THREE-DIMENSIONAL MANIPULATIONS OF NANOLITER WATER-DROPS ON OPEN PLATFORMS USING MAGNETICALLY CONTROLLED HYDROPHOBIC FERRO-DROPS

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ABSTRACT

Here we present a novel and extremely simple method that can manipulate magnetic label-free nanoliter water-drops using micro-nanoliter magnetically controlled hydrophobic ferro-drops used as magnetic mediators. Water-drops and ferro-drops can be dynamically connected under interface force of water/oil, allowing water-drops to be rapidly motioned on three-dimensional open platforms and transferred through space like micro-pipette. Each generated water-drop can be selectively encapsulated with a drop of mineral oil for preventing evaporation and then completely transferred to surfaces of water-phase, oil-phase and solid-phase without any liquid residue due to magnetic repulsion.

KEYWORDS

Three-dimensional manipulation, water-drop, ferro-drop, open platform.

INTRODUCTION

Implementing reaction and analysis within nanoliter water-drop (WD) usually means less consumption of sample and reagent, faster time-to-result and lower cost. Recently, open format-based droplet microfluidics (sometimes called digital microfluidics) has been rapidly developed.[1] Compared with closed platforms containing microchannel network, open platforms could offer larger region and additional degrees of freedom, allowing WD motion on two- (2D) even three-dimensional (3D) platforms. Magnetically controlled WD motion is an attractive method and can be easily achieved by low-cost commercial permanent magnets.[2] Because WD has a very low magnetic susceptibility, usually some hydrophilic/hydrophobic magnetic nano/micrometer materials are added into WD in response to external magnetic field gradient. However, the adding of magnetic materials results in difficulty in fully transparent WD detection through optical detection and implementing high-density parallel operation.[3-4] Herein, we report a novel methodology that demonstrates the feasibility of 3D manipulations of magnetic label-free WDs by combining magnetic force with interfacial force.

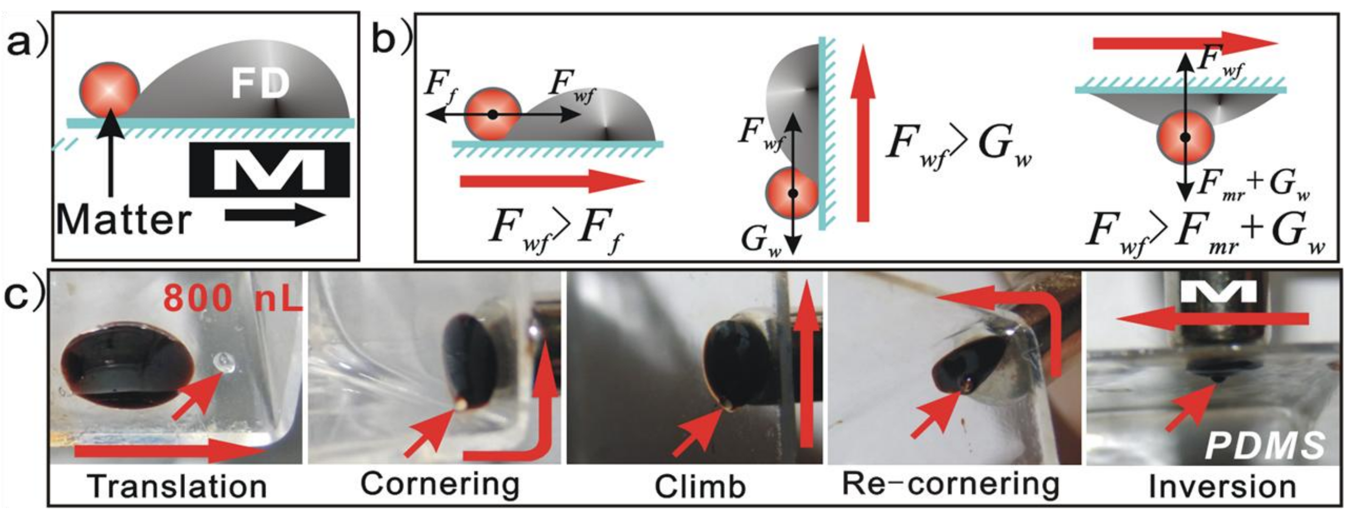

Figure 1. Schematic diagram and photographs of three-dimensional WD manipulation on open platform.

EXPERIMENT

PDMS (Polydimethylsiloxane) layer (about 100 μm thickness) was coated on five inner surfaces of polystyrene (PS) cube (2 cm length) as an open solid platform in Figure 1c. PTFE (polytetrafluoroethylene) film (about 1 mm thickness) was sticked on a glass slide in Figure 5a. Magnetic field was provided by NdFeB permanent magnet. The flow rate in Figure 2 was adjusted by precise syringe pump (Harvard pump 11 plus) with a flat tip stainless needle (100 μm ID).

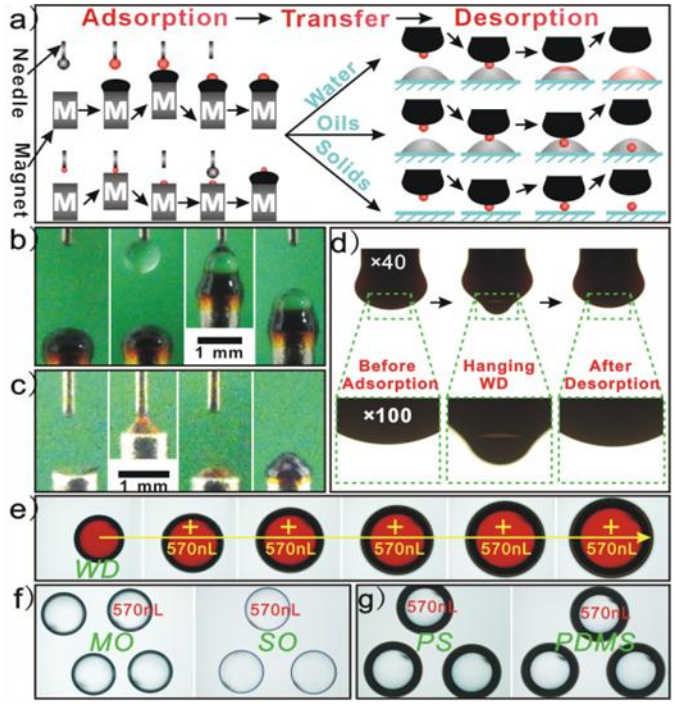

Figure 2. a) Schematic showing the whole process of WD adsorption, transfer and desorption. WD adsorption b) by soft tweezer and c) by rigid magnet. d) Microscope images of soft tweezer in different states involving before adsorption, hanging WD and after desorption. Complete WD (each 570 nl) desorption to e) water-phase (red WD), f) oil-phase (MO and SO), and g) solid-phase (PS and PDMS) surfaces, respectively.

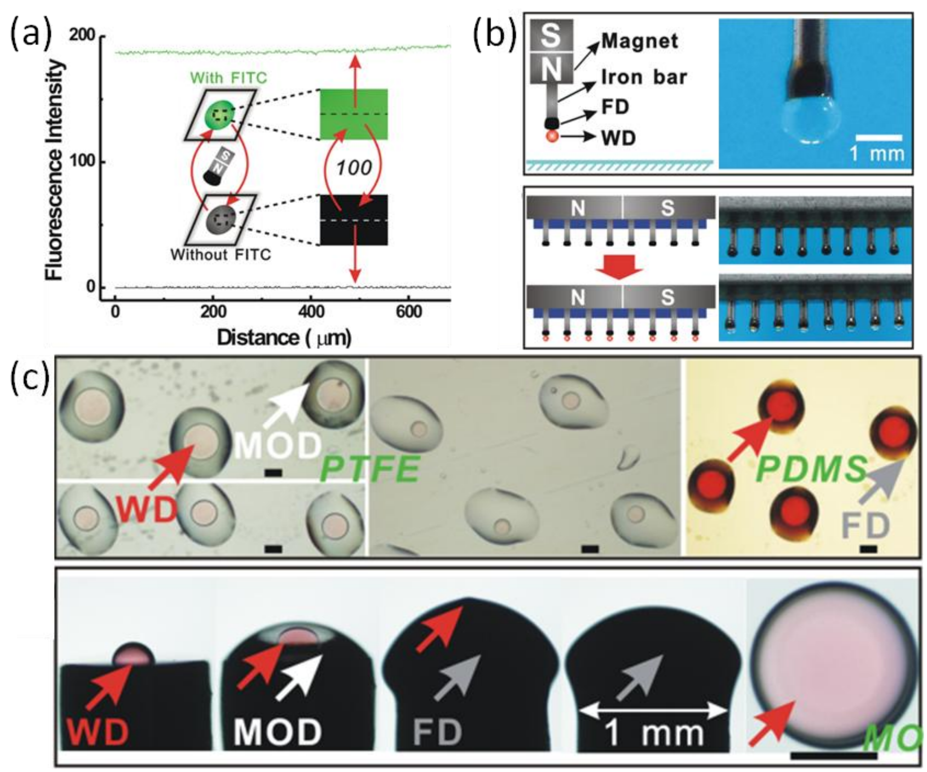

Figure 3. (a) A soft tweezer is forced to contact with a deionized WD and a FITC-labeled WD back and forth over 100 times, and then fluorescence intensity is respectively measured to demonstrate non cross-contamination. (b) Adsorption of WD using arrayed soft tweezers. (c) Evaporation control of WD with two compatible ways. Scale bar, 200 μm.

RESULTS AND DISCUSSION

The obtained ferro-drops (FDs) had both the fluid properties of mineral oil (MO) and the superparamagnetic properties of Fe_3O_4 nanoparticle,[2] allowing them to be transported at controlled speed and direction on open platforms by magnetic attraction. When interfacial force of WD/FD (F_{wf}) was larger than friction of WD/substrate (F_f) and gravity of WD (G_w), WDs enabled to be moved on 3D platforms (Figure 1). The unshaped FD could be tightly adhered at magnet tips to form shaped FD which was called soft tweezer. Soft tweezers could be used to adsorb, transfer and completely desorb WDs to surfaces of water-phase, oil-phase and solid-phase without any liquid residue due to magnetic repulsion (Figure 2). This phenomenon has been well demonstrated by fluorescence analysis-based experiment (Figure 3a). Because shaped FDs were stable at magnet tips, soft tweezers could be arranged in high-density such as a straight line (Figure 3b), allowing demand to operate multiple WDs simultaneously. In order to decrease trouble from liquid evaporation such as concentration increase of solution, two compatible ways were developed to support the present method for reducing WD evaporation rate (Figure 3c). This simple method does not require magnetic label procedure, microelectrode patterning, microvalve integration, complicated surface treatment or a chip containing microchannel, and is expected to achieve various miniaturized biochemical applications.

CONCLUSION

A novel magnetically controlled method for multidimensional manipulations of microliter-picoliter magnetic label-free water-droplets is presented. Because interfacial force is one of widespread forces in nature and exists at all immiscible phase interfaces, this method is suited to handling various matter including liquid (i.e. blood, serum, tissue fluid and urine), solid (i.e. microparticles of polymer and metal) even gas (i.e. air bubble). And droplets can not only be transferred on three-dimensional open platforms but also through space like micro-pipettes. Furthermore, the platform building and operation process are very simple, not including microelectrode patterning, microvalve integration, complicated surface treatment and design/fabrication of microchannel network. These advantages suggest that this novel and general method could have wide application potentials including synchronized analysis/synthesis and single-cell analysis. In the future all operations might be achieved automatically by using programmable electromagnet.[5-6]

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