Paper-based Microfluidics: Alternative Analytical Devices

Orawon Chailapakul [1,2,*]

[1]Electrochemistry and Optical Spectroscopy Research Unit.
[2]Department of Chemistry , Faculty of Science,
Chulalongkorn University, Phyathai road, Bangkok 10330, Thailand
Email: corawon@chula.ac.th and chaorawon@yahoo.com

Currently, the economic crisis has become increasingly important all over the world; therefore, low cost, high quality devices for analytical chemistry are becoming more widely needed. Paper-based microfluidic devices are emerging as a new technology that provides many interesting benefits and applications in diagnostics, life sciences, food safety and environmental monitoring. Using paper as the primary material for devices provides several advantages, including low cost, light weight, easy storage, and portability.

Paper is typically made of cellulose and can be chemically modified to incorporate a wide variety of functional groups that covalently bind to small molecules. Because paper is flammable, paper-based devices can be incinerated after use. Paper has been used extensively in analytical and clinical chemistry methods including dipsticks, litmus paper and lateral-flow strip devices. Microfluidic systems can be devised in a way that incorporates with paper-based technology so that they have more functions and advanced applications.

Paper-based microfluidic devices are inexpensive and were designed specifically for use in developing countries. The first use of this type of paper device was from Whitesides's group [1, 2], which focused on diagnostic devices. These diagnostic devices were constructed from patterned paper, which are a new platform designed for affordable, sensitive, specific, user-friendly, rapid and robust, equipment free and deliverable to end-users. These tools are faster, less expensive, and highly multiplexed compared to current diagnostic tests. They also require very small volume of fluid, with no requirement for pumps or power because fluid movement is controlled by capillarity and evaporation. There are several methods that can be used to fabricate paper-based microfluidics, including photolithography, plotting detecting, wax printing, inkjet etching, plasma etching and cutting. All of these techniques require that the paper be constructed with hydrophilic channels that are isolated by hydrophobic barriers, which extend through the entire thickness of the paper. The advantage of photolithography is that it generates very small hydrophobic barriers and very tiny hydrophilic channels. However, photolithography requires the use of organic solvents to remove unused photoresist and leaves a layer of hydrophobic organic scum on the paper. Solid wax printing is quite popular due to the short amount of time required for fabrication. This method provides hydrophilic channels and test zones that are never exposed to chemicals, so reaction zones do no become contaminated. Wax printing provides moderate feature resolution.

A more complex device design may allow for additional sample analysis [2]. Two examples of this are paper-based microzone plates constructed from paper and three-dimensional (3D) paper-based microfluidics designed with an array or layered footprint. The construction of a microzone plate in which the wells are represented by an array of circular or square test zones in a plate has been proposed. These devices were designed to be useful for laboratories in developing countries and for high-volume applications in the developed world. The cost of paper microzone plates is low, and the plates are easy to stack, store and transport; furthermore, the paper plates are compatible with the technology developed for plastic plates. The proposed device offers new types of management for collection and transport of data from offsite locations to the laboratory. Three-dimensional channels can be fabricated by stacking alternating layers of array-patterned paper and double-sided adhesive tape. An electrochemiluminescence immunoassay was introduced into the microfluidic 3D paper-based analytical device by screen-printing electrodes directly onto paper, four tumor markers were identified in real clinical serum samples [3].

Paper-based microfluidic devices can be used for qualitative and quantitative studies [1-4]. These devices, when combined with colorimetric assays, are typically suitable for rapid screening because they are easily read by the human eye. Using other types of detection and data output, such as a camera and scanner, can standardize the method and provide reproducible quantitative results. The intensity of the color that develops in each test zone is a function of the concentration of the analytes, which enables a quantitative assessment of the analytes. Moreover, we can use multiple indicators for a single analyte with paper-based microfluidic devices in an effort to improve the ability to visually discriminate between analyte concentrations. Electrochemistry on paper-based microfluidic device can provide a different benefit. Quantitative multiplex results can be obtained. Commercial electrochemical readers can also be integrated with paper-based microfluidic devices. To obtain two different outputs on one piece of paper, a novel device combining electrochemical and colorimetric detection was proposed for the rapid screening of Au(III) in the presence of it common interference element, Fe(III) [4]. This technique can be used with industrial waste solutions. The simple and rapid procedure with dual detection in paper-based microfluidic devices makes the approach especially attractive for agricultural, water, food, and environmental samples. The excellent results that have been obtained indicate that paper-based microfluidic devices have a promising future.

References

[1] A.W. Martinez, S.T. Phillips, E. Carrilho, S.W. Thomas, H. Sindi, G. M. Whitesides Anal Chem 80, 3699 (2008)
[2] A.W. Martinez, S.T. Phillips, G.M. Whitesides, E. Carrilho Anal Chem 82, 3 (2010)
[3] L. Ge, J. Yan, X. Song, M. YAN, S. Ge, J. Yu Biomaterials. 33, 1024 (2012)
[4] A. Apilux, W. Dungchai, W. Siangproh, N. Praphairaksit, C.S. Henry, O. Chailapakul Anal Chem 82, 1727 (2010)