Featuring work from the Laboratory of Prof. Axel Guenther, University of Toronto, Canada.

Title: Bubble gate for in-plane flow control

Simultaneous operation of 128 miniature gate valves is used to controllably trap a red-coloured solution in a pattern that display the Maple Leaf, the National Flag of Canada. Bubble gates are miniature gate valves that provide for simple, substrate-independent and scalable control of liquid flow in microfluidic devices.

As featured in:
Lab on a Chip

See Axel Günther et al., Lab Chip, 2013, 13, 2515.
Lab on a chip Canada – rapid diffusion over large length scales

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The roots of lab on a chip in Canada are deep, comprising of some of the earliest contributions and first demonstrations of the potential of microfluidic chips. In an editorial leading off this special issue, Jed Harrison of University of Alberta reflects on these early days and Canada’s role in the field’s development (DOI: 10.1039/c3lc50522g). Over the last decade, microfluidics and lab-on-a-chip research efforts grew exponentially – rapidly diffusing across the vast Canadian length scales.

A recurring theme in the microfluidics community is commercialization and the discovery of the “killer app”. Among the Canadian vastness and maple (syrup) trees, a factory the size of several football fields produces ~140 000 labs-on-a-chip daily and generates tens of millions in annual revenue. In 1983, Imants Lauks left a faculty position at the University of Pennsylvania and moved to Ottawa to launch Integrated Ionics Incorporated, commonly known as i-STAT. Lauks’ pioneering vision that integrated an electrochemical chip, a cartridge, and a hand-held reader with a pneumatic actuation system to displace liquids across the chip was a lab-on-a-chip before its time. i-STAT was acquired by Abbott Point-of-Care in 1999 and is now distributed globally. Although the i-STAT system initially only measured physiological parameters, such as pH, salt, and O₂ concentration, it now comprises 25 different tests, including protein immunoassays for Troponin I and a cardiac biomarker (measured in just 10 min with a 20 pg ml⁻¹ limit-of-detection). In 2002 Lauks founded a

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second point-of-care company called Epocal, which was recently acquired by Alere in another multimillion dollar deal. Canada also hosts Edmonton-based Micralyne Inc., one of the first global leaders in commercial microfluidic chip fabrication. Their ‘standard’ microfluidic-cross glass chips were indeed a mainstay of many research programs in the early 2000s, and Micralyne continues as a stalwart of microfluidic instrumentation and MEMS technologies.

This Canadian special issue brings together 24 contributions from across the country, and includes a notable concentration of young research groups with exciting new directions. The papers give a snapshot, both of Canadian efforts and those of the larger field, with a combination of advanced nanotechnology and trapping, process integration for health applications, new functionalities for droplet- and paper-based devices, and applications reaching beyond analytical chemistry and medicine into energy and the environment.

The diversification of microfluidics is apparent from these Canadian contributions. There are contributions on electrokinetics and on-chip valving, which were the focus of the early micro-Total Analysis Systems community, but with new twists. Many of the major microfluidic areas are covered, including droplet-, digital-CD- and PDMS- and paper-based microfluidics, but also emerging areas, such as plant mechanics, microfluidic batteries, salt precipitation, gas-oil bubbles, and a lung-assist device, as well as a point-of-care system using modular capillary tubes. Harrison argued that microfluidics is rooted in the concept of planar networks of microscale channels running across chips, and indeed most manuscripts conform to this paradigm. However, a number of papers break out of flatland, and into vertical filtration, 3D tissue engineering, and even chips folded into cones. Finally, a series of contributions describe chip-based electrochemical and plasmonic sensors and protein traps. Interestingly, there is also a healthy balance between integration for practical applications, and the study of basic phenomena including on-chip gelation, salt precipitation, bubble trapping and allosteric effects in enzyme inhibition, reflecting the tremendous flexibility and utility of the lab-on-a-chip approach.

Canadian scientists have led the way in the emerging area of nanohole-based plasmonic sensors. Carlos Escobedo from Queens University reviews nanohole array based sensing, detailing the development of these photonic-turned-fluidic structures and their implications for on-chip sensing (DOI: 10.1039/c3lc50107h). He outlines the optofluidic concepts and fabrication advances that have enabled this area, as well as new directions. The issue also includes two notable additions in the Canadian nanohole technology narrative. Zehtabi-Oskuie et al. from University of Victoria describe the optical trapping dynamics of double nanohole structures, and the co-trapping and binding of individual biomolecules (DOI: 10.1039/c3lc00003f). Tellez et al. from University of Victoria, University of Ottawa and Carleton University demonstrate highly sensitive refractive index sensing enabled by atomically flat symmetric nanohole arrays (DOI: 10.1039/c3lc14114f).

Applications involving cells and microfluidics have long been a topic of interest for Canadian scientists. Zheng et al. from University of Toronto provide a comprehensive review of recent advances in single-cell biophysical characterization (DOI: 10.1039/c3lc50355k). The wide spectrum of microfluidics-based approaches to assessing mechanical and electrical properties of living cells are detailed, as well as future technological opportunities and health applications. Lin et al. provide a comprehensive review of recent developments in microfluidics-based chemotaxis studies (DOI: 10.1039/c3lc50415h). Advances in exploring cell migration in controlled chemical gradients are reviewed, as well as chemotaxis in complex environments and high-throughput approaches. Nezhad et al. from Concordia University and Université de Montréal present a microfluidic approach to the study of the mechanical properties of plant cells (DOI: 10.1039/c3lc00012e). Their bending-lab-on-a-chip quantifies the stiffness of the cell wall of a single pollen tube. Lilge et al. from the University of Toronto approach cell propulsion from an optical perspective, employing radiation pressure from end-faced waveguides integrated on-chip (DOI: 10.1039/c3lc14119k). They assess the optical and geometrical variables influencing the motion of leukemia cells. Chen et al. from University of Toronto describe an “organ-on-a-chip” device that is useful for modeling cardiovascular systems (DOI: 10.1039/c3lc00051f). Endothelial cells in one channel were found to profoundly affect the phenotype of interstitial cells in a separate channel (separated by a porous membrane), particularly when the endothelial cells were exposed to shear stress. Wu et al. from McMaster University present a chip-based lung assist device for newborn infants (DOI: 10.1039/c3lc0003f).
The porous PDMS microfluidic oxygenator provides excellent gas exchange of oxygen and carbon dioxide, and would connect directly to umbilical vessels. Finally, Shahini and Yeow from University of Waterloo describe a system for on-chip electroporation that makes use of the unique properties of carbon nanotubes (CNTs) (DOI: 10.1039/c3lc41416g). Intricate 3D electrode structures were grown here on glass, substantially reducing cost without sacrificing performance. Oskooei et al. from the University of Toronto report the development of a microfluidic microvalve enabled by fine control over gas bubbles (DOI: 10.1039/c3lc50401h). Excellent scalability was demonstrated via a network of 128 valves, which were used to generate spatial patterns of particular “Canadian” interest. The work of Manage et al. brings together researchers from the University of Alberta, an Alberta Provincial Laboratory for Public Health, Aquila Diagnostics Inc., and Western University (DOI: 10.1039/c3lc41419a) in the development of a self-contained disposable and inexpensive gel capillary cassette for DNA amplification. Targeting point-of-care applications, the PCR reagents are desiccated and stable for months, prior to rehydration with a raw sample, with test results from multiple patients in under an hour. Kirby et al. from University of Toronto put a new twist on digital microfluidics (DOI: 10.1039/c3lc41431k). In developing a roll-up device they link the sample handling advantages of digital microfluidics-based synthesis to the analytical capabilities of mass spectrometry (ms). Li et al. from McGill bring valve functionality to paper-based microfluidics (DOI: 10.1039/c3lc00006k). A fluid-triggered electromagnetic circuit engages a paper bridge, accommodating automated protocols for multi-step assays in paper. Li et al. from Western University present an electrochemical lab-on-a-CD device for parallel whole blood analysis (DOI: 10.1039/c3lc00020f). By incorporating simple blood separation and electrochemical detection, glucose, lactate and uric acids are quantified from 16 μL whole blood samples in minutes. Tamanna et al. from York University present electrospray ms-coupled microfluidics for protein structural analysis using rapid hydrogen/deuterium exchange pulse labelling (DOI: 10.1039/c3lc00007a). Hua et al. from the University of Alberta and the National Research Council present a multichannel sample pretreatment device with sheath flow-assisted electrokinetic pumping (DOI: 10.1039/c3lc50401h). Their approach enables multiple fractionation beds leading to a single downstream analysis channel as required for integrated fractionation and proteomic analysis.

Chemically functionalized particles are also a hot topic among Canadian scientists with expertise in materials. Wang et al. from University of Toronto explore a direct injection method of generating polymer microgels in microfluidics (DOI: 10.1039/c3lc41385c). By separating emulsification and subsequent gelation unit operations, this approach expands the range of accessible gel constituents, most notably to include highly viscous polymer solutions. Didar et al. from McGill University and the National Research Council present a particle sorting method based on a fully thermoplastic multilayer device with polycarbonate membrane filters (DOI: 10.1039/c3lc50181g). Tuning via integrated pneumatic peristaltic pumps and valves enables separation of a range of micro- and nanoparticles, as well as cells.

Three papers showcase the potential of lab-on-a-chip devices in energy, targeting oil recovery, energy storage, and the mitigation of carbon dioxide emissions. Fisher et al. from the Schlumberger DBR Technology Center in Edmonton present a microfluidic approach to measuring equilibrium gas-oil-ratios of reservoir fluids (DOI: 10.1039/c3lc00013c). The microfluidic technique offers several improvements over conventional methods for measurements central to oil recovery operations. Lee et al. of Simon Fraser University developed a membraneless microfluidic redox battery (DOI: 10.1039/c3lc50499a). Dual-pass flow-through porous electrodes enable efficient charging and discharging in a compact unit. Kim et al. of University of Toronto present the aquifer-on-a-chip concept providing a pore-scale view of carbon sequestration – a green house gas mitigation strategy. Pore-scale quantification shows two dominant forms of salt precipitation during CO2 injection into deep subsurface saline aquifers (DOI: 10.1039/c3lc00031a).

We thank Lab on a Chip for this special issue and their editorial support, and we thank the lab-on-a-chip community and all our contributors for a great sample of Canadian efforts. We thank Andrea Kirby and Thomas de Haas for generating the distinctly Canadian cover art, and perhaps most importantly, we acknowledge two decades of support for microfluidics and lab-on-a-chip research from the Canadian government through the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Canadian Institutes for Health Research (CIHR). Thank you for enabling Canadian excellence in this area; you put the Canada in lab-on-a-chip.