OPTICAL ACCESSIBILITY IMPORVEMENTS FOR THE CHARACTERIZATION OF THE NANOPEDE

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ABSTRACT

Although microfluidic droplet production is a well-developed field, high-yield production of monodisperse nanoscale droplets is still in its infancy. Here, we present improvements made on the Nanopede chip, presented last year by Tregouet et al., which aims to fill this vacancy in the field. By improving both the chip and the chip holder, imaging at high magnification was achieved, allowing us to observe the droplet generation in order to elucidate the generation mechanism.

KEYWORDS: Droplets, step emulsification, nanoscale, microfabrication.

INTRODUCTION

The need for monodisperse droplets, for tasks such as reaction vessels to produce particles or to function as carriers, has matured the field of droplet generation. However, methods to produce monodisperse nanoscale droplets at high yield are still lacking. Such technologies would enable the development of fields such as particle production.

Last year Tregouet et al.[1] presented the Nanopede chip, aiming to alleviate this problem. The Nanopede, based on the millipede chip created by Amstad et al.[2], employs triangular nozzles to produce monodisperse droplets via step emulsification. It allows the production of milliliter-quantities of monodisperse nanoscale droplets within four days, compared to the years that a flow focusing system would need. Here we present further improvements to the system, enabling imaging the droplet generation mechanism.

THEORY

The chip (Fig. 1A) employs 5000 parallel nanochannels for droplet formation. From an equivalent electrical model for the chip we found that the flow rate through the nanochannels is approximately constant throughout the Nanopede (Fig. 1B), enabling monodisperse droplet generation. The model also enabled us to calculate the maximum flow rate attainable before leakage becomes a major issue, as the inlet pressures can be determined.

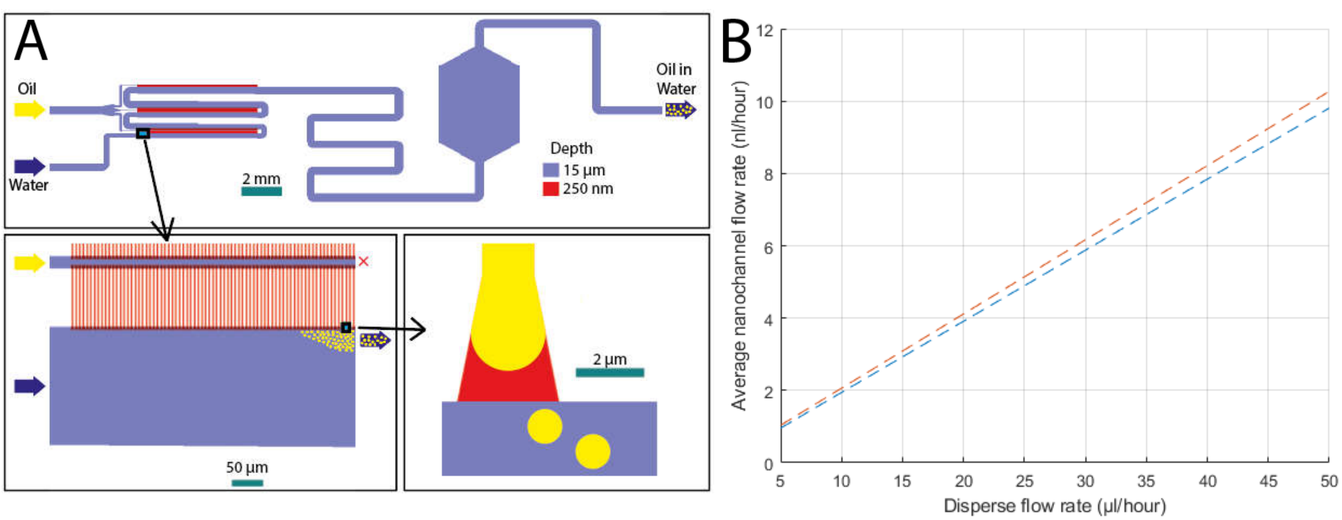

Figure 1:A) A schematic representation of the Nanopede chip. B) The spread of flow rates through single nanochannels for different incoming disperse flow rates. The dotted lines represent the maximum and minimum flow rates calculated.

EXPERIMENTAL

A new silicon/glass design of the Nanopede was introduced, eliminating chip deformation caused by the previous bonding method. The chip was fabricated by reactive ion-etching of channels in a Si wafer and anodically bonding it to a glass wafer. To minimize lens working distances, a thin glass wafer (200 µm) was used. Fluids (Cont. Fluid: H_2O + 0.01M Sodium Dodecyl Sulfate, 50 µl/hour; Disp. Fluid: Hexadecane, 10 µl/hour) were introduced to the chips using side inlets (Micronit BV).

RESULTS AND DISCUSSION

Using the new chips and a redesigned chipholder (Fig.2A), a high magnification lens could be used to observe the droplet generation mechanism (Fig. 2B). The mechanism appeared similar to the one described by Amstad et al., although details were unclear due to the high formation speed. Future further investigations will aim at resolving the scaling issue raised by the groups of Weitz and Nakajima.[3,4] The droplet generation frequency of a single nozzle was determined to be 74 Hz, which extrapolating to the 5000 nozzles results in a device droplet generation frequency of 370 kHz.

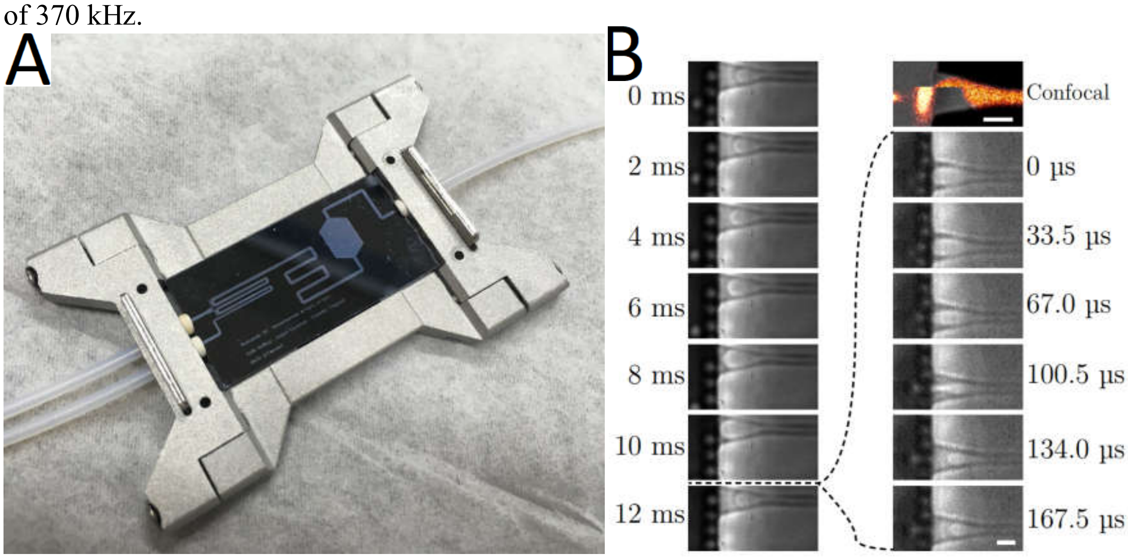

Figure 2: A) The glass/silicon Nanopede chip in the redesigned chip holder. Due to the removal of excess material on the side of the chip, high magnification lenses can reach the chip and image the nanoscale nozzles. B) The droplet production mechanism of the Nanopede. The left column shows the full formation cycle of one droplet, while the right column shows the moment of release at $3x10^4$ frames per second. Images were procured using a full glass chip.

CONCLUSION AND OUTLOOK

Improvements in material choice and bonding methods have made the Nanopede accessible for optical characterization, allowing study and elucidation of the droplet formation mechanism and formation rate in the nanometer-sized nozzles.

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REFERENCES

1. Tregouet, C. B. M. *et al*. in *MicroTAS* 971–972 (2019).
2. Amstad, E. *et al*. *Lab Chip* **16**, 4163–4172 (2016).
3. Nakajima, M. *Lab Chip* **17**, 2330-2331 (2017).
4. Amstad, E. and Weitz, D.A. *Lab Chip* **17**, 2332-2333 (2017).

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