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Topological liquid diode

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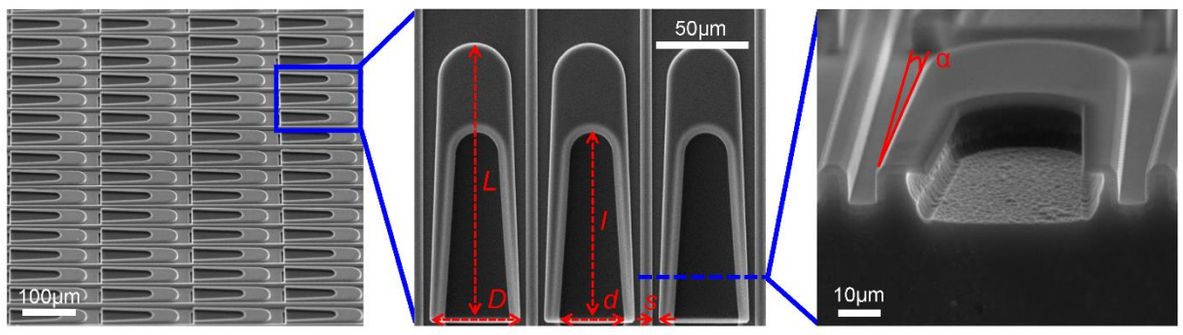
Abstract

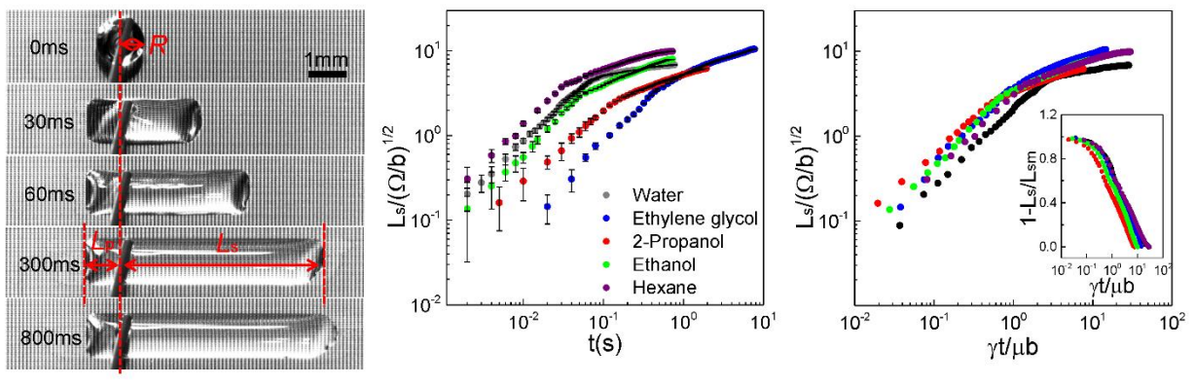
The last two decades have witnessed an explosion of interest in the field of droplet-based microfluidics for their multifarious applications. Despite rapid innovations in strategies to generate small-scale liquid transport on such devices, the speed of motion is usually slow, the transport distance is limited, and the flow direction is not well controlled because of unwanted pinning of contact lines by defects on the surface. Here we report a new method of microscopic liquid transportation based on a unique topological structure that breaks the contact line pinning through efficient conversion of excess surface energy to kinetic energy at the advancing edge of the droplet whilst simultaneously arresting the reverse motion of the droplet via strong pinning. What results is a novel topological fluid diode that allows for a rapid, directional, and long-distance transport of virtually any kind of liquid without the need for an external energy input.

Liquid diode structure



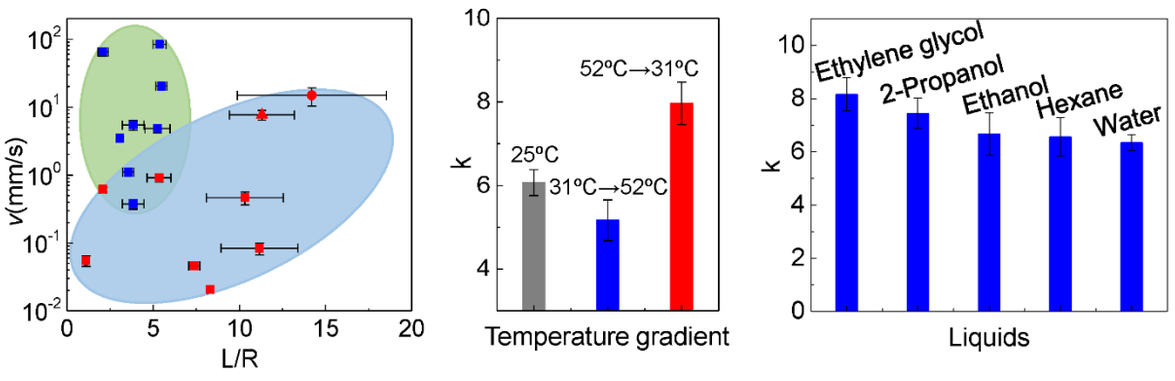
- The liquid diode consists of U-shaped island arrays spatially confined in periodically patterned fences.
- The width of the U-shaped islands is designed to decrease gradually from the opening end to the other end, thus two diverging side-channels are naturally formed within fences.
- The inner side of cavity in the U-shaped island is specially designed with a reentrant structure.

Liquid transport



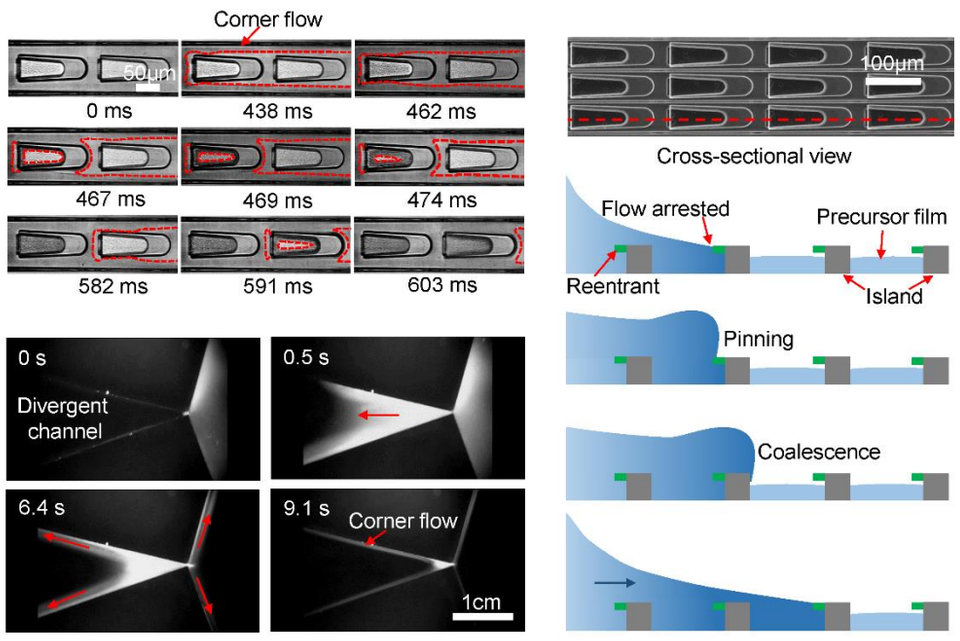
- Liquid transport on liquid diode consists of two different spreading regimes.
- **First stage**: The spreading length increases almost linearly with time, signifying a unique characteristic of the liquid diode.
- **Second stage**: The spreading exhibits a logarithmically slowing-down kinetics.

Discussion



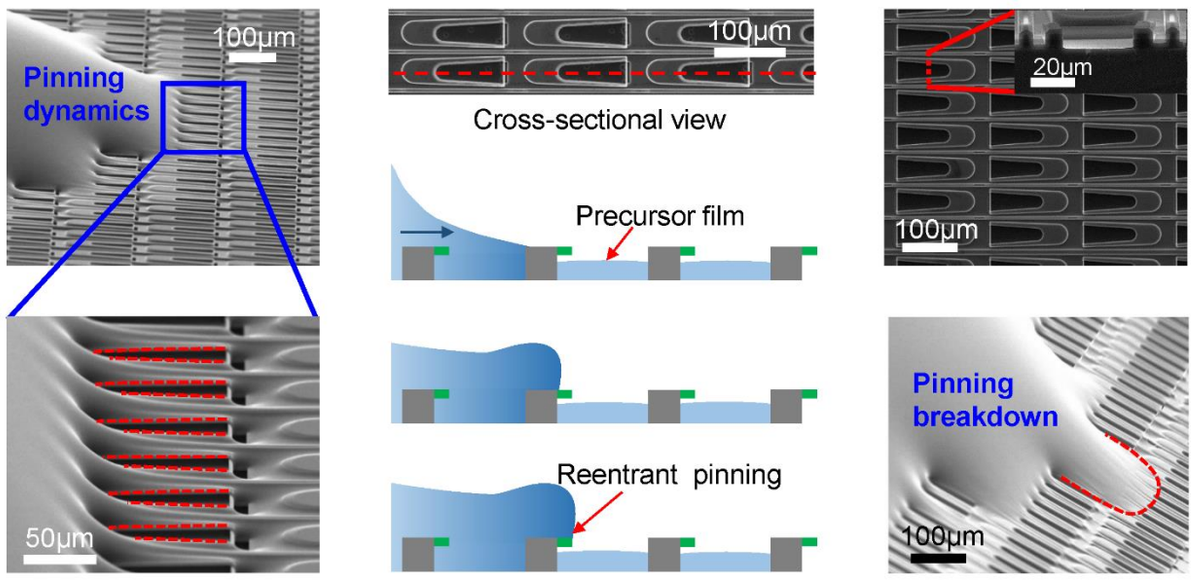
- The liquid diode enables a unidirectional liquid transport with a higher spreading velocity and a longer spreading distance compared with previous strategies.
- The liquid diode can transport different liquids.
- The liquid diode can transport liquid along various pathways.
- The liquid diode can transport liquid overcoming temperature gradient.

Spreading dynamics



- A visually perceptible thin liquid film continues to spread ahead of the primary droplet.
- **Precursor film**: The precursor liquid firstly wets the straight sidewall of side-channels. Upon contact with the sidewall of U-shaped islands, it progresses spontaneously in the side-channels. Subsequently, the reentrant cavity and asperities between two neighboring U-shaped islands become wetted, triggering a diode-like global propagation of liquid.
- **Primary droplet**: The droplet stops for a brief period during which the precursor film continues to flow. This discontinuous phase has a series of wetting phenomenon, including pinning, bulging up, jumping and coalescence with precursor film.

Pinning dynamics



- Despite the corner flow and hydraulic jump, the backflow of the liquid droplet is strongly thwarted around the reentrant edge.
- Such a pinning is also assisted kinetically by the continual removal of liquid through the corner flow in the diverging channel, as the curvature of the liquid meniscus becomes progressively concave starting from the mouth of the diverging channel towards its tail.
- For the surface without the presence of reentrant feature, the liquid easily penetrates the cavity and the pinning effect is totally broken down.

Publications

Topological liquid diode, ***Science Advances***, In press.