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The Fourth Decade of Microfluidics

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The basic concepts that underly the field of microfluidics started in 1990 from a vision of integrating all chemical analysis processes onto a microfabricated chip. A decade later, pioneering work by George Whitesides, Steven Quake and others on polydimethylsiloxane (PDMS)-, multilayered and droplet-based devices inspired rapid growth in the development and applications of microfluidics.[1–6] These microfluidic devices can be easily fabricated or assembled in research labs, enabling microscaled flows to be controlled by precision pumps and analyzed using microscopes coupled to a high-speed camera. This has led to unprecedented opportunities and interest in the study of microscale fluid dynamics, miniaturized chemistry and biological reactions, and has resulted in applications in agriculture, biotechnology, thermal engineering, medicine, nanomaterial synthesis and environmental engineering. Microfluidics is now widely used in fields that require fluid manipulation, including physics, chemistry, biology, mechanical engineering, biomedical engineering, chemical engineering, material engineering, life sciences and translational medicine.

For the last decade, the applications of microfluidics have extended to biochemical and medical applications, for instance, in miniaturized chemical/biological assays, high throughput screening, point-of-care diagnosis and synthesis of novel biomaterials (article numbers 1904673, 1903916, 1903931, 1903388, 1903798, 1903736 and 1901943). Microfluidic technologies continue to contribute to emerging fields, including "organ-on-a-chip," "tissue engineering," "3D cell-coculturing," "3D bioprinting" and "droplet-based single cell analysis" (article numbers 1904321, 1903899, 1903905, 1903739, 1903822 and 1903402). Researchers in these fields have taken advantage of unique features offered by microfluidics to screen drugs, generate therapeutic strategies, understand cell and cancer biology, mimic biological systems and probe heterogeneity among cell populations.

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Entering the fourth decade of microfluidics, in this Special Issue we have assembled a collection of works featuring innovations and developments in microfluidics from the past decades. This Special Issue has 17 original research articles and 22 reviews that introduce and discuss developments and progress in single cell analysis (article numbers 1903905, 1903739, 1903402 and 1902889), droplet manipulation (article numbers 1901751, 1903849 and 1901819), flow control (article numbers 1903605, 1903944, 1904344, 1904032, 1903872, 1905318 and 1903788), synthesis of novel biomaterials (article numbers 1904673, 1903798, 1903736, 1901943, 1902262, 1904190, 1903939 and 1903940), bioinspired materials (article numbers 1903931, 1903849, 1901819, 1903812, 1903884, 1903879, 1903925 and 1904282), novel in-vitro analytical biotechnology (article numbers 1903916, 1903388, 1904321, 1903899, 1901001, 1904076 and 1904469), tumor-on-chip (article numbers 1904321 and 1903899), bioelectronics (article numbers 1903822, 1903841 and 1903204) and regenerative tissue engineering (article numbers 1904673, 1903798, 1903736, 1901943, 1902262, 1903940 and 1905055). We thank the following authors and groups for their contributions: Daxiang Cui, Di Chen, Su Chen, Wenwen Chen, Sujit Datta, Emilie Dressaire, Wenbin Du, Xuemin Du, Jun Bing Fan, Alberto Fernandez-Nieves, Xu Hou, Weihua Huang, Yanyi Huang, Jian Jin, Jin Woong Kim, Shin-Hyun Kim, Tuomas Knowles, Daeyeon Lee, Guangtao Li, Qionglin Liang, Jin Ming Lin, Dayu Liu, Hong Liu, Zhou Liu, Christoph Merten, Lijia Pan, Hélder Santos, Alban Sauret, Amy Shen, Yi Shi, Ho Cheung Shum, Scott Tsai, Shutao Wang, Yong Wang, Zuankai Wang, David Weitz, Ruohao Wu, Chaoyong Yang, Leslie Yeo, Xin Zhao, Yuanjin Zhao, Yongmei Zheng, Shaobing Zhou, Xuechang Zhou, and co-workers.

We envision that microfluidics will continue to be integrated into different research topics and applications, with new innovation through combination with emerging disciplines, such as artificial intelligence,[7,8] metamaterials[9] and neuromorphic engineering.[10] As the field has matured, microfluidics has played a key role in numerous applications and products that will reshape segmented markets. As a result, the microfluidics market is expected to continue to grow by 11.7% from 2019 to 2024, with numerous microfluidics-based solutions and products being developed.[11] The number of leading companies and recognized start-ups using microfluidics exceeded 1000 worldwide in 2019.[11] Representative microfluidics-based products are mainly found in two key fields of biotechnology, point-of-care (PoC) diagnostics and genomics.[12–14] These include centrifugal microfluidic biochips for PoC diagnostics, single cell analysis systems for antibody discovery, fluorescent-activated cell sorting systems for rare cells and enzyme activity, digital microfluidic-based real-time PCR systems, and droplet digital PCR (ddPCR) systems. With the needs of the segmented market now being explored with active industrial efforts toward specific customer sectors, we envision that the commercial potential of microfluidics will continue to grow in this coming decade.

[1] G. M. Whitesides, *Nature* **2006**, *442*, 368.
[2] A. S. Utada, E. Lorenceau, D. R. Link, P. D. Kaplan, H. A. Stone, D. A. Weitz, *Science* **2005**, *308*, 537.
[3] J. Liu, C. Hansen, S. R. Quake, *Anal. Chem.* **2003**, *75*, 4718.
[4] T. Squires, S. Quake, *Rev. Mod. Phys.* **2005**, *77*.
[5] P. Garstecki, M. J. Fuerstman, H. A. Stone, G. M. Whitesides, *Lab Chip* **2006**, *6*, 437.
[6] P. B. Umbanhowar, V. Prasad, D. A. Weitz, *Langmuir* **2000**, *16*, 347.
[7] D. G. Rackus, I. H. Riedel-Kruse, N. Pamme, *Biomicrofluidics* **2019**, *13*, https://doi.org/10.1063/1.5096030.
[8] J. Riordon, D. Sovilj, S. Sanner, D. Sinton, E. W. K. Young, *Trends Biotechnol.* **2019**, *37*, 310.
[9] K. V. Sreekanth, Y. Alapan, M. Elkabbash, E. Ilker, M. Hinczewski, U. A. Gurkan, A. De Luca, G. Strangi, *Nat. Mater.* **2016**, *15*, 621.
[10] E. R. W. Van Doremaele, P. Gkoupidenis, Y. Van De Burgt, *J. Mater. Chem. C* **2019**, *7*, 12754.
[11] Status of the Microfluidics Industry, Yole Développement, **2019**.
[12] L. R. Volpatti, A. K. Yetisen, *Trends Biotechnol.* **2014**, *32*, 347.
[13] D. I. Walsh, D. S. Kong, S. K. Murthy, P. A. Carr, *Trends Biotechnol.* **2017**, *35*, 383.
[14] Z. Liu, X. Han, L. Qin, *Adv. Healthc. Mater.* **2016**, *5*, 871.