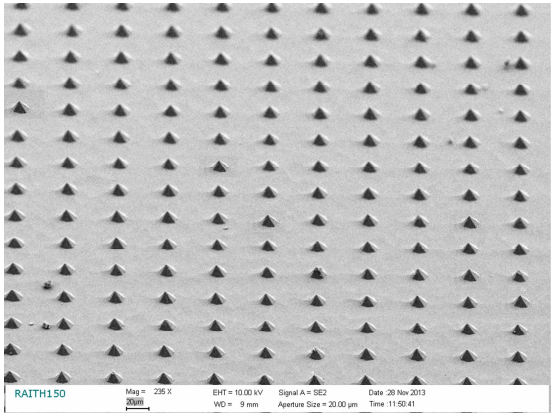
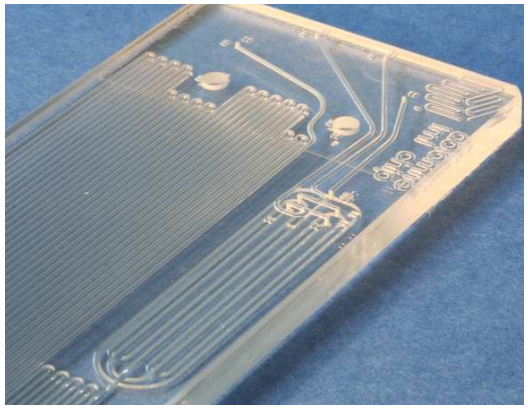
MICROFLUIDICS FEATURES

Needles

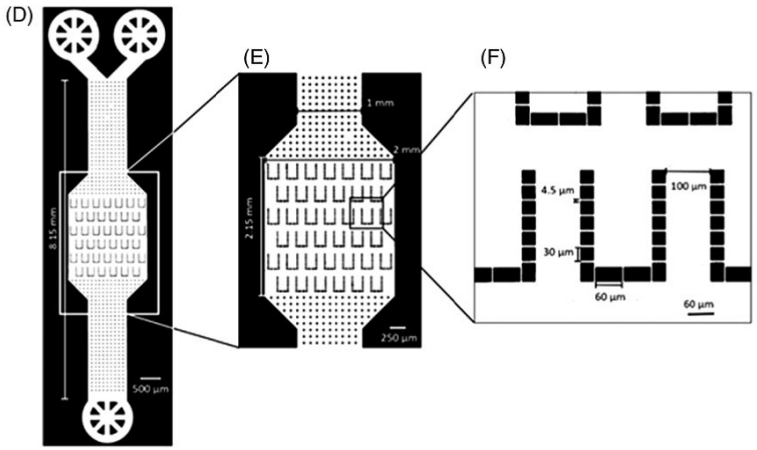


Reactors

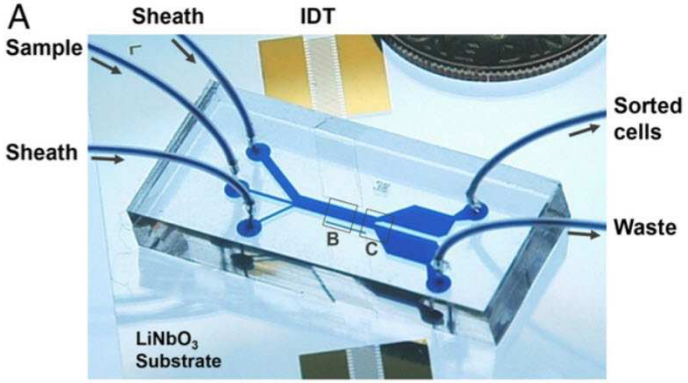


Dispensers

Filters



Separators

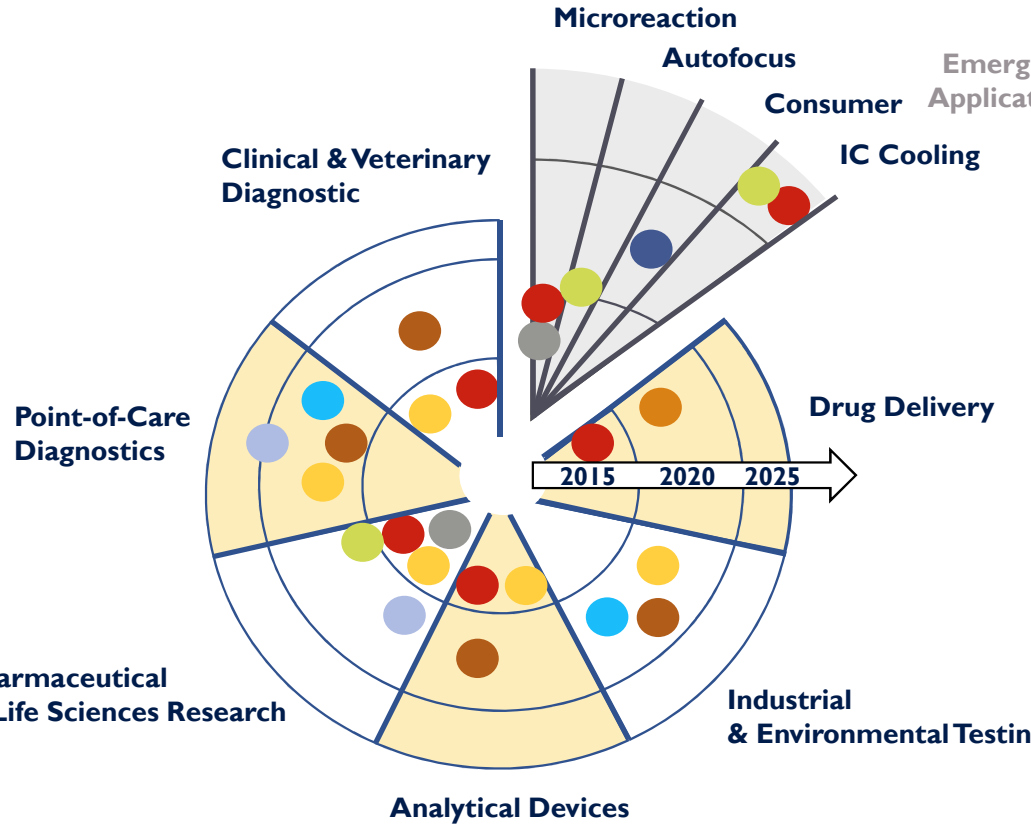


MICROFLUIDIC TECHNOLOGY/APPLICATIONS ROADMAP

(Source: Microfluidic Applications in the Pharmaceutical, Life Sciences, In-Vitro Diagnostic, and Medical Device Markets report, Yole Développement, June 2015)

Promising new technologies and applications suggest a bright future for microfluidics.

(Source: Yole Développement)



- Micropumping
- Microneedles
- Droplet generation
- Paper-based microfluidics
- Electrowetting / digital microfluidics
- Acoustic microfluidics
- Mixing
- Touchscreen
- Sample preparation techniques

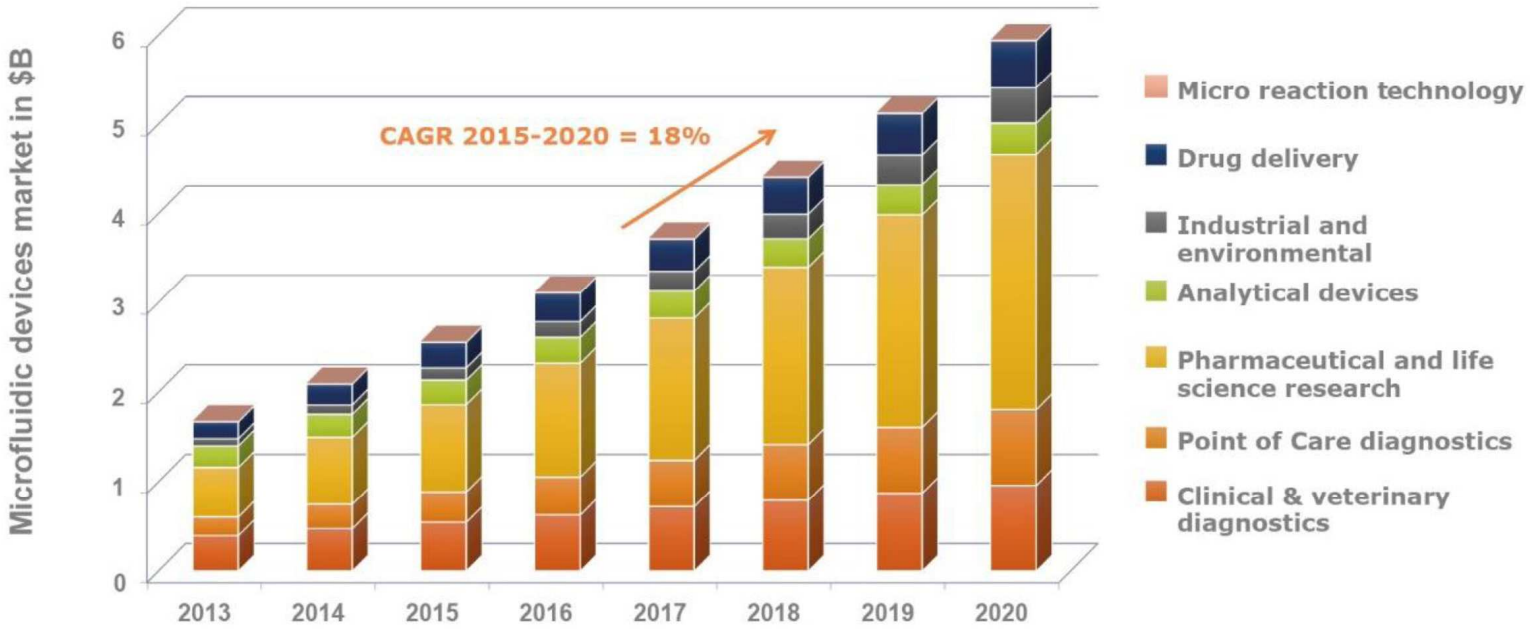
http://www.yole.fr/Microfluidic_Applications_Technologies.aspx#.Wc-WtsZry00

MICROFLUIDIC DEVICES MARKET IN $B

(Source: Microfluidic Applications in the Pharmaceutical, Life Sciences, In-Vitro Diagnostic, and Medical Device Markets report, Yole Développement, June 2015)

The microfluidic industry is now well structured for further growth.

(Source: Yole Développement)



https://www.slideshare.net/Yole_Developpement/microfluidic-applications-reportjune2015sample

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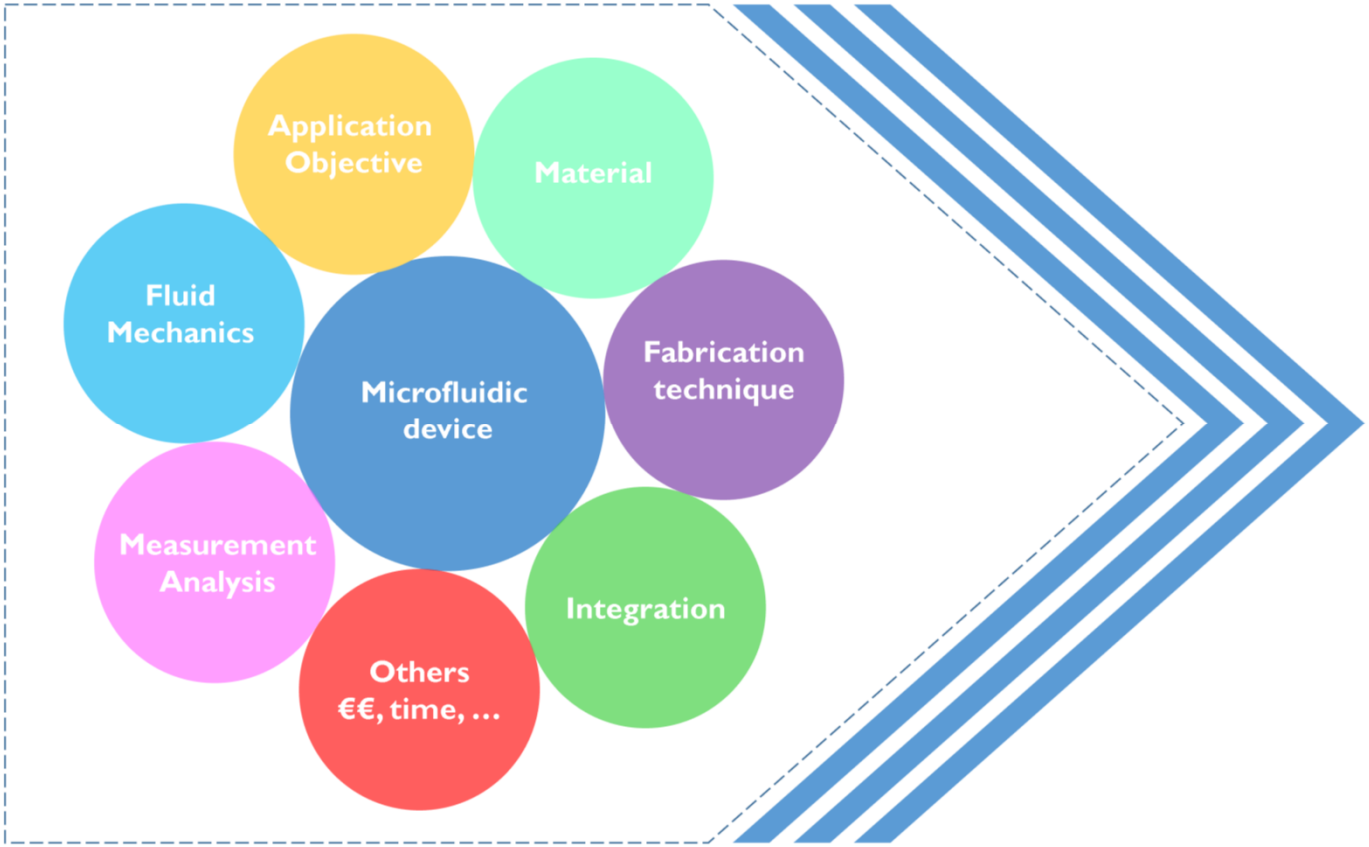
How to start ?



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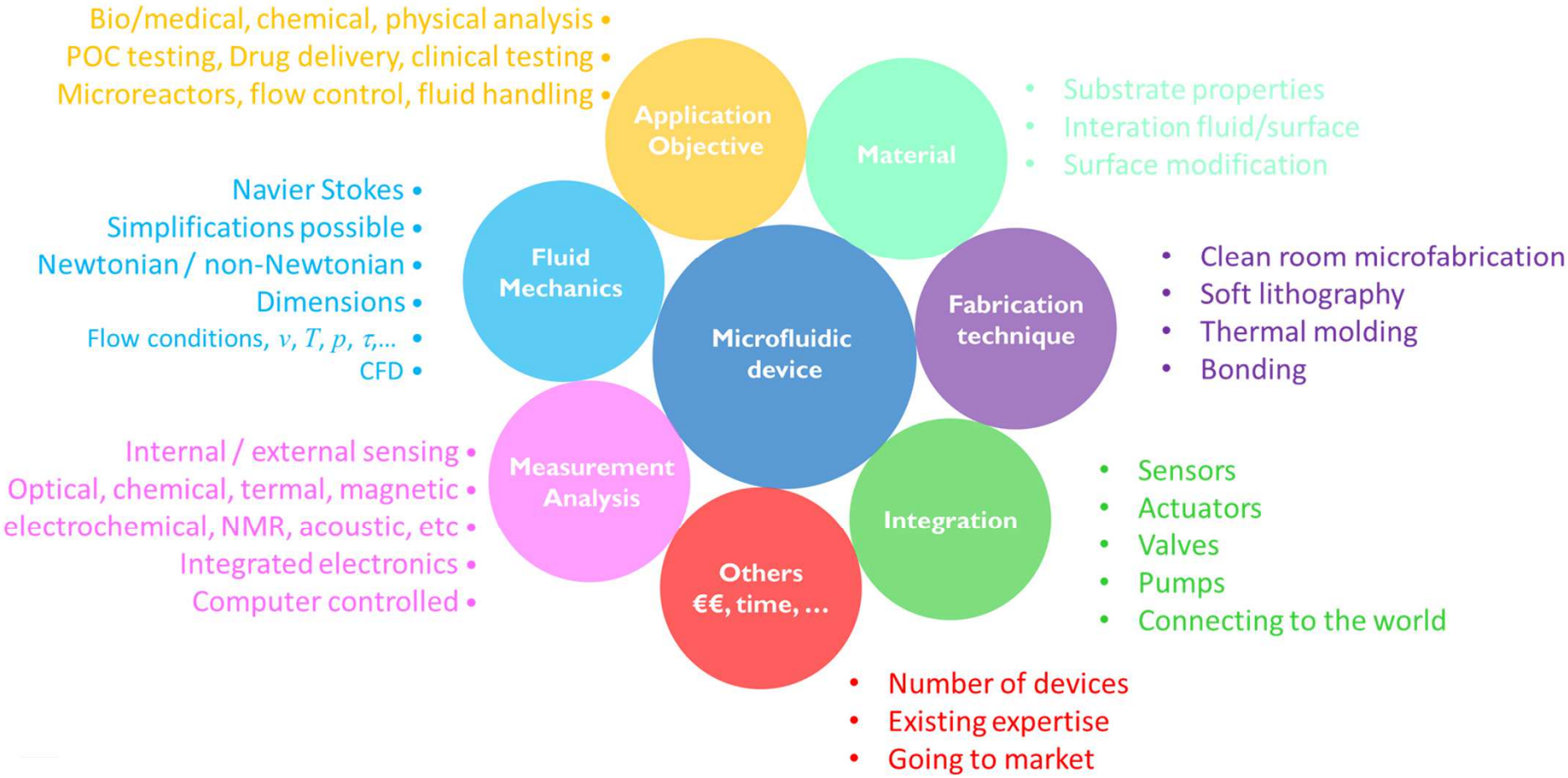
How to start ?



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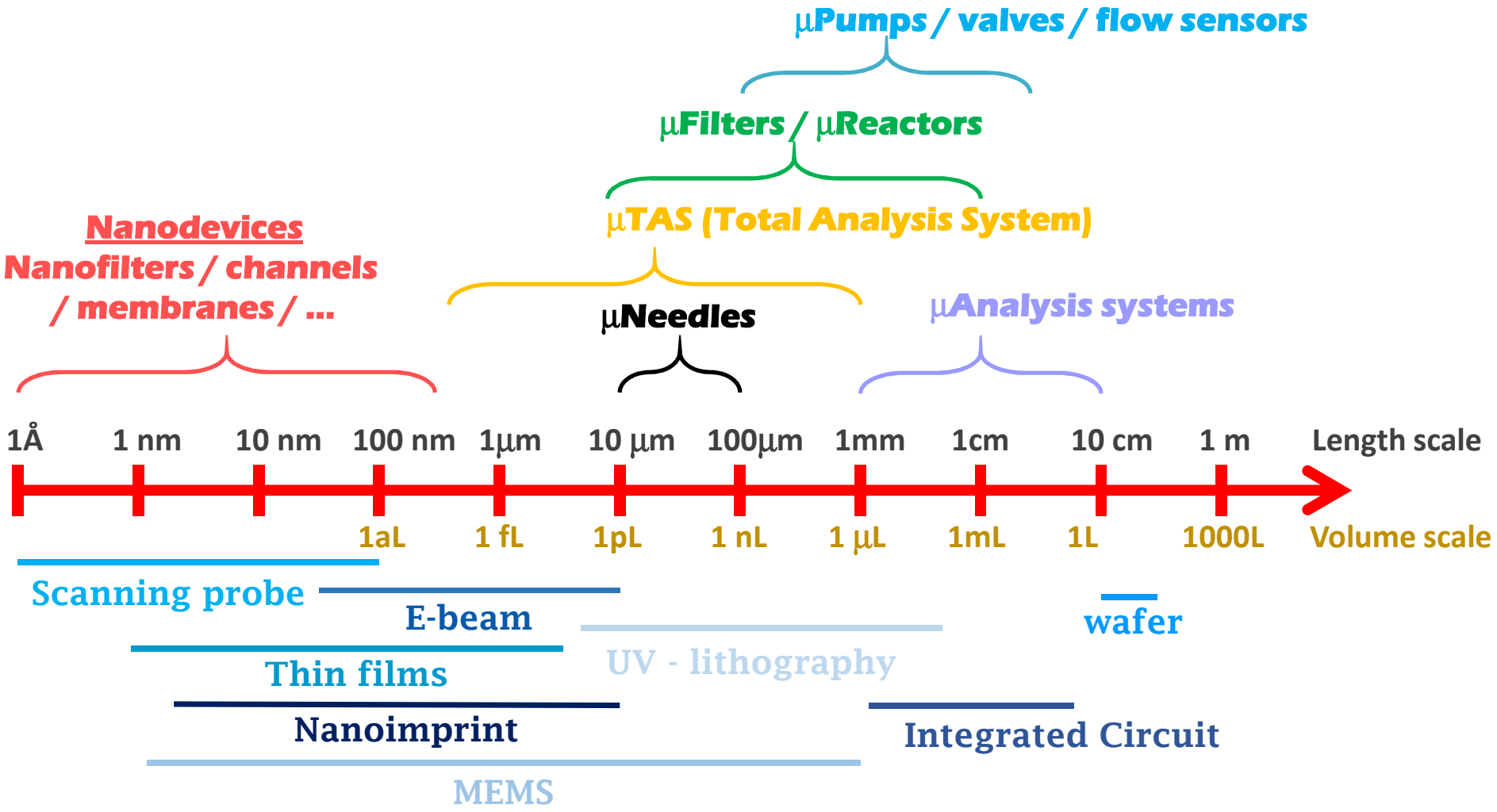
LENGTH SCALES



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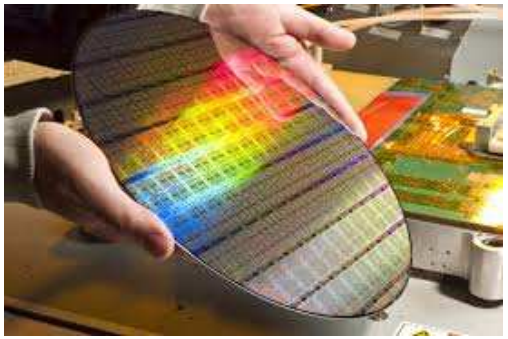
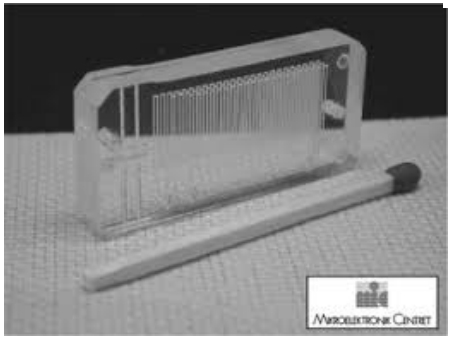
MICROFABRICATION MATERIALS

Silicon

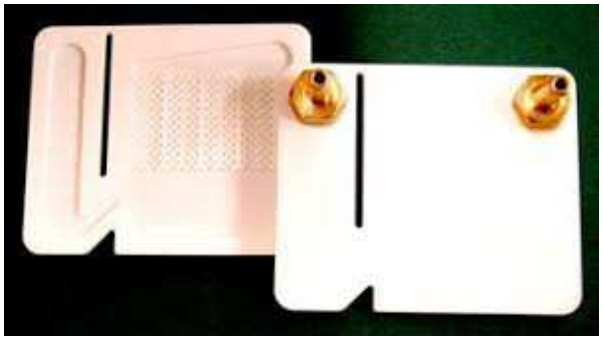


Glass, Quartz



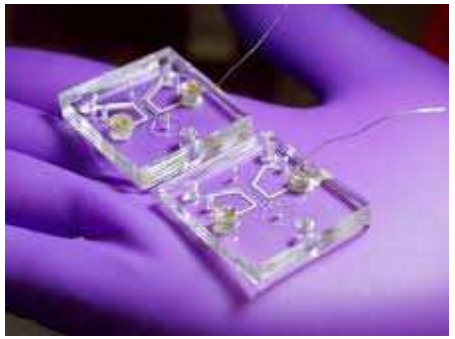
Thermoplastics: PMMA, PC, PEEK, COC, COP, PS

Ceramics

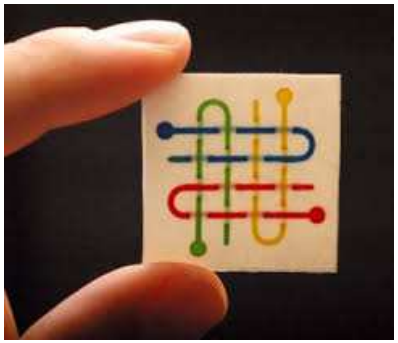


Metals

Elastomers: PDMS



Paper



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KEY FABRICATION TECHNOLOGIES

Si / Glass

- Lithography
- Wet etching
- Dry etching
- Thin film deposition
- Wafer bonding

Elastomer

- Hardmask
- Coating
- Soft lithography
- Elastomer casting
- Bonding

Polymer

- Hot embossing
- Micromilling
- IM and HE mold (insert)
- Injection moulding
- Bonding

General / back-end

- Electrical, analytical and/or fluid Interfacing
- Coating
- Hybrid assembly
- Flip-chip bonding
- Dicing/packaging

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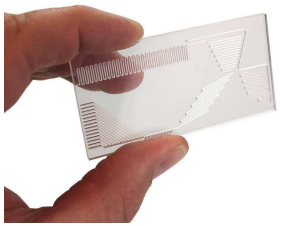
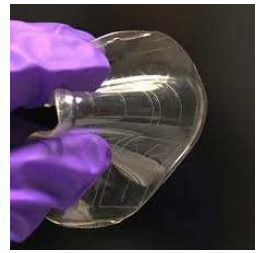
MICROFABRICATION TECHNIQUES

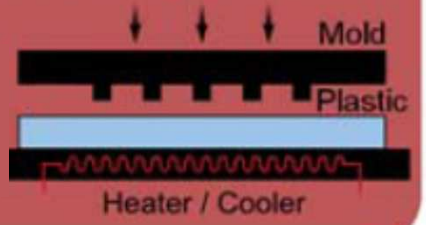


QUICK



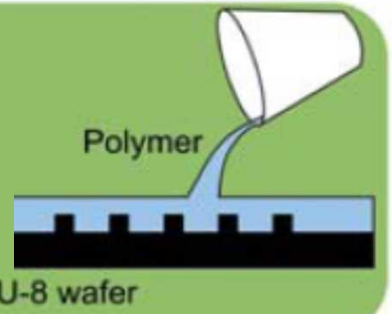
Injection Molding and Hot Embossing

+ : High-throughput
- : Cost, Features, Equipment



Replica Molding

+ : Easy, Time, Cost
- : Deformable, Pressure

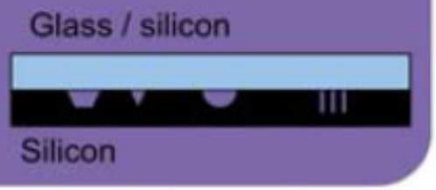


EXPENSIVE

CHEAP

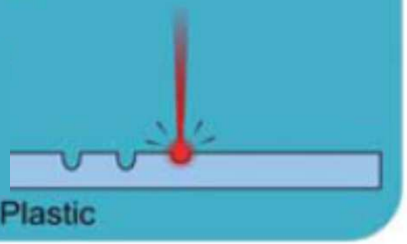
Silicon and Glass Machining

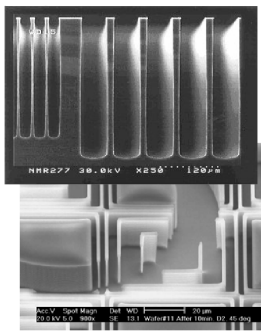
+ : Features, Pressure
- : Cost, Time, Equipment

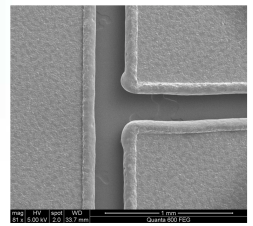


Polimer Machining and Laser Ablation

+ : Integration, Cost
- : Time, Features, Pressure







(a)

SLOW

http://pubs.rsc.org/en/content/articlehtml/2011/lc/c1lc20514e

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INESC-MN INFRASTRUCTURES

- Cleanroom Class 10/100 (~100m^2)

Maximum Number of Particles in Air (Particles per cubic meter)

ISO Class	Fed-Std 209E Class	Particle Size ≥ 0.1µm	≥ 0.2µm	≥ 0.3µm	≥ 0.5 µm	≥ 1µm	≥ 5 µm
ISO 1		10	2				
ISO 2		100	24	10	4		
ISO 3	(Class 1)	1,000	237	102	35	8	
ISO 4	(Class 10)	10,000	2,370	1,020	352	83	
ISO 5	(Class 100)	100,000	23,700	10,200	3,520	832	29
ISO 6	(Class 1,000)	1,000,000	237,000	102,000	35,200	8,320	293
ISO 7	(Class 10,000)				352,000	83,200	2,930
ISO 8	(Class 100,000)				3,520,000	832,000	29,300

- Silicon backened processing for feature sizes down to **20 nm**
- Up to **8 inch wafer (200 mm)** processing
- Area for support equipment and film deposition cleanroom Class 10000 (~150m^2)
- Chemical wetbench for biological processing
- Laboratories for film and device characterization

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Microsystems and Nanotechnologies

INESC-MN INFRASTRUCTURES

- Cleanroom C (~100m^2)
- Silicon backe to **20 nm**
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- Laboratories

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INESC-MN INFRASTRUCTURES

- Controlled temperature (20°C), air pressure, humidity, airbone particles, vibration, lighting, etc.

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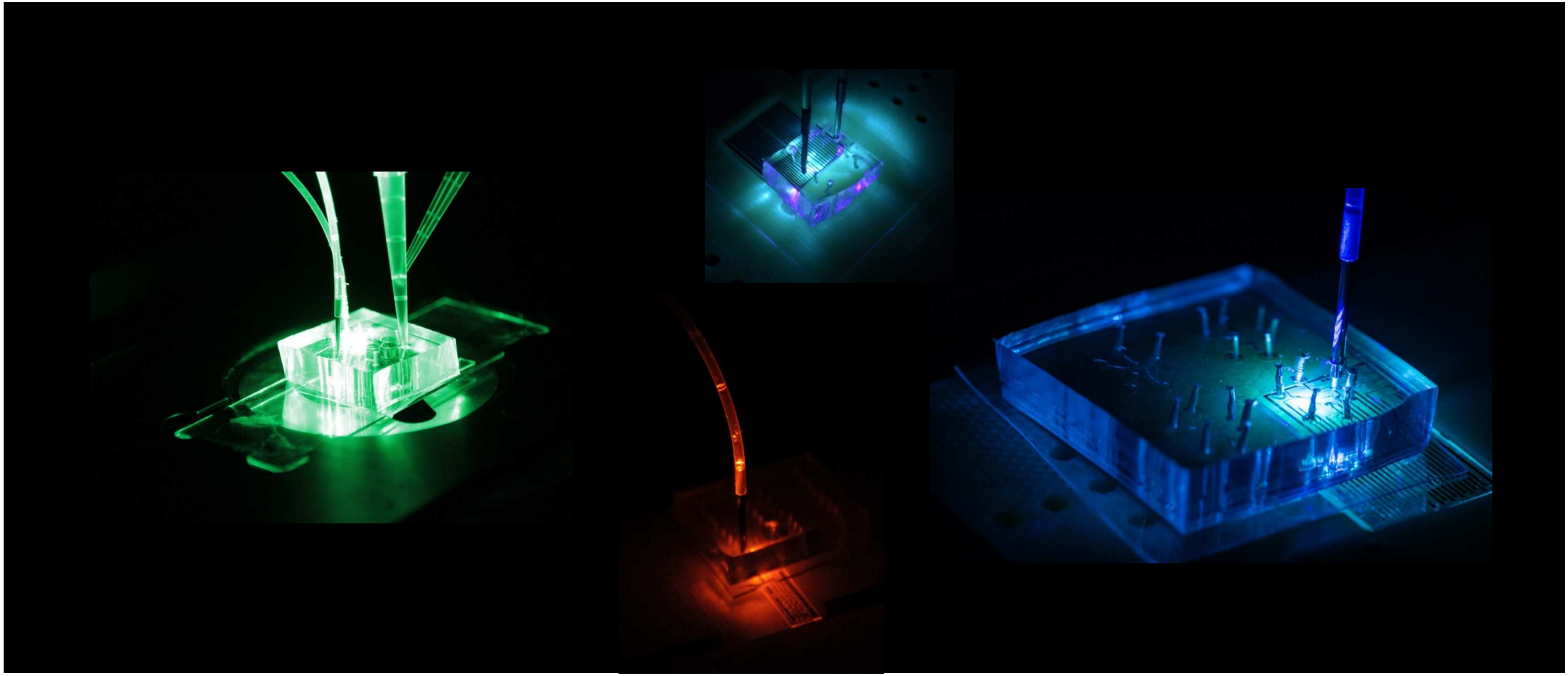
MICROFLUIDIC DEVICES AT INESC-MN



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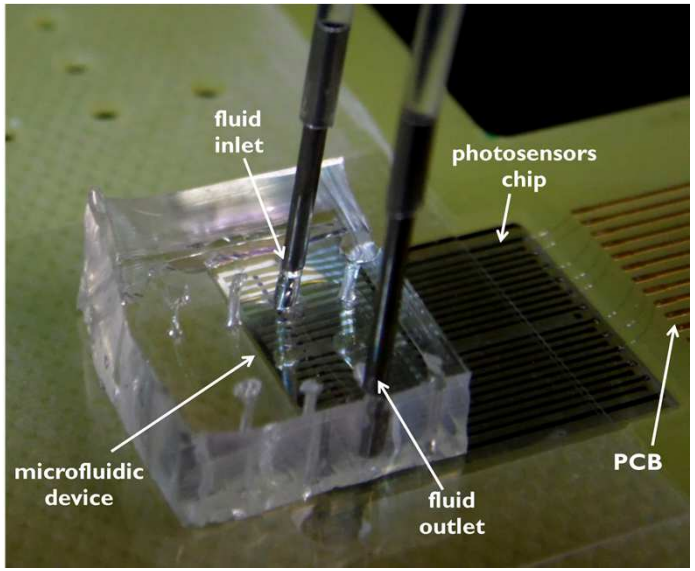
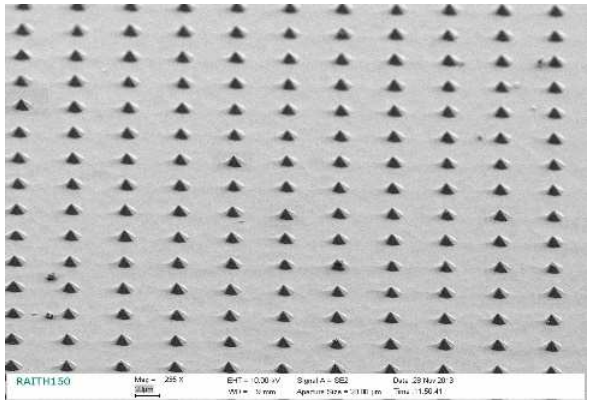
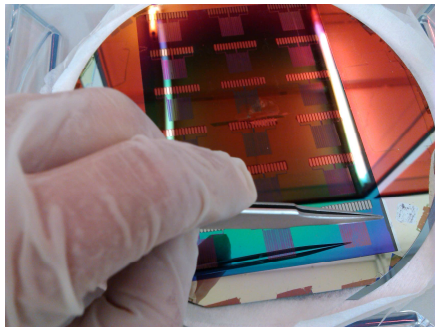
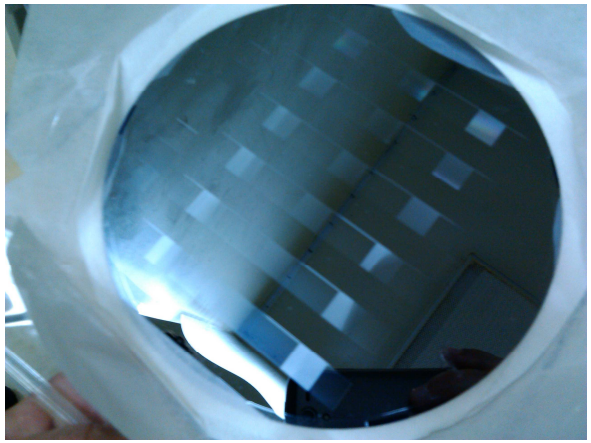
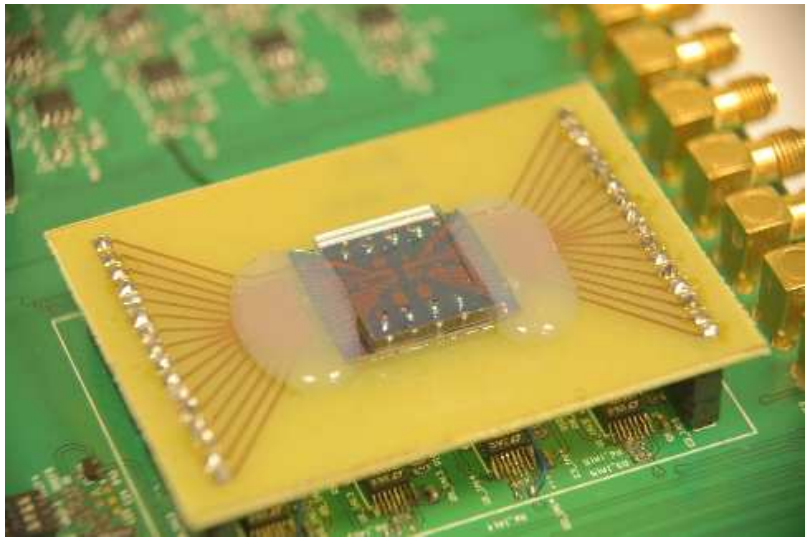
MICROFLUIDIC DEVICES AT INESC-MN

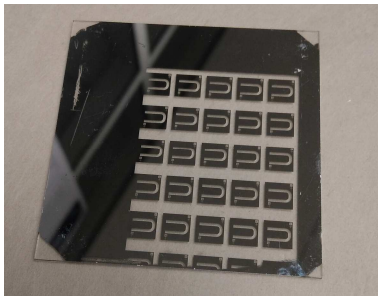


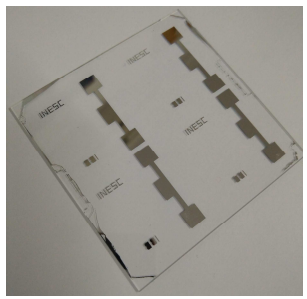












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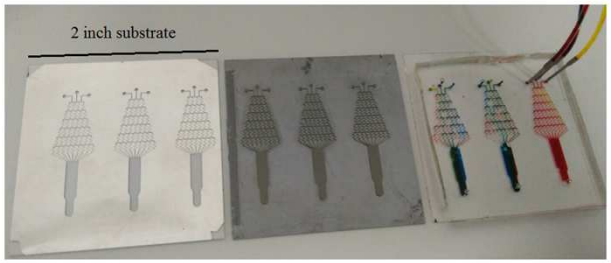
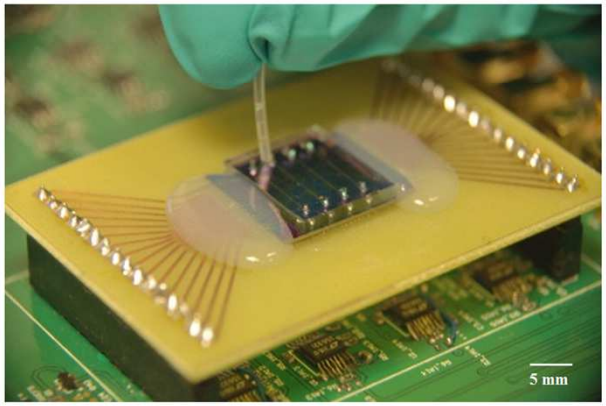
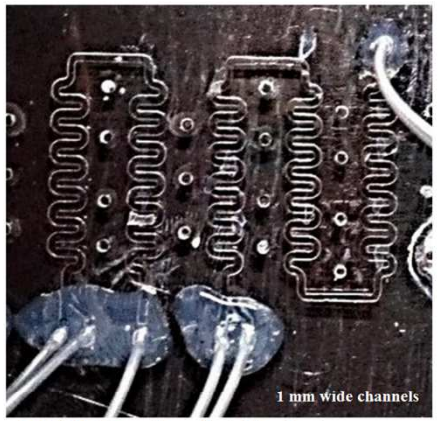
MICROFLUIDIC DEVICES AT INESC-MN



a) Hardmask, mold and PDMS microfluidic device



b) Integration of PDMS microfluidic device with magnetic sensors and electronics



c) PMMA microfluidic device fabricated by 3D micromilling

d) Microfluidics on paper

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ACCURATE and TRACEABLE
measurements
of
micro-to-femto volumetric flow rates
are still
a technological challenge

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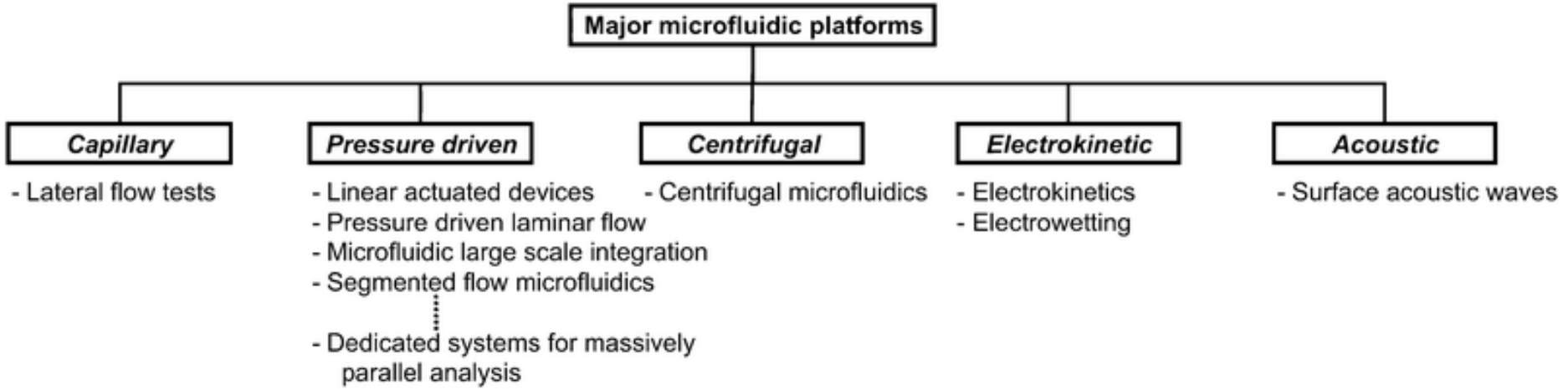
FLOW CONTROL AND MEASUREMENT



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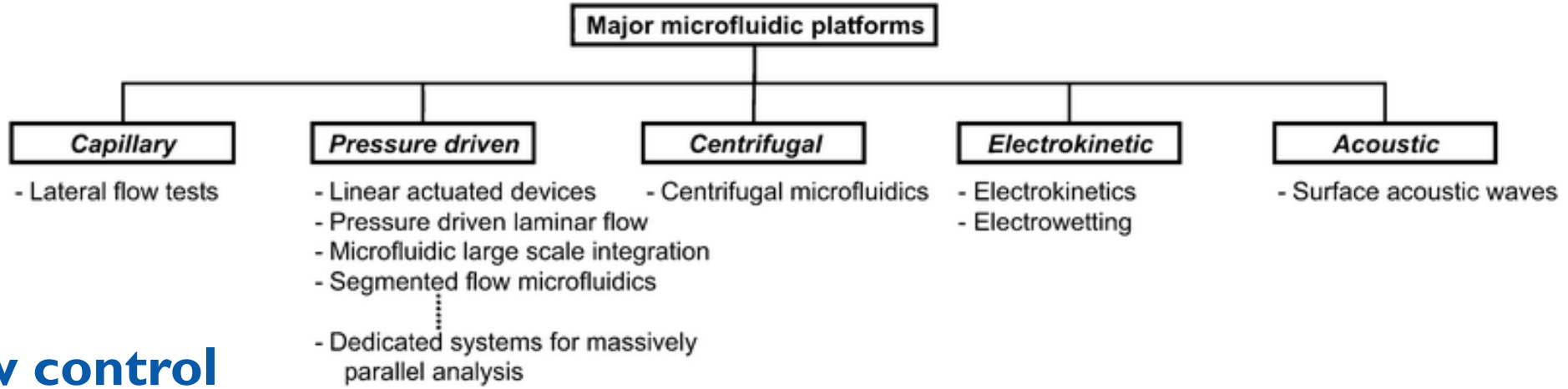
FLOW CONTROL AND MEASUREMENT



Flow control

- Magnetic actuation
- Quake valves
- Surface modification

Flow measurement

- μPIV: fluorescence measurements of channel dimensions and flow velocity
- Spin valve sensors: chip integration of flow velocity measurements

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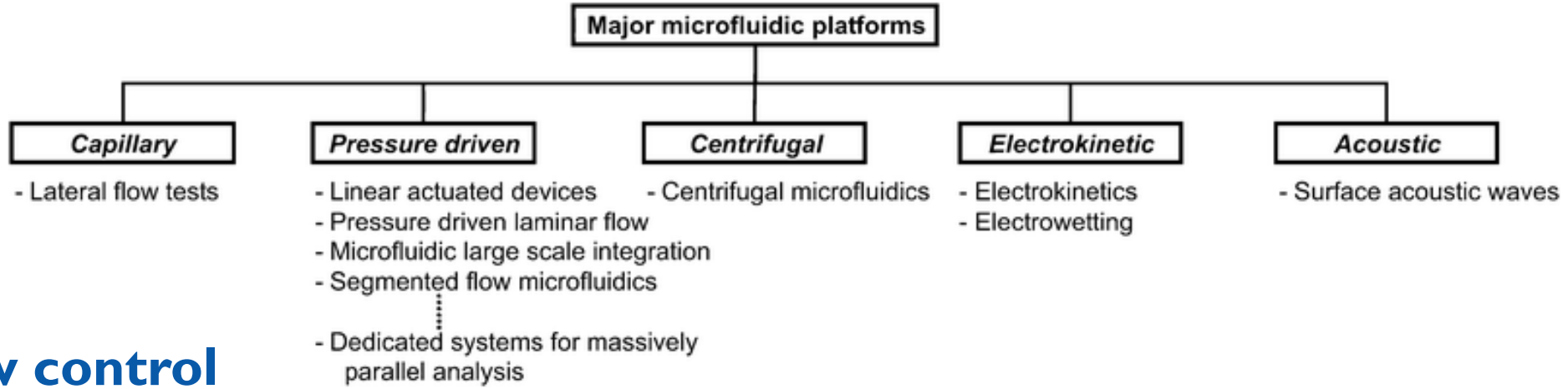
FLOW CONTROL AND MEASUREMENT



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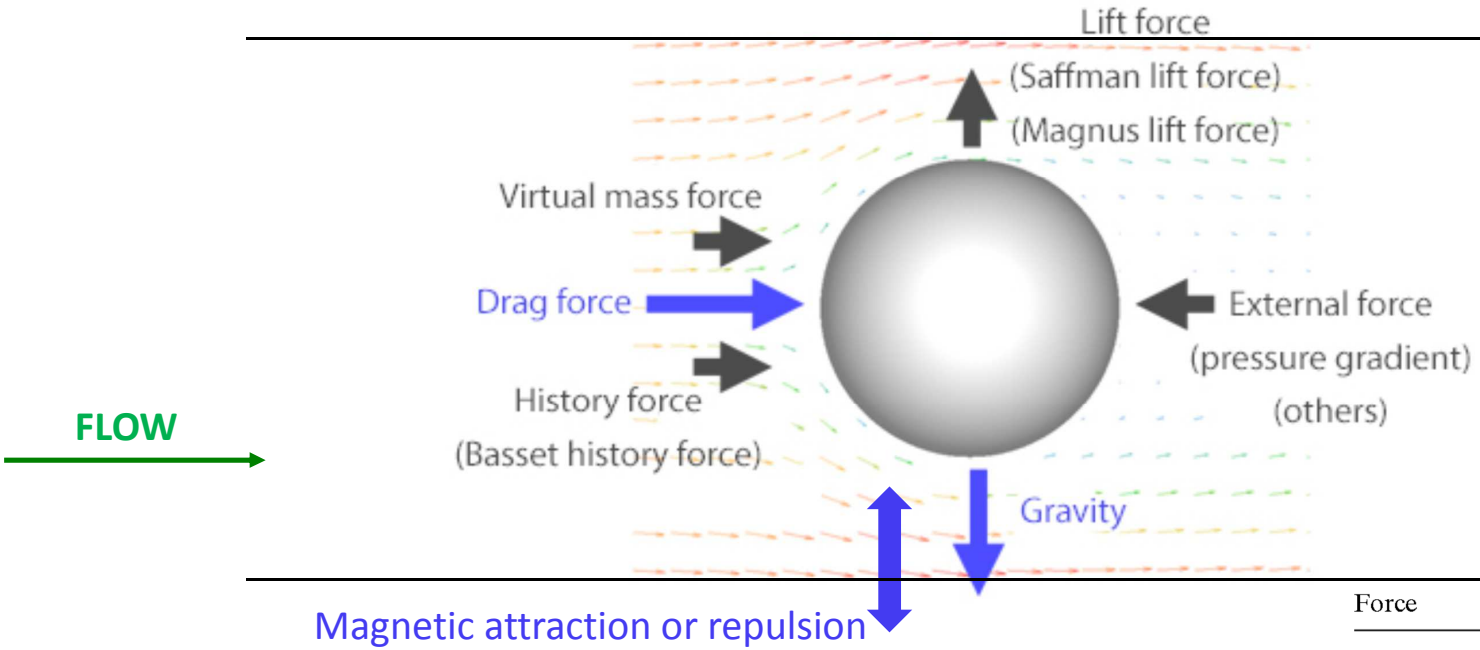
FLOW CONTROL AND MEASUREMENT



$$F_{drag} = -6\pi a \eta v$$

where a = sphere radius, η = viscosity, v = particle velocity

Force	Order of magnitude relative to particle inertia/drag
Drag force	1
Saffman lift force	$\mathrm{Re}_G^{1/2}$
Magnus lift force	Re_G
Added mass force	χ
Pressure-gradient force	χ
Basset history force	$(\mathrm{Re}_f \varepsilon_d \mathrm{St})^{1/2} = \mathrm{Re}_p^{1/2}$
Gravitational force	$(\varepsilon_d \mathrm{Fr}^2)^{-1}$
Brownian force	$(1/\varepsilon_d \mathrm{St}\,\mathrm{Pe}_f)^{1/2} = \mathrm{Pe}_p^{-1/2}$

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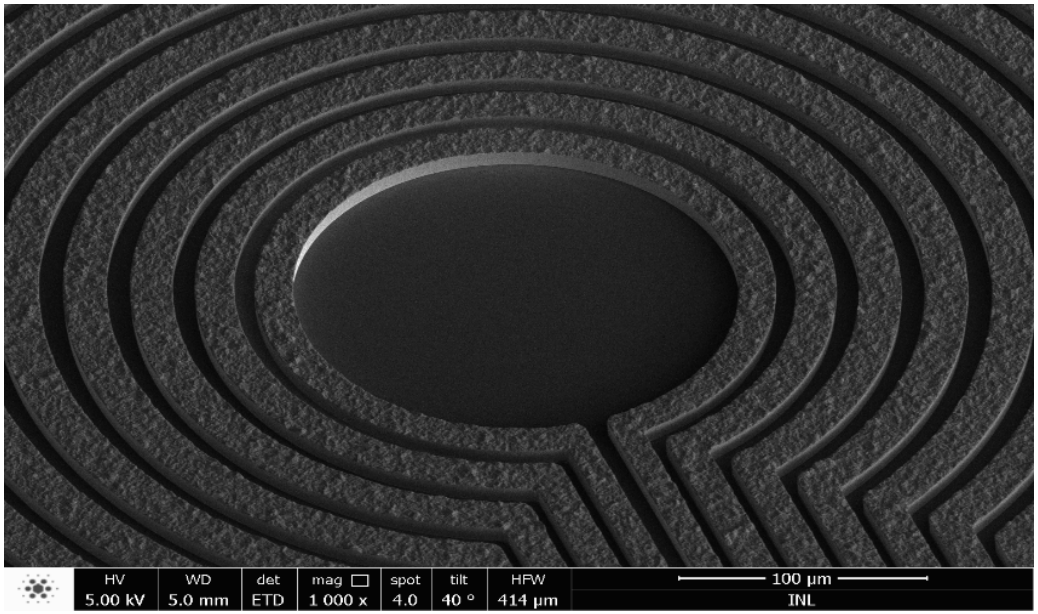
FLOW CONTROL AND MEASUREMENT

Electroplated Copper Coils



Silverio V. *et al.* (2017) On-Chip Magnetic Nanoparticle Manipulation and Trapping for Biomedical Applications, DOI:10.1109/TMAG.2017.2715848

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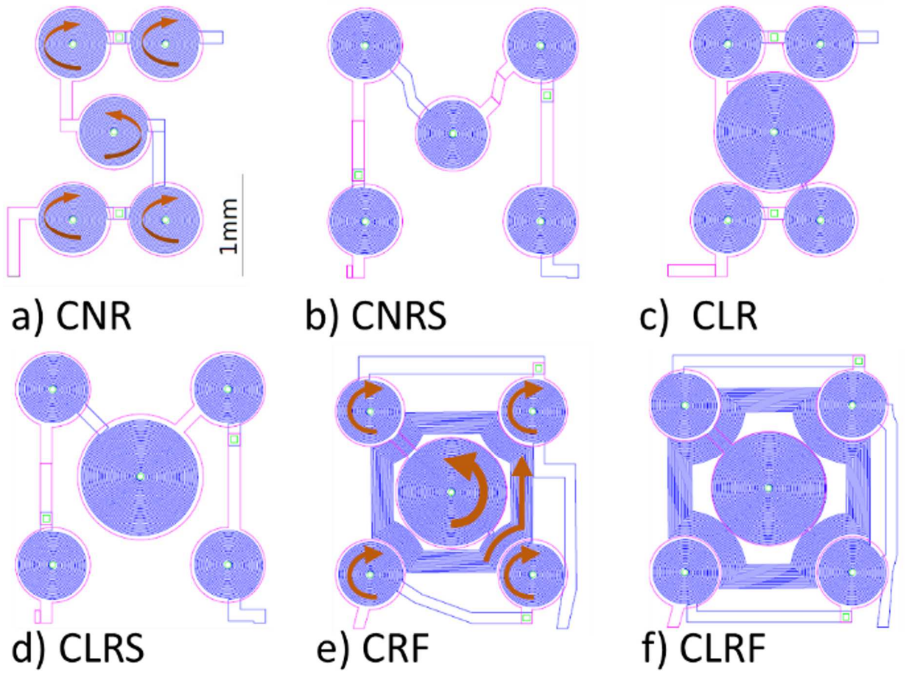
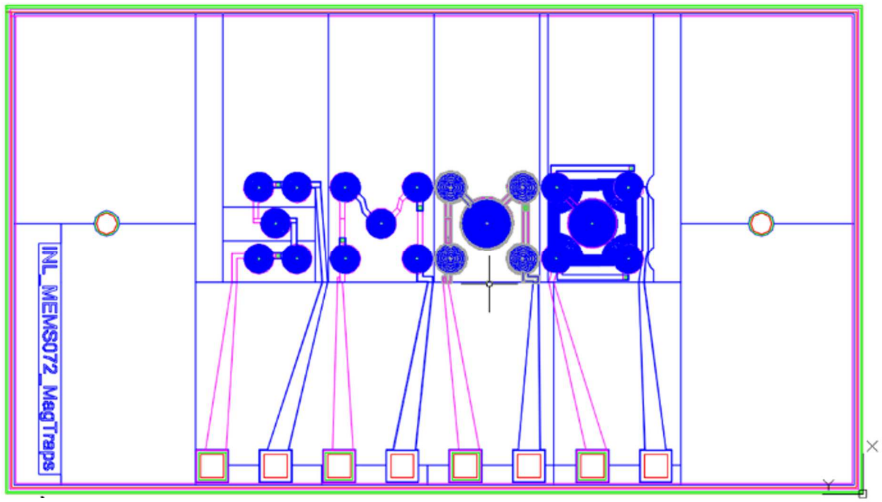
FLOW CONTROL AND MEASUREMENT

MEMT Design: **4** external coils in series and **1** central coil connected for opposite direction of trapping



Central -C, Normal -N, Reversed -R, Squared -S, Large -L, Filling -F



different designs were combined in 8 chips to a total of **56 chips in one 8" wafer**

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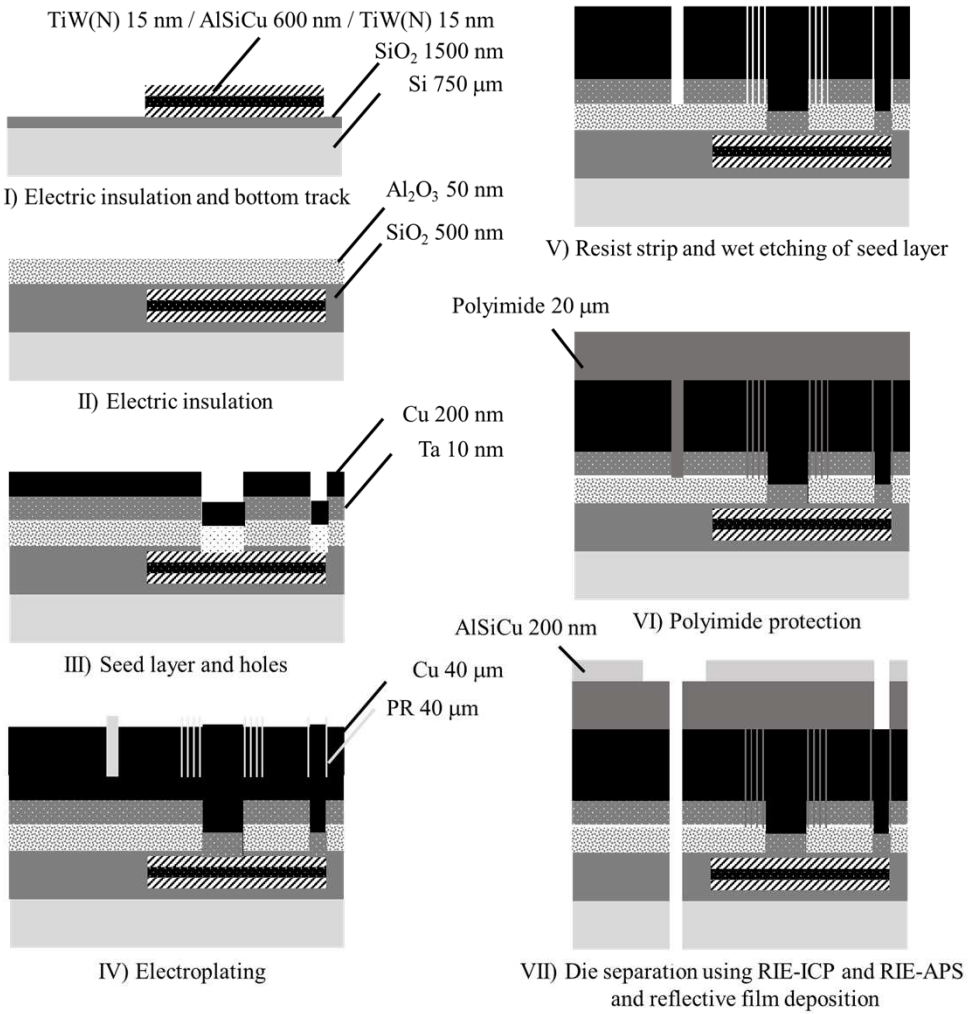
FLOW CONTROL AND MEASUREMENT



- 8" single side polished 725 µm-thick Si wafer
- isolation layer - SiO_2 (1500nm)
- Bottom track - TiW(N) (15nm)/Al (600nm)/TiW(N) (15nm)
- Optical lithography + ICP etch
- Isolation Layer - SiO_2 (500nm)
- Stopping layer for Ta seed layer etch - Al_2O_3 (50nm)
- Optical lithography, RIE etching (Al_2O_3 layer to SiO_2 layer) and RIE-APS etching (SiO_2 layer to TiW(N) layer).
- seed layer - sputtering of Ta (10nm) /Cu (200nm)
- patterning of 40 µm-thick photoresist preceded the Cu electroplating (Cu deposit on H_2SO_4, 280min, 5mA.cm^{-2}, 24°C, 12rpm agitation)
- Etch seed layer - (1:2 H_2O:Al etchant)
- Ta layer removed by XeF_2 dry vapor-phase etching
- spin coating polyamide (20 µm) for passivation, uniformization of surface topography and structural reinforcement
- Separation and holes - Si Etching, AlSiCu/TiW(N) wet etching
- Reflective coating of AlSiCu (200nm)

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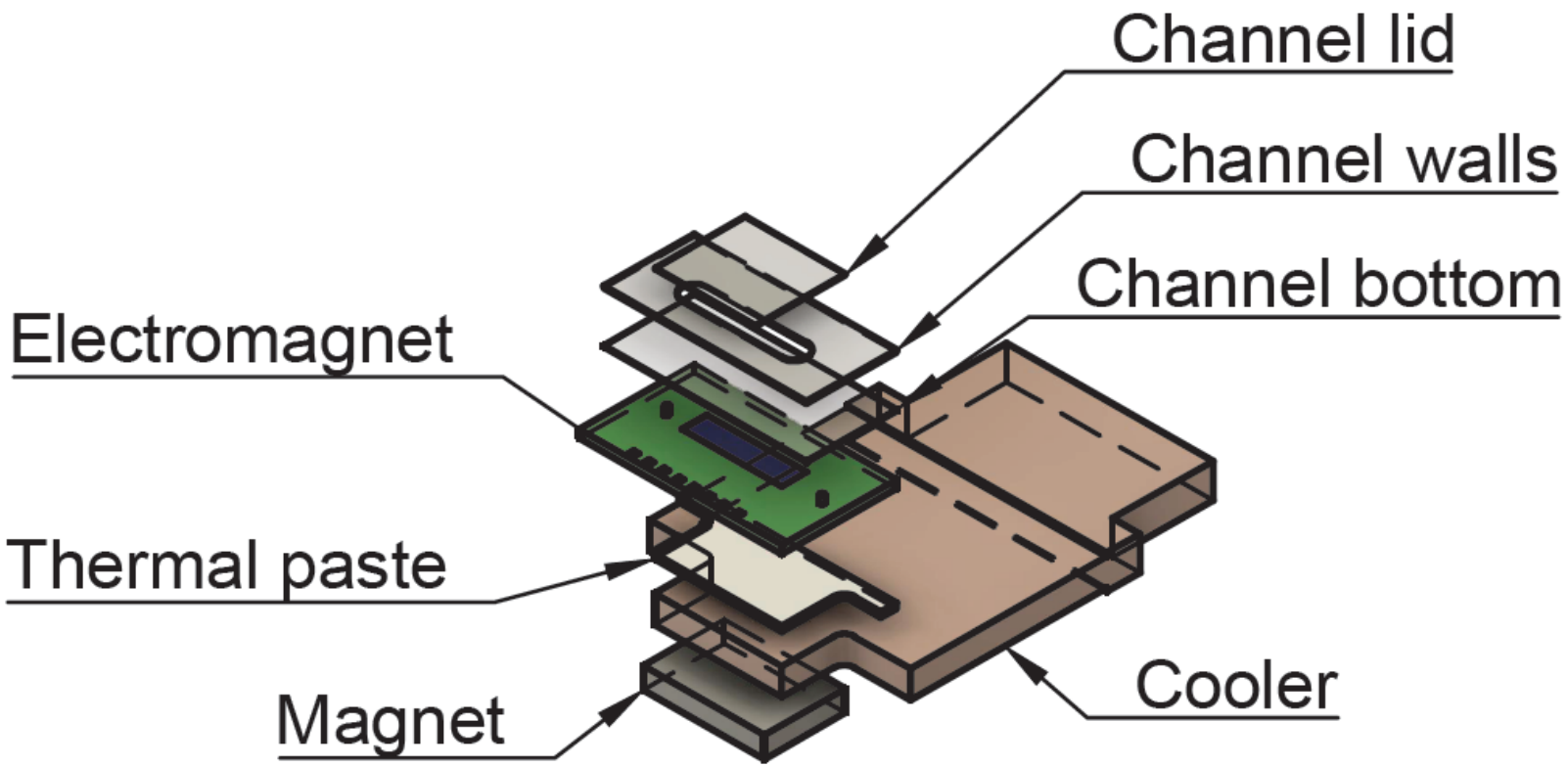
FLOW CONTROL AND MEASUREMENT



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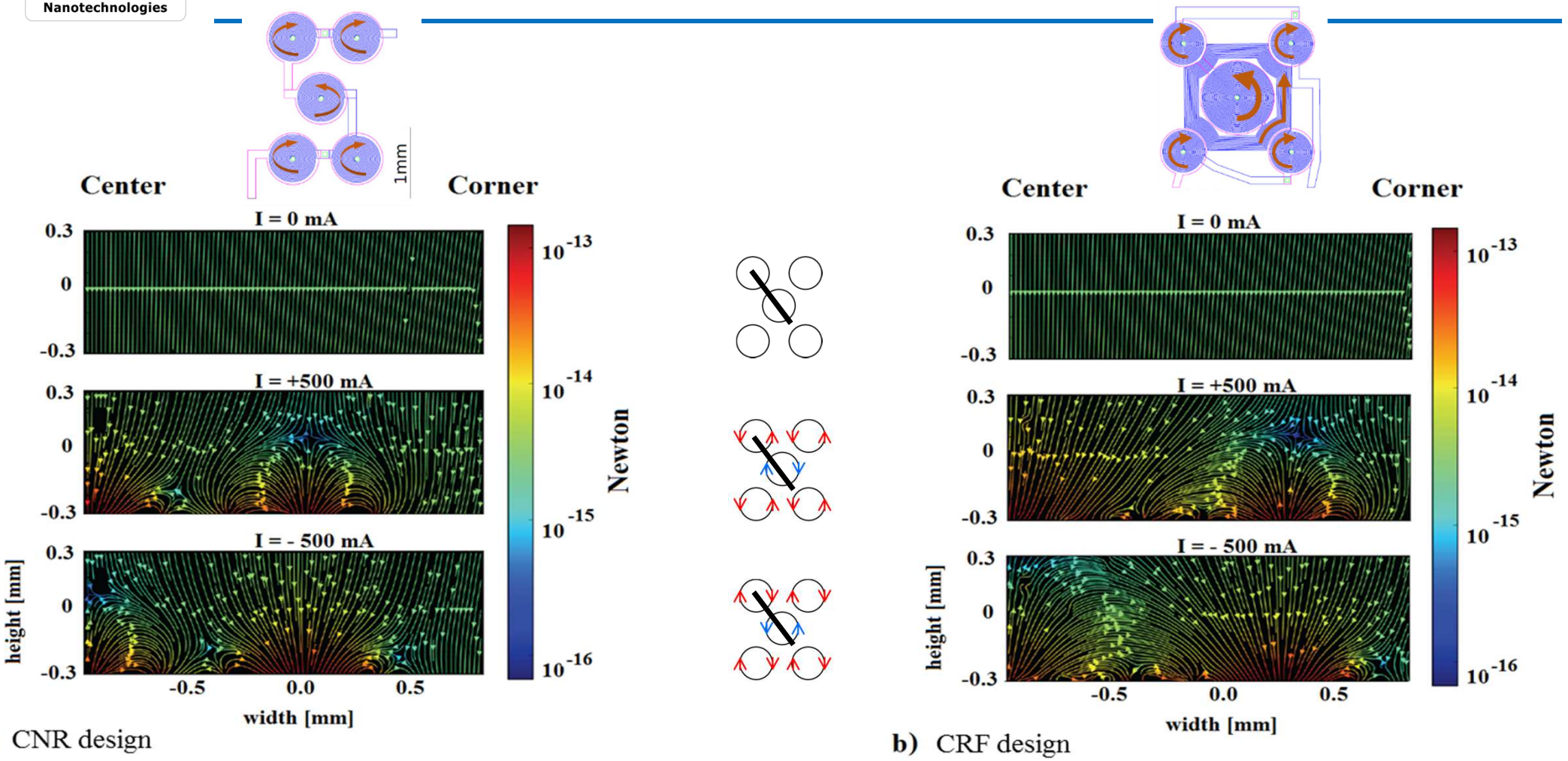
FLOW CONTROL AND MEASUREMENT



a) CNR design

b) CRF design

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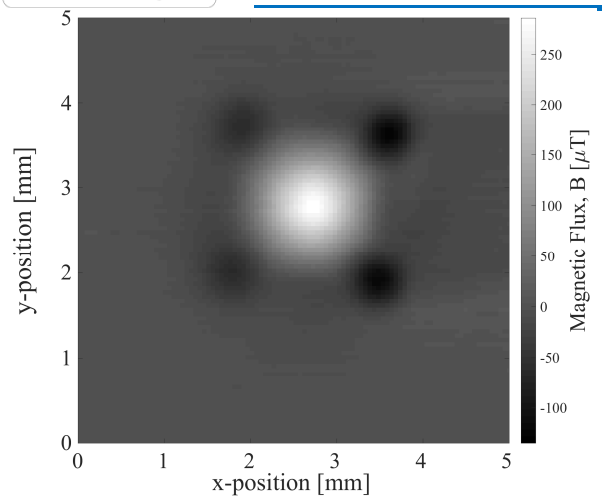
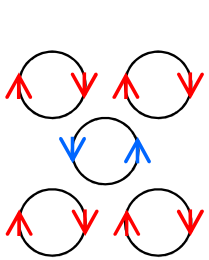
FLOW CONTROL AND MEASUREMENT

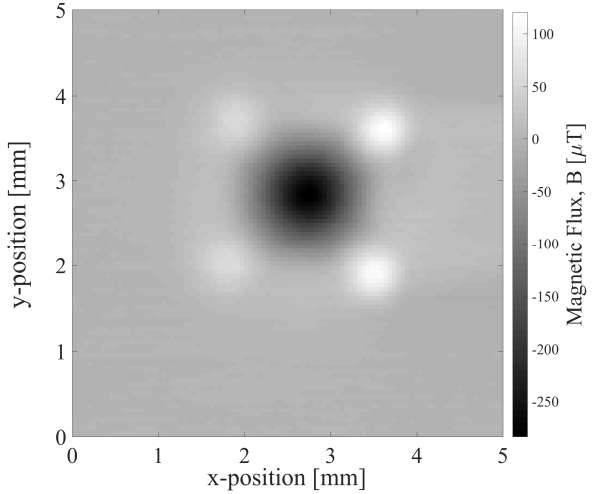
magnetoresistive scanner



-30 mA

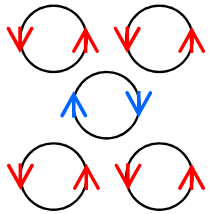
Sensor @ 200 µm from the chip surface





+30 mA

Sensor @ 200 µm from the chip surface



Magnetic Tunnel Junction (MTJ)
sensitivity -26.4 $\Omega.Oe^{-1}$, dimension 58.5 × 4 μm^2

The vertical magnetic field over the **central coil** is **opposite** to the vertical field in the **4 outer coils**

- favorable for particle trapping and cell concentration - repulsion

The field generated by -30 mA was measured to range to +280 µT

1000 mA actuation + PM field

- larger magnetic fields: up to 3000 µT
- sufficient to generate a magnetic force to deflect the MNP trajectories and trap them

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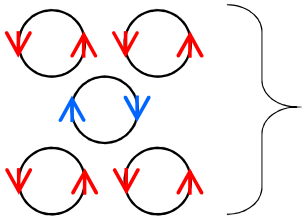
MNP ACTUATION

16 pulses @ +750 mA

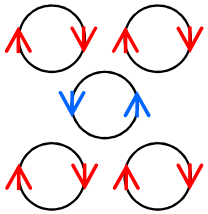
1 s ON + 2 s OFF + 1 s ON + …



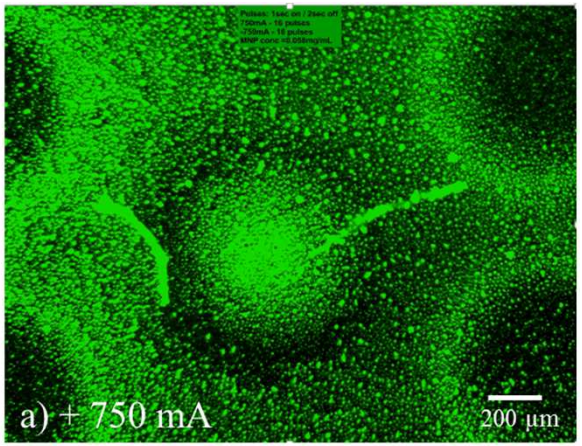
direction of the current in the coils

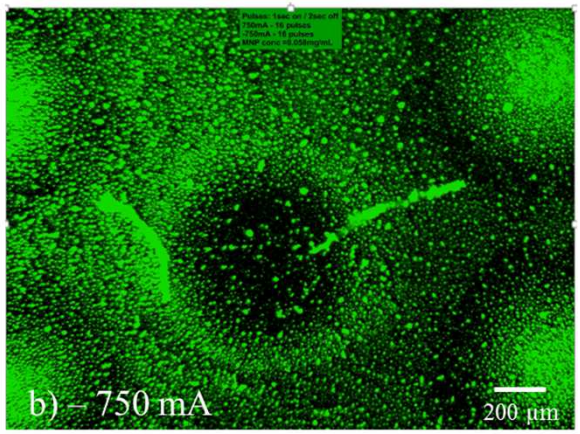
16 pulses @ –750 mA

1 s ON + 2 s OFF + 1 s ON + …

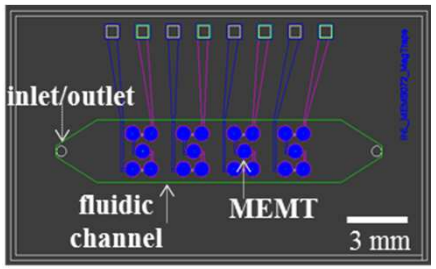


$T_{surf,max}$ = 37 ◦C

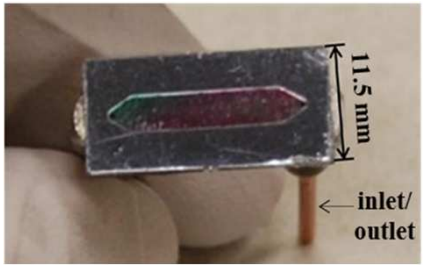




MEMT chip + microfluidic channel



microchannel



MNP concentration
0.058 mg.mL^{-1}

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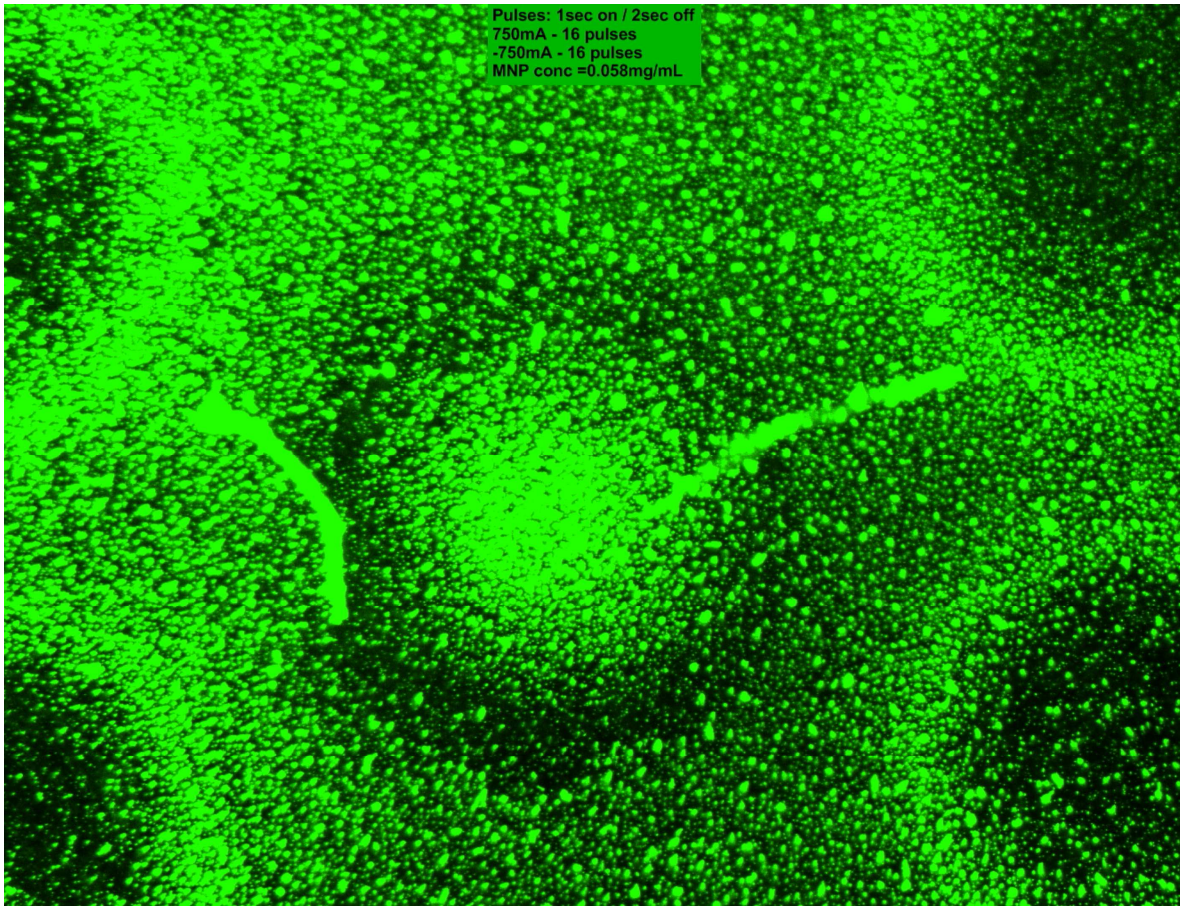
MNP ACTUATION



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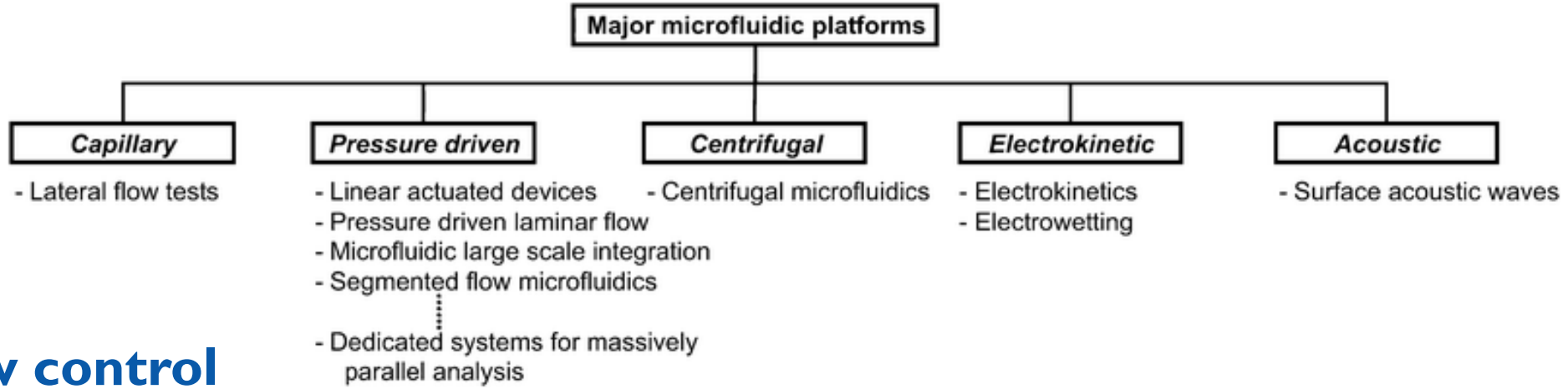
FLOW CONTROL AND MEASUREMENT



Flow control

- Magnetic actuation
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- µPIV: fluorescence measurements of channel dimensions and flow velocity
- Spin valve sensors: chip integration of flow velocity measurements

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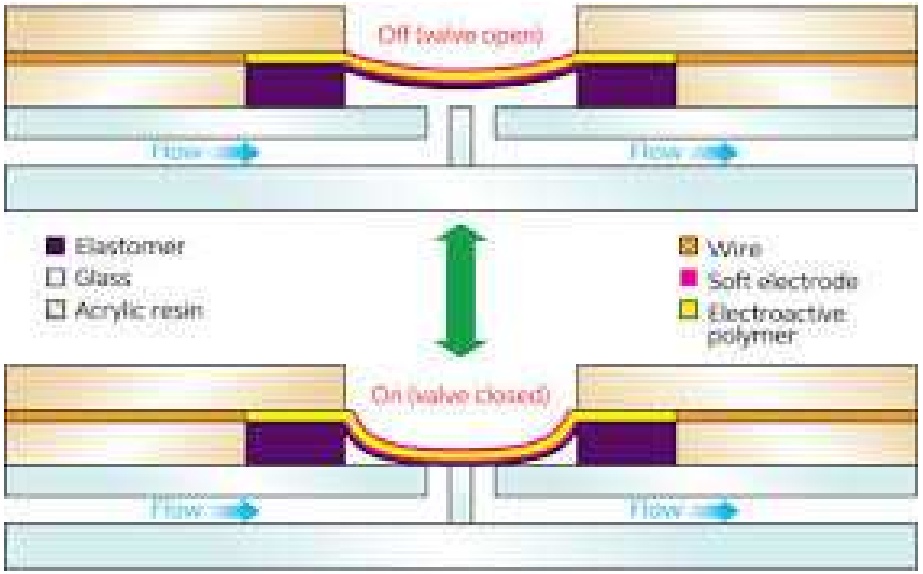
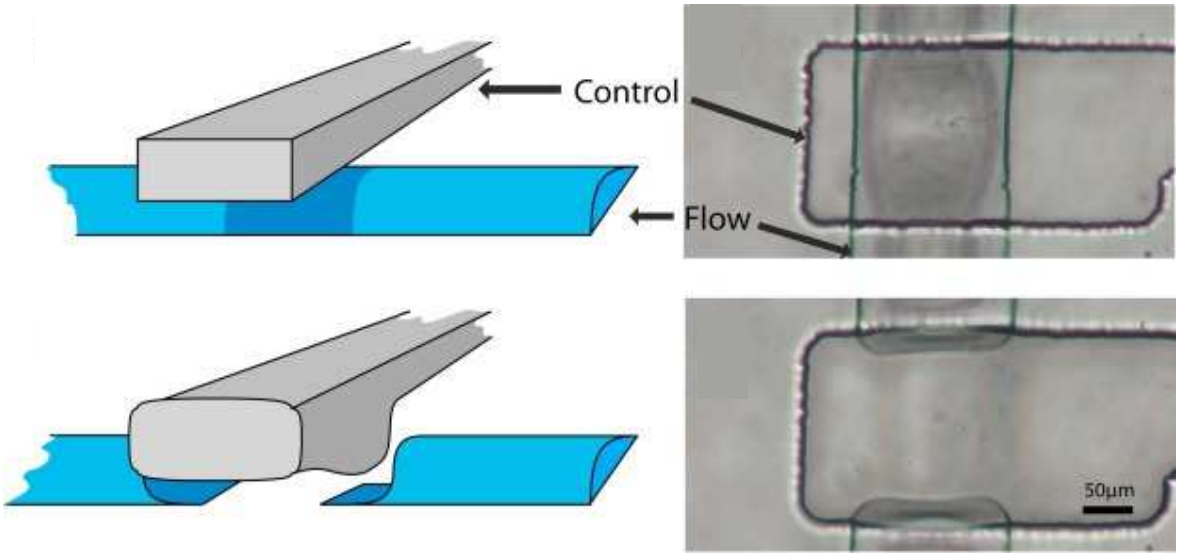
QUAKE VALVES





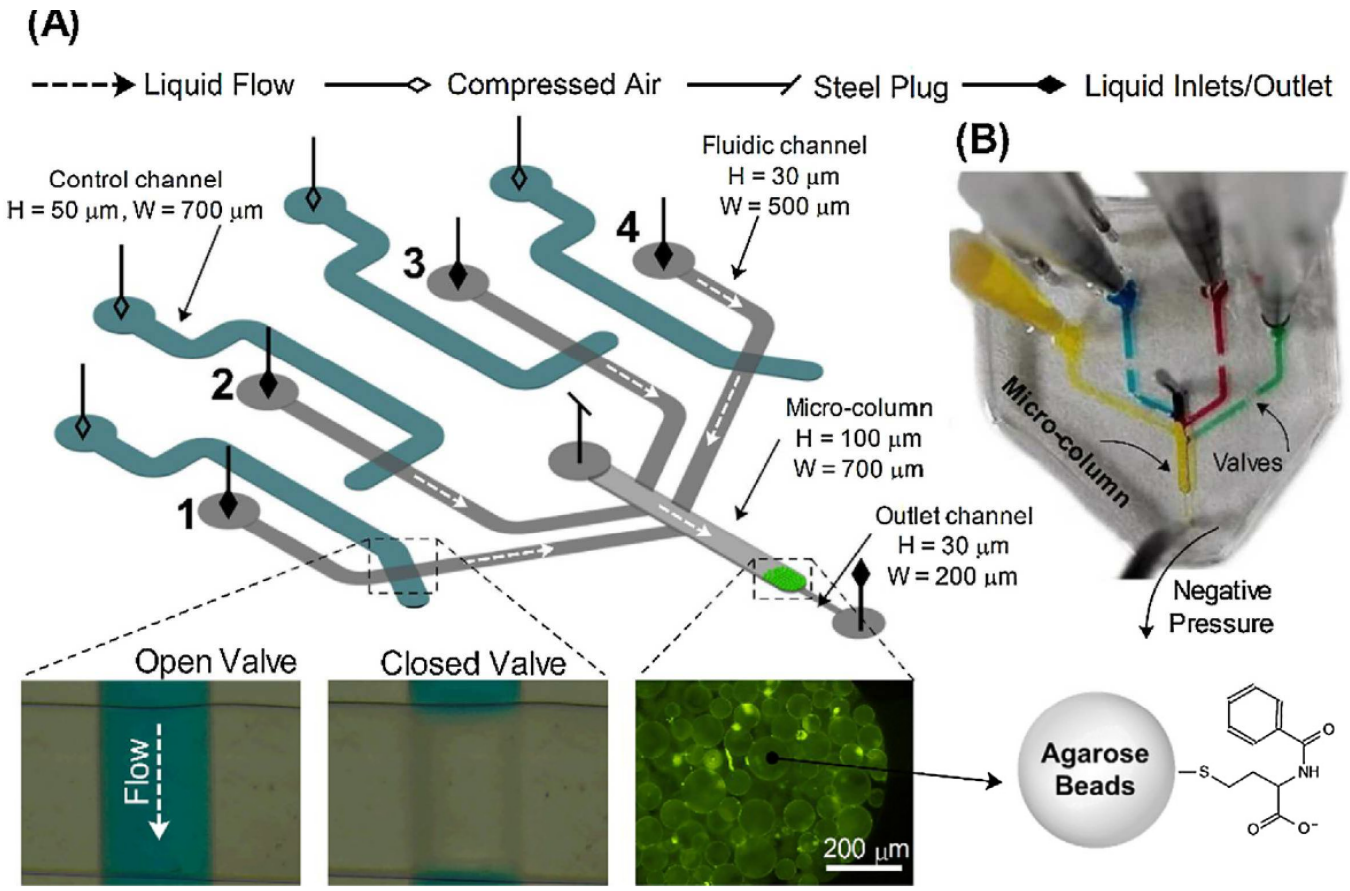


Fig. 2. Regenerable microfluidic structure comprising a main channel for bead packing and four fluidic channels for sequential liquid insertion controlled by integrated pneumatic valves. (**A**) Agarose beads functionalized with a chromatography multimodal ligand (Capto™ MMC) were packed in a micro-column and evaluated in their ability to capture a target monoclonal antibody labeled with Alexa 430 from a cell culture supernatant. Different solutions were flowed sequentially in an automatic manner by actuating the pneumatic valves. (**B**) PDMS structure showing the selective flow of 4 different colored solutions towards the micro-column. Liquid was flowed using pipette tips in the inlets and by applying a negative pressure at the outlet.

Pinto I. *et al.* (2018) A regenerable microfluidic device with integrated valves and thin-film photodiodes for rapid optimization of chromatography conditions, Sensors and Actuators B: Chemical, 255(3): 3636-3646, DOI: 10.1016/j.snb.2017.09.167

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SNB-23258: No. of Pages 11
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Sensors and Actuators B xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

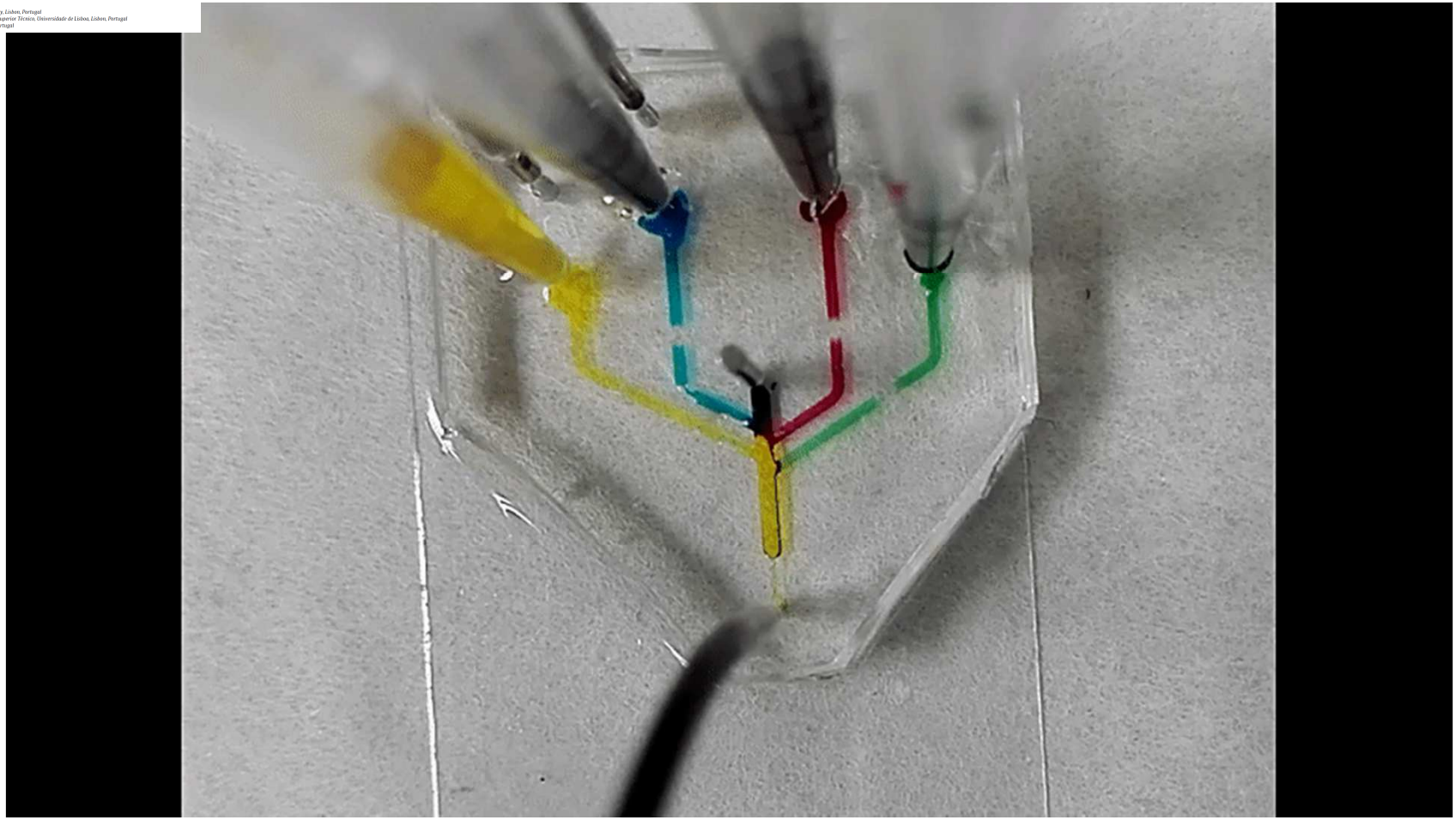
Sensors and Actuators B: Chemical

journal homepage: www.elsevier.com/locate/snb

A regenerable microfluidic device with integrated valves and thin-film photodiodes for rapid optimization of chromatography conditions

I.F. Pinto[a,b], D.R. Santos[a,b], R.R.G. Soares[a,b], M.R. Aires-Barros[b,c], V. Chu[a], A.M. Azevedo[b,c,*], J.P. Conde[a,c,*]

[a] INESC Microsistemas e Nanotecnologias and IN-Institute of Nanoscience and Nanotechnology, Lisbon, Portugal
[b] iBB – Institute for Bioengineering and Biosciences, Department of Bioengineering Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal
[c] Department of Bioengineering, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal



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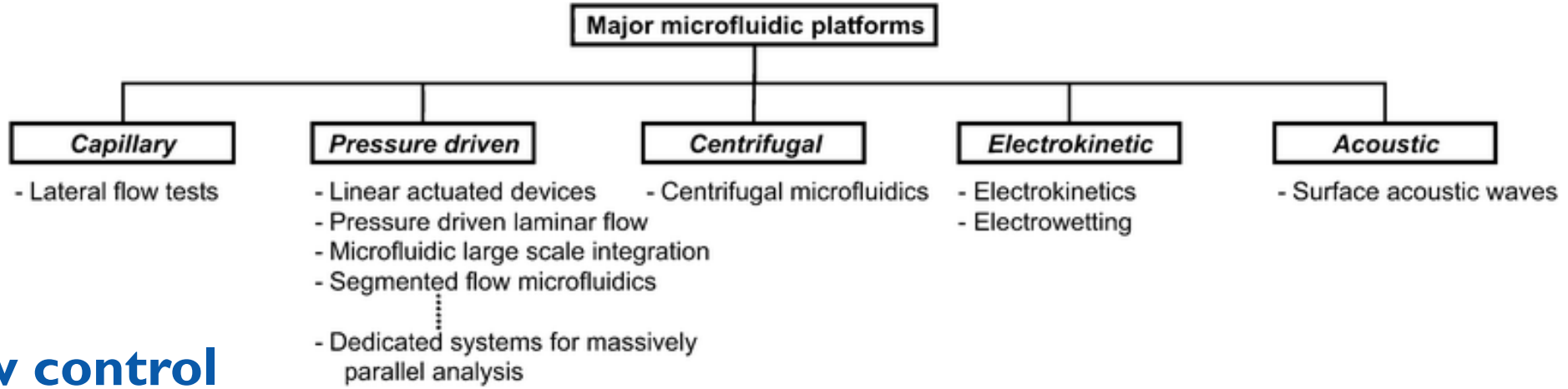
FLOW CONTROL AND MEASUREMENT



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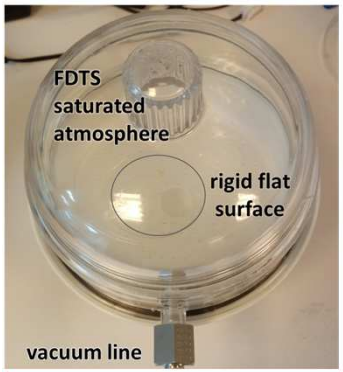
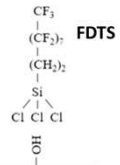
SURFACE MODIFICATION

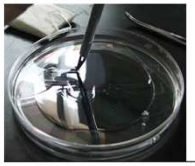


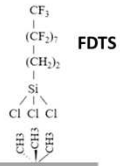
Working Conditions
22 °C, (-0.78 ± 0.09) atm
2 to 50 min CVD exposure

FDTS perFluoroDecylTrichloroSilane ($CF_3(CF_2)_7(CH_2)_2[SiCl_3]$)
M = 581.56 g/mol



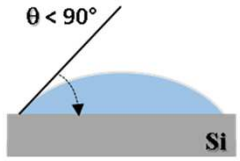
GLASS
76 x 26 x 1 mm



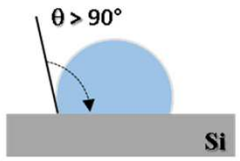


PDMS
10:1, 0.5 mm thickness

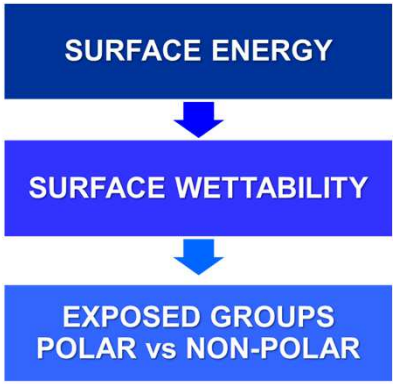
evaluation of contact angle translates the surface wettability



hydrophylic surface



hydrophobic surface



Silverio V. *et al.* (2019) Surface wettability and stability of chemically modified silicon, glass and polymeric surfaces via room temperature chemical vapor deposition, Colloids and Surfaces A: Physicochem. Eng. Aspects, 570(5):210-217, DOI: 10.1016/j.colsurfa.2019.03.032

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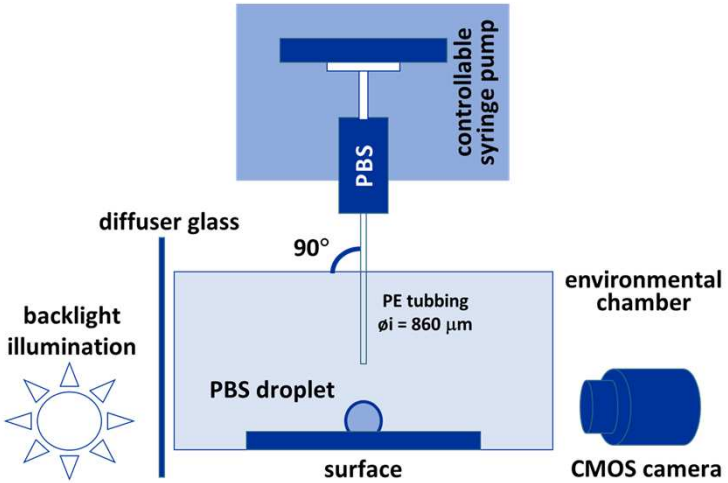
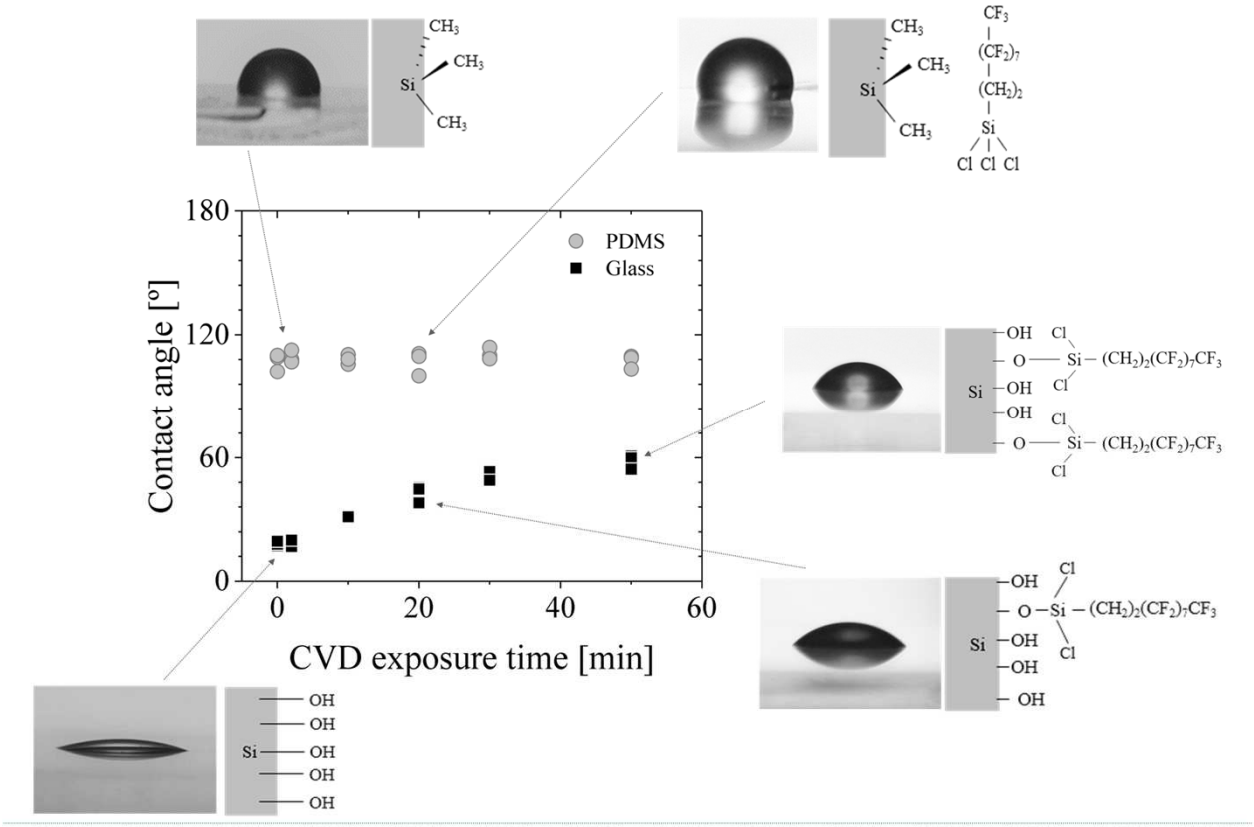
SURFACE MODIFICATION





Silverio V. *et al.* (2019) Surface wettability and stability of chemically modified silicon, glass and polymeric surfaces via room temperature chemical vapor deposition, Colloids and Surfaces A: Physicochem. Eng. Aspects, 570(5):210-217, DOI: 10.1016/j.colsurfa.2019.03.032

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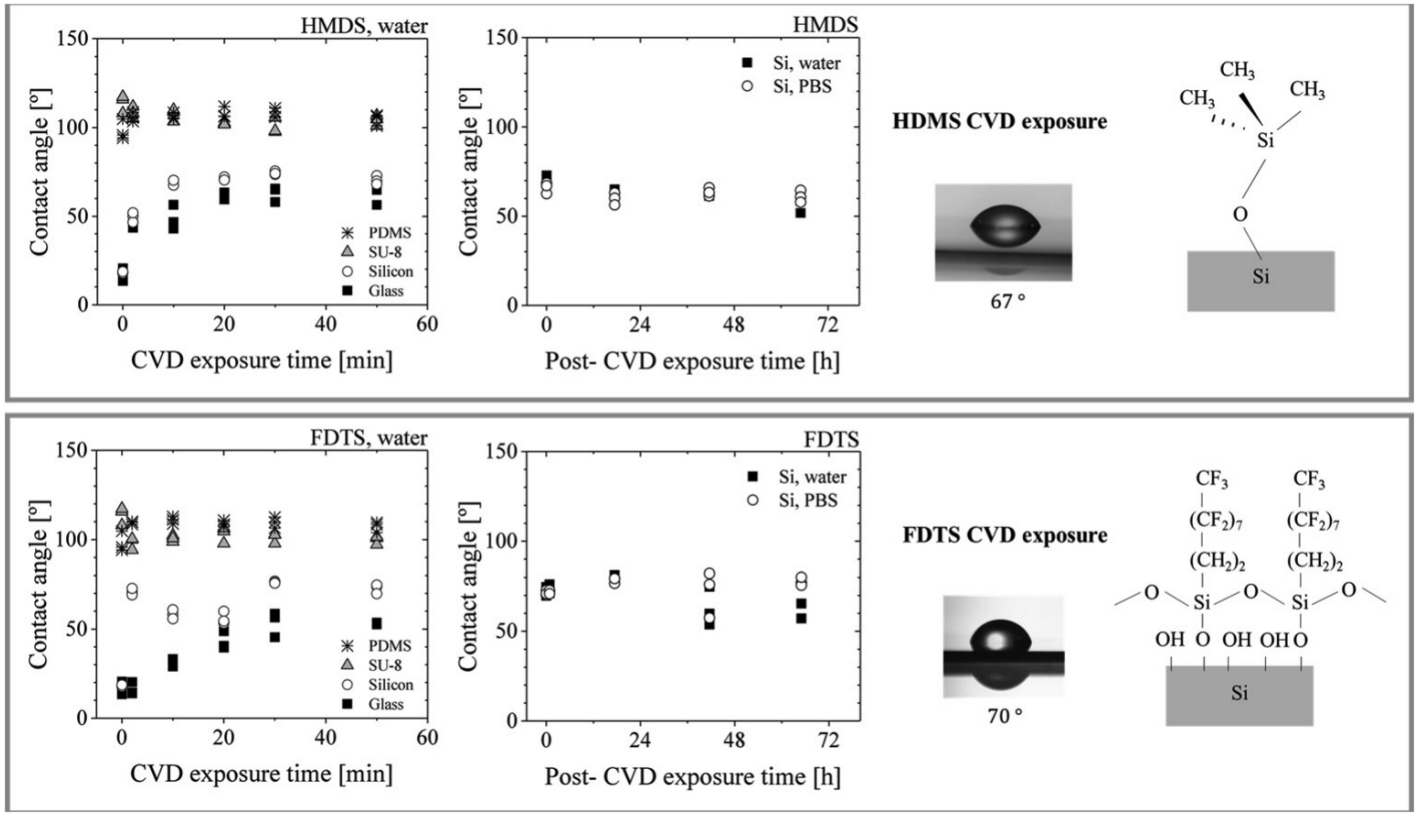
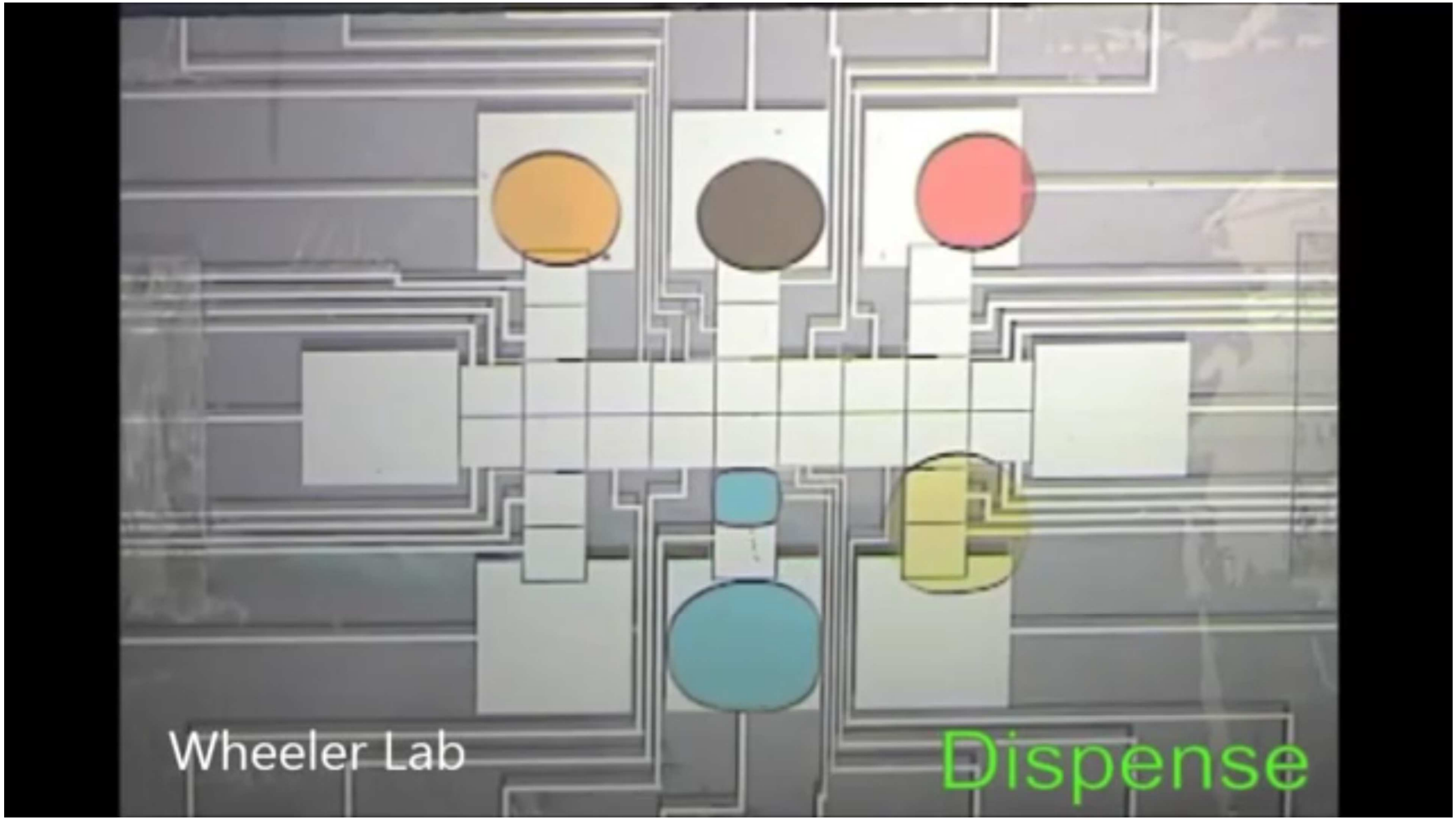
SURFACE MODIFICATION



Silverio V. *et al.* (2019) Surface wettability and stability of chemically modified silicon, glass and polymeric surfaces via room temperature chemical vapor deposition, Colloids and Surfaces A: Physicochem. Eng. Aspects, 570(5):210-217, DOI: 10.1016/j.colsurfa.2019.03.032


Wheeler Lab
Dispense

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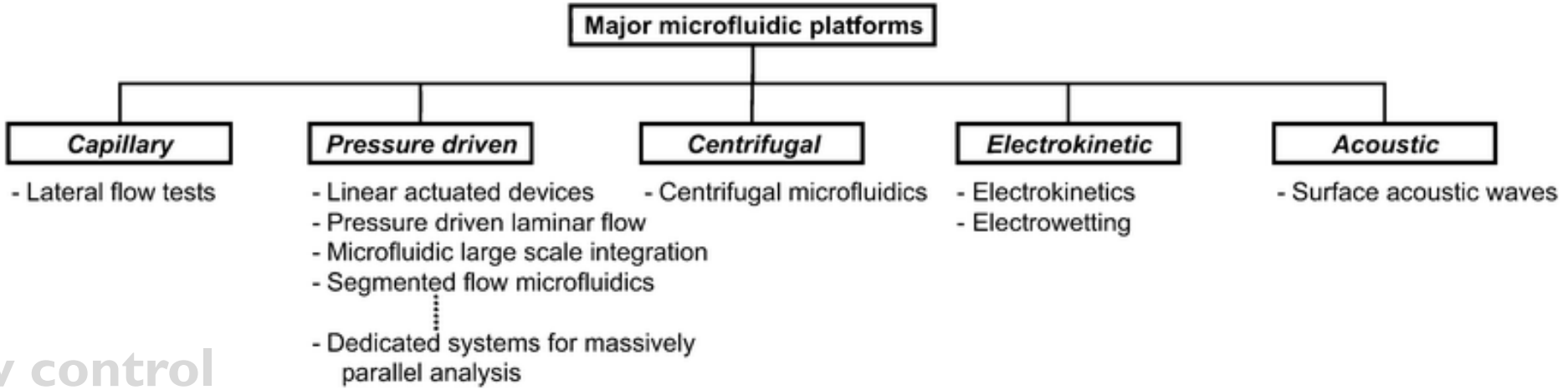
FLOW CONTROL AND MEASUREMENT



Flow control

- Magnetic actuation
- Quake valves
- Surface modification

Flow measurement

- μPIV: fluorescence measurements of channel dimensions and flow velocity
- Spin valve sensors: chip integration of flow velocity measurements

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FLOW CONTROL AND MEASUREMENT

- working fluid is seeded with small fluorescent tracer particles
  - particles ~1μm diameter
  - $\rho_{particle} \sim \rho_{fluid}$

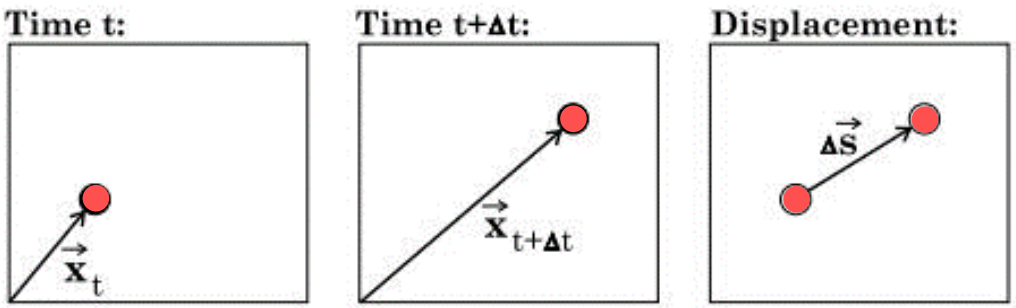

Figure : Left frame: particle position at time t; Center frame: particle position at time $t + \Delta t$; Right frame: displacement vector Δs.

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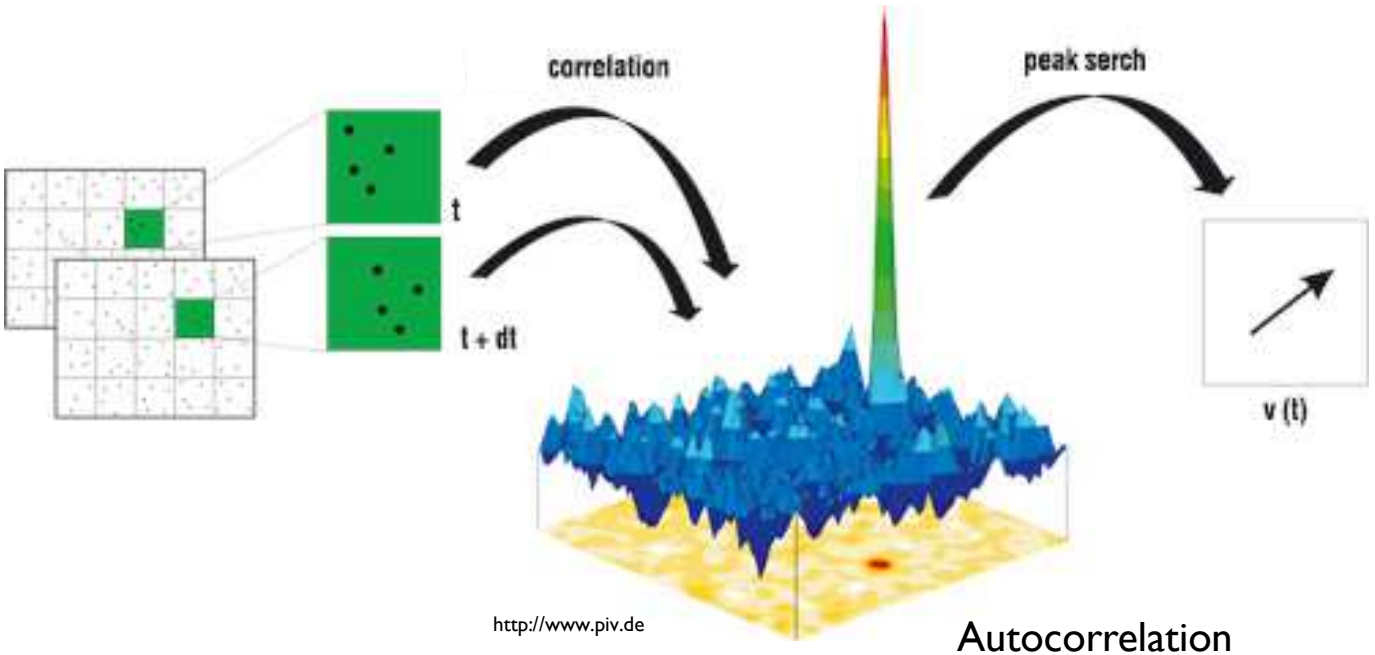
FLOW CONTROL AND MEASUREMENT



Autocorrelation
Cross correlation
Average correlation

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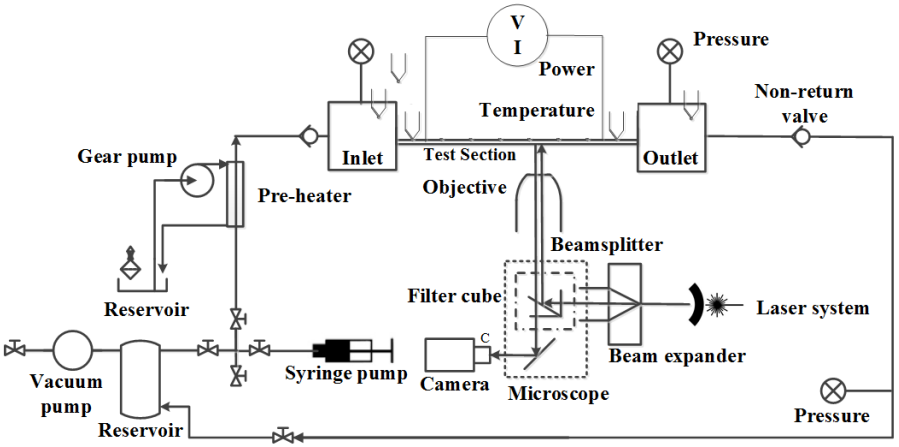
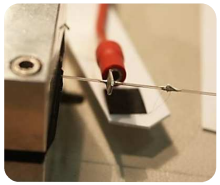
FLOW CONTROL AND MEASUREMENT

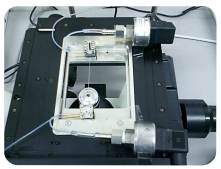
PARTICLE IMAGE VELOCIMETRY – µPIV



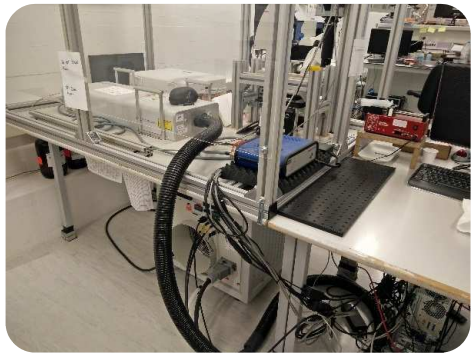
15 Hz µPIV	*HighSpeed µPIV*
Camera Dantec Dynamics FlowSense EO 2M, 44 Hz @ 1600 x 1200 pixel2 , CCD119 (charge-coupled device) sensor with pixel size = 7.41 µm, 8/10 bit intensity resolution	Camera LaVision HighSpeedStar 4G, 2 kHz @ 1024 x 1024 pixel^2, CMOS (complementary metal-oxide semiconductor) imaging sensor with pixel size = 17 µm, 12 bit intensity resolution
Laser New Wave Research dual cavity Nd:YAG Solo II-15 emitting at λ = 532 nm, repetition rate = 15 Hz, E15Hz = 30 mJ	Laser Litron dual cavity Nd:YLF laser LDY301 PIV emitting at λ = 527 nm, repetition rate = 0.2 – 20 kHz, E_{1kHz} = 10 mJ
Inverted Microscope Leica DM ILM	Inverted Laboratory Microscope Leica DM IL LED
Software: Flowmanager V4.0, Dynamic Studio. Synchronization: National Instruments hardware	Software: Davis 8.2.0. Synchronization: LaVision Synchronization: Highspeed controller

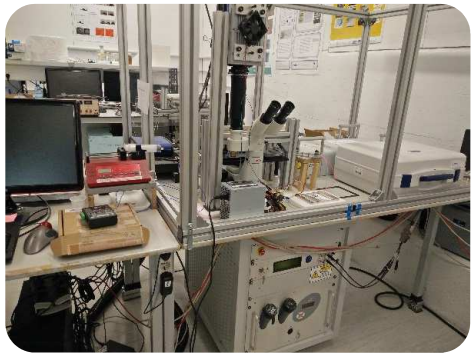
15 Hz µPIV





HighSpeed µPIV





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- gradient parameters that can be derived from the flow velocity information resulting from 2D-PIV, and aid in quantification and interpretation of the flow phenomena studied

Parameter	Stands for:	Equation
Vorticity	Rotationality of the fluid	$\omega = \partial v/\partial x - \partial u/\partial y$
Shear rate	Strength of velocity gradient perpendicular to the local velocity ('sliding of adjacent water layers')	$h = \partial v/\partial x + \partial u/\partial y$
Strain rate	Strength of velocity gradient in the direction of the local velocity ('acceleration within one water layer')	$e = \partial u/\partial x - \partial v/\partial y$
Divergence	Strength of out-of-plane flow rate (water leaving or entering the illuminated plane)	$\Theta = \partial u/\partial x - \partial v/\partial y$
Vortex locator	Finds centre of vortex (e.g. through discriminant for complex eigenvalues)	

Stamhuis, *Aquatic Ecology*, 2006, 40 463–479

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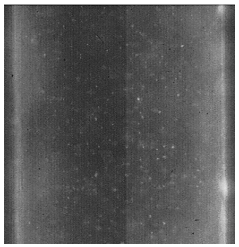
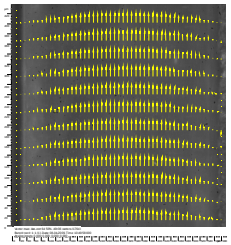
FLOW CONTROL AND MEASUREMENT

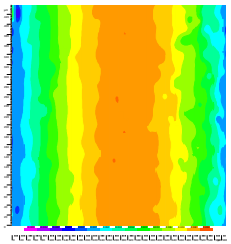
raw image



velocity vector field

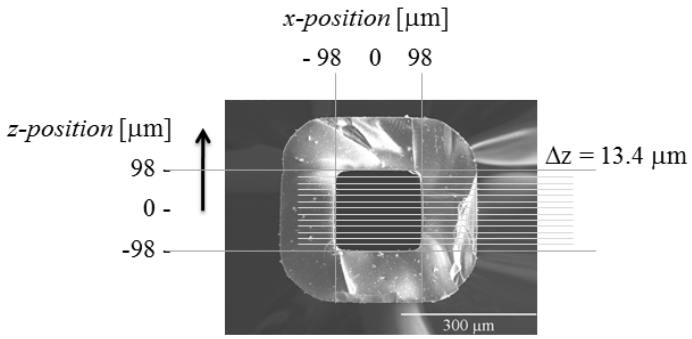


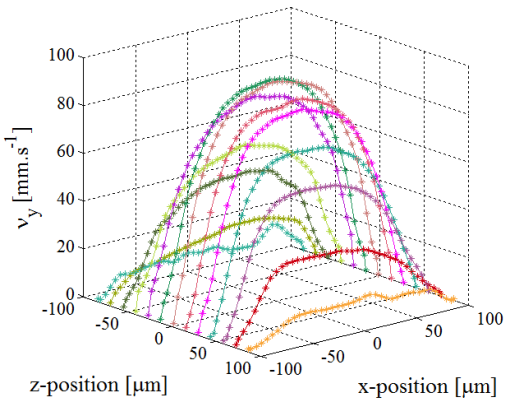
isovelocity magnitude

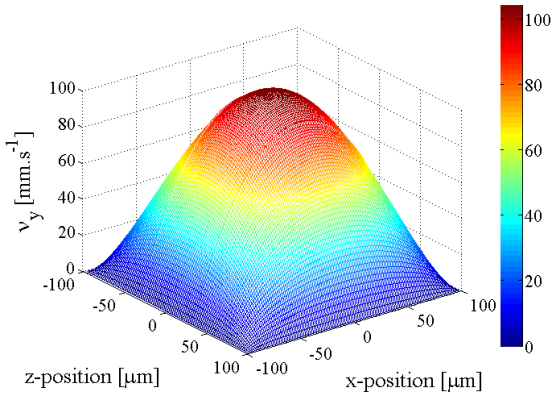


$$-\frac{W}{2} \le x \le \frac{W}{2}, -\frac{H}{2} \le z \le \frac{H}{2}$$

$$v_y = \frac{16\left(\frac{H}{2}\right)^2}{\mu\pi^3}\left(-\frac{dp}{dy}\right)\sum_{i=1,3,5,\ldots}^{\infty}(-1)^{\frac{i-1}{2}}\left[1-\frac{cosh\left(\frac{i\pi x}{H}\right)}{cosh\left(\frac{i\pi W}{2H}\right)}\right]\frac{cos\left(\frac{i\pi z}{H}\right)}{i^3}$$







4.7 % deviation

Silverio V *et al*. (2010) Heat transfer investigations in micro-channel flows, Proceedings of the 15th Int Symp on Applications of Laser Techniques to Fluid Mechanics Lisbon, Portugal, 05-08 July, 2010,Paper #1844

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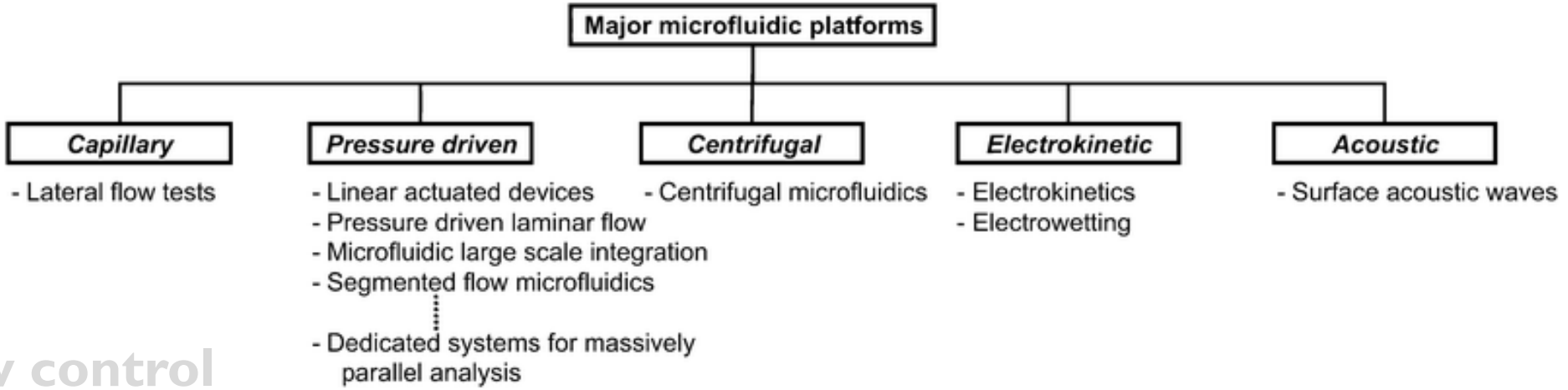
FLOW CONTROL AND MEASUREMENT



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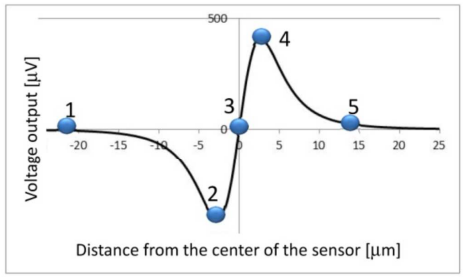
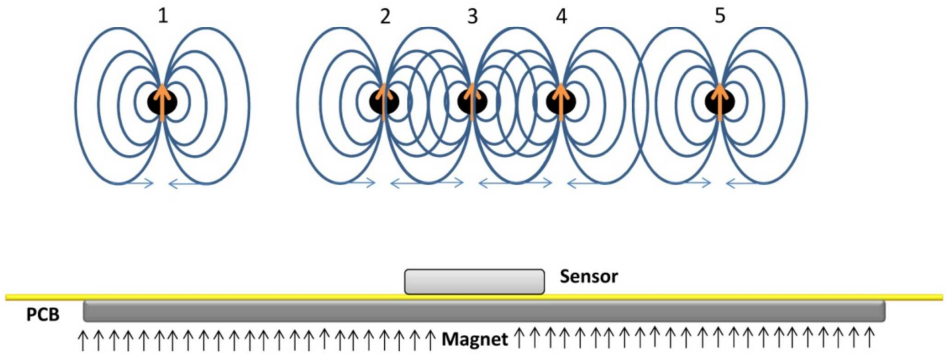
MAGNETIC FLOW CYTOMETRY

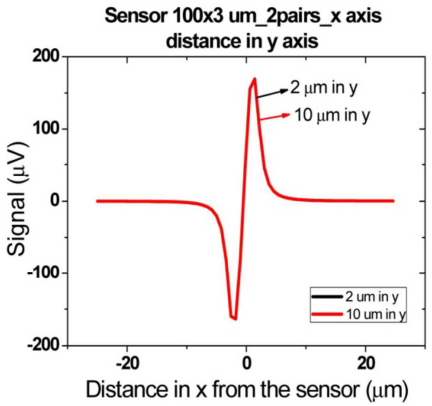


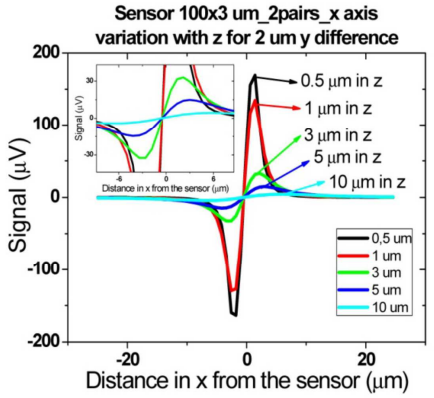
Magnet's field direction

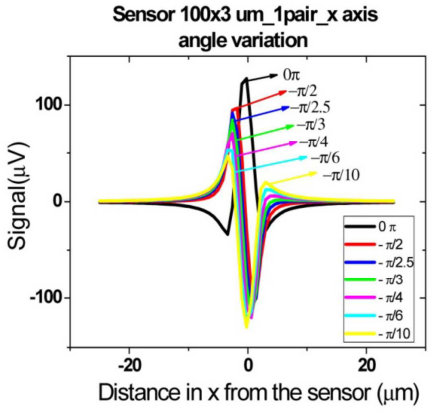
Particle/Cell magnetic alignment with the magnetic field

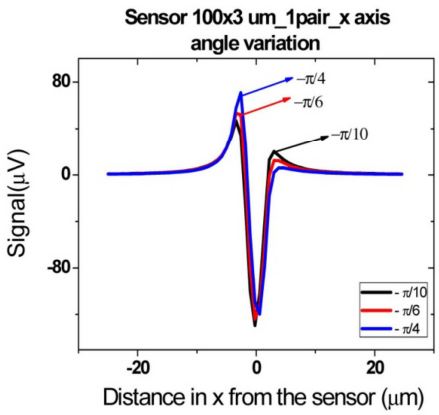
Particle's magnetic fringe field (horizontal component)











Cardoso *et al,* Biosensors (Basel). 2016 Apr 27;6(2):19. doi: 10.3390/bios6020019

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SPIN VALVES FOR VELOCITY MEASUREMENTS

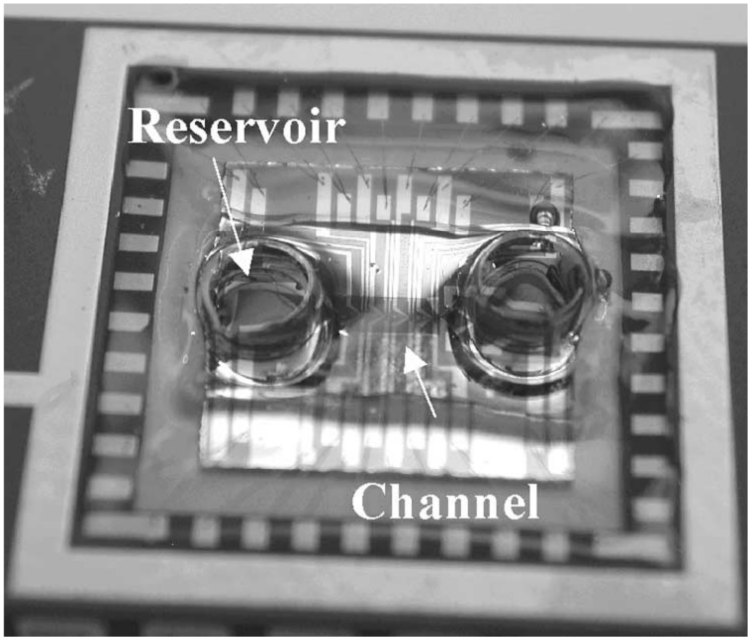
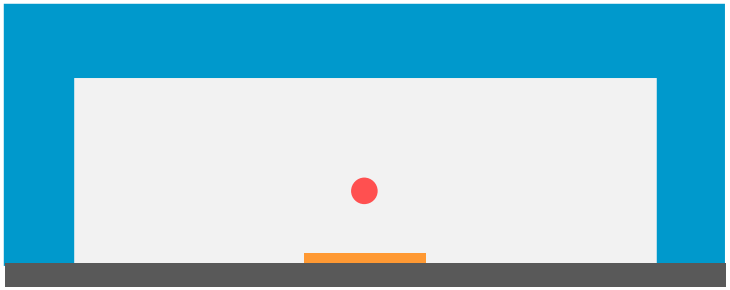


Fig. 1. Spin valve sensor chip with a bonded 1-mm-wide microchannel mounted in a chip-carrier.

The spin valve stack was fabricated by an ion beam deposition system on a 3 in. Si wafer and has the structure Ta 20 Å/NiFe 30 Å/CoFe 25 Å/Cu 26 Å/CoFe 25 Å/MnIr 60 Å/Ta 30 Å/TiW(N) 150 Å. As deposited the spin valve coupon sample has a magnetoresistance ratio (MR) of ~7.5%. The sensors were defined by standard photolithographic techniques and by ion milling.



PDMS channel
H 20 µm, W 100 µm, L 2.8 mm

DI water

SV sensor 2 x 6 µm²

Silicon substrate

250 nm superparamagetic particles

H.A. Ferreira *et al.* (2004) Flow velocity measurement in microchannels using magnetoresistive chips, IEEE Transactions on Magnetics, 40(4):2652-2654 DOI: 10.1109/TMAG.2004.830403

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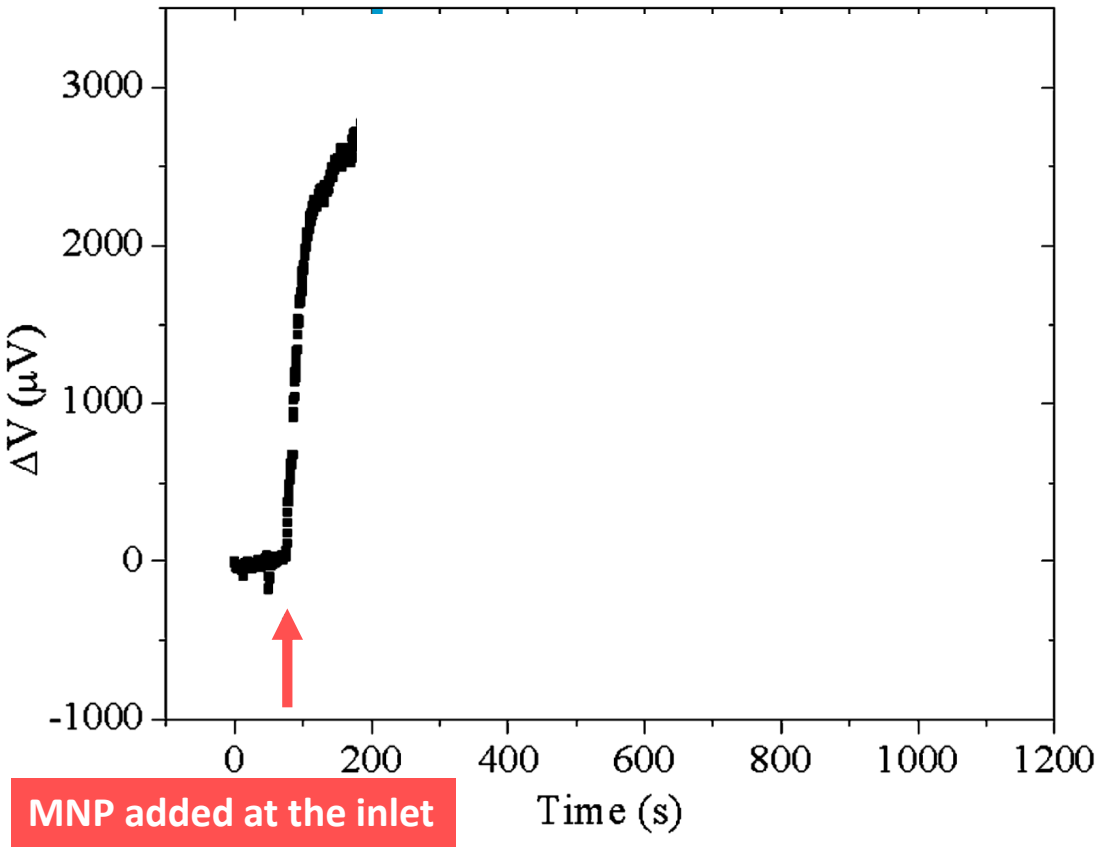
SPIN VALVES FOR VELOCITY MEASUREMENTS

Using 1 sensor



MNP added at the inlet

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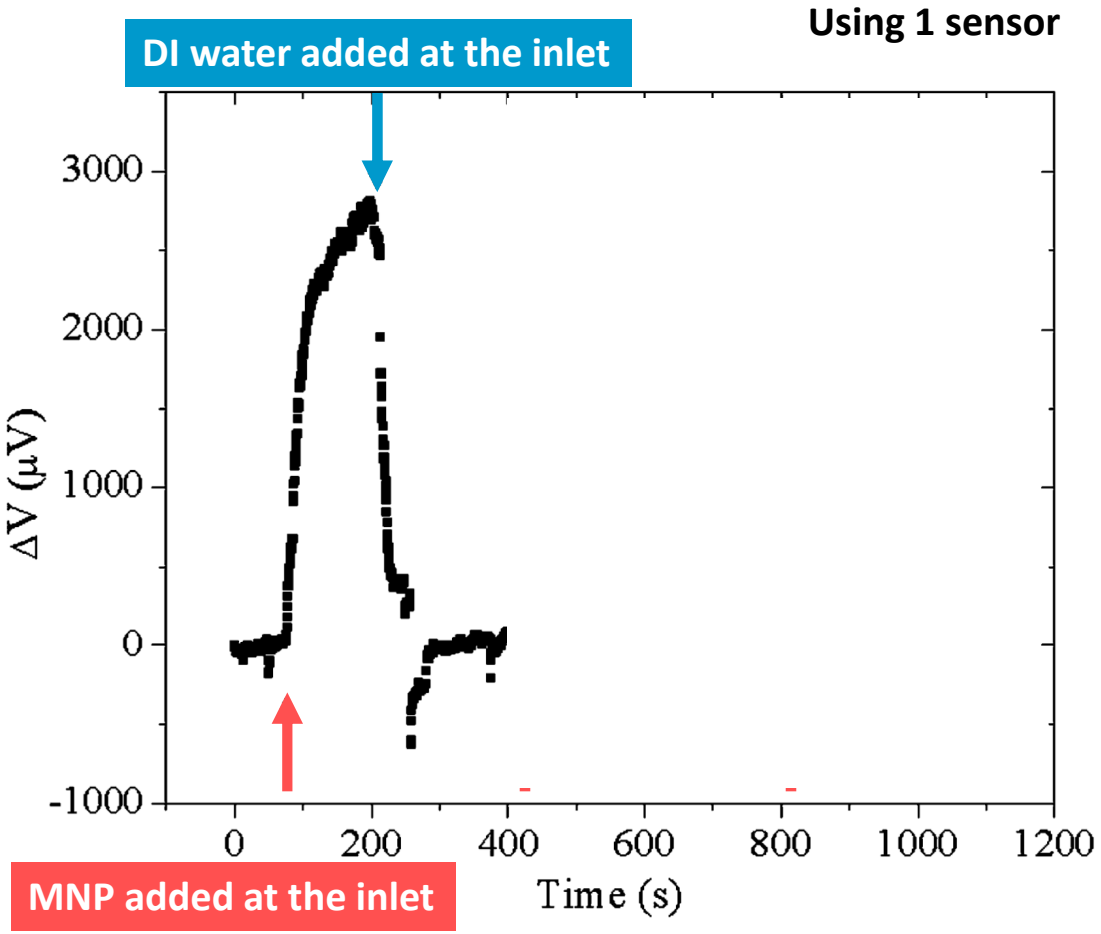
Using 1 sensor



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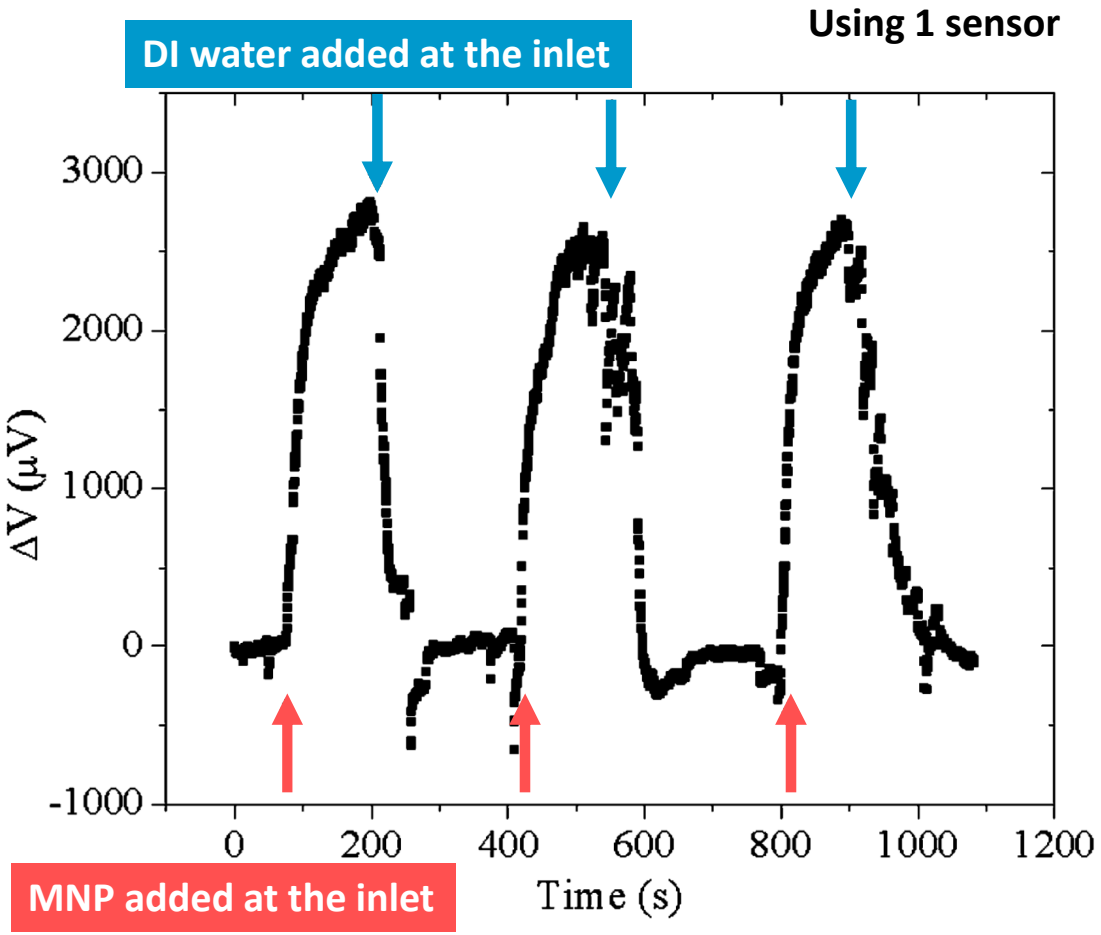
SPIN VALVES FOR VELOCITY MEASUREMENTS

Using 1 sensor



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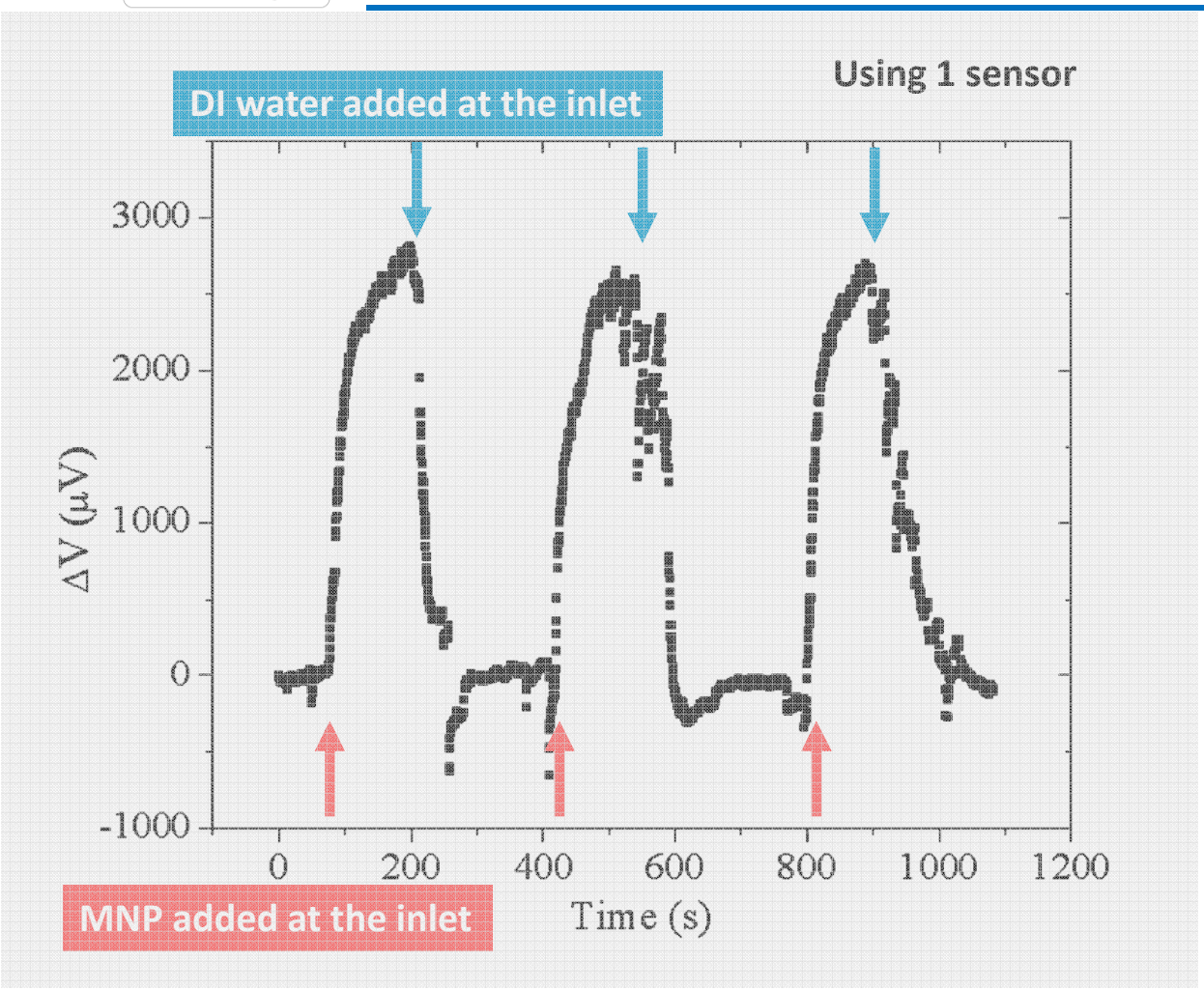
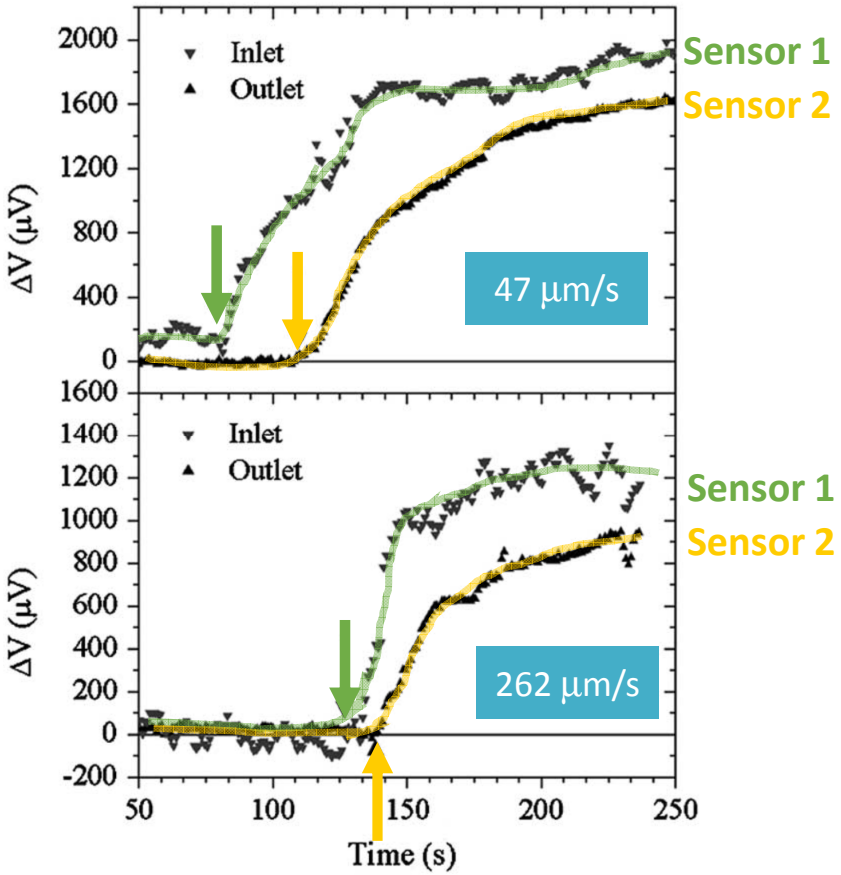
SPIN VALVES FOR VELOCITY MEASUREMENTS



Using 2 sensors



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INTEGRATION

IOP Publishing
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J. Phys. D: Appl. Phys. 50 (2017) 213001 (21pp)
https://doi.org/10.1088/1361-6463/aa66ec

Topical Review

Challenges and trends in magnetic sensor integration with microfluidics for biomedical applications

S Cardoso[1,2], D C Leitao[1,2], T M Dias[1,2], J Valadeiro[1,2], M D Silva[1,2], A Chicharo[2,3], V Silverio[1], J Gaspar[3] and P P Freitas[1,3]

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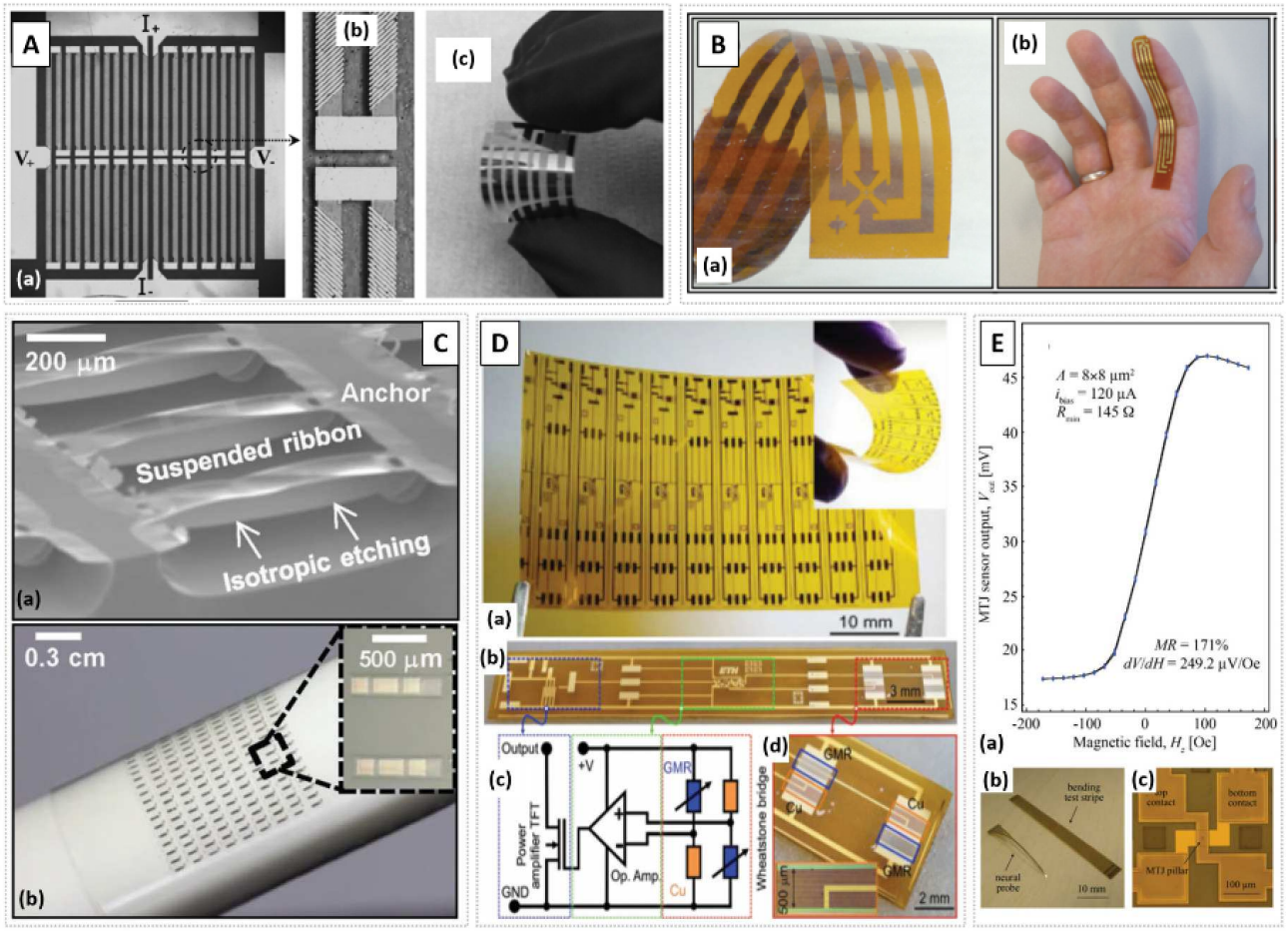

Figure 6. Examples of flexible magnetic sensors. (A) (a) AMR sensors patterned in a Wheatstone bridge configuration on a flexible substrate, (b) zoom over the barber poles on the NiFe layer, and (c) the AMR sensor on a flexible PET foil. [73] John Wiley & Sons. © 2016 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim. (B) (a) Flexible Hall sensor which can be (b) conformed to a finger. [76] Copyright Wiley-VCH Verlag GmbH & Co. KGaA. Reproduced with permission. CC BY-NC 4.0. (C) (a) Si undercut etching under the fabricated and annealed MgO structures for transferring to the (b) flexible substrate. [82] John Wiley & Sons. © 2016 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim. (D) (a) Array of flexible GMR sensors and electronics fabricated on 50 μm polyimide foil and (b)–(d) details over the complete system. [85] Copyright Wiley-VCH Verlag GmbH & Co. KGaA. Reproduced with permission. CC BY-NC 4.0. (E) Representative TMR output of a 8 × 8 μm^2 MgO-MTJ pillar with stack (Ta (5)/CuN (25)) × 6/Ta (5)/Ru (5)/MnIr (20)/$Co_{70}Fe_{30}$ (2)/ Ru (0.85)/CoFeB (2.6)/MgO (1.0)/CoFeB (2)/ Ta (0.21)/NiFe (4)/Ru (0.2)/MnIr (6)/Ru (2)/Ta (5)/Ru (10) (thickness in nm) fabricated and annealed on polyimide substrate; the inset shows an example of released structures and single sensor design. Reproduced with permission from [66]. © Copyright 2017 IEEE.

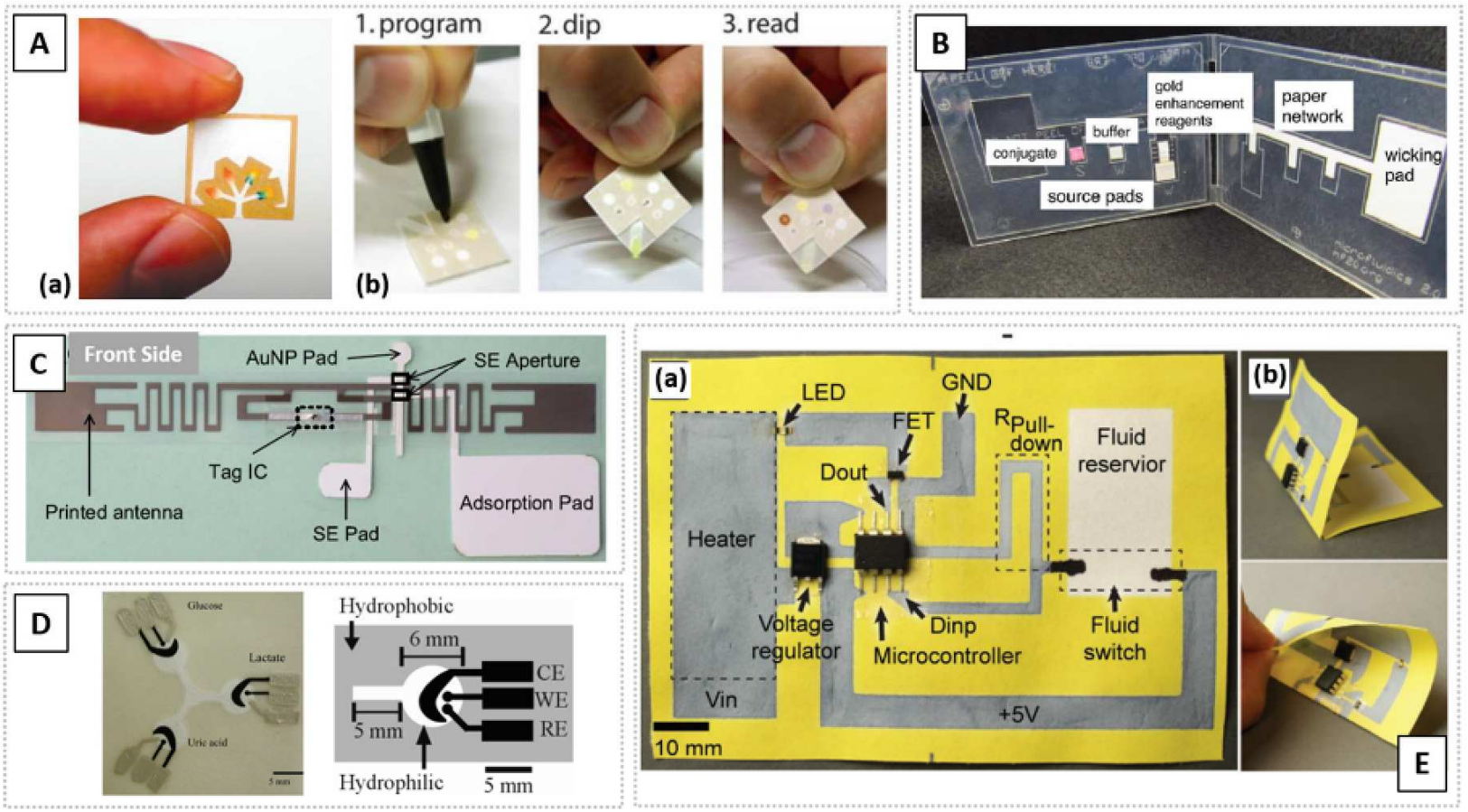

Figure 9. Examples of paper microfluidic applications. (A): (a) Concept of microfluidic paper-based analytical devices (μPAD). Reprinted with permission from [104]. Copyright 2009 American Chemical Society. (b) Strategy used for a programmable μPADs for urinalysis. Adapted from [105] with permission of The Royal Society of Chemistry. (B) A 2D paper network card for an amplified immunoassay. Adapted with permission from [109]. Copyright 2012 American Chemical Society. (C) Self-powered RFID biosensor prototype integrating paper-based microfluidics and a self-assembled RF antenna. © 2016 IEEE. Reprinted, with permission, from [117]. (D) Image and schematic design of the electrode paper-based microfluidic device demonstrated by Dungchai *et al*. Adapted with permission from [114]. Copyright 2009 American Chemical Society. (E) Paper-based integrated system incorporating fluidics and electronic components, with wiring connections fabricated in paper and (b) image of the folded paper circuit. [118] John Wiley & Sons. © 2016 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

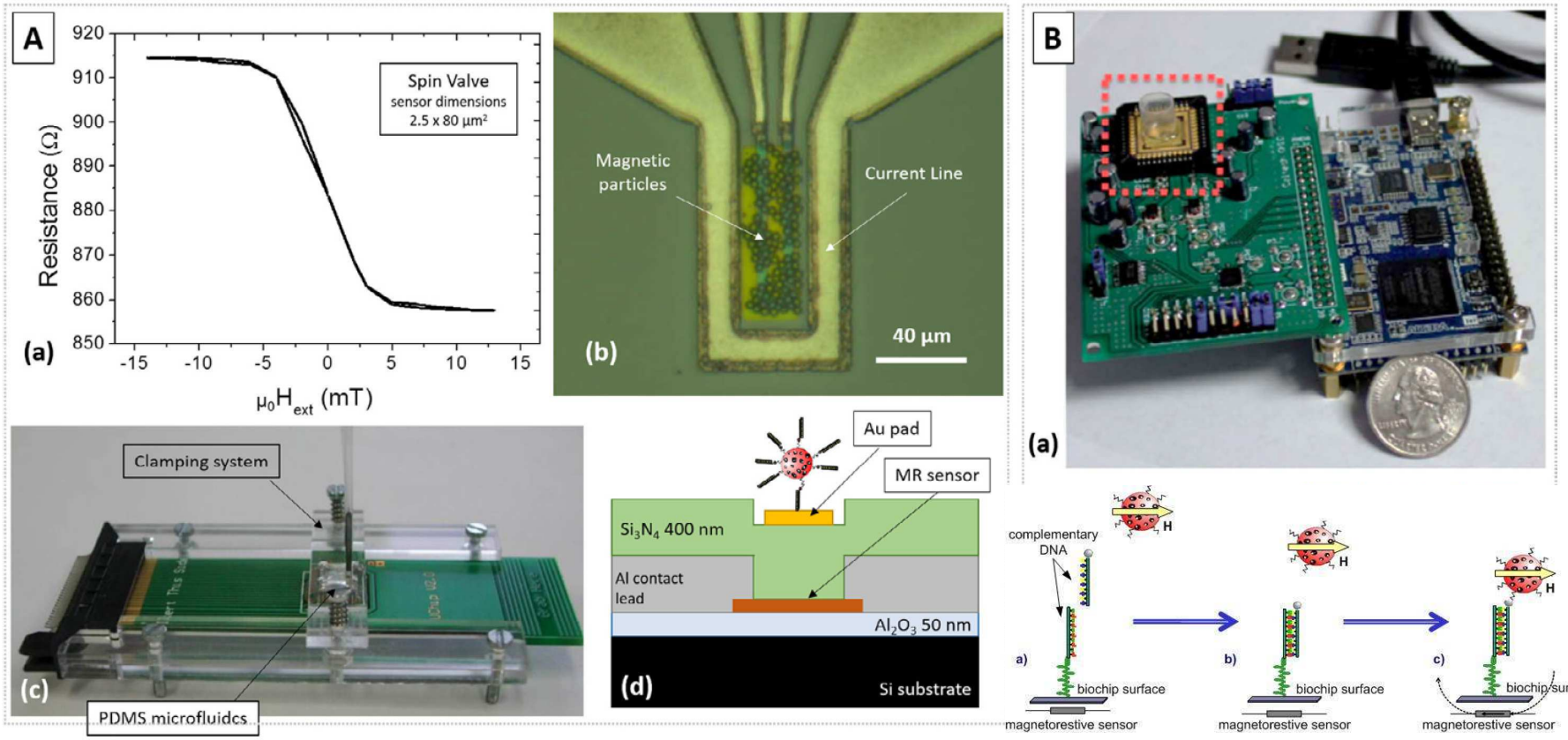

Figure 11. (A) Example of a static detection biochip from INESC-MN. (a) Transfer curve of an SV sensor. (b) Focusing method for magnetic particles using current lines. (c) Clamping device to aid bonding of the PDMS microfluidic channels and (d) cross section of the chip layout. (B) CMOS handheld diagnostic device from Pai *et al* [150]. (a) Device consisting of the plug-in cartridge, circuit board, and USB interface, (b) example of the disposable chip with a polypropylene well and (c) chip layout. [150] Reproduced by permission of The Royal Society of Chemistry. CC BY-NC 3.0.

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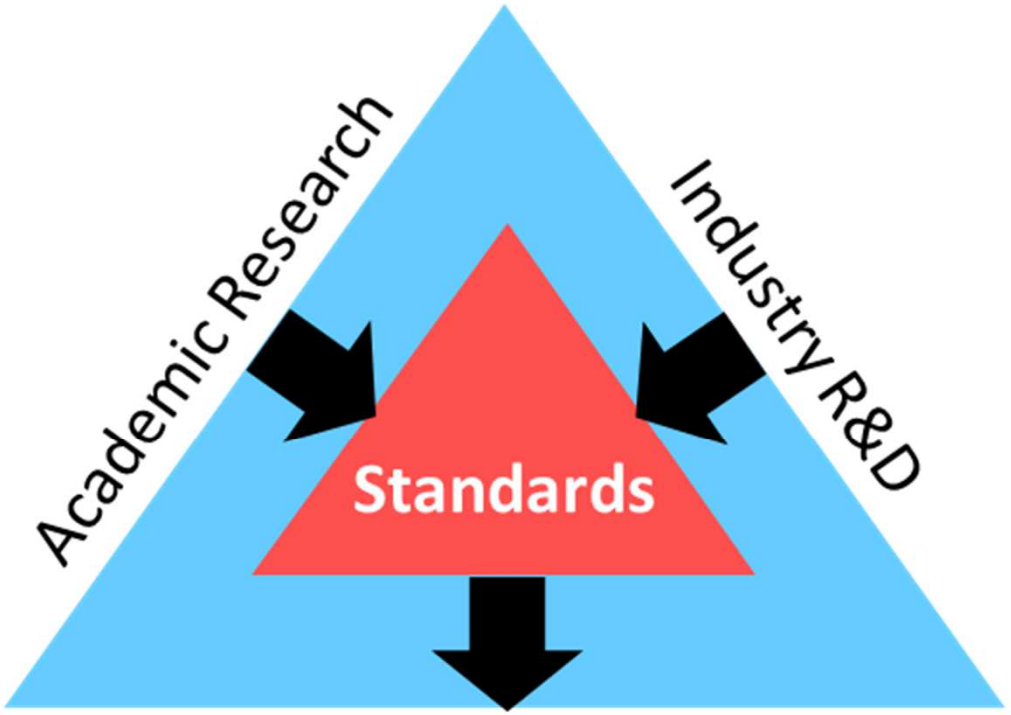
MICROFLUIDICS STANDARDIZATION ROADMAP



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MICROFLUIDICS STANDARDIZATION ROADMAP

NIST

Microfluidics Association

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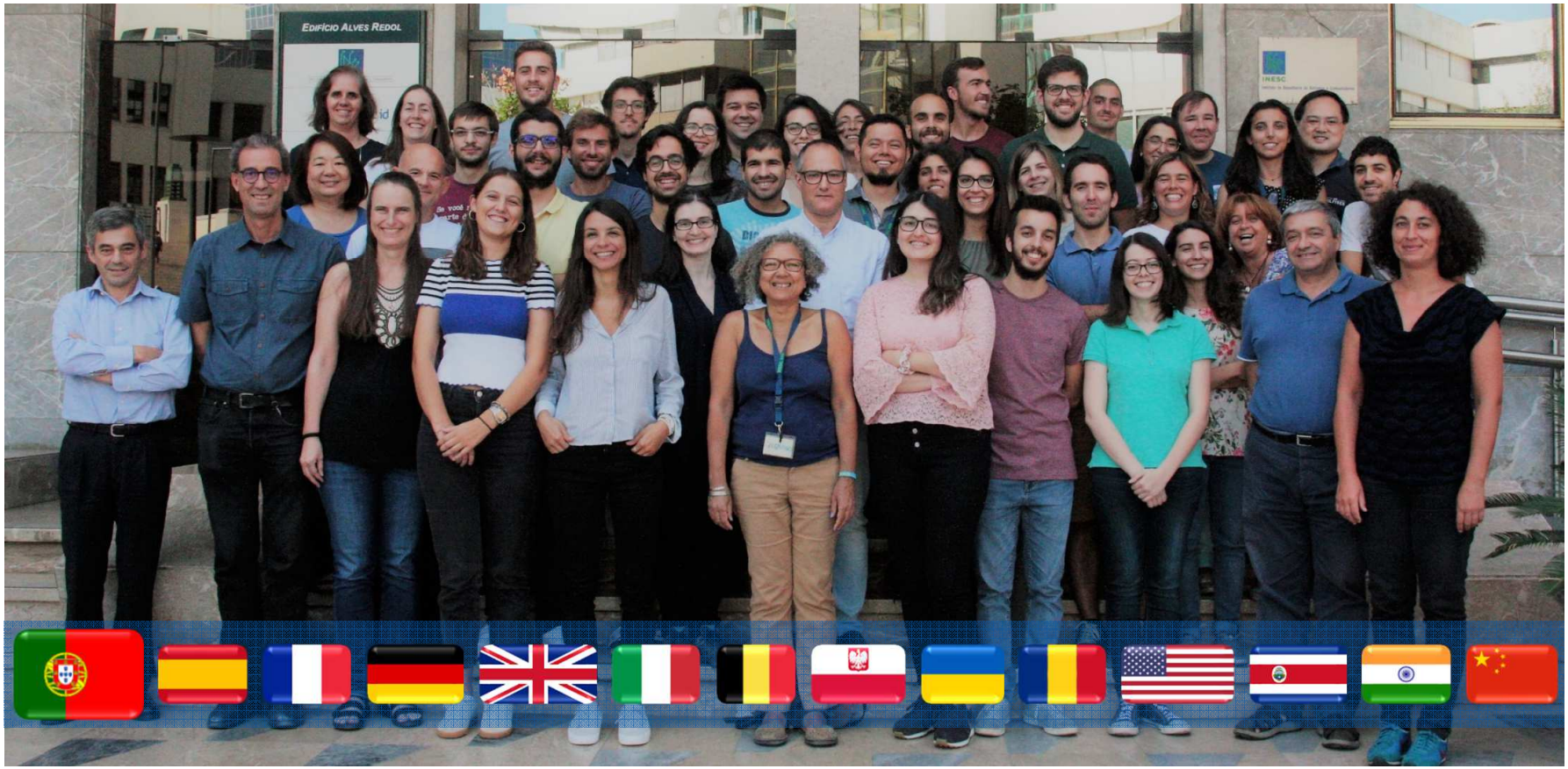
INESC MN's GREAT TEAM !

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