MICROFLUIDIC ENCAPSULATION OF DROPLET ASSEMBLIES

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ABSTRACT

We demonstrate the repeatable, precision generation of bespoke, multicore microcapsules, based on a double emulsion encapsulation, by using a novel variant of a flow focusing junction, where bifurcating side-ducts were incorporated. Microcapsules with up to 15 inner cores could be repeatedly fabricated. The morphology of the polymeric capsules could be precisely controlled and the number of inner core droplets was controllable by varying the dispersed phase flow rate. Numerical 3-D simulations were conducted to study the dynamic droplet breakup process. Such multi-core capsules have many potential applications in synthetic biology and biochemical computing.

KEYWORDS: Multicore microcapsule, microfluidics, synthetic biology, compartmentalisation

INTRODUCTION

New emerging applications of microfluidics, such as carbon capture [1] synthetic biology [2] and chemical computing [3] requires the precise manipulation and distribution of fluid-based matrices in space and time within discrete compartmentalised structures. Bottom-up constructional precision is required to create basic building blocks, within which custom chemical events can be organized, programmed and activated. Multiphase microfluidics offers the potential to construct such multi-core, constructs with a high degree of volumetric precision and spatial organisation. Such constructs, might be configured with chemical codes, which could cause their assembly into superstructures, thus effectively 'growing' new materials (Figure 1). We describe here a novel microfluidic junction which enables the bottom-up, repeatable precision fabrication of such multi-core constructs, with up to 15 cores.

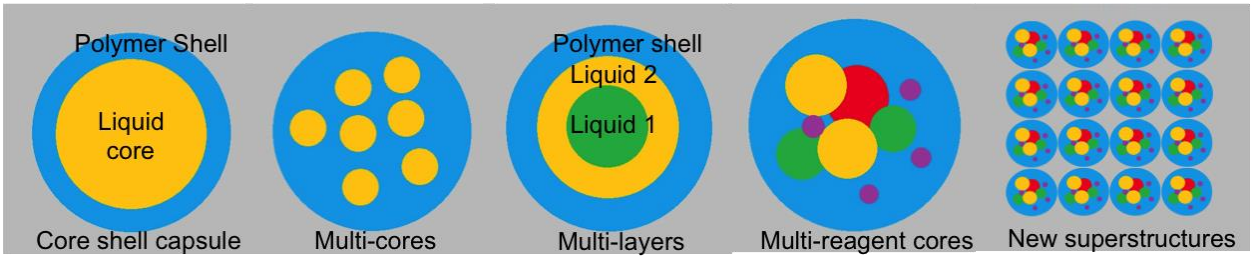

Figure 1: Schematic of core-capsule structures of varying complexity.

EXPERIMENTAL

A novel 'bat-wing' junction was designed around a flow-focusing junction format, by adding bifurcating side-channels, to act in an oscillatory manner on the dispersed phase (Figure 2). Microfluidic duct systems were machined in polytetrafluoroethylene using an LPKF milling machine and assembled as previously published [4]. Numerical simulations were undertaken with COMSOL Multiphysics 4.3b and numerical data obtained to reveal the flow profile in the geometry for time transient analysis. The gas permeable polymer NOA 61 was used to encapsulate aqueous droplets (saturated potassium carbonate solvent with 0.035% w/v thymol blue) and formed a consistent double emulsion, with mineral oil as the carrier phase. NOA 61 rendered the multicore constructs robust and three-dimensionally stable for subsequent metrology, and thymol blue enabled volumetric assessments to determine the repeatability of the fabrication process. The morphology of the double emulsion was precisely controlled by use of syringe pumps and gas-tight, glass syringes (SGE). The dispersed, multi-core constructs were photopolymerized with even illumination from an array of 365nm UV Light-Emitting-Diodes, and collected for further metrology, using a Nikon MM-800 metrology microscope and NI Elements software.

RESULTS AND DISCUSSION

The addition of bifurcating side-channels to create the novel 'bat-wing' junction, allowed the continuous phase to automatically change the route in an oscillatory manner, within the junction, and is regulated, in part, by the dynamic pressure field induced by the movement of the dispersed phase through the junction (Figure 2). Importantly, no satellite droplets are generated with this method.

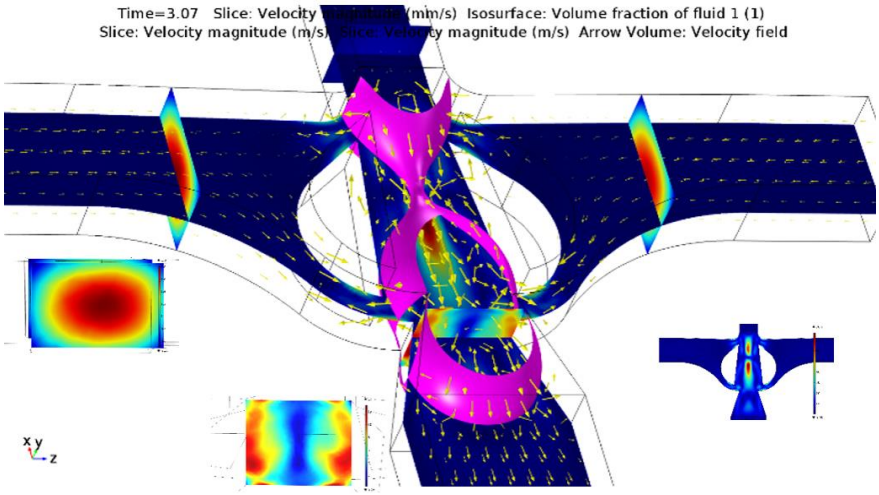

Figure 2: COMSOL simulation of droplet breakup; velocity magnitudes of fluid flow at different cross sections, indicated. Purple film indicates the isosurface between the dispersed and continuous phases; yellow arrows show local flow direction, their size presenting the velocity magnitude in a logarithmic scale.

As predicted by the COMSOL modeling (Figure 2), the oscillatory flow dynamics within the bat-wing junction, casues the dispersed phase to break off, with no residual satellite droplets (Figure 3). For a given set of conditions, the number of cores remained very constant, with only an occasional (~1 in 30) wrong assignment (additional core). The number of cores within a capsule was found to increase with decreasing continuous-phase flow-rate, which provided the principle control feature (Figure 4).

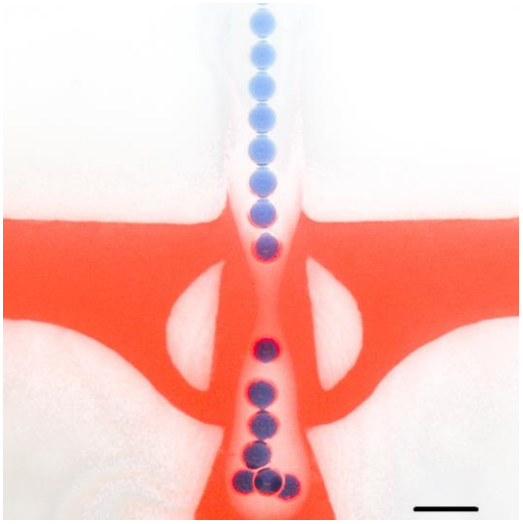

Figure 3: Image of double emulsion formation within the 'bat-wing' junction. Blue=potassium carbonate + thymol blue; white=NOA 61; Re=-mineral oil + oil red O. Scale bar =500um

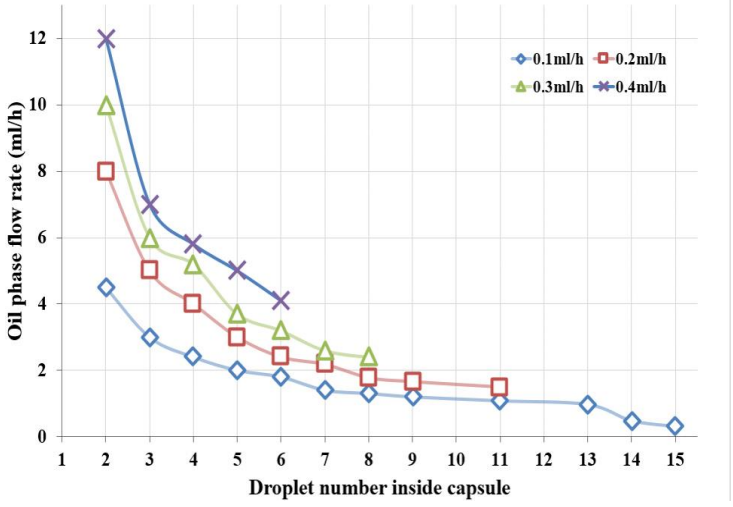

Figure 4: The relationship between droplet number and oil phase flow rate. Here, the aqueous and polymer phases have a constant flow-rate ratio. Aqueous phase flow rates are labelled.

To encapsulate different numbers of inner cores (Figure 5) the flow-rate ratio was varied and up to 15 inner cores could be repeatedly encapsulated within the polymer capsule. Furthermore, repeatable geometric organizations of cores, within a capsule, were evident and which depended upon their number.

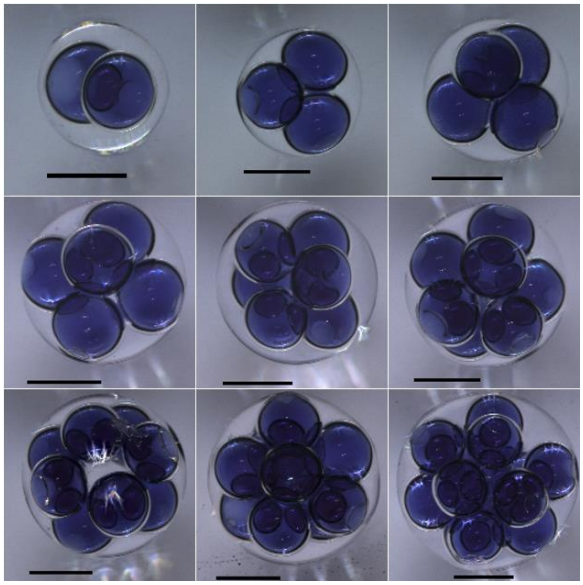

Figure 5: Photocured polymer capsules with defined numbers of aqueous inner cores, each of a defined volume. From top to bottom, left to right, inner cores number sequentially, 2-10. All scale bars indicate 500um.

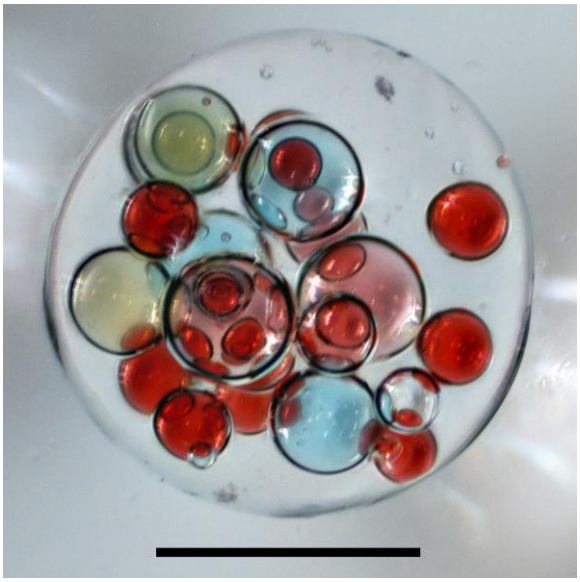

Figure 6: Photocured polymer capsule containing 4 different reagent solutions within different sized aqueous cores. The scale bar indicates 500um.

Figure 6 shows a similarly constructed polymeric capsule with 4 different reagents, each within different sized aqueous compartments, using the same experimental apparatus as in Figure 5. The provision of lipid layers around each of such internal compartments, and their interfacing, is the subject of on-going research in our laboratory, with the aim of creating artificial cells and enabling (bio)chemical computing

CONCLUSION

We have reported a novel microfluidic junction, with bifurcating side arms (so-called 'bat-wing' junction) that enables the repeatable fabrication of multi-core, polymeric constructs, where a given number of cores is determined by varying the relative flow velocity conditions between dispersed and continuous phases. Advantageously, no satellite droplets are generated using this method. This work has potential in diverse fields such as synthetic biology for the creation of artificial cells, drug screening and in chemical computing.

REFERENCES

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