Silicon and Non-Silicon Materials for BioMEMS Fabrication

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Outline

- Short presentation of the Tyndall National Institute, Cork, Ireland;
- Material properties of common polymer substrates;
- Polymer materials and fabrication;
- Evaluation of polymer materials vs. silicon for fabrication of BioMEMS microdevices;
- Properties of different types of polymers
- Examples of existing BioMEMS microdevices for DNA extraction manufactured in polymers;
- Concluding remarks.

- Established in 2004
- Brings together researchers in:
  - Photonics
  - Microelectronics
  - Materials
  - Microsystems
- Originally from the National Microelectronics Research Centre (NMRC), University College Cork (UCC) and Cork Institute of Technology (CIT)
- 300 research engineers, scientists and students
- Creates a critical mass of researchers in the field of ICT

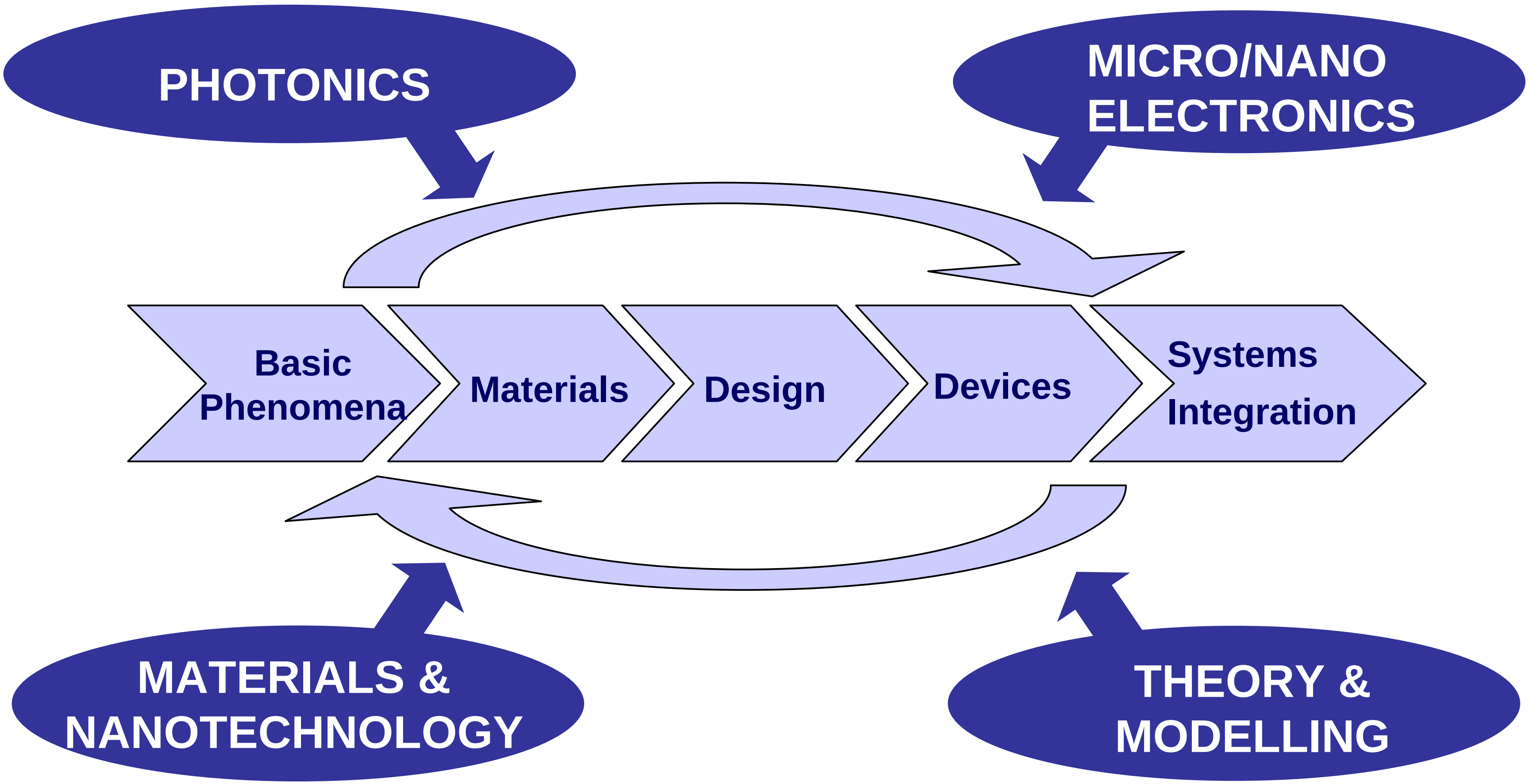
John Tyndall, 1820 - 1893

- Born in Leighlinsbridge, Co.Carlow 1820
- Prof.of Natural Philosophy, Royal Institution 1853
- Succeeded Faraday as Director of the Royal Institution 1863
- Initiated the practical teaching of science in schools
- Developed spectroscopy
- Invented the light pipe
- Tyndall Scattering – explained why the sky is blue
- Tyndallisation – sterilisation process
- Studies of the atmosphere and the ozone layer

Mission Statement:

‘Tyndall will be a Centre of Excellence in Information and Communications Technology materials, devices and systems research, development and graduate education, recognised internationally for the quality of its outputs and its creation of new opportunities for Ireland’s economic growth.’

Research Focus



"from atoms to systems"

"From atoms to systems …….

…… creating value from research"

- Promoting excellence in Irish research and development and attracting the best in international researchers
- Promoting the pull-through to exploitation of the outputs from research
- Working with Irish industry to set the agenda for ICT R&D in Ireland
- Encouraging Irish manufacturing industry to invest in R&D in Ireland
- Producing well-trained postgraduate engineers and scientists to go into Irish industry
- Outreach in science and engineering

Tyndall summary

- Tyndall
  - Broad materials and device processing capabilities, coupled with very strong theoretical understanding of nanoscale electronic devices
  - Strong activity in Photonic materials, systems and devices
  - Strong activity in microsystems, especially for RF sensor modules and life-sciences interface
  - ISO9000 fab with full CMOS process capability
  - Good understanding of the issues involved in putting new materials and processes into practice in real devices
  - Strong motivation to put the devices and systems work into products and industrial applications

Characteristic	
Optical transparency	Can be transparent or opaque to different wavelengths
Thermal conductivity	0.1-0.2 W/mK
Specific heat	~ 1200 - 1500 J/KgK
Electric conductivity	Can be an insulator or a (semi)conductor
Fabrication technology	A diversity of fabrication processes available depending on requirements relating to feature size, material properties, throughput, etc.
Density	~ 900 - 1300 Kg/m^3
Mass production	Many polymer materials are very compatible with low cost, high throughput fabrication processes.
Cost of raw materials	~ 1 $cent/cm^2$
High temperature sterilization	Tendency to deform
Biocompatibility	Dependent on the specific polymer

Characteristic	Polymer	Silicon
Optical transparency	Transparent or opaque, may absorb the UV light	Opaque
Thermal conductivity [w/mK]	0.1-0.2	148
Specific heat [J/KgK]	~ 1200 - 1500	700
Electric conductivity	Insulator or (semi)conductor	Semiconductor
Fabrication technology	Available, high processability	Available from IC industry
Density [Kg/m^3]	~ 900 - 1300	2320
Mass production	Yes, slow processes, high cost	Yes, fast processes, low cost
Cost of row materials	~ 1 cent/ cm.$^{2\ 2}$	~ 1 \$/ cm.^{2}
High temperature sterilization	Tend to deform	Yes
Biocompatibility	Depends on polymer	Yes (needs surface modification)

Properties of different types of polymers

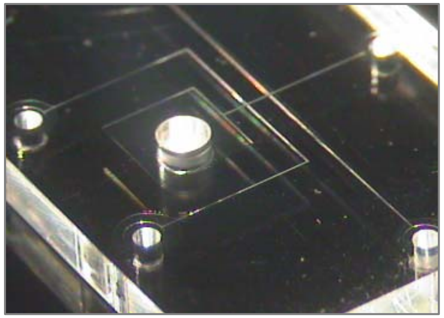
		PMMA	PC	COC	Polyimide	PS	PDMS	Polyaniline
1	Polymer type	Thermo-plastic	Thermo plastic	Thermo-plastic	Thermo-plastic	Thermo-plastic	Elastomer	Thermo-plastic
2	Density [g/cm$^{3]}$	1.16	1.2	1.02	1.39	1.05	1.227	1.4
3	Glass temperature [˚C]	106	150	90-136	285	100	-127	
4	Useful temp. range [˚C]	-70-100	-150-130	-73-80	-73-280	-40-70	-40-150	-70-100
5	Mold (linear) shrinkage	0.001	0.005-0.007	0.001	0.0083	0.004-0.006	0.001-0.006	
6	Linear expansion coefficient [x10-6˚C]	50-90	68	60	46-56	70	10-19	
7	Thermal conductivity [WmK]	0.186	0.21	0.16	0.2	0.18	0.17-0.3	
8	Dielectric Strength [MV/m]	16-20	15-16	-	16-22	19-135	16-22	

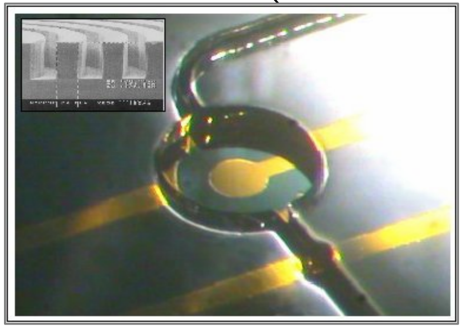
Properties of different types of polymers

		PMMA	PC	COC	Polyimide	PS	PDMS	Polyaniline
	Optical properties							
9	Transmission of visible light [%]	92	89	92-94	87	90	91	
10	UV resistance	Good	Good	Good	Good	Poor	Good	Good
	Chemical resistance							
11	Acid	Good	Good	Good	Fair-good	Good	Fair-good	Good
12	Alkalis	Excellent	Poor	Good	Fair-good	Good	Poor-Fair	
13	Solvent	Poor	Poor	Fair-poor	Fair	Poor	Poor	Good
14	Surface charge (native surface)	Yes	Yes	No	No	Yes	Yes	Yes
15	Possible fabrication methods	Injection, molding, hot embo-ssing, laser ablation	Injection, molding, hot embo-ssing, laser ablation	Injection, molding, hot embo-ssing	Injection, molding, hot embo-ssing, laser ablation	Hot embossing	Soft litho-graphy	Injection, molding, Electropoly-merisation

Melt processing

- Hot embossing
- Injection moulding
- Extrusion
- Blow moulding
- Fibre spinning
- Soft lithography
- Optical lithography in deep resists
- Laser photoablation
- X-ray lithography
- Compression moulding

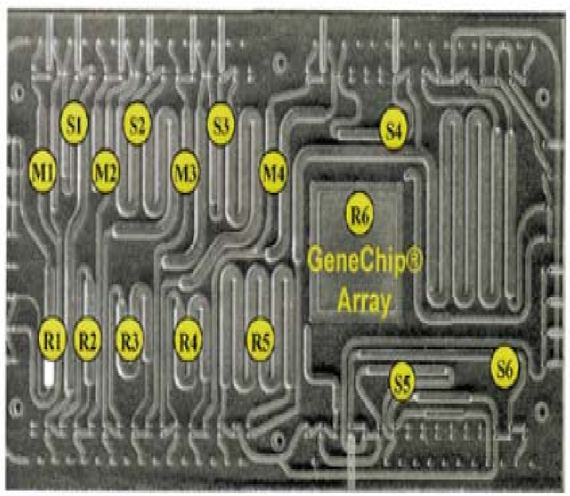




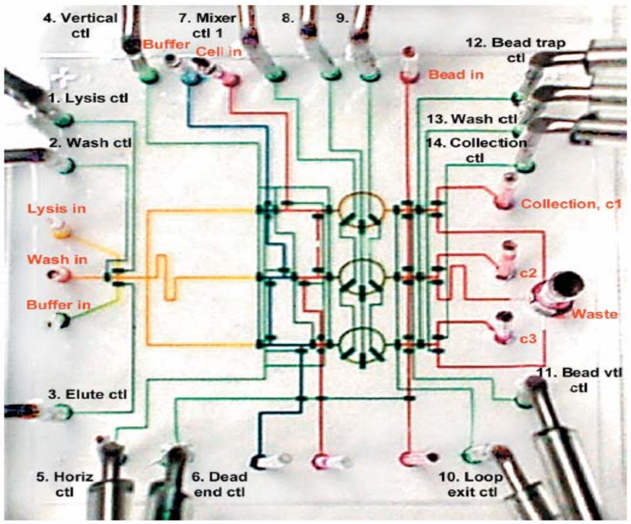
Solution processing

- Coating - films
- Spraying
- Solution spinning – fibres
- Electrospinning - fibres
- Spin coating - films
- Electropolymerization

DNA Extraction microdevices manufactured in polymer materials



Policarbonate, 8x40x70 mm

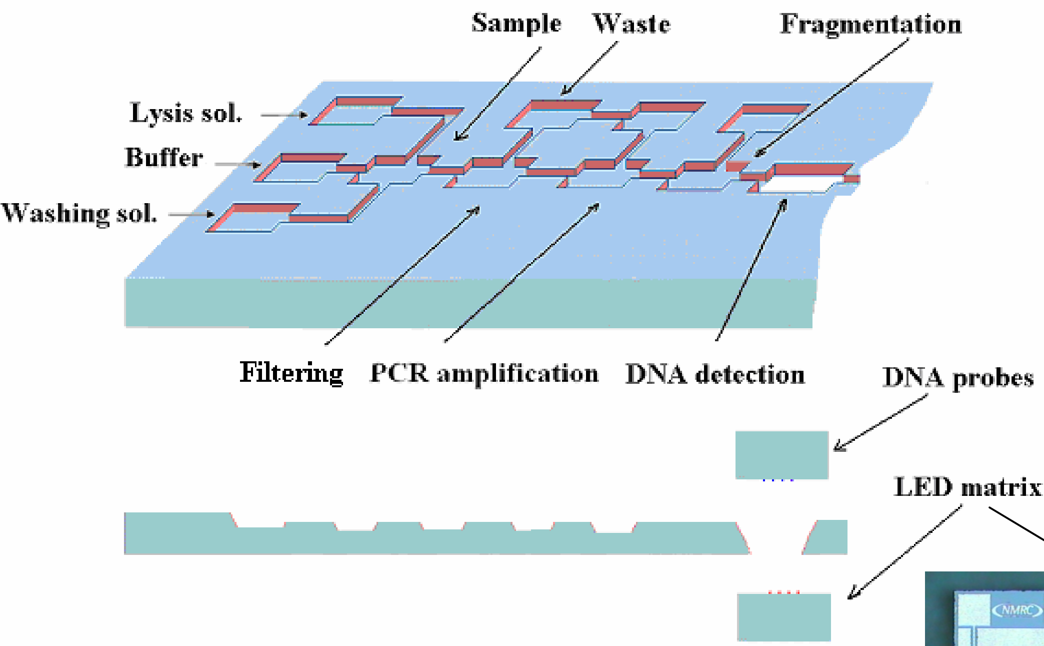


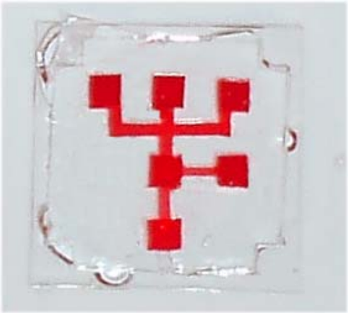
PDMS

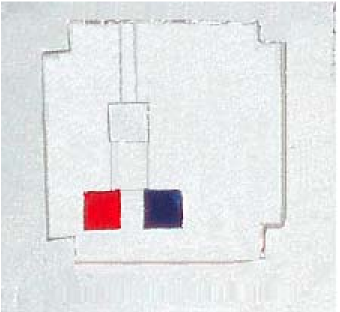
a) Anderson (Affymetrix Inc.)
Nucleic Acid Research, 28 (12), I-VII

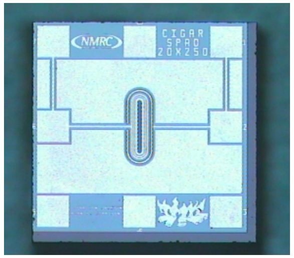
b) Quake et al, Nature Biotech., 4, 438-439, 2004

DNA Extraction and Amplification Module





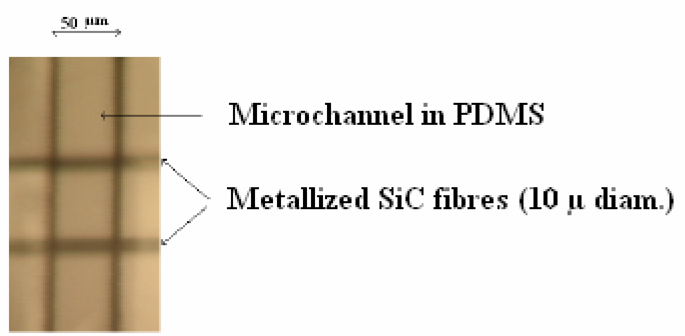


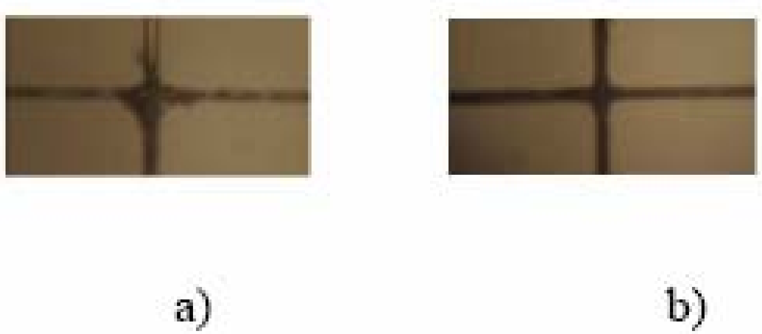


–FP6, IST Program, MICRO2DNA project

Microchannel in PDMS with metallized SiC fiber microelectrodes

- **Additive technique for metallization of microfluidic structures manufactured in PDMS**



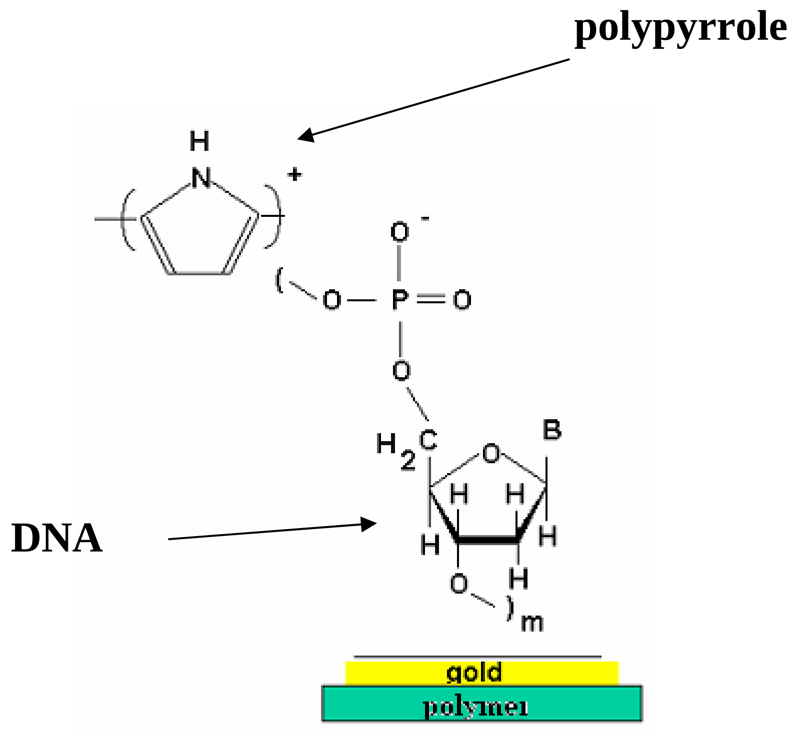


a) Contact resistance < 0.1 ohm; b) contact resistance > 20 Gohm

–FP6, IST Program, MICRO2DNA project

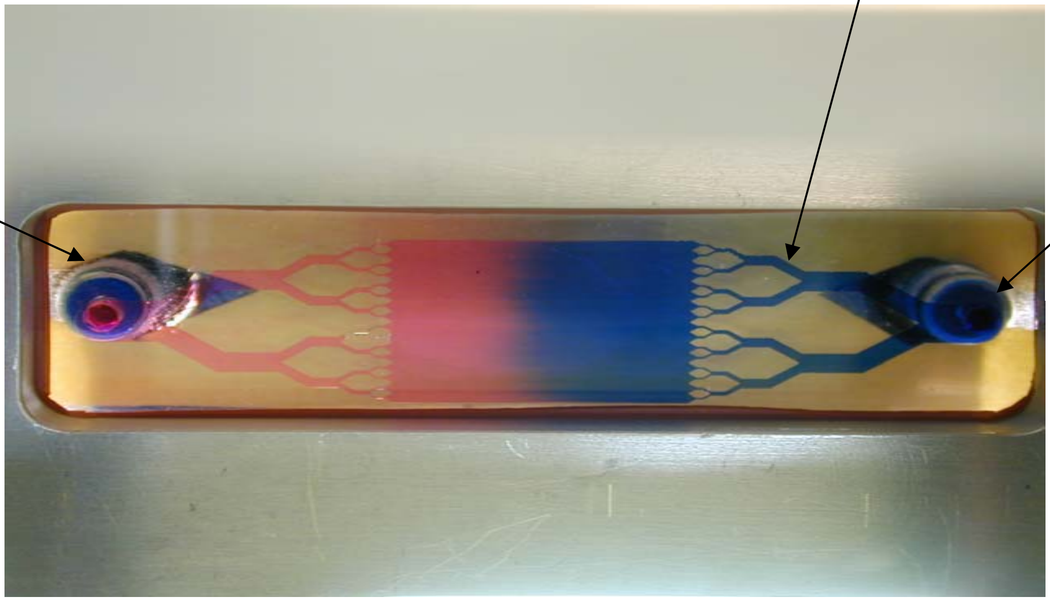
DNA- Conducting Polymers composite material

- **Entraping DNA at specific sites**

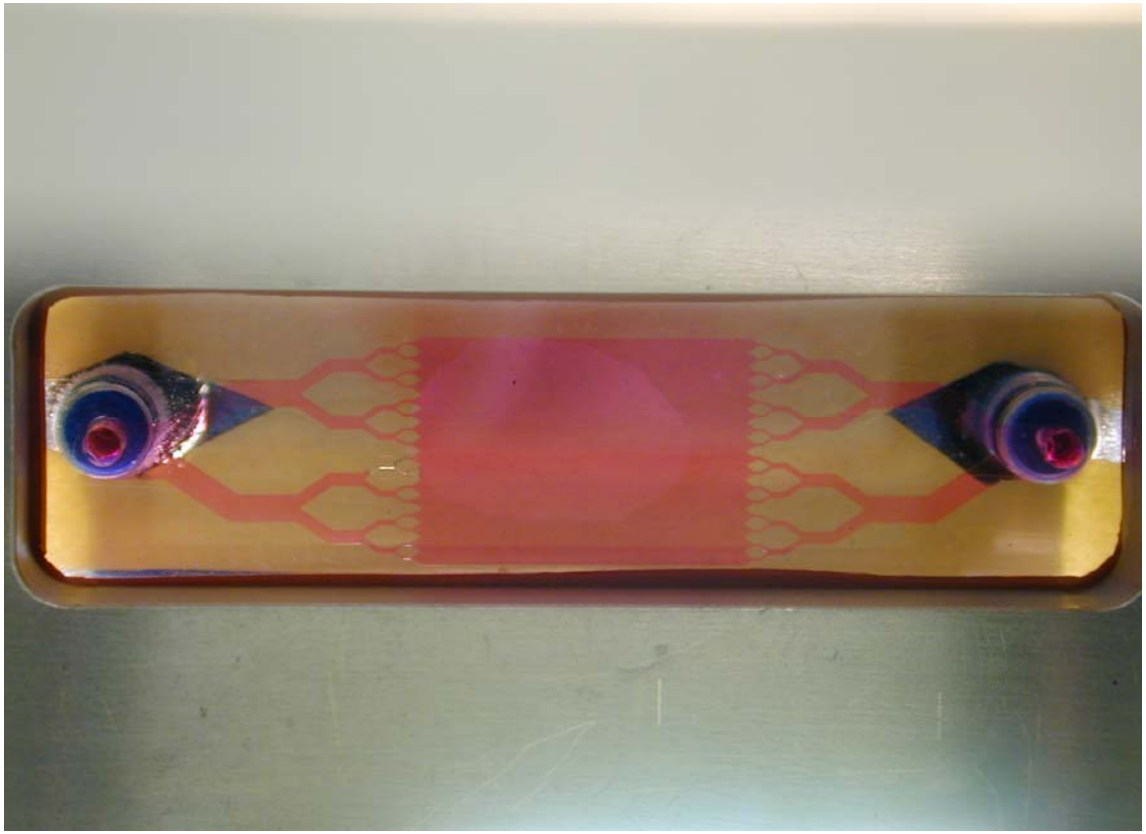


Hybridization chamber prototyped in PDMS

- Laminar flow inside of a hybridization chamber



Flow profile



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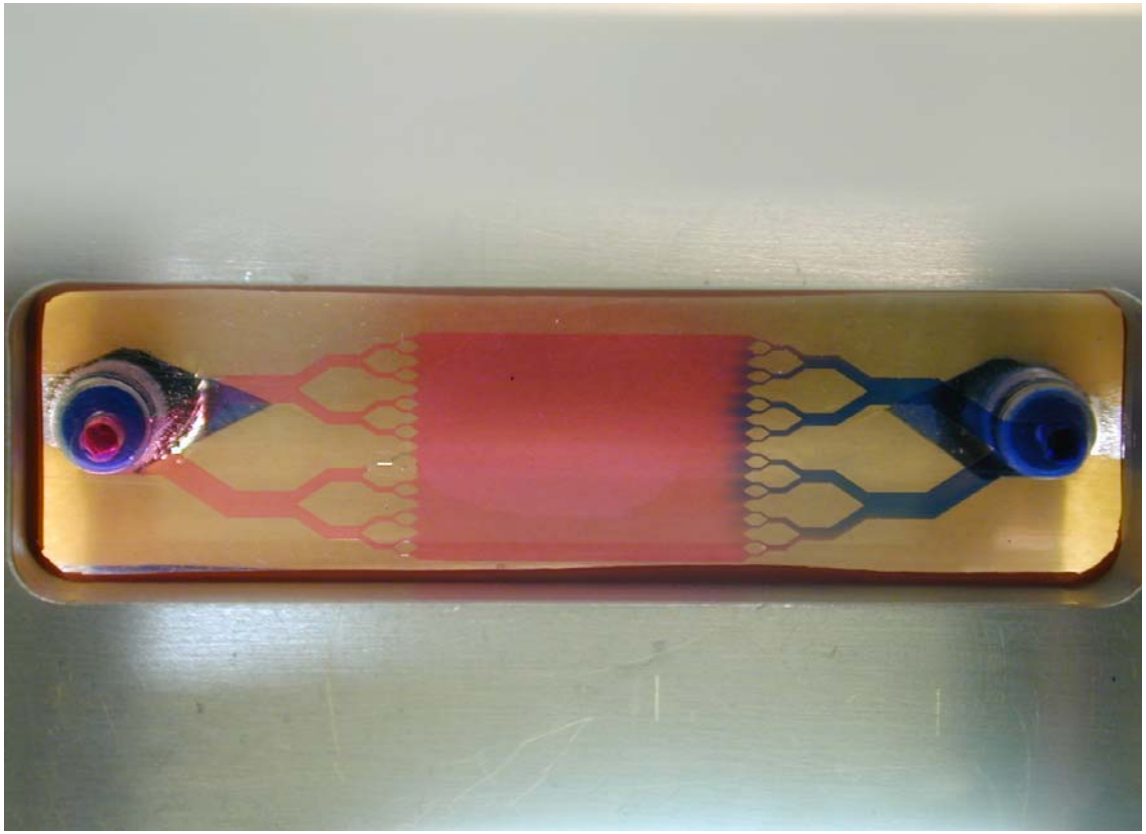

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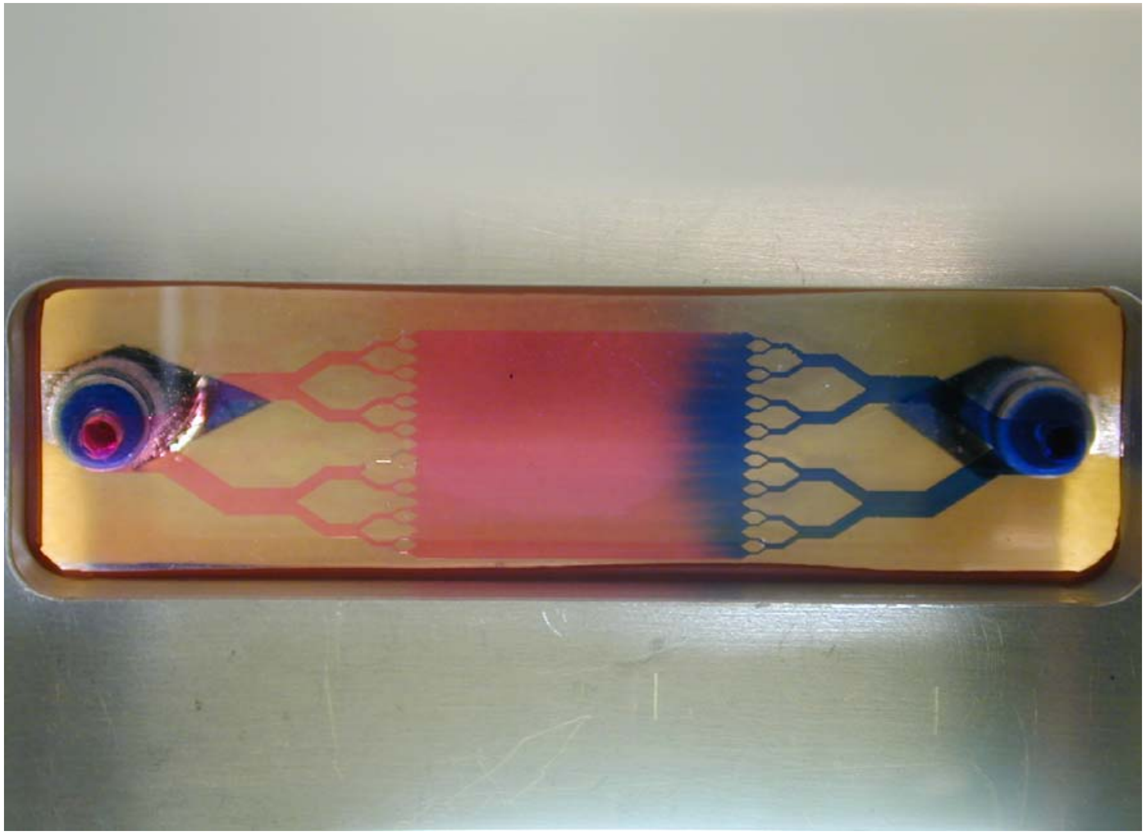

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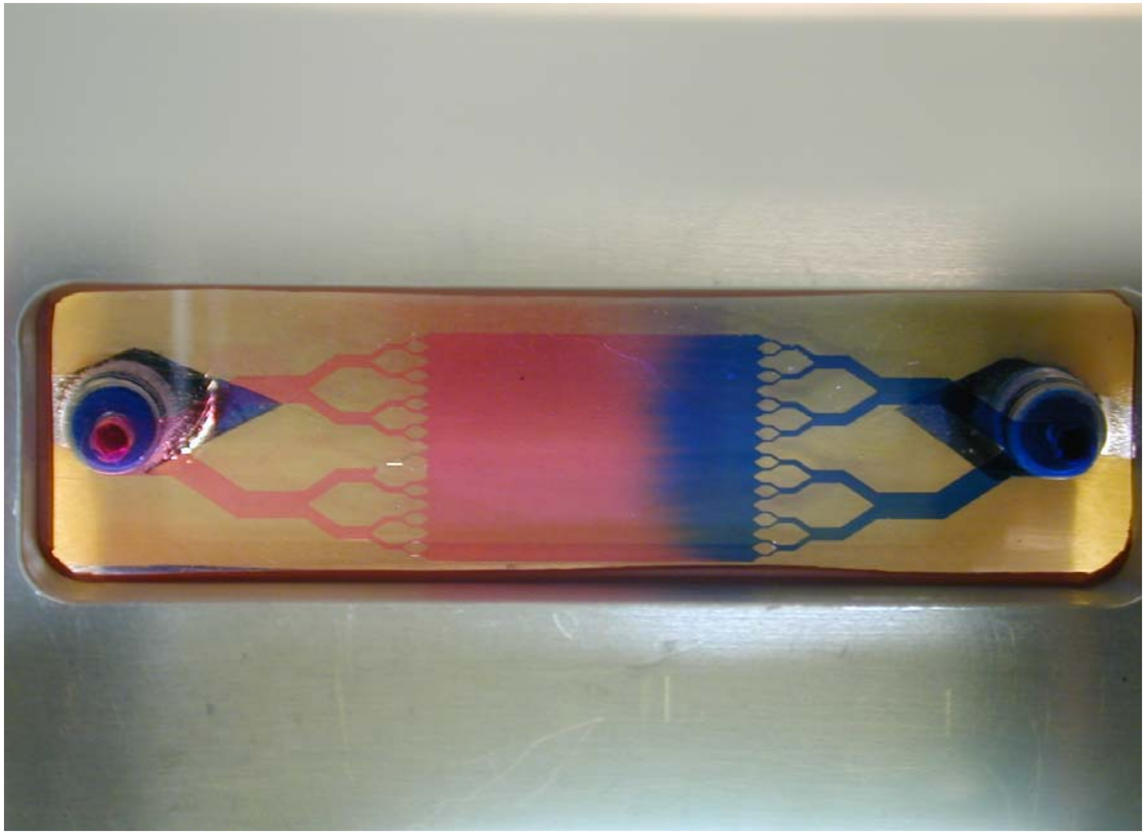

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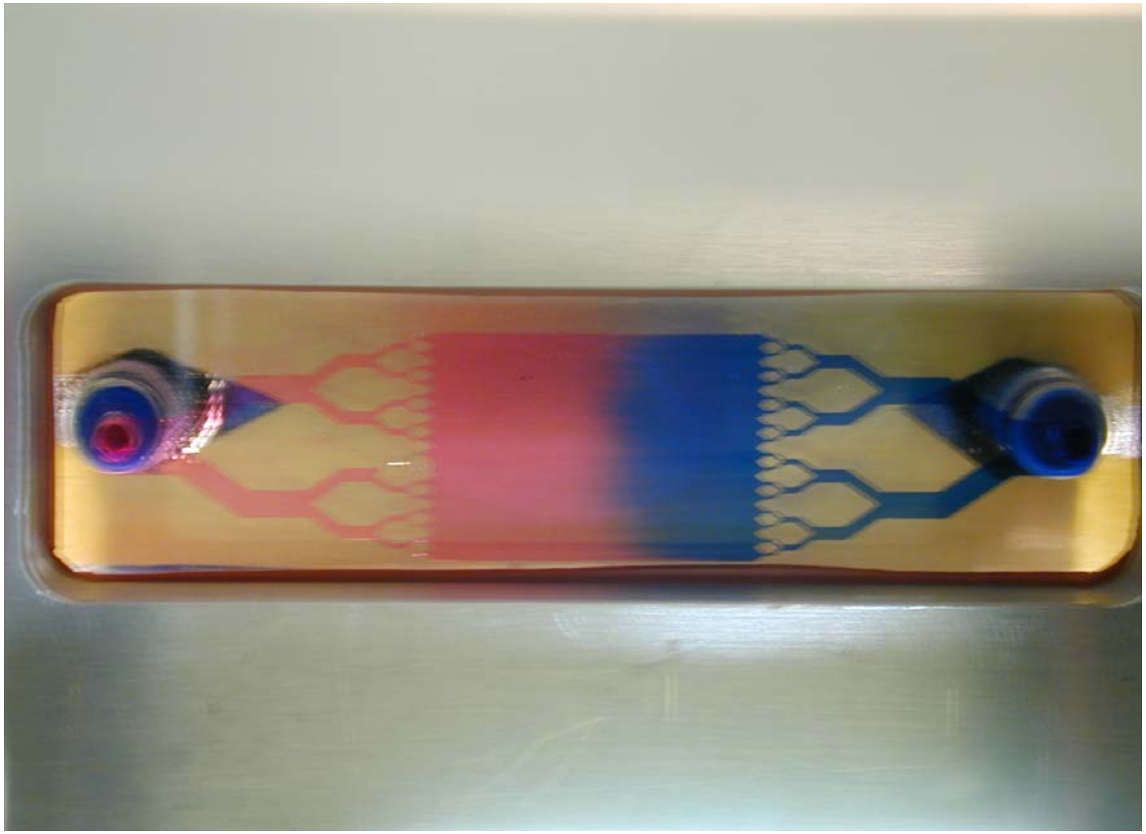

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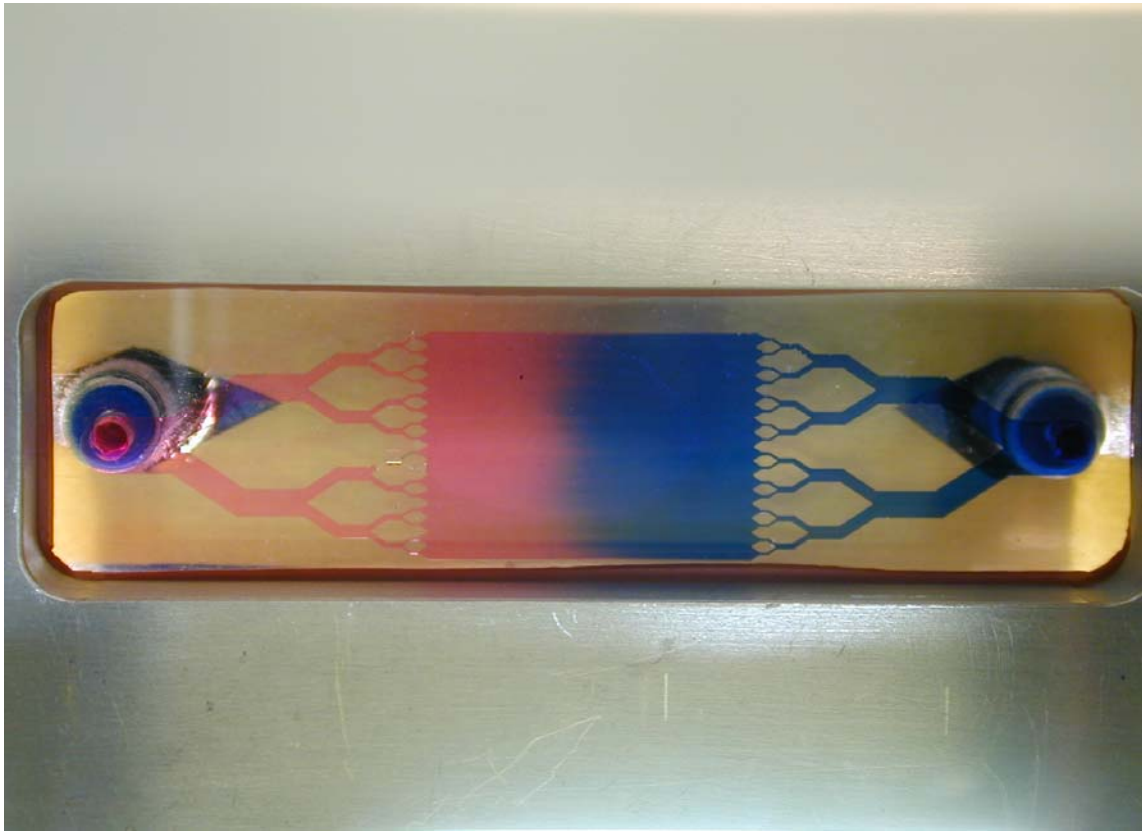

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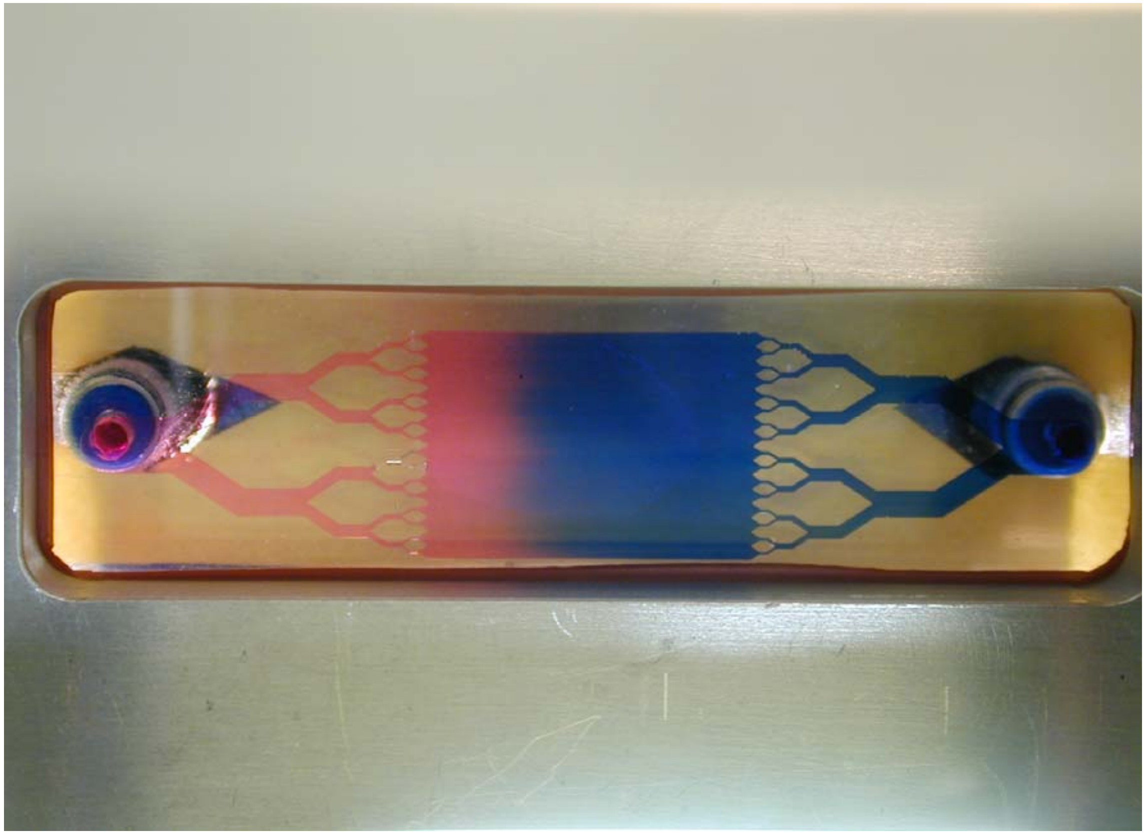

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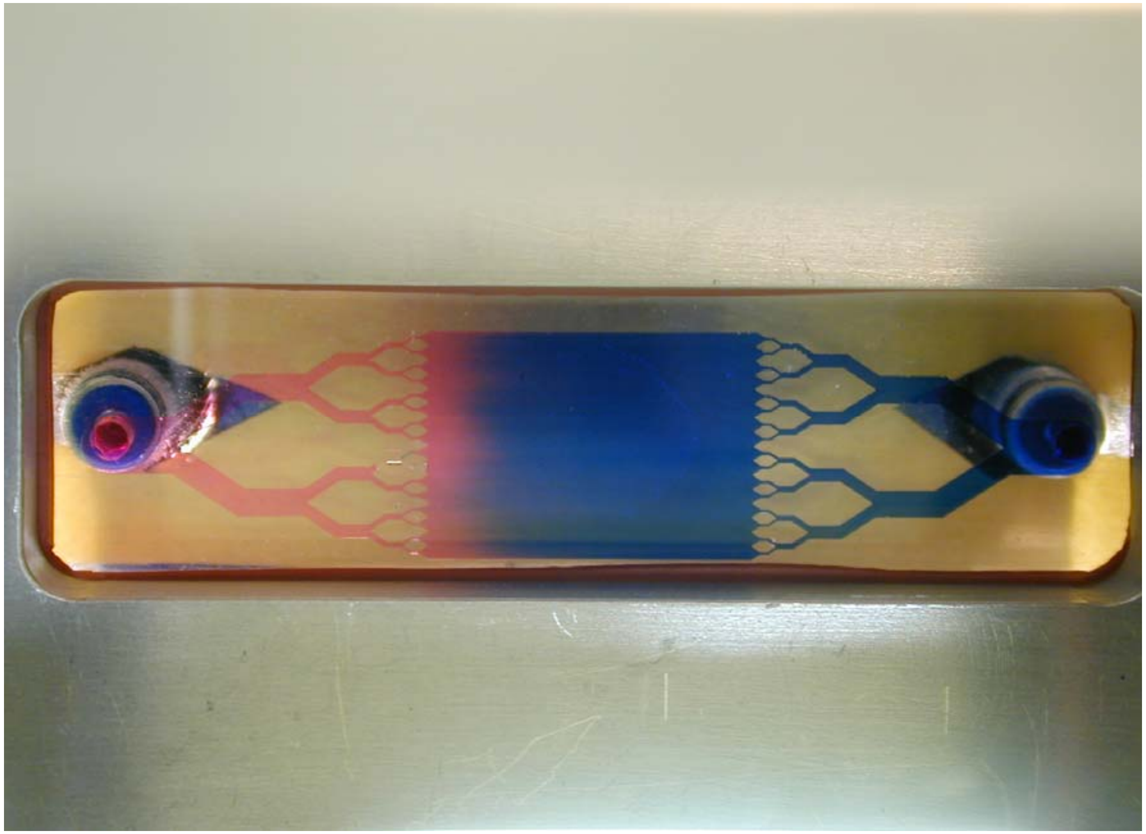

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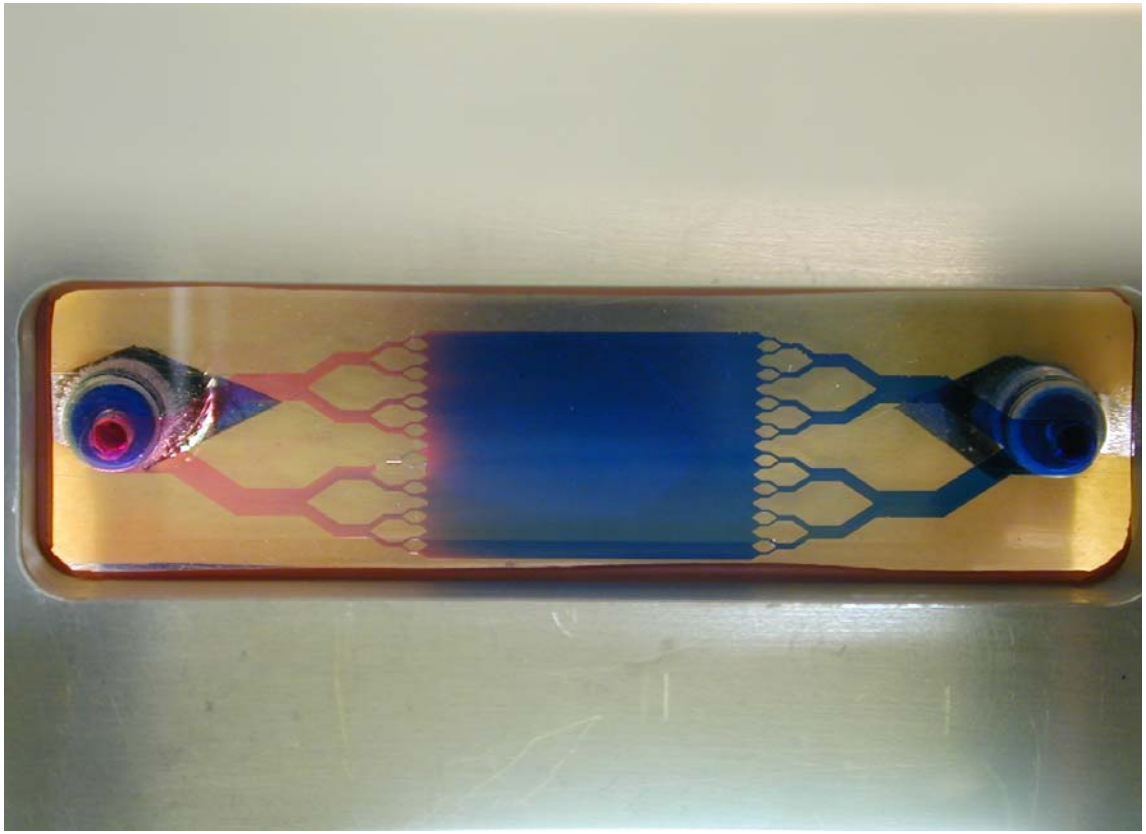

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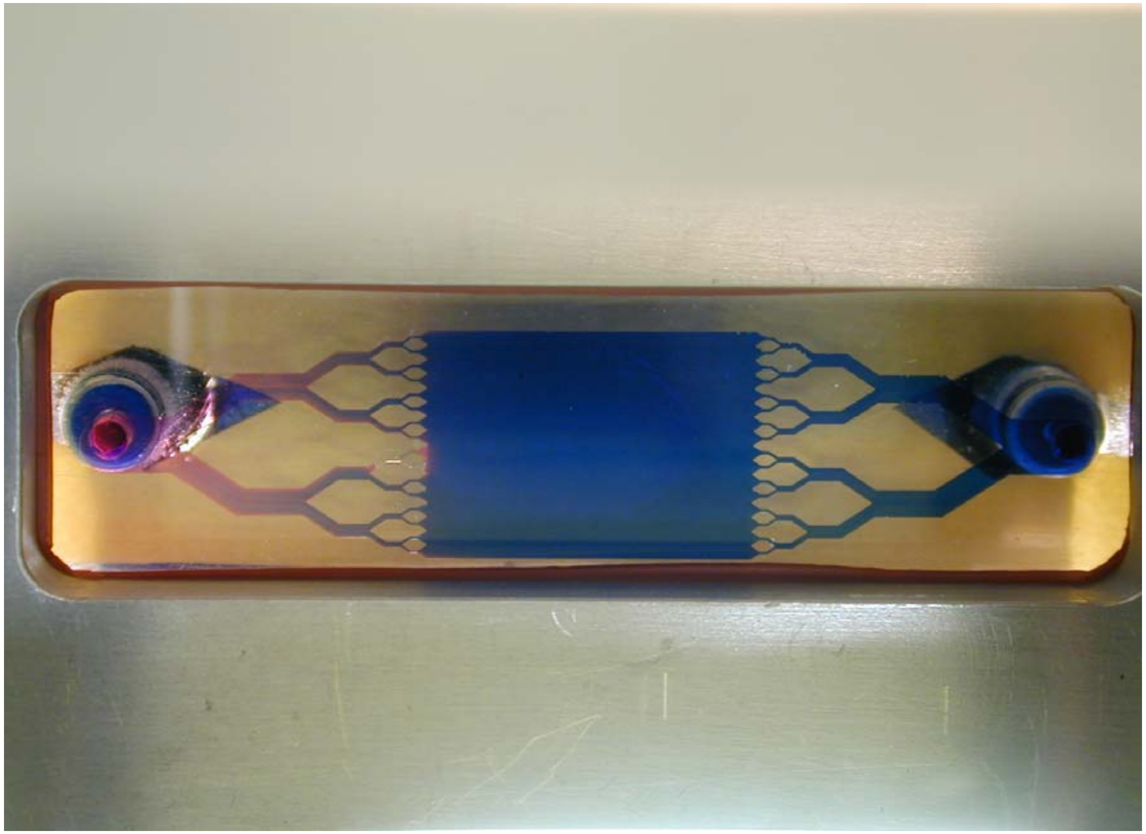

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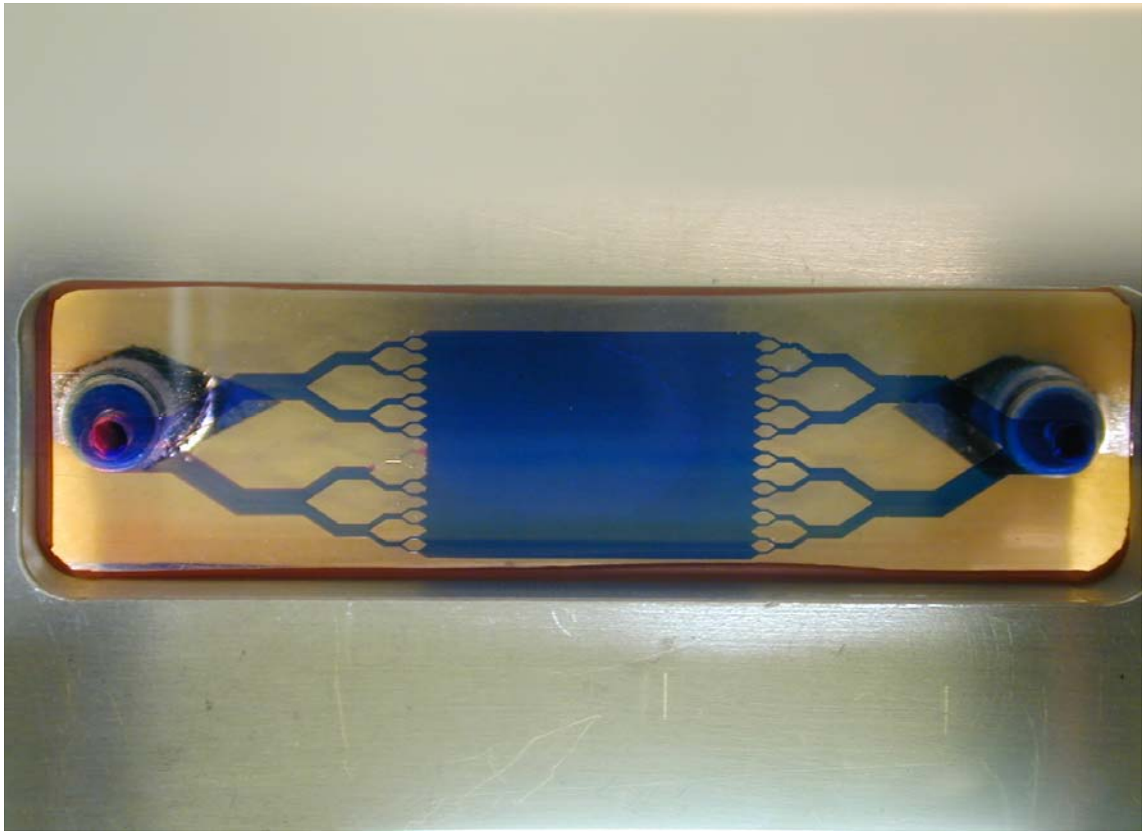
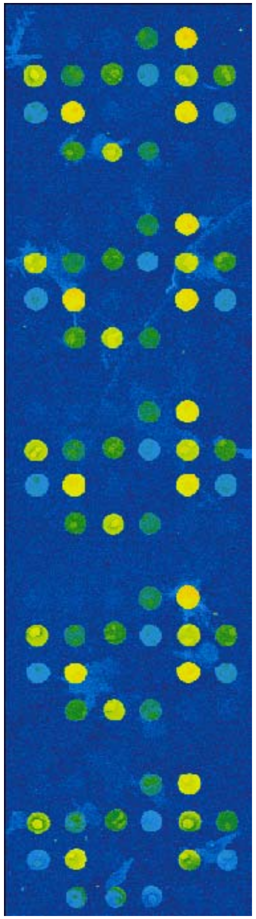
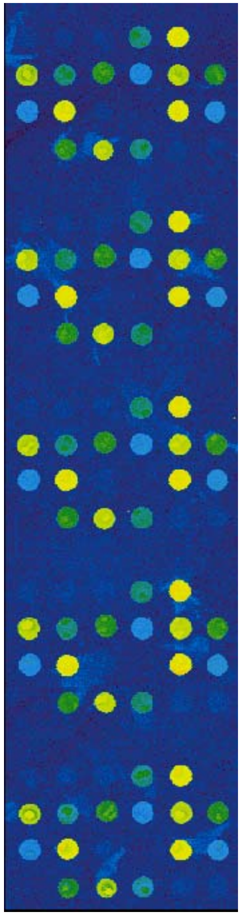


DNA Hybridisation: fluorescent detection

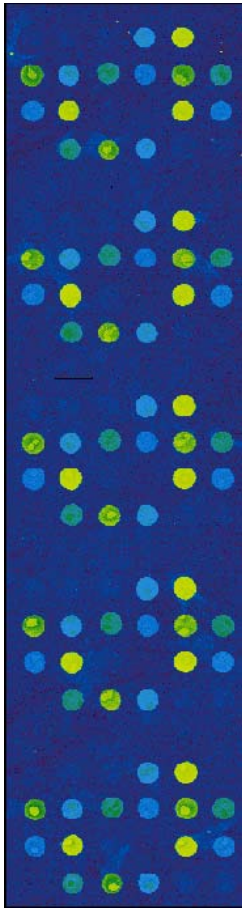
1-st hyb



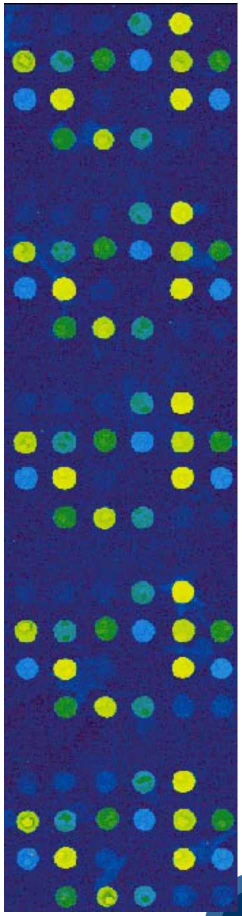
2.nd hyb



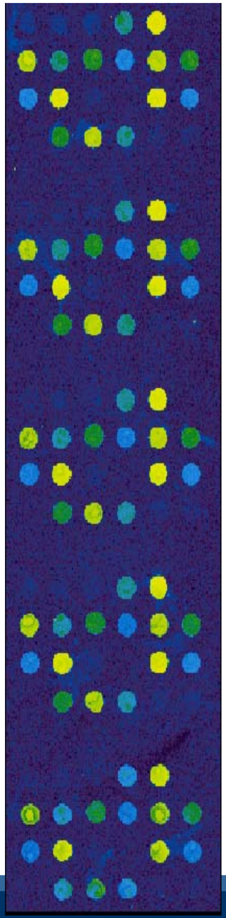
3-rd hyb.



4-th hyb.



5-th hyb.



Conclusions

•Polymers are becoming very promising materials used for the fabrication of BioMEMS having advantageous properties of low cost, easy processability and wide range of material characteristics.

•BIOMEMS type devices will revolutionize the diagnostic tests through the development of compact, potentially disposable, automated systems that can be used in clinical laboratory or a POC setting.

Thank you for your attention