SELF-SYNCHRONIZED GENERATION AND
CONTROLLED MERGING OF DROPLETS

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ABSTRACT

A multifunctional polymeric microfluidic device is presented for the self-synchronized production and merging of droplets. This novel method uses the different dielectric constants of water and oil as the principle of actuation for synchronizing the production of droplets. When an aqueous droplet enters the gap between an electrode pair the potential difference across this pair decreases, causing a corresponding increase in the potential difference across the second pair of electrodes, releasing the second droplet. The device is also able to fuse the generated droplets, enabling precise chemical reactions in several nanoliters on a single platform.

KEYWORDS: Self-synchronized, micromixing, microdroplet

INTRODUCTION

In the past years, pico/nanoliter-sized droplets have been widely used to perform miniaturized chemical and biological processes. Some methods for droplet micromixing have been reported [1]. Specifically, synchronous merging methods have been investigated [2]. In these studies several syringe pumps were necessary to drive the flows in order to produce size dependant flow velocities as means of passive synchronization. However, pump precision will become a limiting factor when handling very small sample volumes. Also, in the previous method, fusion of droplets required that a larger droplet is preceded by a smaller one. Different sized droplet merging requires extra calculation to determine mixing concentration and quantities. In the presented method, fixed driven flows and voltages are used for the synchronized droplet generation.

THEORY

An electrical plate capacitor consists of two parallel metallic plates separated by a dielectric of thickness $d$. The capacitance, $C$, depends on the relative dielectric constant $\varepsilon_r$ of the dielectric:

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

(1)

where $A$ is the area between the plates and $\varepsilon_0 = 8.85419$ pF/m (permittivity of free space). When a droplet passes through the pair of electrodes at $A$ (see Figure 1), their capacitance increases since the droplet dielectric constant is greater than that of the carrier fluid. Since the polarization voltage between $A$ and $C$ is held constant, the change in capacitance causes a current flow through the conductive strip $B$, polariz-
ing it, and increasing the voltage between the electrode and side-channel at C, so introducing a droplet there.

**EXPERIMENTAL**

The schematic of the microfluidic channel pattern is shown in Figure 1. The device was machined from 2 mm thick polycarbonate sheets using a precision milling machine (CAT 3D-M6, Datron GmbH, Muehltal, Germany). Electrodes were made by filling the milled microchannels with silver-loaded epoxy (RS, Corby Ltd, UK). Samples and oil were injected into the channels by hydrostatic pressure. A high voltage unit supplying up to 2000V (Brandenburg, Dudley, UK) was connected to the second sample inlet and the electrode. Heights of the syringes were adjusted so that the water filled the water inlet but did not flow out into the oil channel.

![Figure 1. Schematic design and dimensions of the microfluidic reactor.](image)

**RESULTS AND DISCUSSION**

Figure 2 shows some frames of the self-synchronous generation process. Since the second droplet is produced as the first droplet passes, if the two channels merge at a later stage both droplets will arrive at the junction at the same time and are thus more likely to merge as shown in Figure 3.

![Figure 2. Self-synchronous production of droplets using water as a sample](image)  ![Figure 3. Merging of the synchronized water droplets at the junction](image)

Videos were recorded and analyzed for several voltages applied using different samples. Droplet rates were tested up to 120 droplets/min. Cresol red was used as a sample to demonstrate the dilution efficiency (Figure 4). In Figure 5 the percentage of successfully synchronized mixing of droplets was calculated for a set of voltages to determine the optimum operation voltage.
To illustrate the operation of this device, droplets containing cresol red and acetic acid were self-synchronized produced and merged. Coalesced droplets traveled along the main channel, allowing the observation of the chemical reaction inside the droplet as a function of time as shown in Figure 6.

Figure 6. Self-synchronous production and merging of droplets using cresol red solution and acetic acid solution

CONCLUSIONS

Self-synchronous droplet production has been successfully and repeatedly demonstrated. Droplets created by this system have also been efficiently merged. The results demonstrate the possibility of using fixed flow rates and fixed high voltage electric field to create and mix synchronized droplets.

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REFERENCES
