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Short Communication

Application of Microfluidics in Chemical Engineering

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INTRODUCTION

Microfluidics is the science and technology that involve the study of behaviors of fluids, controlled fluid manipulations, and the design of such devices or systems that can reliably perform such tasks in microchannels with typical dimensions of tens to hundreds of micrometers. For over two decades, applications of microfluidics haven been extensively explored at the interface of biology, chemistry, and engineering [1]. Microfluidics has been broadly employed to miniaturize analytical methods and chemical/biological processes, because it promises significant increase in analysis speed, reduction in sample volume and reagent consumption (10^{-9} to 10^{-18} L), and enhanced system performance and functionality by integrating different components onto individual devices [2,3]. These applications are usually called micro total analysis systems (μTAS) [4] or lab on a chip (LOC) [5].

The high surface-area-to-volume ratio of microfluidic devices leads to enhanced heat and mass transfer and interfacial phenomena that are not usually observed at macroscale, such as the domination of surface forces instead of inertial and body forces [6]. The fluid flow within a smooth-walled microchannel is typically in the laminar region with a Reynolds number (*Re*) less than 100 [7]. Mixing in microchannels is dominated by diffusion but can be further enhanced by using active mechanisms, such as electrokinetics and magnetohydrodynamics [8].

Another important feature of microfluidic devices is their capability of integrating multiple steps onto one single device, such as sample preparation, separation and analysis. By mass production, it is possible to develop high-throughput processes for production using microfluidic devices by parallelization [9,10].

Fabrication of microfluidic devices

The final use of microfluidic devices dictates their choice of materials and fabrication methods. The first generation of microfluidic devices were fabricated with glass and silicon using the well- established photolithographic techniques developed for microelectromechnical systems (MEMS) and microelectronics industry in the 80s. Depending on applications, new materials were later introduced to fabricate microfluidic devices, such as ceramic, steel, silicone, and teflon [11,12]. Polymers are now popular construction materials to replace glass and silicon because of their lower cost and simpler fabrication process without the need for nasty chemicals. Particularly for biological applications, polydimethylsiloxane (PDMS) is the most popular material in microfluidic device fabrication because of its many advantages, such as optical transparency, biocompatibility, elasticity, and a simple fabrication process ("soft lithography") [13–15]. More information on PDMS microfluidic devices is available in several reviews and the references cited therein [16–18].

Despite its many advantages, applications of PDMS are significantly limited to aqueous reactions due to its very low resistance to organic solvents, which are commonly used in chemical synthesis. To circumvent this problem and yet keep a simple fabrication process, different methods have been developed to modify surface and bulk properties of PDMS [19], but they are usually more complicated and still cannot solve the problem effectively. Polymers based on the thiolene chemistry have shown good chemical resistance, high mechanical strength, and compatibility with the fabrication process of soft lithography [20]. A series of commercially available, thiolene-based optical adhesives, such as NOA 81, have been widely used to develop microfluidic devices for applications involving organic solvents [21–23]. An example of such devices is shown in (Figure 1).

Application in chemical engineering

Chemical engineering refers to an engineering branch that applies physical/biological sciences, mathematics, and economics to the development of production processes that convert raw materials to valuable products on an industrial scale. These processes are established by combining different basic steps (unit operations), such as fermentation, filtration and drying. With advances in science and engineering, new products require processes to increase in both production scale and complexity with integrated processing steps. For decades, scaling up from benchtop via a pilot plant to a full blown one has been the standard practice of the development of industrial-scale production processes. However, this practice is now faced with challenges from more stringent requirements, such as size and cost reductions in equipment, lower energy consumption and waste emission, and a safer operation environment, due to the new trend of using sustainable production schemes in these processes. To address these challenges, an approach called "process intensification" has been adopted to develop improved

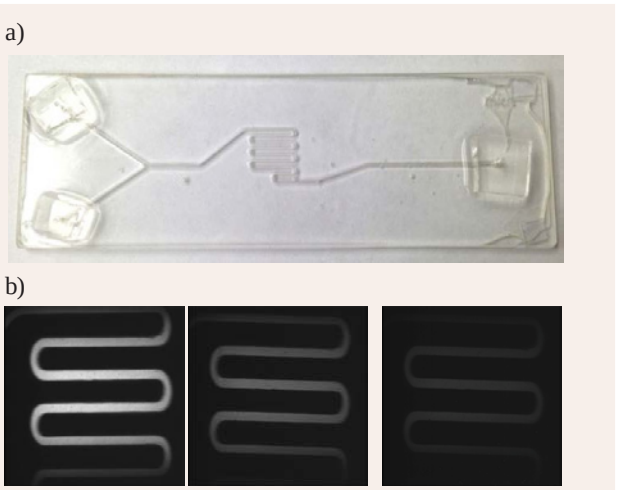

Figure 1 Microfluidic device for the Paal-Knorr pyrrole synthesis. a) A device fabricated with quartz slides and NOA 81 UV optical adhesive. b) Micrographs of caffeine standards in the microchannel for calibrating the UV imaging system for online reaction monitoring. From left to right, the concentrations are 0, 500, and 1000 ppm, respectively. The microchannel became darker and darker due to the increased absorbance at higher caffeine concentrations. The background was completely dark because the stray light was absorbed by the microchannel wall formed by the UV-curable adhesive, which served as a built-in optical slit. The width and depth of the microchannel are 300 and 250 μm, respectively [39].

production processes. It focuses on developing new equipment and methods that lead to more cost-effective and sustainable processes [24–26].

Since the dawn of microfluidics in the 90s [27–29], it has made significant progress as demonstrated by the piling up research results. Microfluidics has found many biological applications, such as gene/protein manipulation and analysis, cell-based systems, biosensors, and drug discovery and delivery [30,31]. Microfluidic devices have recently come into attention as a powerful tool for process intensification because of their low fabrication costs and reagent consumption, small form factors for safe operation in a controlled environment, and capability of integrate multiple basic steps onto one chip. A lot of work has been directed to the development of microreactors for chemical and biological processes. For downstream processing, microfluidic devices have been used to develop systems for separation of cells and purification of therapeutic compounds. The results so far are very promising for miniaturized processes. More information on process miniaturization can be found in the literature [32–35].

The outlook

For over two decades, microfluidics has made great strides and has lead to commercialized products, such as Agilent Technologies' 2100 Bioanalyzer for biomolecule analysis, Caliper Life Sciences' LabChip systems for biomolecule analysis and drug discovery, and FutureChemistry's microreactor systems for process optimization. Although microfluidic systems are still not the mainstream equipment in production processes, they have a promising future as indicated in reported research results so far. Along with advances in materials and fabrication processes, new discoveries of fluid behaviors at microscale might lead to new reaction mechanisms that are not possible on conventional macroscale systems.

Microfluidic systems are also potential for industry-scale production because of their capability of parallelization. The throughput of such systems can be significantly increased by increasing the number of optimized microreactors ("scale out") instead of the conventional scale-up process that is more expensive and carries more uncertainties [36]. Based on reports in the literature and commercial products currently available, it is foreseeable that there will be cost-effective, "plug and play" microfluidic systems with customizable reaction modules for continuous chemical production. This type of reactors are particularly suitable for the production of high-added-value fine chemicals and pharmaceuticals, because of their advantages ranging from controlled process conditions to high production rates and mass throughput, and thus faster time to the market [37,38]. With microfluidics as an enabling technology, chemical engineers will be able to easily tailor their reactors for desired products and quantities by putting together various microreactor modules, just as we do today to upgrade computer systems by swapping plug and play components.

REFERENCES

1. Whitesides GM. The origins and the future of microfluidics. 2006; Nature.442: 368-373.
2. Burns MA, Johnson BN, Brahmasandra SN, Handique K, Webster JR, Krishnan M, et al. An integrated nanoliter DNA analysis device. Science. 1998; 282: 484-487.
3. Thorsen T, Maerkl SJ, Quake SR. Microfluidic large-scale integration. Science. 2002; 298: 580-584.
4. West J, Becker M, Tombrink S, Manz A. Micro total analysis systems: latest achievements. Anal Chem. 2008; 80: 4403-4419.
5. Brivio M, Verboom W, Reinhoudt DN. Miniaturized continuous flow reaction vessels: influence on chemical reactions. Lab Chip. 2006; 6: 329-344.
6. Pennathur S, Meinhart CD, Soh HT. How to exploit the features of microfluidics technology. Lab Chip. 2008; 8: 20-22.
7. Hetsroni G, Mosyak A, Pogrebnyak E, Yarin LP. Fluid flow in micro-channels. Int J Heat Mass Transf. 2005; 48:1982–1998.
8. Capretto L, Cheng W, Hill M, Zhang X. Micromixing within microfluidic devices. Top Curr Chem. 2011; 304: 27-68.
9. Dittrich PS, Manz A. Lab-on-a-chip: microfluidics in drug discovery. Nat Rev Drug Discov. 2006; 5: 210-218.
10. Melin J, Quake SR. Microfluidic large-scale integration: the evolution of design rules for biological automation. Annu Rev Biophys Biomol Struct. 2007; 36: 213-231.
11. Goodell JR, McMullen JP, Zaborenko N, et al. Development of an Automated Microfluidic Reaction Platform for Multidimensional Screening: Reaction Discovery Employing Bicyclo[3.2.1]octanoid Scaffolds. J Org Chem . 2009; 74: 6169–6180.
12. Ren K, Dai W, Zhou J, Su J, Wu H. Whole-Teflon microfluidic chips. Proc Natl Acad Sci U S A. 2011; 108: 8162-8166.
13. Xia Y, Whitesides GM. Soft Lithography. Annual Review of Materials Science 1998; 28:153–184.
14. Whitesides GM, Ostuni E, Takayama S, Jiang X, Ingber DE. Soft lithography in biology and biochemistry. Annu Rev Biomed Eng. 2001; 3: 335-373.
15. Friend J, Yeo L. Fabrication of microfluidic devices using polydimethylsiloxane. Biomicrofluidics. 2010.

16. McDonald JC, Duffy DC, Anderson JR, Chiu DT, Wu H, Schueller OJ, et al. Fabrication of microfluidic systems in poly(dimethylsiloxane). Electrophoresis. 2000; 21: 27-40.

17. McDonald JC, Whitesides GM. Poly(dimethylsiloxane) as a material for fabricating microfluidic devices. Acc Chem Res. 2002; 35: 491-499.

18. Sia SK, Whitesides GM. Microfluidic devices fabricated in poly(dimethylsiloxane) for biological studies. Electrophoresis. 2003; 24: 3563-3576.

19. Zhou J, Ellis AV, Voelcker NH. Recent developments in PDMS surface modification for microfluidic devices. Electrophoresis. 2010; 31: 2-16.

20. Campos LM, Meinel I, Guino RG, et al. Highly Versatile and Robust Materials for Soft Imprint Lithography Based on Thiol-ene Click Chemistry. Advanced Materials 2008.

21. Harrison C, Cabral JT, Stafford CM, et al. A rapid prototyping technique for the fabrication of solvent-resistant structures. J Micromech Microeng. 2004.

22. Hung LH, Lin R, Lee AP. Rapid microfabrication of solvent-resistant biocompatible microfluidic devices. Lab Chip. 2008; 8: 983-987.

23. Wägli P, Homsy A, de Rooij NF. Norland optical adhesive (NOA81) microchannels with adjustable wetting behavior and high chemical resistance against a range of mid- infrared-transparent organic solvents. Sens Actuators B Chem. 20011; 156: 994–1001.

24. Stankiewicz AI, Moulijn JA. Process intensification: transforming chemical engineering. Chemical Engineering Progress. 2000; 96: 22–34.

25. Lutze P, Gani R, Woodley JM. Process intensification: A perspective on process synthesis. Chemical Engineering and Processing. Process Intensification. 2010; 49:547–558.

26. Moulijn JA, Stankiewicz AI. Re-Engineering the Chemical Processing Plant: Process Intensification. CRC Press. 2003.

27. Manz A, Graber N, Widmer HM. Miniaturized total chemical analysis systems: A novel concept for chemical sensing. Sens Actuators B Chem. 1990; 1:244–248.

28. Manz A, Harrison DJ, Verpoorte EMJ, et al. Miniaturization of Chemical Analysis Systems A Look into Next Century's Technology or Just a Fashionable Craze? CHIMIA International Journal for Chemistry 1991; 45:103–105.

29. Harrison DJ, Glavina PG, Manz A. Towards miniaturized electrophoresis and chemical analysis systems on silicon: an alternative to chemical sensors. Sens Actuators B Chem. 1993; 10:107–116.

30. El-Ali J, Sorger PK, Jensen KF. Cells on chips. Nature. 2006; 442: 403-411.

31. Yeo LY, Chang HC, Chan PP, Friend JR. Microfluidic devices for bioapplications. Small. 2011; 7: 12-48.

32. Asanomi Y, Yamaguchi H, Miyazaki M, Maeda H. Enzyme-immobilized microfluidic process reactors. Molecules. 2011; 16: 6041-6059.

33. Marques MP, Fernandes P. Microfluidic devices: useful tools for bioprocess intensification. Molecules. 2011; 16: 8368-8401.

34. Mills PL, Quiram DJ, Ryley JF Microreactor technology and process miniaturization for catalytic reactions—A perspective on recent developments and emerging technologies. Chemical Engineering Science. 2007; 62: 6992–7010.

35. Wirth T. Microreactors in Organic Synthesis and Catalysis. John Wiley & Sons

36. Fortt R, Wootton RCR, de Mello AJ. Continuous-Flow Generation of Anhydrous Diazonium Species:?? Monolithic Microfluidic Reactors for the Chemistry of Unstable Intermediates. Org Process Res Dev. 2003; 7:762–768.

37. Pashkova A, Greiner L. Towards Small-Scale Continuous Chemical Production: Technology Gaps and Challenges. Chemie Ingenieur Technik. 2011; 83: 1337–1342.

38. Bieringer T, Buchholz S, Kockmann N. Future Production Concepts in the Chemical Industry: Modular – Small-Scale – Continuous. Chemical Engineering & Technology. 2013; 36:900–910.

39. Lo et al. Unpublished raw data.

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