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Oral presentation

An automated system for the shape optimization of double emulsion droplets used in the fabrication of Inertial Fusion Energy target shells

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Introduction

In this work, we present a control system (Figure 1) for the fabrication of inertial fusion energy target shells, that automatically optimizes the shapes of double emulsion droplets. The system uses an on-flow droplet detection module, a data acquisition module (DAQ) for the real-time signal analyzing, and a coded Labview-based program.

Inertial fusion energy (IFE) targets are millimeter-sized, extremely spherical and concentric (sphericity>99.9%, concentricity>99.99%), fuel capsules, encapsulating frozen deuterium and tritium, to enable inertial confinement fusion reactions at ~150M℃, using high power laser facilities [1]. Such targets will be consumed at ~10^6 per day in future IFE power plants. Droplet microfluidics provides an efficient approach to form monodisperse double emulsion droplets, which can be used as the templates to produce the polymeric shells with the required geometry specifications. During their formation, such polymer shells may endure shape distortion, when solidified, due to photopolymerization shrinkage and resulting stresses. Hence, to minimize defects in the shape of the polymer shells, one necessary procedure is to maximize the sphericity and the concentricity of the double emulsion droplets, before the shell phase curing process is actuated.

In our previous work [2], we demonstrated a promising method to scale up the fabrication of such polymeric shells, using (i) surfactant-free, double emulsions, (ii) inertial centralization, (iii) on-flow double emulsion droplets detection, and (iv) millisecond-length (70ms) shell-phase curing, using precisely actuated UV pulses, from eight 365nm wavelength LEDs. The results indicate that the flow conditions, such as the droplet size, flow rate, and carrier phase viscosity, all influence the shapes of the double emulsion droplets in the continuous flow. To further improve shell quality, we developed an automated system, to optimize the shape of double emulsion droplets. In this system, a feedback loop was established to tune the inflow rates, based on a digital signal readout. The shapes of double emulsion droplets, and the resultant optoelectronic signals, were predicted by computational multi-physics simulations (Figure 2), and were used as the reference signals in the LabVIEW program. Once the double emulsion droplets were detected to have sufficient concentricity, the droplet curing process was actuated to solidify the shells.

Experiment

The details of microfluidics, to generate monodisperse double emulsion droplets, can be found in our previous work (2). The automated system, which contains the syringe pumps, laser pens, phototransistors, DAQ block, and Labview program, is shown in Figure 1.

Result & Discussion

The results in Figure 3, showed that the system enabled the optimization of the double emulsion droplets shapes, from an initial inner droplet offset state to a concentric shape, by changing the carrier phase inflow rates. Current work is focused on automatically controlling other factors, such as liquid phase temperatures and reagent concentrations within the shell phase, to improve further, the concentricity and sphericity of the polymeric IFE target shells . This work may also benefit other applications, that need to precisely control the droplet morphology for the fabrication of uniform compartmentalized microparticles.

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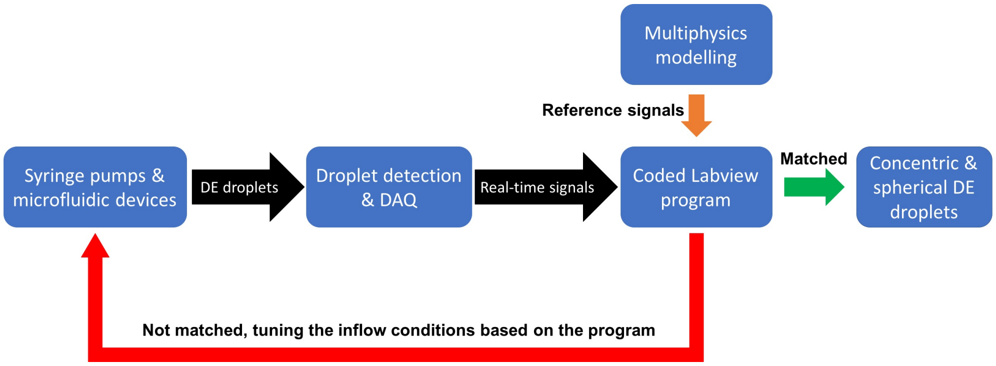
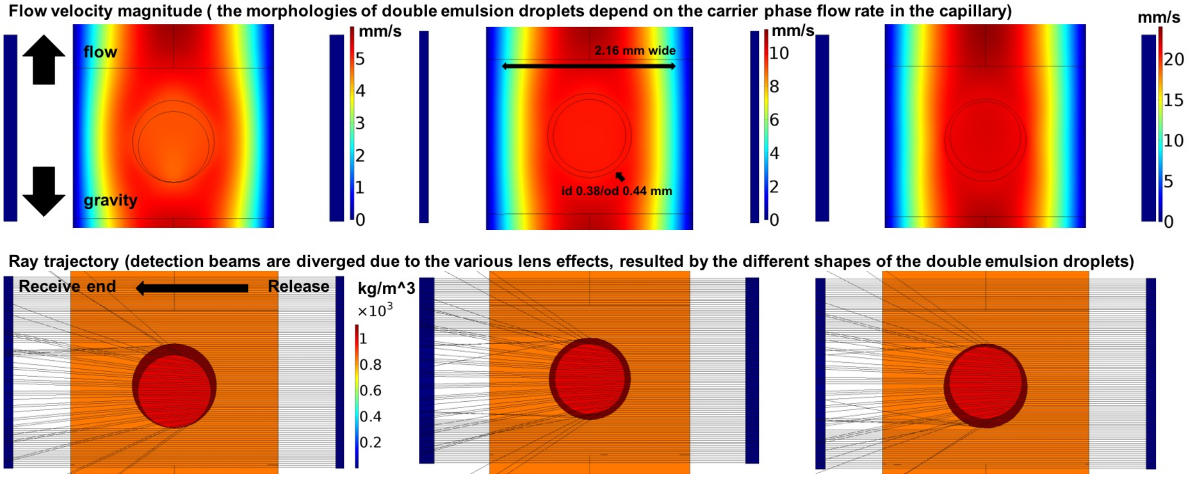
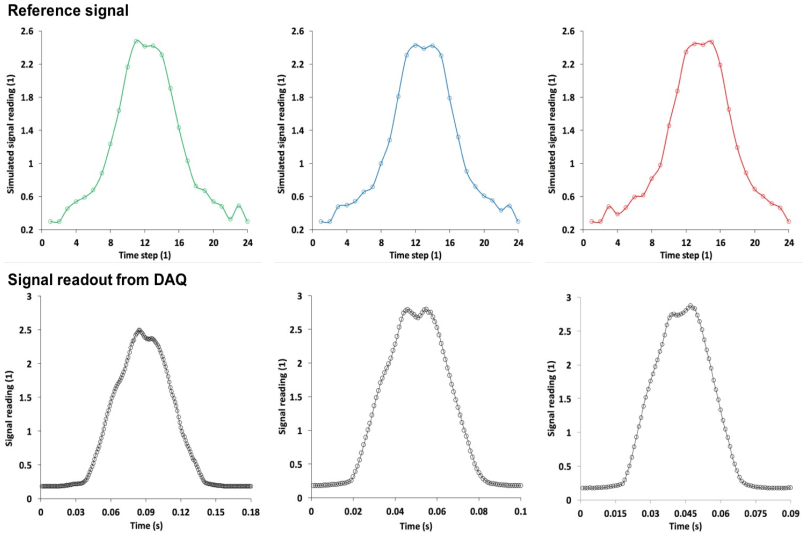


Figure 1. Flow chart of the automation system to improve the concentricity and sphericity of double emulsion droplets.


Flow velocity magnitude (the morphologies of double emulsion droplets depend on the carrier phase flow rate in the capillary)

Ray trajectory (detection beams are diverged due to the various lens effects, resulted by the different shapes of the double emulsion droplets)

Figure 2. Computational multi-physics modellings of the double emulsion droplet centralization and detection. The top row images are from three-phase laminar flow simulations that indicate the different morphologies of the same double emulsion droplet in different flow fields. The bottom row images are the geometrical optics simulations that indicate the detection beams are diverged by the double emulsion droplets. This is due to the different refractive indices of the materials, resulting in different amounts of photon energy upon the receiving end (phototransistor).


Reference signal

Signal readout from DAQ

Figure 3. The top row images are the simulated results showing that a concentric double emulsion droplet generates an M-shaped signal at the phototransistor output, whilst the offset shapes leads to signal distortions. The order of the images refers to Figure 2. These were used as the reference signals in the LabVIEW program. The bottom row images are the data collected from the DAQ, showing when 0.8/1mm double emulsion droplets flowed in the 80ml/hr, 120ml/hr, and 140ml/hr continuous phase stream within a 2.16mm wide tubing, from left to right, respectively. The signal shape readings from the DAQ were mathematically compared with the reference signals by the LabVIEW program, which subsequently controlled the operation of the syringe pumps. This referencing process was repeated until the double emulsion droplets attain concentric shapes.

Reference:

1. "High-power laser fusion facility for Europe." M. A. Dunne, *Nature Physics* **2**, 2-5 (2006).
2. "Continuous and scalable target-shell processing for inertial fusion energy", J. Li, J. Lindely-Start, A. Porch, D.A. Barrow, *Scientific Report*, under revision.