MICROFLUIDICS

It is a multidisciplinary field, emerged in the beginning of the 1980s, with practical applications to the design of systems like biosensors in which very small volumes of fluids is used. It is used in the development of inkjet print-heads, DNA chips, lab-on-a-chip technology, etc.

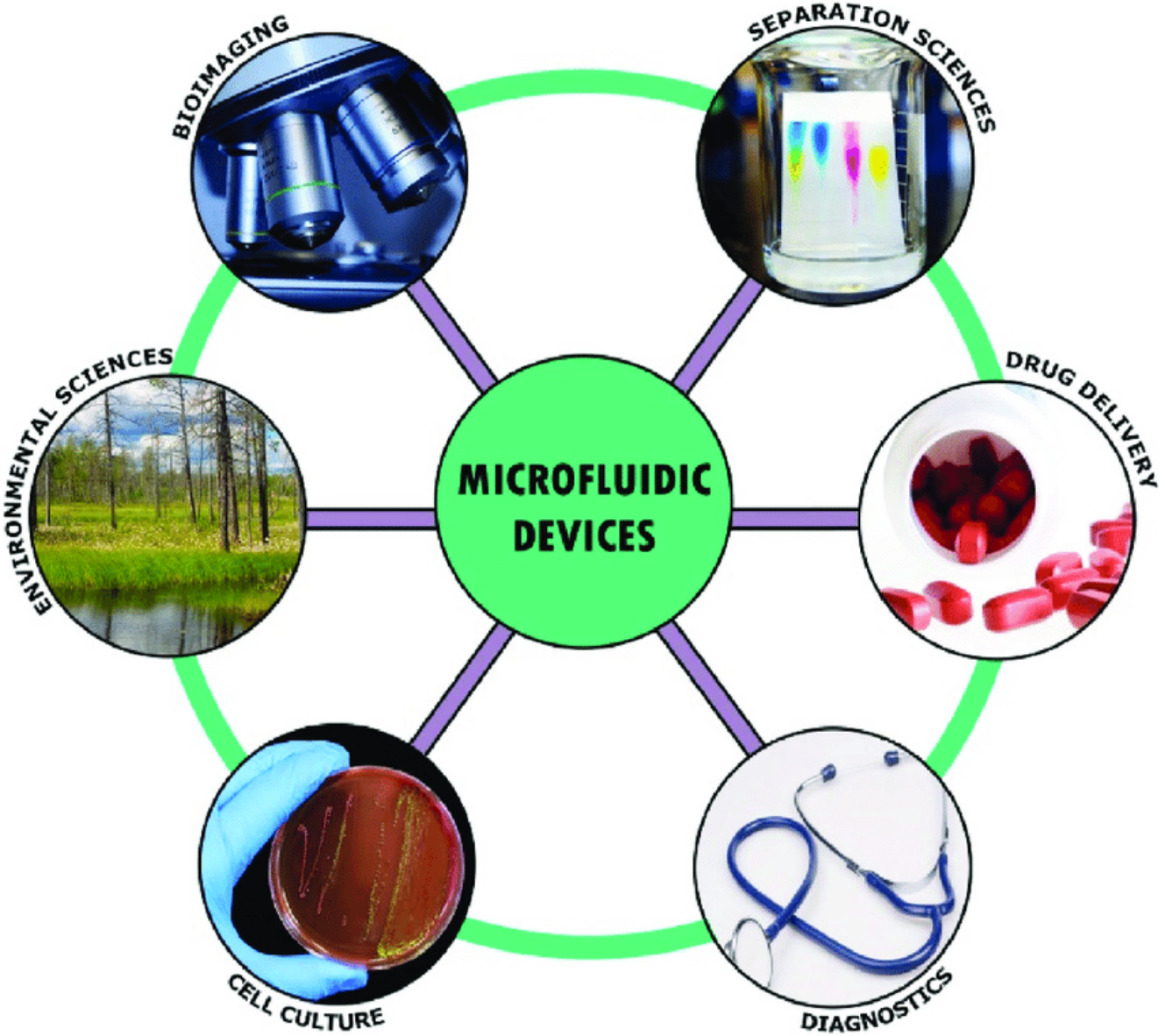
A lab-on-a-chip (LOC) is a device that integrates one or several laboratory functions on a single chip of only millimeters to a few square centimeters in size. It deals with the handling of extremely small fluid volumes down to less than pico liters for analysis purposes.

Another term "Micro Total Analysis Systems" (μTAS) is dedicated to the integration of the total sequence of lab processes to perform chemical analysis. The term "Lab-on-a-Chip" was introduced later on when it turned out that μTAS technologies were more widely applicable than only for analysis purposes.

Microfluidics, help in developing lab-on-a-chip, integrate analytical process like sampling, sample treatment, reaction, detection and data analysis onto a micrometer-scale chip.

Microfluidics is currently under the spotlight for medical diagnostics and many other bio-analysis as its physical size manifested numerous advantages over lab-based devices.

Smaller analysis platform means low consumption of reagent and power and of course the portability, and hence low cost.


MICROFLUIDIC DEVICES
BIOIMAGING
SEPARATION SCIENCES
ENVIRONMENTAL SCIENCES
DRUG DELIVERY
CELL CULTURE
DIAGNOSTICS

A fluid can be defined as a material that deforms continually under shear stress or more specifically, with the application of an external force attempting to displace part of the fluid elements at boundary layer (i.e. surface).

The fluids we encounter in everyday life are gases and liquids. Other complex systems consisting of several phases can also be classified as fluids (blood, suspensions, etc.).

Fluid characteristics

Flow characteristics

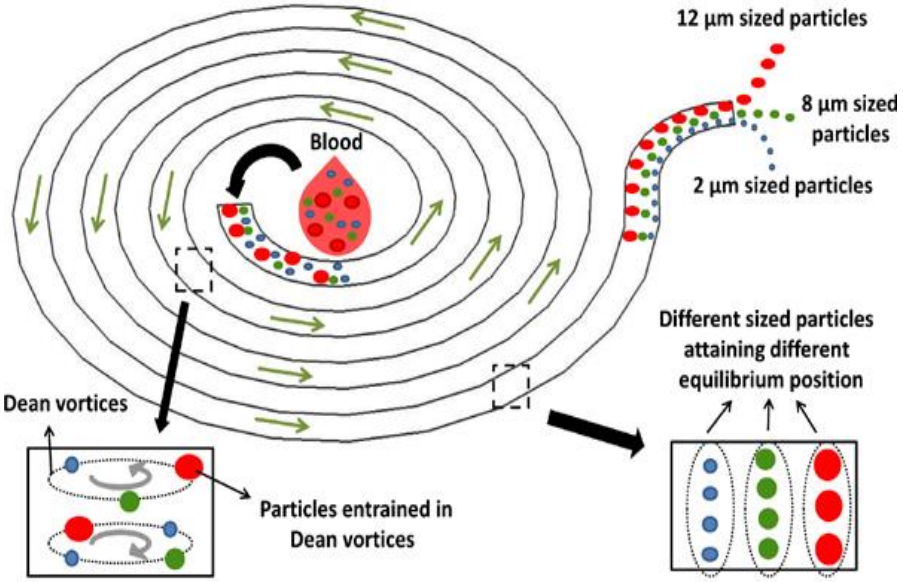
TRANSPORT MECHANISMS

Fluid characteristics:

The three important parameters characterizing a liquid are its density, ρ, pressure, *P*, and viscosity, η.
The density is defined as the mass, *m*, per unit volume, *V*.

Pressure in the liquid only depends on the depth (i.e. pressure increases when going from the surface to the bottom). But in planar microsystems with channel depths of micrometer range, pressure differences because of different depths can be ignored.

Microchannels have inlets and outlets, so any pressure difference induced externally at these openings is transmitted to the liquid, thereby inducing the liquid to flow.



Design and Computational Modeling of Spiral Microfluidic Channel.

Viscosity is the resistance to the effort to set the liquid into motion.

The coefficient of viscosity, η, can then be defined as the ratio of the shear stress to the shear rate:

$$\eta = \frac{F / A}{v / l}$$

The coefficient of viscosity, η, can then be defined as the ratio of the shear stress to the shear rate. force, *F*, area, *A*, velocity, *v*, thickness *l.*

Newtonian fluid : The shear stress of a fluid is directly proportional to the velocity gradient. For example, water, oil, glycerin are Newtonian fluids.

Non-Newtonian fluid: the viscosity changes with the shear stress; example : blood. The viscosity of liquids usually decreases with increased temperature.

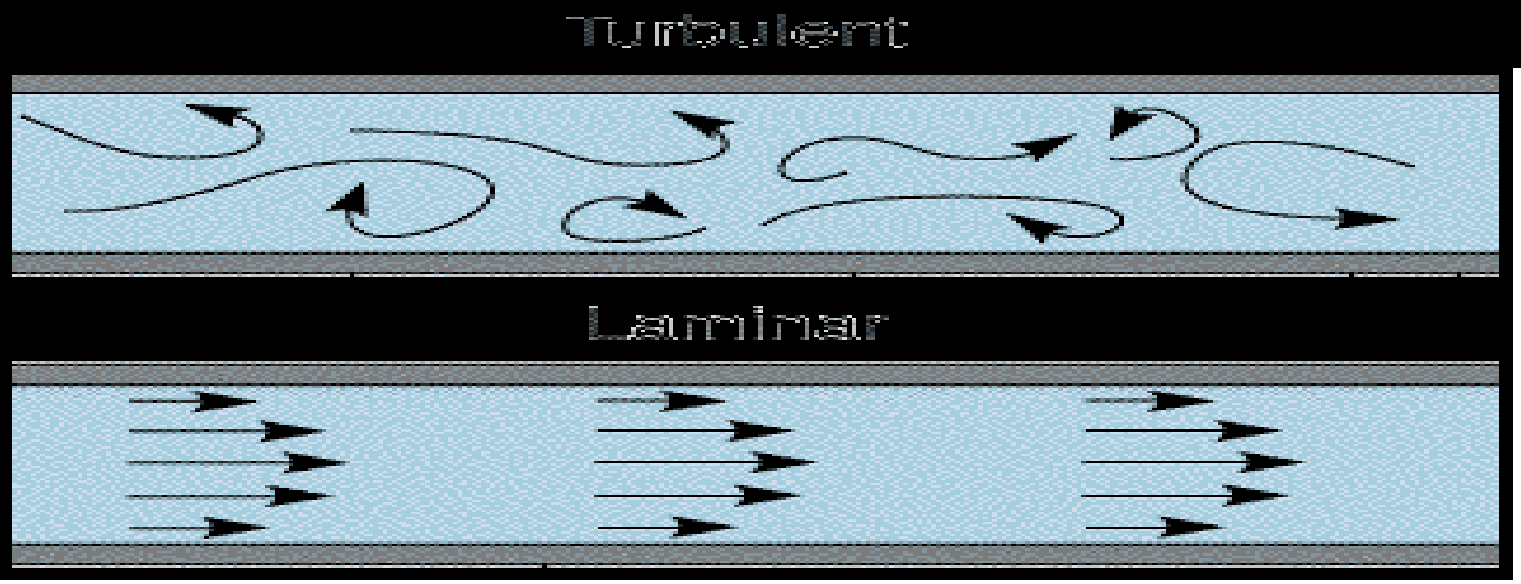
The use of non-Newtonian fluids as compared to Newtonian fluids is more promising for the development of microfluidics devices.
For example: There can be turbulent-like instabilities in flows. These "elastic turbulence" could be generated in microfluidic channels to act as efficient mixers

Flow characteristics

The fluid flow conditions in microsystems can be determined based on the relation between the magnitudes of the **inertial and viscous** forces. Expression below is the dimensionless Reynolds number, *Re*:

$$\mathrm{Re} = \frac{\rho d v}{\eta}$$

Where *d* is the typical length scale (e.g. diameter or channel depth), and *v* is the average velocity of the moving liquid.



turbulent flow

laminar flow

From an empirical studies:

Re>2300 correspond to *turbulent flow*. Under this regime, inertial forces are dominant.

Re< 2000 is referred to as the *laminar flow* regime.

From the equation it is obvious that low Re attained at lower velocities, smaller dimensions, smaller densities, or higher viscosities. Therefore, in microchannels, laminar flow regime is dominant due to the small dimensions, where the velocities of flow would have to exceed the speed of sound before the onset of turbulence.

$$\mathrm{Re} = \frac{\rho d v}{\eta}$$

The fluidic resistance increases drastically as the channel dimensions are reduced. Whish can be explain by using ***Poiseuille (or Hagen-Poiseuille) flow equation.***

For a capillary with cylindrical cross-section the volume flow, *Q*:

$$Q = \frac{\Delta V}{t} = \frac{\pi R^4}{8\eta L}\Delta P$$

Where R is the radius of the capillary, L is its length and ΔP is the pressure drop across this length (also called hydraulic pressure).

The term, $8\eta L/\pi R^4$ is also called the fluidic resistance. The dependency on $1/R^4$ implies that the fluidic resistance increases drastically as the channel dimensions are reduced.

Consequently, higher pressure drops are necessary to move liquid through smaller conduits/micro-channels.

TRANSPORT MECHANISMS

Generally, there are two different types of transport in microfluidic systems – directed transport and statistical transport.

Directed transport is controlled by exerting work on the fluid. The work is often generated mechanically by a pump or electrically by a voltage.
Flow that is driven mechanically is called **pressure-driven flow**, and flow driven by a voltage is called **electro-osmotic flow**.

Statistical transport, on the other hand, is an entropy-driven transport, meaning transport only occurs if, after transport, the fluid is more disordered than before. This statistical transport is called diffusion.

Peclét number

To evaluate the various flow situations, we can examine the ratio between the mass transport due to directed flow and that of diffusion. This ratio is a dimensionless number, the Peclét number (Pe):

$$P_e = \frac{vd}{D}$$

Where *d* is a characteristic length of the microfluidic system. D, diffusion coefficient **(m^2/s)**.

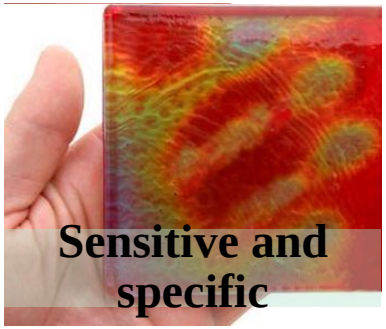
If the Peclét **number < 1, then diffusion dominates** the microfluidic flow, and directed flow is secondary importance.

If the Peclét **number is >1, then the molecules of interest flow mainly according to the externally applied driving force**, and diffusion has only a minor influence.

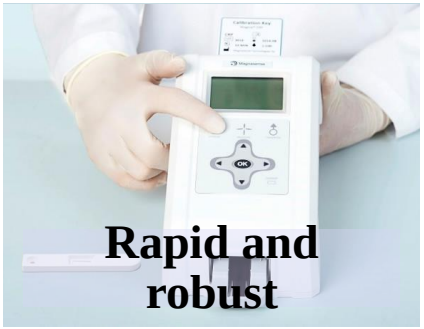
In microsystems, the flow velocities are usually comparatively small. The crucial variable that determines the Peclét number is therefore the channel lengths *d*. For long enough channels, the Peclét number is always larger than 1, and the flow is thus directed.

Affordable,
Sensitive,
Specific,
User-friendly,
Rapid and robust,
Equipment free and
Deliverable to end-users


Affordable


Sensitive and specific

User friendly

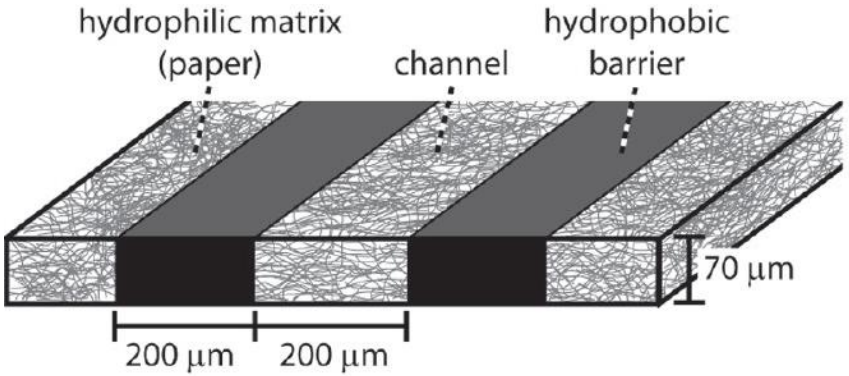

Rapid and robust

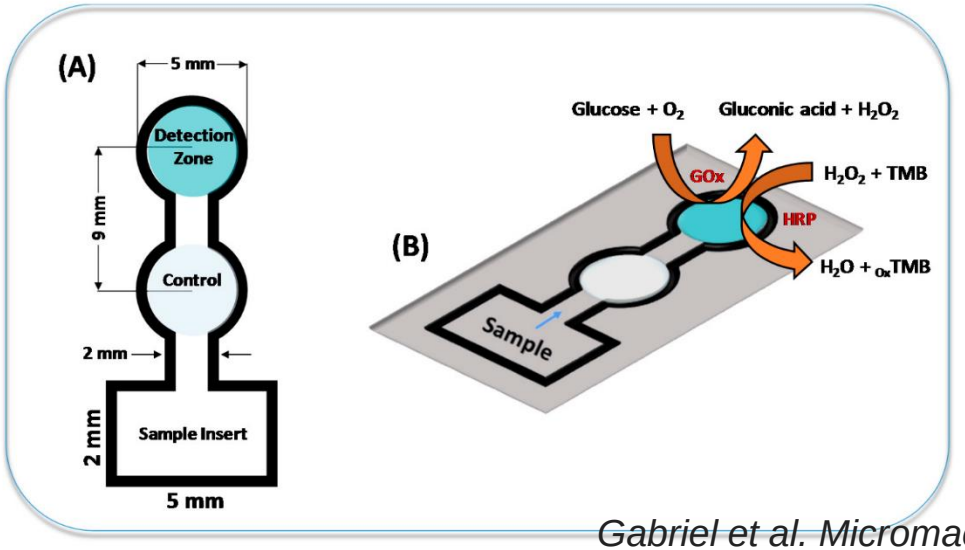
Equipment free

Deliverable to end users

Chromatographic Paper as diagnostic /detection platform complies well ASSURED CRITERIA:

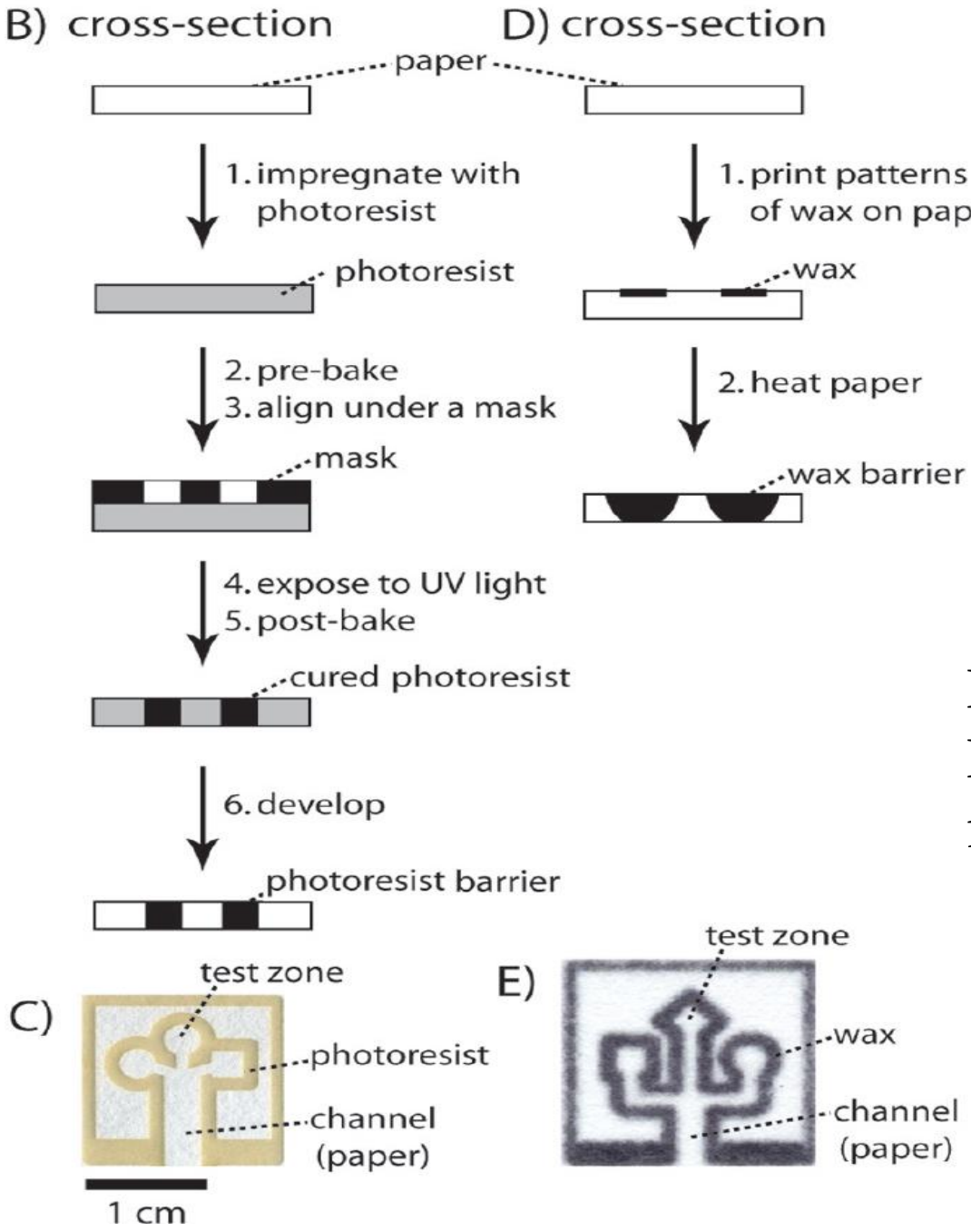
- Available and inexpensive
- Passive transport of fluids
- Thin, lightweight easy to stack, store, and transport
- Compatible with biological samples
- Easy fictionalization
- Good medium for colorimetric tests
- Can be disposed of by incineration
- compatible with a host of existing printing technologies
- Available in a wide range of highly engineered





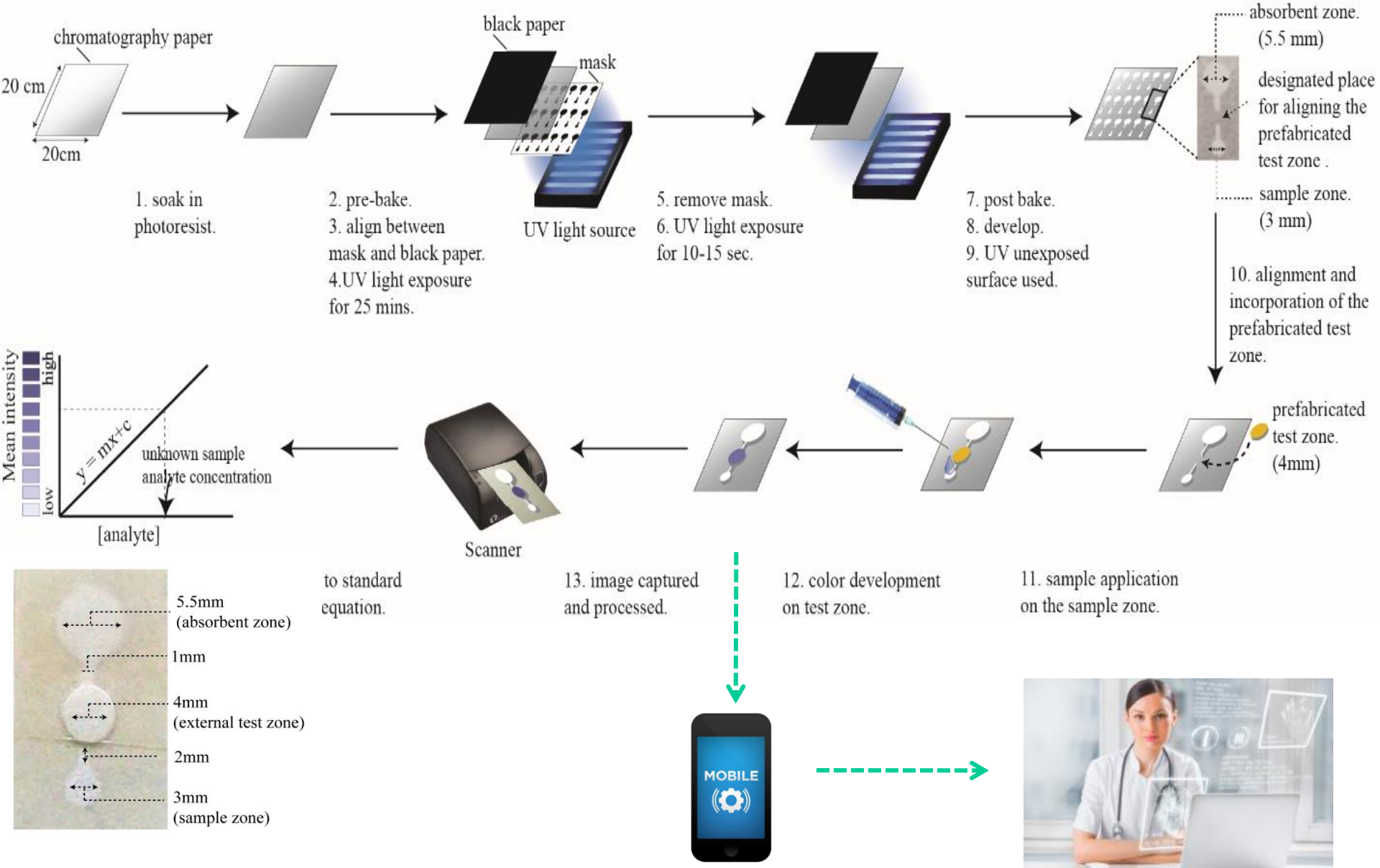
Gabriel et al. Micromachines **2017**, *8*(4), 104

Method (References)	Channel (μm)	Barrier (μm)	Advantages	Disadvantages
Photolithography (10)	186 ± 13	248 ± 13	Can pattern a wide variety of papers up to 360 μm in width.	Hydrophilic areas exposed to polymers and solvents.
Plotting (30)	~1000[a]	~1000[a]	Hydrophilic channels not exposed to polymers or solvents; hydrophobic barriers are flexible.	Requires a customized plotter.
Inkjet etching (31)	420 ± 50	—[b]	Reagents can be inkjet printed into the test zones using the printer.	Requires a customized inkjet printer; hydrophilic areas exposed to polymers and solvents.
Plasma etching (32)	~1500[a]	—[b]	Useful for laboratories equipped with a plasma cleaner that wish to make many replicates of a few simple patterns.	Hydrophilic areas exposed to polymers and solvents; metal masks must be made for each pattern; cannot produce arrays of free-standing hydrophobic patterns.
Cutting (29)	1000[b]	700[b]	Hydrophilic channels not exposed to polymers or solvents.	Devices must be encased in tape; cannot produce arrays of free-standing hydrophilic patterns.
Wax printing (33,34)	561 ± 45	850 ± 50	Rapid (~5 minutes); requires only a commercially available printer and hot plate; hydrophilic channels not exposed to polymers or solvents.	The design of the patterns must account for the spreading of the wax in the paper.



B: Photolithography and
D: Wax printing on paper
for creating micro channels

Fabrication of microfluidic devices in paper using modified FLASH (Fast Lithographic Activation of Sheets)

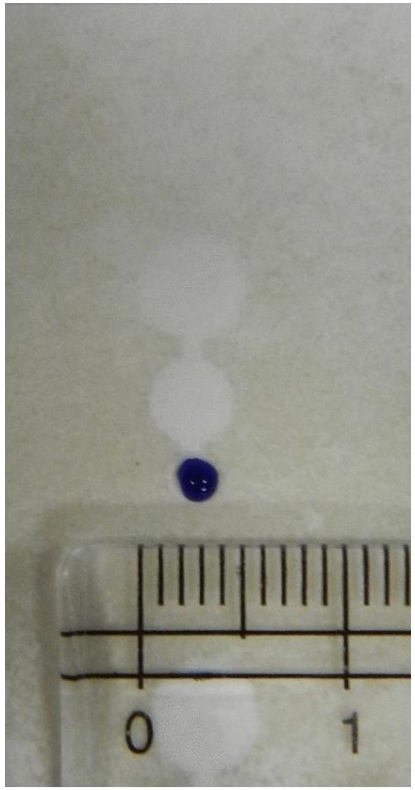


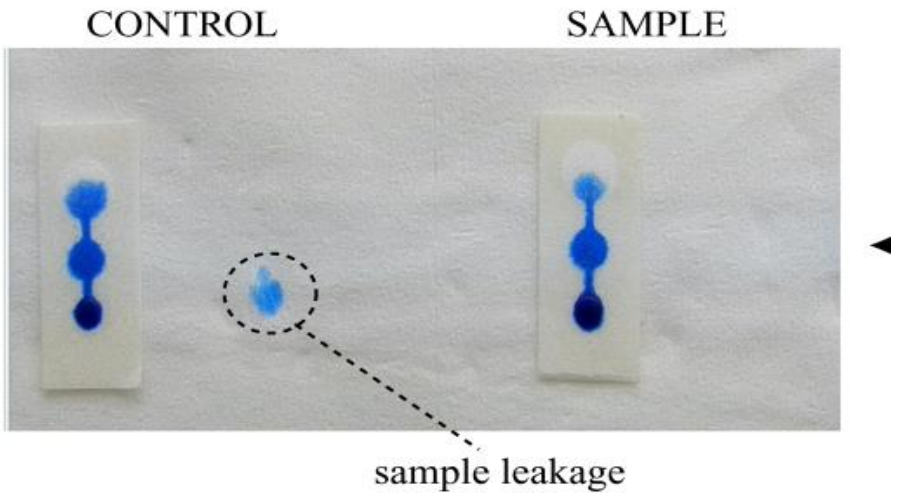
Kakoti, Siddiqui, Goswami* ***Biomicrofluidics*** 9, 1-11 (2015).

Paper based microfluidic device with leak proof sensor surface and prefabricated test zone

ESI 3.wmv

ESI 1.wmv





- Detection time: ~20s respectively.
- Sample volume: ~ 7 µl
- Leak proof
- Prefabricated test zone: prevent sample and reagent loss, facilitate transport, storage, easy loading of reagent etc

Goswami & group: Patent application no.: 1126/KOL/2014.

Patent application no. 1365/KOL/2014.