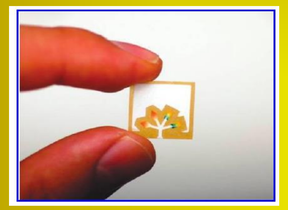
Advances in Paper-Based Microfluidic Devices for Energy and Medical Applications

Flavia Cavalcanti and Nastaran Hashemi

Department of Mechanical Engineering, Iowa State University, Ames, IA, 50011

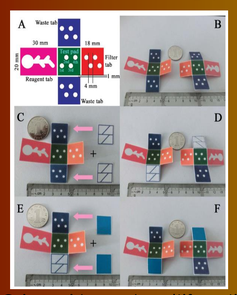
Introduction

The purpose of this research is to study the potential of paper-based microfluidic devices (micro-PADs) in the medical and energy field. Now a days the demand for an efficient, cheap, highly accessible, and eco-friendly device has increased exponentially. Usually the problems that come about with today's devices is its fabrication costs (highly expensive limiting their accessibility to developing economies) and their detrimental side effects to the environment. As such, research related to paper -based microfluidic devices is drawing an increasing amount of attention as paper is shown to be an exemplary substrate for such devices. It is easily accessible, inexpensive, and its wicking capabilities, allows the movement of fluids within the device without the use of external pumps,

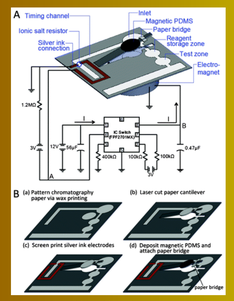


Fabrication Methods

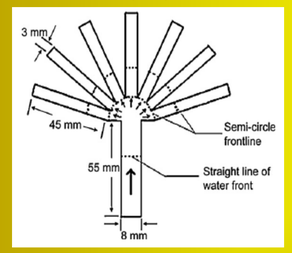
There are about seven general fabrication methods for the fabrication of paper-based microfluidic devices, these include: photolithography, plotting, inkjet printing, plasma etching, flexographic printing, wax printing, and cutting patterns of channels from a sheet of paper.



3D Origami-based multifunction integrated immunodevice



Magnetic timing valves for fluid control



Tree- Shaped paper strip with self-calibration

Medical Applications

Paper-based microfluidic devices have a large potential in the area of medical diagnostics, as it is capable of providing an accurate and cheap diagnostic for developing countries.Their fabrication process is simple, not requiring extensive training nor complex equipment. The Whitesides group introduced POCKET, a portable microfluidic-based system, which has the ability to run quantitive immunoassays with the same sensitivity as benchtop ELISAs, but several times faster, and at a fraction of the price. Other research groups have shown that the micro-PADs have potential in the area of HIV rapid tests, cancer and tumor diagnosis, detection of DNA (study of hereditary diseases), among others...

Table 1: Medical Applications

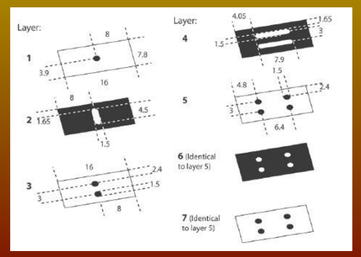
Author/ Group	Fabrication Method	Type of Assays	Objective	Advantages	Disadvantages
Andres W. Martinez, et al. Emanuel Carrilho	Photolithography	Diagnostic Assays	Develop low cost medical assays for developing countries.	Portable, cheap, fast and accurate results, comparable to bench top ELISAs.	Project suffered from the light scattering from the paper and from non-uniform wicking rate of the paper.
Whitesides Group	Photolithography	General health care and environmental assays.	New method of fabricaton by generating hydrophilic-hydrophobic contrast on the paper's surface.	Allows the precise insertion of biomolecules and indicator reagents, developing biochemical sensing zones.	N/A
Wang S, et al.	Wax printing	*Chemiluminescence* immunoassay, cancer diagnosis	3D microPAD immunodevice, with multiplexed CL detections, blood plasma separation from whole blood samples, and automated rinse steps.	Excellent analytical performane in the detection of tumor markers. Capable of performing multianalyte assays.	N/A
Whitesides group	modified x,y plotter used for printing a solution of hydrophobic polymer (PDMS)	General Diagnosis. The device showed accurate results in assays for the presence of glucose and proteins.	The development of cheaper methods to define hydrophilic channels in paper	Does not require the expensive reagents nor the cleanrooms needed in photoligthography. Showed good results in a wide variety of papers.	Still relies on computer aided design and reagents which are not widely available.

Table 2 : Energy Field

Author	Application	Advantages	Disadvantages
Liangbing Hu, et al.	Energy storage (highly conductive paper)	Use of paper significantly lowers the cost of the final product, while also improving adhesion, simplifying the coating process.	N/A
Victor L. Pushparaj, et al.	Flexible energy storage devices based on naocomposite paper	Sturdy final device, shown to be able to recover from being twisted and bent.	For good results, it may require the use of batteries.
Nicole K. Thom, et al.	“Fluidic Batteries”-energy generation for powering small devices	Capable of generating its own power when a smaple (used to conduct an assay and for powering its components. Device did not show a loss of performance after being left for week to the open air.	N/A
Šeila Selimović, et al.	Self powered microfluidic device	Does not require external equipement, efficient in powering small devices.	May require the use of external energy sources to power on-chip sensors or read-out elements.

Energy Applications

As most of our energy is generated through the use of fossil fuels, a finite an non-environmental friendly energy source, research has begun to intensify in the area of the fabrication of an efficient and inexpensive device for energy generation/storage. Studies have shown that paper has the potential of being made highly conductive with a lowered resistance per square(as low as 1 ohm per square) through the conformal coating of a single-walled nanotube and silver nanowire films. This resulted in a highly conductive paper that can be a very scalable solution for high-performance energy storage devices. Paper is especially ideal for such a process as it readily binds with CNTs, making its fabrication much easier to perform than one using plastic or glass. Such an idea could also be implemented to fuel cell batteries, which can be composed of up to twenty Four Batteries. In this figure, an expanded view of the Two-battery cell is depicted.
Size ~16mm wide x 7.8 mm
Long. The components are: Salt bridges (4th layer) and the Electrolytes (6th).
Al and Ag(7th layer), Covered by copper tape, acting like and electrode and connection between the two cells.



Conclusions

Technologies related to disease diagnostics and energy storage would benefit greatly from further research in the area of paper-based microfluidic devices. Using paper as a substrate has several advantages as this material is very inexpensive, is easily stored, is highly accessible, and produces devices which are flexible and easily manufactured, while also delivering very accurate results. Such devices would be highly useful in developing economies and remote countries, as its simple fabrication methods and convenient portability, would increase their access to these remote locations.In the energy field, the use of galvanic cells are beginning to show a lot of potential, as their use would allow the fabrication of a self-powered micro-PAD. The microfluidic devices also demonstrated exceptional ability in recognizing tumor markers, further exemplifying its potential use in biological assays.

Aknwoledgements

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References

1) Liangbing Hu *et al*., “Highly conductive paper for energy-storage devices”, PNAS, 06 (51) 21490-21494, 2009.
2) Deidre Sechi, Shayla M. Carlin, and Nastaran Hashemi, "A 3-D Diagnostic Device Based on Paper-Based Microfluidics“, Iowa EPSCoR All Hands Meeting, Iowa City, IA, July 31, 2012.
3) Nicole K. Thom, Kimy Yeung, Marley B. Pilliona, and Scott T. Phillips “Fluidic batteries” as low-cost sources of power in paper-based microfluidic devices”, Lab Chip, 12, 1768-1770, 2012.