Double encapsulated emulsion generation using a novel dual chip design

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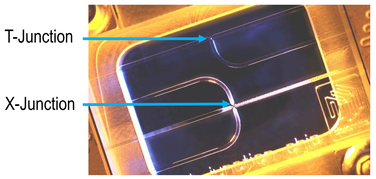
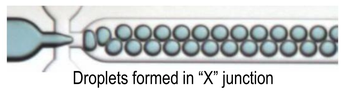
BACKGROUND

Many industrially and commercially useful products are emulsions. Examples include paints, salad dressings, coatings, and pharmaceuticals. In recent years, much research attention has been focused on generating well controlled monodisperse emulsions using microfluidic droplet generation systems. These systems commonly use flow focusing junctions of "T" or "X" format, such as the Dolomite Mitos Droplet Junction chip shown below:

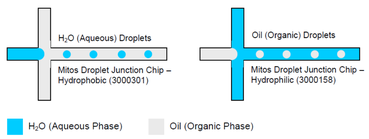


Droplets formed in "T" junction

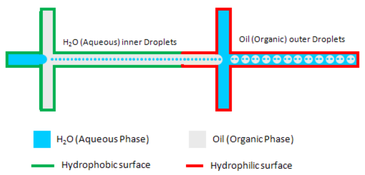


Droplets formed in "X" junction

Many common emulsions are formed as either "oil droplet in water" or "water droplet in oil". In each case, it is important that the flow channels have the correct hydrophobic or hydrophilic properties to promote droplet formation. This is readily achieved either by selection of an appropriate primary substrate for example hydrophilic glass or hydrophobic polymer. Alternatively surface properties and contact angle can be modified by a coating process.



Whilst these methods are well validated, methods of forming *double emulsions* for research projects (both oil in water in oil, and water in oil in water) are less mature. This is partly because the droplet forming channels must have both hydrophobic and hydrophilic sections in order to create either of the required droplet formats. Selective coatings have been demonstrated previously by flowing coating solutions along selected channels (1) and by using UV light to activate the coating in selective regions (2). These methods however have limitations in the range of coating processes and reagents that can be used. This in turn limits coating performance and the range of applications.



Double Encapsulation: Water – in – Oil – in – Water

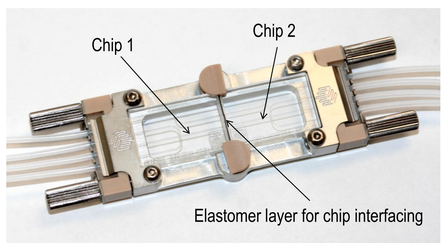
This poster describes a novel and simple method of assembling two droplet forming chips in series to allow creation of controllable double emulsions. The method uses standard parts and can be readily extended to allow the user to configure any desired droplet format. The results of initial testing of the chipset are presented, demonstrating good performance and ease of setup and use. Limitations on the flow stability of conventional syringe pumps are highlighted which can be addressed with the use of pressure-based pumping systems.

MICROFLUIDIC CHIP DESIGN

Mitos Droplet Junction chips are normally mounted in a Chip holder, with fluid inlet and out via Edge Connectors. For this application, a new holder was designed to fit two droplet chips.

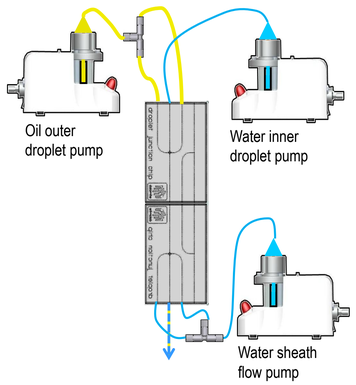
A thin elastomeric layer was laser cut to allow the chips to be pressed together and seal the channels.

By selecting one Hydrophobic coated chip (Chip 1) and one plain glass chip (Chip 2), it was expected that the desired water/oil/water droplets could be generated in this chipset Reversing the order of the chips would allow oil/water/oil droplets to be created.

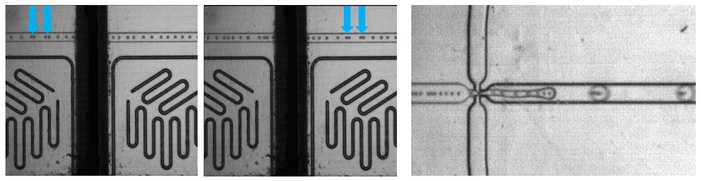


EXPERIMENTAL SETUP AND CHIP VALIDATION

The double emulsion chipset was connected to three syringe pumps, to allow independent control of flow rate for inner droplet, outer droplet, and sheath flow with the general connection format shown right:



Initial testing aimed to validate that droplets could pass from one chip to the other without disruption to the droplet quality or flow. The chipset was mounted on a Leica microscope and a Redlake camera system was used to record droplet production. The images below show the chip to chip transfer region. Note that the two pairs of droplets indicated by blue arrows can be clearly seen to pass cleanly across the chip junction:

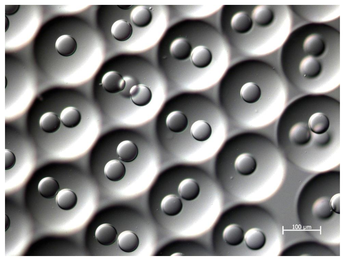


Fluid flow details: Aqueous inner droplet flow: DI Water 0.4 to 1.0 μL/min
Oil droplet phase: Medium Chained Triglyeride with 1.25% PGPR surfactant @ 25 to 50 μL/min
Water sheath phase: DI water with 0.2% whey protein isolate @ 250 to 350 μL/min

Following successful generation and transfer of aqueous droplets of ~50 μm diameter, the next stage was to encapsulate these droplets in the oil, by passing the oil/water mix into the second flow focusing junction in the hydrophilic chip. The image on the right shows oil droplet formation, leading to encapsulation of 1 – 3 water droplets in each 200 μm oil drop.

REVIEW OF RESULTS

Emulsion was collected by passing the outlet flow from the chipset via a short length of tubing to a glass collection vial. Flow was collected for several minutes and then a sample taken via manual pipette. The sample was dispensed onto a microscope slide for review. The photograph right shows typical result. One to three water droplets of consistent size are encapsulated in monodisperse 200 μm oil droplets.



Adjustment of the three flow rates was performed to observe the range of droplet sizes that could be created. Although further work is continuing in this area, and not all combinations of inner and outer droplet diameter can be achieved with a single chip pair, it is possible to achieve inner droplet diameters in the range 25 to 50 μm and outer droplet diameters of 150 to 200 μm.

The chipset allows rapid replacement off either chip with alternative designs from the Mitos chip family, allowing optimization of the available range of droplet sizes. The chipset design can also be readily extended to offer a combination of T and X junctions, triple encapsulation, temperature control for droplet polymerization, etc.

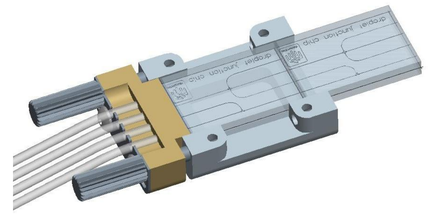
CONCLUSIONS AND NEXT STEPS

The results of preliminary testing of the Mitos double encapsulation chipset have shown successful generation of monodisperse encapsulated droplets. The chipset is easy to assemble and flexible in mode of use (oil/water/oil or water/oil/water). Transfer of droplets between chips is successfully achieved for inner droplets around 30% or less of the channel width. Further work is now being carried out to reduce elastomer seal layer thickness to further enhance this performance with larger inner droplets.

Double encapsulation is successfully achieved in the second droplet chip. A wider range of channel geometries will be explored to increase the available range of droplet diameters for inner and outer phases. We also plan to investigate different types of coatings and materials for the chips with an aim to extend the range of oils and aqueous phases that can be used.

Encapsulation performance was found to be strongly linked to pump flow stability. Consistent inner droplet count in each outer droplet is improved by use of pressure based pumping rather than syringe pumps.

Collection of the double encapsulated emulsion can be performed by connecting the chipset to a collection vessel. A modified chipset format is now under test which allows direct exit of the emulsion into a bulk collection vessel. This is expected to extend the range of fluid / surfactant combinations which can be successfully produced, by reducing shear stress on droplets exiting the edge of the chip.



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(2) Abate A., Lee D., Holtze C., Krummel A., Do T., Weitz D. (2009) Functionalized glass coating for PDMS microfluidic devices. Lab-on-a-Chip Technology: Fabrication and Microfluidics, Caister Academic Press, 2009.

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