Control the Poly-Dispersed Droplet Breakup Mode in a Droplet-based Microfluidic Device By External Electric Field

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Abstract

Droplet-based microfluidics has received special research attentions in last two decades due to its superior control over fluid flow as well as other unique advantages[1]. By introducing two immiscible fluids into microfluidic systems, the reagent fluid is encapsulated inside discrete droplets or slugs of nanoliter volume [2]. Interestingly, two breakup modes, termed as "mono-dispersed" and "poly-dispersed" breakup modes, have been observed in the dripping regime. The mono-dispersed breakup mode generates droplets of uniform sizes [3-5]. In contrast, the poly-dispersed breakup mode, which is governed by the nonlinear dynamics of the breakup process, can lead to droplets of broad size distributions [4, 6, 7]. A typical poly-dispersed breakup mode in the dripping regime is shown in Figure 1. After the primary droplet is separated from the dispersed phase, the fluid neck continues to grow inside the orifice and generate one or multiple secondary droplets of smaller sizes. Based on the analyses on the dynamics of drop deformation and breakup, Stone and Leal [8] have concluded that the capillary instability leads to poly-dispersed breakup mode. The instability requires a certain amount of time to develop, and the developing time is a function of viscosity ratio. Therefore, we hypothesize that the droplet breakup mode can be controlled by manipulating the breakup time, which can be achieved by utilizing external electric field.

In order to validate our hypothesis, we have applied numerical simulations to study the droplet breakup process inside a microfluidic flow-focusing device. An external direct-current (DC) electric field is connected to the microfluidic system in the way as shown in Figure 2(a): The left inlet channel of the continuous phase is connected to a high voltage DC supply while the right inlet channel is connected to the ground. Such configuration can generate strong electric field inside the disperse phase, especially in the neck region. The droplet breakup process is modeled by the conservative level-set method coupled with the electric static model in COMSOL Multiphysics® software. The conservative level-set method is used to track the motion of the fluid interface[9] while the electric static model estimates the Maxwell stress on the fluid interface[10]. The results indicate that electric field can induce electric body force on the fluid interface due to the different electric permittivity of the two phases. As shown by the white arrows in Figure 2(b), the electric body force can point inward to the dispersed phase if the electric field is placed properly. Such electric body force provides an additional handle to control the droplet breakup mode other than manipulating the flow rates of the continuous and

dispersed phases. As illustrated in Figure 3, the droplet breakup mode shifts to "mono-dispersed" if V0 = 120 V is applied to microfluidic system. Such results confirm our hypothesis that the electric field can provide effective control over the droplet breakup mode inside droplet-based microfluidic devices.

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