Influence of Microfluidic Geometry on Micro-droplet formation

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Introduction: Micro-droplet technologies are a novel platform for performing chemical or biological analyses. These suspended micro-droplets (water-in-oil) that encapsulate reagents for chemical and biological reactions are generated by utilizing flow instabilities in microfluidic channel structures and are formed with controllable compositions and drop size, stably for long operating times. The nature of the device fabrication process however can introduce differences in identical microfluidic designs from device to device. For example, over-exposing UV light during the pattern transfer step may result in a silicon master with corners that are less sharp with larger device widths than the expected tolerances. These deviations, though seemingly minor, if present in the droplet formation region, may influence the drop formation process and droplet characteristics. The objective of this work is to characterize the micro-droplet formation process in six droplet formation structures with slight geometric differences. The influence of the microfluidic environments on droplet size and droplet formation is compared.

Materials and Methods: Microfluidic devices were built using standard soft lithography techniques (Whitesides et al., 2001). Water droplets were formed in oil by flow focusing – the oil phase surrounds and breaks off water droplets in the characteristic cross-junction structure. The micro-channels in each device are 100 μm wide and 100 μm deep. The rounding of the corners is quantified by the radius of curvature, R, of the cross-junction which was 0, 50, or 100 μm in all four corners (symmetric) or in only the two downstream corners (asymmetric). Droplet formation was studied over a range of flowrate ratios (oil flowrate to water flowrate). Micro-droplet flows were recorded using a high-speed imaging camera. Drop sizes and pinch off positions were determined using image processing software.

Results and Discussion: Figure 1 shows droplet formation in each of the flow focusing geometries. The symmetric and asymmetric 0 μm radius of curvature are identical geometries. For every geometry, droplet diameters decrease with increasing flowrate ratio. For both the symmetric and asymmetric geometries, there is little drop size difference between 0 and 50 μm rounding for each flowrate ratio, however the 100 μm rounding produces droplets with larger diameters. For the same rounding, asymmetric geometry produces larger drop diameters across all flowrate ratios. Interestingly, the drop diameter for the asymmetric, 100 μm round junction approaches that of the symmetric, 100 μm round junction as flowrate ratio is increased. The pinch-off location for droplet formation for the more rounded junctions occurs farther downstream than less rounded junctions indicating differences in the droplet formation mechanisms.

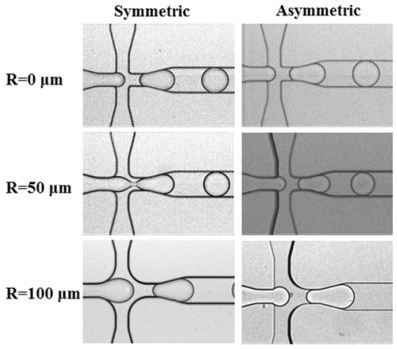

Figure 1. Flow focusing geometries with rounding in all four corners (symmetric) or in the two downstream corners (axisymmetric). The radius of curvature (R) in the rounded corners is either 0, 50, or 100 μm.

Conclusions: An increase in drop diameter for the largest rounding geometries implies higher drop volume as compared with smaller rounding at the same flowrates. Hence, if device fabrication cannot be held to strict tolerances, drop volumes may differ between devices. This may be problematic for performing downstream operations where volume control (or alternately mass control) is essential, such as chemical or biological reactions that require delivery of precise reagent volumes or masses. Future work will focus on simulations of flow in these geometries to relate the pinch-off location with the corresponding velocity field to better understand the influence of pinch-off position on drop size.

References: G.M.Whitesides et. al, Annu Rev Biomed Eng, 2001, 3, p.335–73