Liquid Transportation using Micron-Scaled Selective Heating Elements and the Leidenfrost Effect

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Abstract: The Leidenfrost phenomenon, first discovered in 1756, describes a metastable state of a droplet on a substrate heated significantly above the boiling point of the liquid [1]. The droplet is levitated by an instantaneously generated vapour layer (100 µm to 200 µm) caused by the initial contact of the droplet with the substrate. The levitation yields a virtually frictionless contact between the droplet and substrate, therefore playing a key role in drag reduction for potential liquid flow. Moreover, the vapour layer acts as a thermal insulator, preventing rapid droplet evaporation despite the high temperature of the substrate. The Leidenfrost effect can also be used to transport, or rotate droplets and disks of solid ices [2]. However, substrates are usually uniformly heated to a constant and high temperature requiring a significant input of energy. Here, we report an approach to activating the Leidenfrost effect in both a spatially and temporally localised manner thereby significantly reducing the energy input required [3].

In our approach, we selectively trigger Leidenfrost levitation of a droplet by the application of a voltage to micrometre-scaled serpentine shaped heating units, which have been micro-fabricated on the substrate in groups to create voltage addressable heating arrays. We demonstrate that the heating arrays were able to generate a Leidenfrost effect transition for droplets of isopropanol, acetone, and deionised water. Experimental data for thermal distributions were compared with COMSOL simulation results for the phase diagrams describing metastable levitation of droplets as a function of device designs. To provide a proof-of-concept for low friction droplet transport and microfluidics, we conducted experiments on droplet transport down a tilted substrate with voltage addressable heating arrays. In these experiments, four heating arrays were used with typically three activated and one inactive. In each case, low friction, high-speed droplet transportation ($65\,\mathrm{mm\,s^{-1}}$) across the activated heating arrays on a substrate tilted by 7° was observed. Droplet motion ceased when the inactive electro thermal heating array was encountered.

References

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