DOI 10.5162/EUROSENSORS2025/MP49

Voltage-Triggered Wetting in Bio-Inspired Microfluidic Channels

Michael Weiß[1,2], Werner Baumgartner[1], Bettina Heise[3], Elisabeth Leiss-Holzinger[3], Martin Kaltenbrunner[4], Stefan Puttinger[2], and Gerda Buchberger[1]
[1] Institute of Biomedical Mechatronics, Johannes Kepler University Linz, Altenberger Str. 69, 4040 Linz, Austria,
[2] Department of Particulate Flow Modelling, Johannes Kepler University Linz, Altenberger Str. 69, 4040 Linz, Austria,
[3] Research Center for Non-Destructive Testing GmbH (RECENDT), Altenberger Strasse 69, 4040 Linz, Austria,
[4] Department of Soft Matter Physics, Johannes Kepler University Linz, Altenberger Str. 69, 4040 Linz, Austria
gerda.buchberger@jku.at

Summary:
This work presents bio-inspired microfluidic channels that form liquid diodes and are then equipped with a needle-like electrode to create "liquid triodes," analogous to electronic triodes. The devices transport liquid uni- or (bi)directionally over centimeters at velocities in the range of mm/s in response to high-voltage signals. Fabrication involves laser ablation. The topography of the microfluidic channels was analyzed by optical coherence tomography (OCT). The components have potential applications in biomedical microfluidics, labs-on-a-chip, lubrication, filtration, and electronics cooling.

Keywords: EWOD, fluid diode, directional, capillary, wetting

Background, Motivation and Objective

Devices for directional liquid transport are known as liquid diodes [1], fluid diodes [2], or (micro)fluidic diodes [3–5]. Some are based on bio-inspired designs from animals [4,6,7]. They have gained attention because they are capable of unidirectional liquid transport without requiring external energy input. Lizard- [3,7] and flea-inspired devices [4,8] use asymmetric capillary channels for directional transport. Fabrication techniques include laser ablation [3,4,7], and three-dimensional (3D) printing [8]. Material combinations vary, such as oil on elastomer [6] and soapy water on poly(methylmethacrylate) (PMMA) [4,7]. Inspired by the structures on the integument of Texas horned lizards [3,7] we apply electrowetting to create liquid triodes capable of changing their wetting state. We envision applications such as the transport of cooling lubricants, water-oil separation, and drug coating.

Description of the New Method or System

We succeeded in the fabrication of liquid triodes based on microfluidic channels bioinspired by Texas horned lizards [3,7] (Fig. 1), revealing three wetting states: non-wetting, unidirectional, and (bi)directional liquid transport. To this end, we applied electrowetting [9] to reduce the pristine contact angle to force the liquid into open capillary channels even in the backward direction. A CO_2 laser (Speedy 300 TM laser cutter/engraver from Trotec Produktions- und Vertriebs GmbH, Machtrenk, Austria) was applied to engrave the bio-inspired capillary channels in 3 mm thick PMMA plates. Several of the unit cells shown in Figure 1 were placed consecutively. Capillary channels were fabricated using a Trotec lens with a focal length of 1.5 inches and five cycles with an average power of 95 W, a velocity of 106.5 cm/s, a pulse repetition rate of 42 kHz, and a pulse energy of 2.3 mJ. Nitrogen was used for flushing to prevent burning. OCT with a center wavelength of 1.3 μm served for topography assessment (MEMS-VCSEL Swept Source Laser and a Vega Serie SS-OCT system from Thorlabs, Bergkirchen, Germany).

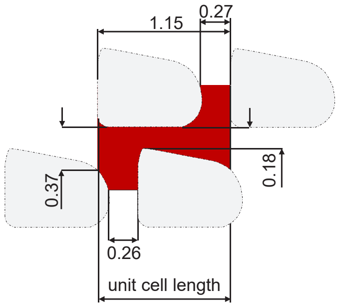

Fig. 1. Bio-inspired capillary channel design. All dimensions are given in mm.

The open-source software Fiji (version 1.53q; ImageJ2 distribution developed by Wayne Rasband and coworkers, National Institutes of Health, Bethesda, MD, USA) was used for OCT data processing, including image filtering and computing the topography with the TopoJ-plugin (quadratic window of 20). For device testing, 0.2 % w/w of the red dye "Ponceau S" (article number: 5938.1, CAS number: 6226-79-5; Carl Roth GmbH + Co. KG, D-76185 Karlsruhe, Germany) was added to distilled water.

Results

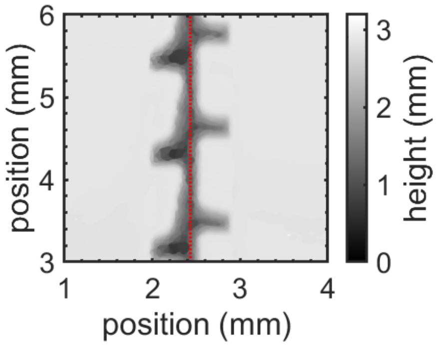

Fig. 2. Topography section of the bioinspired capillary channel. The axis of the capillary channel is highlighted with a dashed red line.

The topography data of the structure reveals maximal capillary channel depths of approx. 2.2 mm (Fig. 2). We dispensed 100 µl of test liquid onto the sample and put the needle-like electrode into it (Fig. 3). Increasing and decreasing the applied voltage in a ramp (from 0 kV to 8 kV in 200 s, plateau of 8 kV for 10 s, from 8 kV to 0 kV in 20 s), the wetting states were switched from non-wetting over unidirectional wetting to bidirectional wetting. The unidirectional wetting started at a threshold voltage of ~1.58 kV.

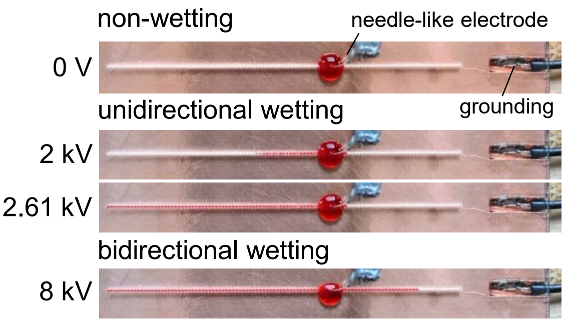

Fig. 3. Increasing the applied voltage, the wetting states were switched from non-wetting over unidirectional wetting to (bi)directional wetting. The capillary channel is 12 cm long.

References

[1] J. Li, X. Zhou, J. Li, L. Che, J. Yao, G. McHale, M.K. Chaudhury, Z. Wang, Topological Liquid Diode, *Science Advances* 3, eaao3530 (2017); doi: 10.1126/sciadv.aao3530

[2] D. Shou, J. Fan, An All Hydrophilic Fluid Diode for Unidirectional Flow in Porous Systems, *Advanced Functional Materials* 28, 1800269 (2018); doi: 10.1002/adfm.201800269

[3] G. Buchberger, R. Baumgartner, A. Kogler, T. Fritz, S. Bauer, W. Baumgartner, Bio-Inspired "Fluidic Diode" for Large-Area Unidirectional Passive Water Transport Even Against Gravity, *Sensors and Actuators A: Physical* 283, 375–385 (2018); doi: 10.1016/j.sna.2018.09.070

[4] G. Buchberger, A. Kogler, A. Weth, R. Baumgartner, P. Comanns, S. Bauer, W. Baumgartner, "Fluidic Diode" for Passive Unidirectional Liquid Transport Bioinspired by the Spermathecae of Fleas, *Journal of Bionic Engineering* 15, 42–56 (2018); doi: 10.1007/s42235-017-0003-7

[5] R.D. Sochol, C.C. Glick, A. Lu, M. Wah, T. Brubaker, K.Y. Lee, K. Iwai, L.P. Lee, L. Lin, Single-Layer Microfluidic Diodes via Optofluidic Lithography for Ultra-Low Reynolds Number Applications, in: Transducers & Eurosensors XXVII: 2201–2204 (2013); doi: 10.1109/Transducers.2013.6627240

[6] F. Hischen, G. Buchberger, C. Plamadeala, O. Armbruster, E. Heiss, K. Winands, M. Schwarz, B. Jüttler, J. Heitz, W. Baumgartner, The External Scent Efferent System of Selected European True Bugs (Heteroptera): a Biomimetic Inspiration for Passive, Unidirectional Fluid Transport, *Journal of the Royal Society Interface* 15, 20170975 (2018); doi: 10.1098/rsif.2017.0975

[7] G. Buchberger, F. Hischen, P. Comanns, R. Baumgartner, A. Kogler, A. Buchsbaum, S. Bauer, W. Baumgartner, Bio-Inspired Microfluidic Devices for Passive, Directional Liquid Transport: Model-based Adaption for Different Materials, in: *Procedia Engineering*: 106–111 (2015); doi: 10.1016/j.proeng.2015.08.576

[8] C. Sammartino, M. Rennick, H. Kusumaatmaja, B. El Pinchasik, Three-Dimensional Printed Liquid Diodes with Tunable Velocity: Design Guidelines and Applications for Liquid Collection and Transport, *Physics of Fluids* 34 (2022); doi: 10.1063/5.0122281

[9] F. Mugele, J.C. Baret, Electrowetting: From Basics to Applications, *Journal of Physics Condensed Matter* 17 (2005); doi: 10.1088/0953-8984/17/28/R01

Acknowledgements

The research was funded by the Austrian Science Fund (FWF) [10.55776/T1270] during the project "Functional Surfaces with Liquid Diode Characteristics". B.H. and E.L. acknowledge the co-financing by the project "HyperMAT" by the federal government of Upper Austria and the European Regional Development Fund (EFRE) in the framework of the EU-program IBW/EFRE & JTF 2021-2027.