From radial to unidirectional water pumping in zeta-potential modulated Nafion nanostructures

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The development of micro/nanomachines which can move in a controlled way and perform useful tasks in a fluid environment is one of the most interesting challenges confronting nanoscience and nanotechnology today. Besides the difficulties of nanofabrication, fighting against the dominance of viscous forces and Brownian motion makes necessary the development of efficient strategies to convert chemical energy into directed motion. In this context, different methods of self-propulsion have been investigated, such as catalytic reactions or bubble propulsion. Ion exchange constitutes an interesting alternative mechanism to achieve self-propulsion, with the potential advantages of using innocuous salts as fuels and be able to work at biologically relevant conditions. In order to explore and harness the capabilities of this mechanism to drive micromotors, it is interesting to work with micrompups, which are the immobilized counterpart of micro/nanomotors, sharing the same working principle, but driving the flow of the surrounding fluid instead of self-propelling in a fluid at rest [1]. Micropumps are also promising platforms for many applications such as mass transport, accumulation, and clearance, material patterning at precise locations, or in sensing applications

We report on a new and versatile self-driven polymer micropump fueled by salt which can trigger both radial recirculating and unidirectional fluid flows [2]. The micropump is based on the ion-exchanger Nafion, which produces chemical gradients with the consequent local generation of electric fields capable to trigger interfacial electro-osmotic flows. By combining new nanofabrication strategies for Nafion structuring in microarrays with a fine tune modulation of the surface zeta potentials it was possible to redirect electro-osmotic flows into unidirectional pumping. The experimental data have been contrasted with numerical simulations accomplishing good agreement.

Nafion micropumps work in a wide range of salt concentrations covering more than four orders of magnitude, and can be regenerated for reusability. Moreover, they are activated using different cations. In particular, we demonstrate that they can work using heavy metal ions, such as the typical water-contaminant cadmium, using the own capture of the contaminant ion as fuel to drive fluid pumping. Thus, this novel system has potential for effective and fast water purification strategies for environmental remediation, where the fluid motion triggered by the contaminant ions also speeds up the ion trapping in the polymer backbone. In addition, this study constitutes a very appealing proof of concept for a new generation of wireless micro/nanofluidic networks which can autonomously propel and steer material to certain locations and be useful for different applications.

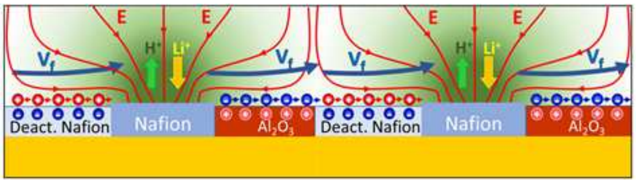

Fig. 1. **Unidirectional pumping**. Scheme of the design of a pump based on the periodic repetition of a basic unit made of alternating strips of deactivated Nafion (negative zeta potential)/Nafion/Al_2O_3 (positive zeta potential) which would lead to unidirectional fluid flow along the patterned surface. The charged interface in the Nafion has been omitted to lighten the content of the figure. The Al_2O_3 patches with positive zeta potential accumulate negative counterions that in the presence of the tangential component of the electric field generated by the ion-exchange will move also to the right, dragging the fluid along to the next repeating unit, achieving unidirectional flow.

[1] M. J. Esplandiu, K. Zhang, J. Fraxedas, B. Sepulveda, and D. Reguera, Acc. Chem. Res. **51**, 1921 (2018).

[2] M. J. Esplandiu, D. Reguera, D. Romero-Guzmn, A. M. Gallardo-Moreno, J. Fraxedas, submitted.