Vol. 2 No. 2, Dec. 2022

FUAM Journal of Pure and Applied Science

Available online at
www.fuamjpas.org.ng

An official Publication of
College of Science
Joseph Sarwuan Tarka University,
Makurdi.

FUAM Journal of Pure and Applied Science
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https://fuamjpas.org.ng/
Vol.2. No. 2. December, 2022

Sustainable Analytical Approaches to the Applications of Polymeric Microfluidic Sensors for Chemical and Biochemical Systems.

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Received: 10/09/2022 **Accepted**: 20/10/2022 **Published online**: 04/11/2022

Abstract

The concept of polymer microfluidic and its application to divers' forms of sensing have drawn enormous interest in the field of engineering and applied sciences. However, this technical article aims to increase reliability of research on the capability and precision of micro fluidic sensors (MFS) through a Meta analytical concept of some recent advance concepts with ways of efficient fabrication. It is necessary to explore the technicalities in this field through scientific inquiries, new methods of fabrication and essential ways to optimize the state-of-art MFS. This report aims to add to knowledge; hence all the choice of papers herein were carefully selected for the need of a clear methodological design on micro-fabrication techniques to avoid repetition of process design.

Keywords: Microfluidic; dry film resist; developer; substrate; sensor; sustainable.

Introduction

The world is faced with a growing challenge of environmental pollution and public health concerns these have raised the need for a sophisticated systems of detection and amelioration of the causes of the menace, it is however paramount to investigate ways to develop a field of research that will provide adequate simple solutions. For these reasons and many more the field of analytical chemistry and its instrumentation, microsystem technology has been most remarkable, in the development of the microfluidics. This concept of Microfluidics leads to on-site and real-time monitoring, high-speed and high-throughput analysis, resulting from a small sample volume, rapid operation procedure and a small measuring device space [1,2]. New developments in research fields as microelectronics, Environmental molecular biology, optical and computer technologies have pioneered and progressed in the miniaturization of Detection system which deliver a swift outcome with simple methods in less time [3,4].

General applications of microfluidic devices

Microfluidic devices have been used in varieties of chemical and biochemical analytes [5-8], biomedical applications [9,10], Applications in electrochemical sensing and multi-step molecular assays [11], Blood plasma separation [4], Complex fluid handling [12], Magnetic

nanoparticle clean-up [9], Multifuntional particles [13], liquid interfacial tension measurement [14], cyanobacterial hervesting [15].2.0 Material Substrates employed for the Fabrication of microfluidics

Microfluidic devices have been fabricated majorly from glass substrate [16-21], paper-based substrate [22-24], Graphene [25], silicon, quartz, and many more types of polymeric materials [26-33]. A polymeric material that includes poly methylmethacrylate [27-30, 34] and poly (dimethylsiloxane) (PDMS) [31,33-35], Numerous nanoparticles and micro lens materials as polymer [36-39], silica [35,40], diamond, and sol-gel [41,42], Collagen sources [43]. The main challenges faced by many experiments are the fabrication involving high-priced charges and complex processes and equipment [44]. But sustainable Microfluidics has great potential for large-scale fabrication of disposable analytical systems, due to their ease of fabrication, low cost, and great versatility [45], however, a sustainable material and process is encouraged beyound doubt to put in check the issues of ecotoxicity which should never be left unattended [46], see Figure 1.

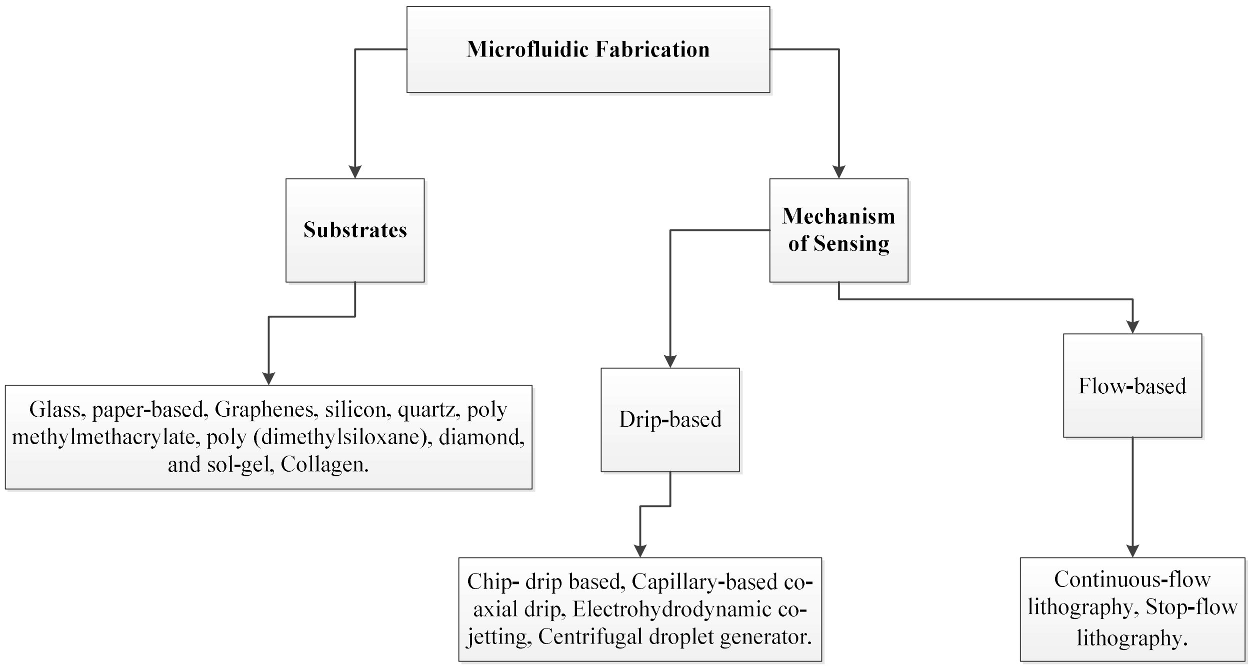

Figure 1: Substrates for the fabrication of microfluidic devices and mechanisms of sensing.

Microfluidic sensors are the future of sensing analytes in chemical and biochemical systems, this is because the technique requires only minimal amount of resource such as the analyte and material space to be achieved by strategies that are highly flexible, inexpensive with high throughput. The need to understand the substrates and various methods of fabricating optimal microfluidics, while keeping cost low and sustainable is the goal and emphasies of this report.

Abdul et al. [1], utilised poly dimethyl-siloxane to fabricate microfluidic able to process and analyses refractive index. Dimension of the refractive index sensor was 7.5 cm in length and 2 cm in width. Characterization was achieved with air condition and solution concentration from 0.1 M to 1 M. A miniscule volume of 10 µL analyte is required for high performance refractive index measurement. Microfluidic sensors are highly significant in the fields of genetic and proteomic analysis, drug screening, clinical diagnosis and much more. As demonstrated by Basant [4], while fabricating a paper microfluidic sensor for blood-plasma separation. A Whatman filter paper (2.5 cm diameter), permanent magnet, and glass slide were required to test a 10 µL of blood sample.

Kewen et al. [13], performed immunoassay on microfluidic system that incorporated a centrifugal platform. The immunoassay analysis of targeted antigen detection was successful and the report proved that microfluidic incorporation with centrifugal platform can be potentially useful for a wide variety of biological/medical applications.

Processes and methods adopted for Microfluidic channel fabrication

For polymeric devices, a number of processing techniques can be used to create the required network of microchannels, and all of these approaches have been employed and examined for use in the fabrication of polymeric microfluidic devices including photolithography, wire imprinting, hot embossing, powder ablation, laser photoablation, casting, and injection molding [35-39,47,48], versatile plug microvalve process using PDMS [49]. Nowadays, disposable plastic-based substrates have become extremely popular for use in microfluidic applications because of their ease of fabrication and cost effectiveness [50].

Photoresist

Photoresist is a photosensitive material employed by the microelectronics industry to design a patterned coating on a substrate surface. The as designed pattern is then transferred from a photomask to the wafer by photolithography process [51-55].

Types of photoresists

Three types of photoresists are in use, specifically; viz, liquid photoresist, dry film, and SU-8 photo epoxy. Every single photoresist has its merits and demerits conditional on the type of needed application.

(i) Liquid Photoresist.

The Liquid photoresists has found more application in the microelectronics industry. The resist comprises three basic elements: a resin or base material, a photo active compound, and a solvent which regulates the paramount mechanical properties as the viscosity [56,57]. These Liquid resists are applied to the wafer by a spin coating process in which the wafer, along with the resist, is rotated at high speed to form a uniform coating. The liquid resists employed in large-volume inner layer production have essentially proved themselves both technologically and economically, especially when their use has been integrated into a highly automated plant [58,59]. The failure of liquid resists to cover holes is disadvantageous in certain applications [60]. Hence, dry film resists are used to bridge this inadequacy [61].

(ii) Dry film Photolithography

The New approach to dry film photolithography applies a means or a technique that can be performed simply and continuously without the requirement for a restrictive and expensive conventional clean room operating environment [62]. A process that can be performed without the use of a spin coating apparatus and does not include time-consuming baking procedures. It is an alternative to the use of a SU-8 liquid type photoresist. Thus, the dry film photolithographic technique could be used for the rapid integration of prototype microchips. Miniaturized microfluidic devices in which features of photolithographic technologies and capillary electrophoresis (CE) are combined, have recently become a major focus of interest for the preparation of micro total analysis systems (µTAS, also known as lab-on-a-chip systems) [63]. Sudarsan and Ugaz demonstrated the use of printed circuit technology for the fabrication of plastic-based microfluidic devices [40]. Do-Lago *et al.* [64], establish a dry process for the production of microfluidic devices based on a xerographic process and the lamination of laser-printed polyester films. Dry film resists (DFRs) were originally developed 30 years ago for printed circuit board (PCB) fabrication. Although application for MEMS (Microelectro-mechanical systems) fabrication is uncommon, DFRs have been reported to be useful for the fabrication of electroplating molds, for sealing fluidic channels and as a mask for powder blasting of microchannels [65]. The overall set up cost for dry film processing is significantly lower than for liquid resists [66].

(iii) SU-8 Epoxy Based Photoresist.

SU-8 is a negative, epoxy type, near-UV photoresist that was originally developed and patented by IBM in 1989. Due to its low optical absorption in the UV range, this photoresist can form thick films (40-200 Qm). The SU-8 resist contains a few percent of photoacid generator that will produce a strong acid when a photochemical transformation takes place upon absorption of a photon. This photoacid acts as a catalyst in the subsequent crosslinking reaction that takes place during post exposure bake (PEB), that is, crosslinking occurs only in regions that contains acid catalyst and mainly during PEB [67-69]. However, a lot of photoresists generally are seen to be sacrificial materials, liquid-type negative photoresists, example, Typical SU-8 processing consists of spin coating, exposure, polymerization and development. The SU-8 is spin coated onto a substrate and soft baked in order to evaporate the solvent. In the exposure step the SU-8 film is exposed to near-UV light through a mask. Once initiated by the exposure, the polymerization process is assisted by thermal energy in the post-exposure bake, or PEB. Finally, the unexposed SU-8 is dissolved by organic solvent, leaving only the cross-linked SU-8 structures on the substrate [70-72]. It has been found that process steps like soft bake, exposure, post-exposure bake and development have strong influence in the internal stress of the SU-8 resist structures, resolution and aspect ratio [73], SU-8, is also used to fabricate microchannels in micro fluidic chips [41,42,44,74]. This is important as a structural component of a microfluidic device [75].

Advantages of the dry film photoresist over the Liquid photoresist

Compared to a liquid photoresist, the dry film photoresist offers a variety of advantages, including good conformability, excellent adhesion to other substrates, uniform distribution, no liquid handling, low exposure energy, and short processing time [76]. Furthermore, a commercially available dry film photoresist itself has a uniform thickness, since it is used for constructing micro channels with a specified depth. A report on the fabrication and application of a new plastic microchip that features a negative dry film photoresist (an acrylate-based photopolymer) as a structural material laminated in a PMMA sheet was conducted successfully by Tsai and team of researchers [63]. Off-channel amperometry detection was employed to evaluate the performance of the dry film photoresist-based microchip. A platinum wire electrode serving as a decoupler along with a copper working electrode, which was incorporated into the bottom PDMS sheet. Catechol was used to demonstrate the performance of the microchip capillary electrophoresis (CE) with an amperometry detector.

Advancement in Novel micro fluidics and 3-D Printing
Phurpa *et al* [77], reported on 3D printing of integrated microfluidic platforms containing microchannels and embedded sensing electrodes for capacitively coupled contactless conductivity detection (C^4D). The achieved results exhibited an exponential correlation with the data obtained by optical measurements. Kyuyoung *et al.,* [78], reported a new method to directly fabricate 3D multiaxial force sensor using fused deposition modeling (FDM) 3D printing of functionalized nanocomposite filaments. The 3D-printed multiaxial force sensor could detect the sub-millimeter scale deflection and its corresponding force on each axis. its customizability, rapid manufacturing, and economic feasibility, this manufacturing approach allows direct fabrication of multiaxial sensors without additional assembly or integration processes. Dong *et al.* [77], reported a novel 3D-printed hybrid finger embedding ECF (electro-conjugate fluid) microp-umps inspired from the hydraulic mechanism of spider legs. Characteristics experiments including output pressure and output flow rate measurement demonstrated that the fabricated ECF micropump had high output power density. The hybrid finger with ECF micropumps was successfullyrealized and its driving experiments validated the feasibility of our concept. Leanne *et al.,* [80], developed a New method to 3D print multiphase materials with tailored microstructures could expand additive manufacturing capabilities to include structures with unprecedented complexity, the device operating parameters, ink properties and printed microstructures structure provide key insights to future designs of actuated print nozzles, which target new microstructures enabled by field-assisted control. Fernandes and colleagues [10] Produced a novel microfluidic cell-culture platform for studying the communication between two different cell populations, a process of critical importance not only in Parkinson Disease (PD), but also in many biological processes, the platform developed in there study affords novel opportunities for the study of the molecular mechanisms involved in PD and other neurodegenerative diseases. Several techniques have been applied in the design and fabrication of effective and high throughput Microfluidics this include microfluidics integrated with temperature actuated microvalve [81], using fused deposition process [82], by electrospinning and picosecond laser pulses [83], Fractal design [84], Photoresist free high grade photolithographic mask design [85], compact design based on wax [86], Free flow electrophoresis [87], cell-laden microgels with channel geometry [88], optimised acoustic energy process that enables the minute usage of sample volume in medical diagnostic applications of microfluidic [89], Electrosprayed cell-laden electrospun hybrid tissue concept [91], Advanced patterning in microfluidic [90].

Microfluidic in sensing

Microfluidic Channel technology allows designers to create small, portable, robust, low-cost, and easy-to-use diagnostic instruments that offer high levels of capability and versatility it is a system that processes or manipulates small amounts of fluids, using channels dimensions of tens to hundreds of micrometers [2,47,91]. The microfluidic system offers so many advantages: the ability to use very small quantities of samples and reagents and high resolution and sensitivity, and small footprints for the analytical device, will decrease reagent consumption and reduce cost per analysis. It also reduces analysis time and provides better controllable process parameters in chemical reactions [48]. For certain applications, only small amounts of sample analyte might be usable. The analyte has to be exploited as much as possible.

Micro fluidics in biological and chemical analytics.
Fiber optic biosensor can be an efficient method for reliable detection of pathogen in the effort to reduce its fatal effect. Several studies have successfully employed biosensors to detect *E. coli* [76,92-94], detection of pathogenic salmonella [95], Microfluidic sensing of infectious diseases [96], Cell analysis [97], viral Detection [98], including the development of fluorescent based fiber optic biosensor hybridized with DNA sequences to detect oligo-nucleotides as an indication of *E. coli* infection [99]. Zhimei. *et al* [100] Reported on the 3D Screen-printed copper oxide (CuO) and CuO/few-layer graphene on graphite electrodes were used to fabricate the ultrasensitive nonenzymatic glucose biosensors. The efficiencies of two non-enzymatic glucose biosensors for glucose determination were comparable with that of a commercial enzymatic sensor. Force sensing for selectively isolating a particle from a solution [101]. Tan *et al.* [102] in a review article titled "Advances in developing rapid, reliable and portable detection systems for alcohol" Detection system for alcohol has been an instinctive demand not only in traditional brewing, pharmaceutical, food and clinical industries but also in rapidly growing alcohol based fuel industries.

Micro fluidics for optical fiber sensor
Optical sensing has been broadly studied to measure many parameters such as temperature, refractive index (RI), strain, displacement, humidity, pressure, stress and curvature. It has benefit for many applications for example chemical industry, biochemical analysis, medical diagnostics and environment and contamination assessment [104]. Refractive index and temperature are the most important parameters in these applications especially biochemical analysis for monitoring molecular bindings or biochemical reactions [1]. Abdul et al. [1] reported an experiment performed to produce a refractive index sensor by using 3-dimension (3D) grayscale lithography techniques. Optical fiber with taper diameter of 12 µm was embedded in a closed micro fluidic channel, the results of the report

showed an ease of repeatability and also a low temperature cross-sensitivity. Several sensors integrated with fiber optics have found several applications in different fields of research as; effective and efficient fluoride detection in tea samples [105], Pathogenic bacteria detection [103], optimised microfluidic chip biosensor [106], Mercury sensing [107].

Conclusion

In conclusion the best form of microfluidics (MFs) to be adopted is the dry film resist form as enumerated in the article sections. It is a very easy process that involves a sustainable and efficient (considering ecotoxicity) approach with no need for a clean room to fabricate. However, the design and fabrication of a sustainable micro fluidics will include arrays pattern and the flow channel pattern for which a very sustainable approach is required to achieve state of the art end goal reusability and not sacrificing efficiency and efficacy of the device so produced, the field of micro fluidics and its application is still widely unsaturated. Hence, more applications in the environmental field of detection and analyzing pollutant both in solutions and gaseous forms are needed with higher throughput and reliability.

Declaration of conflicting interests

The author declared no potential conflicts of interest

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Cite this article

Gideon W., Pudza M.Y., [3]Y.M. Ibrahim Y.M. and Moses S. (2022). Sustainable Analytical Approaches to the Applications of Polymeric Microfluidic Sensors for chemical and biochemical systems. FUAM Journal of Pure and Applied Science, **2**(**2**):34-44