Microfluid Nanofluid
DOI 10.1007/s10404-013-1268-8

RESEARCH PAPER

A facile on-demand droplet microfluidic system for lab-on-a-chip applications

Hongbo Zhou · Shuhuai Yao

Received: 13 May 2013 / Accepted: 14 September 2013
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Abstract We present a facile microfluidic droplet-on-demand (DOD) system in which a pulsed pressure generated by a high-speed solenoid valve is used to control the formation and movement of water-in-oil emulsion droplets in a T-junction microchannel. We investigated the working principle of the DOD system and established a scaling model for the droplet volume in terms of the amplitude and duration of the pulse and the hydraulic resistance of the injection channel. The droplet formation was characterized in three designs at various pressure pulses. The experimental results support our scaling model very well. In the DOD system we developed, nanoliter-volume droplets with a throughput of a few droplets per second were on-demand generated. Moreover, we examined the applicable scope of the DOD system. As examples of practical applications of the DOD system, we demonstrated a digital display module to show droplets formed at a prescribed time and a droplet array with a concentration gradient to show droplets formed with a precise volume. We expect our work can provide design guidelines for a robust DOD system and improve the capabilities of droplet-based microfluidics in 'lab-on-a-chip' systems.

Keywords Droplet on demand · Pressure control · Solenoid valve · Microfluidics

1 Introduction

Droplet-based microfluidics offers significant advantages for performing screening and assays (Zheng et al. 2003; Niu et al. 2011), due to their unique features such as reduced sample consumption, less cross-contamination, fast kinetics (Song et al. 2003), and isolation of individual space (Atencia and Beebe 2004; Stone et al. 2004). In order to automate the droplet platform for multi-step, multi-reagent biological and chemical studies, it is essential to generate droplets on demand: at a prescribed time and with a prescribed volume. Formation of picoliter- or nanoliter-volume droplets using water-in-oil emulsion has usually been realized in two configurations: T-junction (Thorsen et al. 2001) and flow-focusing (Anna et al. 2003). Based on these two structures, the most common method for controlling droplet-forming process is achieved by adjusting the inlet pressure or by dictating a constant flow rate using a syringe pump. The correlation between droplet size, distance between droplets, droplet velocity, and formation rate has been extensively studied (Baroud et al. 2010; Garstecki et al. 2006), and it is found that it is almost impossible to obtain any combination of those parameters (Bransky et al. 2008), e.g., in a required volume at a required generation frequency. However, in many biological and chemical assays, precise and flexible control of the formation, composition, and size of individual droplets is often desired. Moreover, the system response time, the time needed for stabilization of droplet formation in these conventional systems, is quite long (e.g., several minutes), which may interfere with the integration and automation of droplet microfluidics in practical applications.

Electronic supplementary material The online version of this article (doi:10.1007/s10404-013-1268-8) contains supplementary material, which is available to authorized users.

H. Zhou · S. Yao (✉)
Department of Mechanical Engineering, The Hong Kong University of Science and Technology, Hong Kong, China
e-mail: meshyao@ust.hk

H. Zhou
State Key Laboratory of Transducer Technology, Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Science, Shanghai, China

Published online: 26 September 2013