Nanowicking:

Multi-Scale Flow Interaction with Nanofabric Structures

Thesis by

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Abstract

Dense arrays of aligned carbon nanotubes are designed into strips — nanowicks — as a miniature wicking element for liquid delivery and potential microfluidic chemical analysis devices. The delivery function of nanowicks enables novel fluid transport devices to run without any power input, moving parts or external pump. The intrinsically nanofibrous structure of nanowicks provides a sieving matrix for molecular separations, and a high surface-to-volume ratio porous bed to carry catalysts or reactive agents.

This work also experimentally studies the spontaneous fluid transport along nanowicks. Liquid is conveyed through corner flow, surface flow, and interstitial flow through capillary force and the Marangoni effect. The main course for corner flow and surface flow follows Washburn behavior, and can deliver liquid centimeters away from the input blob with a speed on the order of millimeters per second depending on the nanowick configuration and the amount of input liquid. Corner flow can be minimized and even eliminated through proper nanowick and input design. Otherwise, corner flow interacts with surface flow in the first 2mm of the pathway closest to the input point. Interstitial flow dominates the late stage. It is driven by both capillary force and concentration-gradient-induced Marangoni force. The concentration gradient is determined by two competing rates: surfactant diffusion in solution and adsorption onto nanotube surfaces. The flow inside nanowicks may wick hundreds of microns in seconds or tens of seconds. A non-conventional advancing front may develop in the flow around nanowicks. They are seen as (i) Rayleigh instability-induced fingering in surface flow on millimeter-wide nanowicks, (ii) viscous instability-induced branching near almost-stagnant surface film at low surfactant concentration, and (iii) disjointed wetting domains at very low concentration.

Additional keywords: microfluidic, microdevices, nanowicking, spontaneous transport, carbon nanotubes, nanoarrays, nanoporous, nanopillars, nanocarpets, nanoforests, capillarity.