

Optothermal Manipulation of Liquid Droplets

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Abstract: Optothermal manipulation of liquid was studied with surfactant-free oil-in-water emulsions. Trapping, assembly, and fusion of pure liquid droplets in an aqueous medium were demonstrated by applying an optothermal stimulus and adjusting medium compositions. © 2021 The Author(s)

1. Introduction

Manipulation of liquid by light is one of the promising methods for precisely handling small amounts of liquid such as in microfluidic devices. Studies on this field have used specific photoresponsive materials either coated on solid substrates or as surfactants to induce interfacial tension gradients that enabled the movement of liquid [1–3]. Such requirements in the material composition along with inherently slow kinetics call for a versatile and effective technique for manipulating pure liquid. Here, we studied the utility of optothermal tweezers [4,5] in manipulating pure liquid droplets. It was found that surfactant-free oil droplets in water can be trapped, dragged, and assembled in response to a light-induced temperature gradient at a significantly low optical power. Based on mechanism analyses, the oil–water interface was shown to be charged by ordered structures of water molecules and autoionized ions. By tuning the composition of aqueous media, it was also possible to control the trapping and fusion of droplets.

2. Results and Discussion

As shown in Fig. 1a, oil was emulsified into water to produce microscale droplet dispersion. Upon the irradiation of a focused green laser on a gold nanoislands substrate, droplets were rapidly trapped and assembled within seconds. Although the fluid was a mixture of two liquids without any additives, the fusion of adjacent droplets was barely observed, implying the presence of stable charges at the interface. The working principle of trapping was analyzed that an electric field was induced by water polarization in a response to an optically driven temperature gradient and negatively charged microdroplets were trapped by the electric field (Fig. 1b). The zeta potential of droplets was measured to be negative, which was consistent with the trapping mechanism. Moreover, the precise positioning of individual droplets was also achieved in a diluted condition (Fig. 1c).

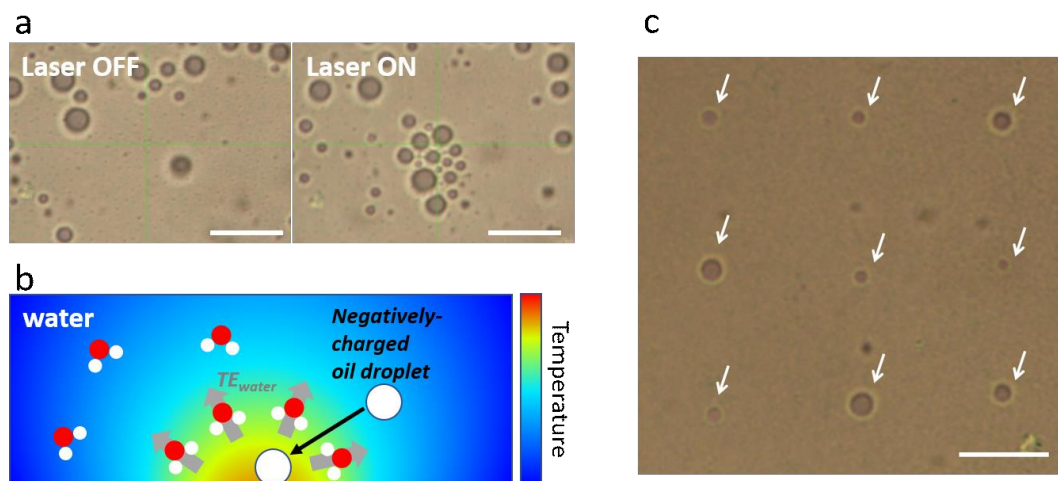


Fig. 1. (a) Optothermal trapping and assembly of oil droplets in water. (b) Working principle of droplet trapping (TE_{water} and gray arrows indicate a thermoelectric field induced by water polarization). (c) 3x3 array of oil droplets (Arrows indicate printed droplets while others are dispersed droplets). Scale bars: 10 μ m.

Further studies were conducted in trapping and fusion behaviors of droplets in different solvents. As the oil–water interface possessed the ordered structure of water and ions, we hypothesized the charged interface and resultant trapping/fusion of droplets can be affected by additional solvents. By introducing different water-miscible solvents into water, it was able to modulate trapping and fusion of droplets (Fig. 2). This result implies the interfacial molecular structure play a critical role in droplet manipulation, which can be interfered by other polar molecules. In this context, this tool can be used to unravel the nature of water’s interfacial charging which has long been under debate.

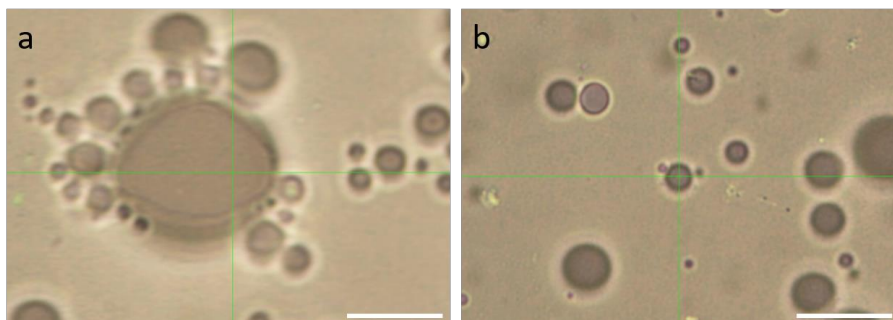


Fig. 2. Fusion behaviors of optothermally assembled droplets in different media. (a) Fusion of droplets in acetonitrile/water (1:1 v/v) and (b) weakened trapping without fusion in ethylene glycol/water (1:1 v/v). Scale bars: 10 μm .

To conclude, we demonstrated the optothermal manipulation of pure liquid droplets in water. An optically induced temperature gradient and concomitant water polarization enabled trapping and assembly of individual droplets. It was further shown that the fusion of droplets strongly affected by other polar molecules in water. This study on liquid-in-liquid manipulation will suggest a way to utilize liquid manipulation in chemical reaction, purification, and sensing as well as providing detailed understanding of water’s interfacial charging phenomenon, which further helps revealing unprecedented roles of water in biosystems and environment.

3. References

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