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Microfluidics

Andrew deMello

The last two and a half decades have seen a spectacular evolution in the development and application of microfluidic systems for use in the chemical and biological sciences. Much of this activity has been driven by a need to perform efficient experiments on small sample volumes. However, at a more fundamental level, interest in microfluidic (and nanofluidic) systems has been stimulated by the simple fact that physical processes can be more easily controlled, manipulated and enhanced when characteristic dimensions are reduced to the micron scale. In this regard, microfluidic systems have been highly successful in defining new operational paradigms and fundamentally changing the way in molecular synthesis and materials production is now performed. Accordingly, I am delighted to introduce this special issue of *Advanced Materials Technologies*, which highlights the use of microfluidic systems in the synthesis of functional materials with advanced and customized properties. As many of you will know, *Advanced Materials Technologies* is a relatively new addition to the *Advanced Materials* journal family, bridging the gap between fundamental laboratory research and industry, and with a special focus on energy, healthcare, electronics, safety, and environmental technologies. The contributions to this special issue highlight the growing importance of microfluidic tools in all these areas and represent an invaluable snapshot of contemporary microfluidic technologies.

To begin, *Albert Folch* and colleagues report the development of a novel poly(ethylene glycol)diacrylate resin that can be stereolithographically printed at sub-pixel resolution using commercial 3D-printers, without compromising transparency or biocompatibility. After optimization of the resin chemistry, the University of Washington team show that a range of passive and active microfluidic devices can be made in a direct manner. This approach allows the fabrication of stacked and overlapping microchannels, and significantly allows for the robust printing of features down to 27 microns. In a related study, *Don DeVoe's* group at the University of Maryland describe the use of laser stereolithography using digital light projection to form microfluidic flow focusing devices. Such a method is especially powerful for device prototyping, since high-resolution and high aspect ratio features may be formed on short timescales. Importantly, the additive nature of the fabrication process allows monolithic integration of high-pressure interconnects, and thus enables the use of large volumetric flow rates for the controllable and high-throughput synthesis of nanoscale lipid vesicles.

This themed issue also includes four perspective articles, which assess and review the development and application of microfluidic tools to timely biological problems. In the first, *Zhongze Gu* and associates assess some of the most important advances in microfluidic technologies for bioassays, biofabrication and tissue engineering purposes. This comprehensive analysis highlights how the precise and controllable manipulation of sub-nL volumes has been used to good effect in either enhancing traditional assay technologies or realizing completely new tools for use in biomedical engineering studies. In the second article, *Jinqi Deng* and *Xingyu Jiang* from the National Center for Nanoscience and Technology in Beijing appraise the emerging field of "self-contained point-of-care diagnostics". Key features of this analysis are an assessment of robust strategies for reagent storage, reagent release and drug delivery. Additionally, the authors provide a personal view of the state-of-the-art and predictions on how the field will develop in the short-to-medium term. Next, *Hélder Santos* and colleagues from the University of Helsinki discuss the materials used for the fabrication of microfluidic devices and key parameters that influence the production of biomaterials. This timely analysis is driven by the recognition that many nanotechnology-based therapies are compromised by issues related to cost, complexity and reproducibility. Accordingly, the use of microfluidic systems in both the production of advanced biomaterials and disease diagnosis is an appealing alternative to more traditional technologies. Finally, *Liang-Yin Chu* and associates at Sichuan University highlight recent advances in the use of microfluidic reactors to fabricate polymeric particles (with tailored internal structures) for the controlled encapsulation and release of drugs. A key highlight of this analysis is an in-depth consideration of recent biomedical applications.

As noted, a key theme of this special issue is the application of microfluidic tools and devices to the controllable and scalable synthesis of functional materials with bespoke properties. In this regard, *Jianhua Qin* and co-workers at the Dalian Institute of Chemical Physics report the direct generation of biocompatible gelatin methacrylate microgels using droplet-based microfluidics. Such materials have attracted much recent attention due to their similarity to natural extracellular matrices and utility as scaffolds in a range of tissue engineering applications. The success of the production method is evidenced through the exquisite control of both core and shell dimensions, with encapsulated liver cells showing excellent viability for extended periods of time. In a related study, *Eugenia Kumacheva's* group at the University of Toronto describe the microfluidic extrusion of structurally anisotropic hydrogel sheets. Here, the authors beautifully leverage the temperature-responsivity and

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shear-thinning properties of a novel precursor ink to control the extent of structural anisotropy in the produced hydrogels. Importantly, such anisotropy can be preserved at physiological temperatures for periods in excess of one week, suggesting wide application in biomedical research.

The final two contributions to this special issue highlight the utility of microfluidic systems in the flow-based synthesis of novel materials. First, *Josep Puigmartí-Luis* and colleagues at ETH Zürich leverage the exquisite spatiotemporal control over reagent concentrations within simple continuous flow environments to control the formation of compositional gradients of metal-organic frameworks (MOFs) on microchannel surfaces. This exciting but simple methodology is likely to allow the formation of a range of novel MOF architectures and devices. In addition, *Esther Amstad's* group at the École Polytechnique Fédérale de Lausanne present a surface acoustic wave (SAW)-based spray-dryer that both forms and dries micron-sized drops to produce amorphous particles of bespoke size and composition. The ability to control the formation and resulting properties of such amorphous materials is particularly importantly when optimizing a range of physical and chemical properties, and therefore the general approach is likely to have significant utility in a range of scalable processes.

Finally, I would like to congratulate and thank all our authors in this special issue of *Advanced Materials Technologies* for their excellent contributions and hope you will enjoy reading their papers as much as I have.

Andrew deMello is currently Professor of Biochemical Engineering in the Department of Chemistry and Applied Biosciences at ETH Zürich and Head of the Institute for Chemical and Bioengineering. Prior to his arrival in Zurich he was Professor of Chemical Nanosciences in the Chemistry Department at Imperial College London. He obtained a first-class degree in Chemistry (1992) and a PhD in Molecular Photophysics from Imperial College London (1995). He subsequently held a postdoctoral fellowship in the Department of Chemistry at the University of California, Berkeley working under the guidance of Professor Richard Mathies. His group's research interests cover a broad range of activities in the general area of microfluidics and nanoscale science. Primary specializations include the development of microfluidic devices for high-throughput biological and chemical analysis, ultra-sensitive optical detection techniques, imaging flow cytometry, novel methods for nanoparticle synthesis, the exploitation of semiconducting materials in diagnostic applications and the development of intelligent microfluidic systems.