Tuning the wettability of nanoporous materials for active fluidic control

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Abstract

Nanofluidic transport exhibits novel interesting properties and is widely present in different processes such as energy conversion, filtration, water desalination, and analytical separation of small molecules. One issue of interest is the spontaneous imbibition of fluids in bodies with a nanoscale pores size [1]. Contrary to previous studies we here use conductive nanoporous bodies. This allows us to control the electrode potential at the solid-fluid interface [2]. Electrocapillary techniques exhibit great advantages in nonmechanical electrofluidic manipulation, e.g., flow actuation in micro-/nano- channels.

Nanoporous gold (NPG) with uniform pore- and ligament size of ~45 nm was fabricated by dealloying an $Ag_{75}Au_{25}$ alloy [3]. Spontaneous imbibition of aqueous electrolytes obeys the Lucas-Washburn law. Interestingly, the estimated tortuosity has the low value ~3.2 (3 is expected for an isotropic sponge). Electrocapillary effects were then used to manipulate the imbibition dynamics. As a result of the enhanced wetting by the electrocapillary effects, we observed an acceleration of the imbibition by ~30%. When air as the pore fluid is replaced with cyclohexane, we show for aqueous electrolyte imbibition in nanoporous gold that the fluid flow can be reversibly switched on and off through electric potential control of the solid–liquid interfacial tension, that is, we can accelerate the imbibition front, stop it, and have it proceed at will. Our findings demonstrate that the high electric conductivity along with the pathways for fluid/ionic transport render nanoporous gold a versatile, accurately controllable electrocapillary pump and flow sensor for minute amounts of liquids with exceptionally low operating voltages.

On the other hand, although on–off switching was demonstrated, the hydrophilic nature of Au required preloading of another solvent (cyclohexane) to prevent spontaneous imbibition of water (in order to completely switch off), which consequently restricted the flow rate during the “on” state. A CNT sponge is a macroscopic assembly of nanotubes with high porosity, electrical conductivity, intrinsic hydrophobicity, and mechanical flexibility [4]. We show that these CNT sponges could also serve as an electrocapillary imbiber to achieve efficient water imbibition under low voltages and on–off switchability [5]. The conductive CNT network, interconnected flow channels throughout the open-porous sponge, and suitable effective pore sizes are key factors for enhanced imbibition performance. Compared to elastomeric or metal-based porous materials studied before, the CNT sponges show distinct advantages such as easy on–off control, fast imbibition and high capacity, as well as being compressible and pore size tunable.

It is expected that these nanoporous materials could be shaped and integrated into a variety of micro- and nanofluid systems for biological, environmental, and other applications.

Keywords: Wettability, Nanoporous gold, Carbon nanotube sponges, Nanoscale fluid control, Electrocapillary effects.

References

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