Optofluidic droplet lasers on polycarbonate chip

Han Zhang and Yuze Sun*
Department of Electrical Engineering, University of Texas at Arlington, Arlington, TX 76019
**sun@uta.edu*

Abstract: We demonstrated optofluidic droplet lasers using micro-nozzle structures. Easy fabrication, reproducible generation and manipulation of microdroplets provide a promising platform to achieve integrated laser system on chip.
OCIS codes: (140.3460) Lasers; (140.2050) Dye lasers

1. Introduction

Optofluidic droplet lasers [1-4], which integrate microdroplets (optical cavities) with microfluidics, have been gaining a lot of attention recently in the field of biological sensing and biomedical diagnosis. Microdroplets with high quality factor (*Q*) offer specific advantages to achieve ultralow threshold, and tunable and adaptive laser source on chip. Additionally, microfluidics and its integration with the laser cavity plays an important role in the development of optofluidic droplet lasers [1, 4]. Efficient microfluidics in an optofluidic laser provides unique capability to generate and manipulate microdroplets, and thus enables unconventional lasing properties. To date, most of the work has focused on continuous generation of microdroplets and demonstrated lasing on the flow [1, 4]. Such microdroplet laser configuration offers a limited time window to track and study the lasing properties from individual microdroplets and is not suitable to perform laser-based optofluidic sensing. Here, we develop and demonstrate an integrated optofluidic droplet laser using micro-nozzles fabricated on a polycarbonate chip and study the lasing performance.

2. Experiments and Results

As shown in Fig. 1, the integrated optofluidic droplet laser system consists of a top microfluidic channel (contain water phase) and a bottom microfluidic channel (contain oil phase). The two channels are bridged by a micro-nozzle structure. The Oil phase in the bottom channel is controlled by a high-precision syringe pump. Due to immiscibility between oil and water, oil phase forms a microdroplet in the top microfluidic channel with smooth surface. The size of the microdroplet can be accurately controlled by the syringe pump. Since the refractive index of the oil phase is higher than that of the water phase, whispering gallery modes (WGMs) are supported through total internal reflection (TIR) occurred at the microdroplet surface. Under external excitation, WGMs interact with the gain medium dissolved in the oil phase and provide feedback to the laser system. When the gain overcomes the total loss, lasing emission starts to emerge. Microdroplets can be released by water rinsing in the top microfluidic channel and further regenerated by pressurizing the bottom microfluidic channel. In this work, micro-nozzle structures are made of polycarbonate (PC). The advantages of using PC in our laser system are low cost, good machining properties, high glass transition temperature (Tg ~145 °C), transparency for wavelengths in the visible range, and easy surface modification and biofunctionalization. Due to the good machining properties of PC, the fabrication of micro-nozzle structures is simple and straightforward. Micro-nozzle structures and microfluidic channels are created through micro-machining and thermally bonded (125 °C for 45 min) to form a complete microfluidic device. Then the device was treated by ethanolic solution of $SnCl_2$ [20% (w/w)] to make its surface hydrophilic, which helps to decrease the contact area between the microdroplet and the nozzle, and thus to achieve a higher Q-factor.

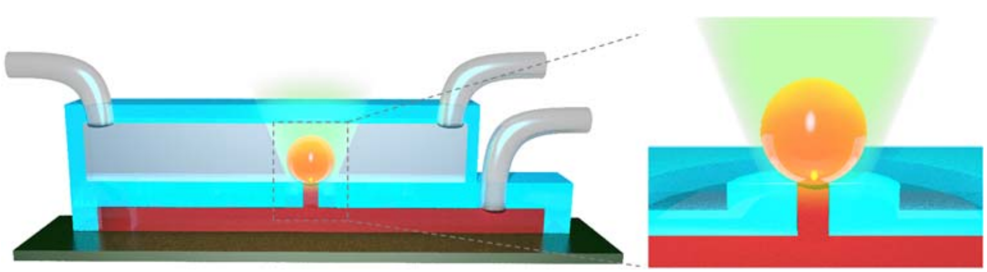

Fig. 1. Illustration of optofluidic droplet lasers. Inset: zoom-in image of the droplet generation area.

Fig. 2(a) shows the top-view of a fabricated micro-nozzle structure. The detailed structure of the micro-nozzle, as shown in Fig. 2(b), has a nozzle hole in the center for the oil phase delivery and a ring-shaped trench for separating the microdroplet from the substrate. Fig. 2(c) shows the dimensions of the bottom channel. Fig. 2(d) shows the side-view of the generated droplet. Every droplet is formed by immersion oil doped with 500 μM Nile Red.

To study the lasing performance, we test the lasing spectra from a microdroplet of 563 μm in diameter under different pump energy densities, as shown in Fig. 2(e). The lasing peaks emerge at the longer wavelength side of the Nile Red fluorescence spectrum. The maximal intensity is observed at around 635 nm. After subtracting the fluorescent background from the lasing spectra, the integrated intensity for each lasing spectrum is plotted as a function of pump power density. As depicted in Fig. 2(f), the lasing threshold derived from linear fitting is approximately 12 μJ/mm^2, which is among the best in previous presented work on microdroplet lasers.

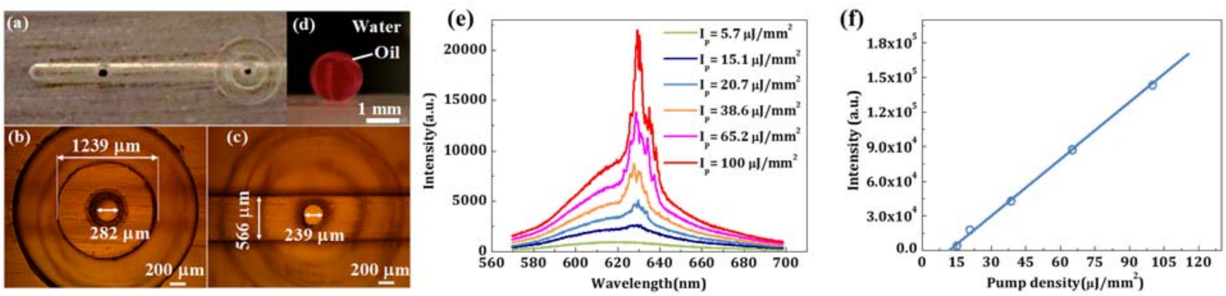

Fig. 2. (a) Top view of the actual micro-nozzle structures. (b) Top view of the nozzle, the diameter of nozzle is 282 μm. (c) Bottom view of the nozzle, the diameter of nozzle is 239 μm and the width of bottom channel is 566 μm. (d) Droplet generation. (e) Fluorescent and lasing emission spectra from a microdroplet with 563 μm diameter under different pump energy densities. (f) The plot of integrated lasing intensities as a function of laser pump density. The lasing threshold derived from the linear fitting curve is approximately 12 μJ/mm^2.

3. Conclusions

In summary, we demonstrate optofluidic droplet lasers on chip generated by micro-nozzle structures. The micro-nozzle platform provides a repeatable and on-demand droplet generation method and can be readily scaled-up to form a laser array on chip.

This work is supported by US National Science Foundation under Grant No. 1554013.

4. References

[1] M. Tanyeri, R. Perron, and I. M. Kennedy, "Lasing droplets in a microfabricated channel," Opt. Lett. **32,** 2529-2531 (2007).

[2] A. Kiraz, A. Sennaroglu, S. Doğanay, M. Dündar, A. Kurt, H. Kalaycıoğlu, and A. Demirel, "Lasing from single, stationary, dye-doped glycerol/water microdroplets located on a superhydrophobic surface," Opt. Commun. **276,** 145-148 (2007).

[3] H. Zhang, A. Balram, D. D. Meng, and Y. Sun, "Optofluidic lasers with monolayer gain at the liquid–liquid interface," ACS Photonics **4,** 621-625 (2017).

[4] S. K. Tang, Z. Li, A. R. Abate, J. J. Agresti, D. A. Weitz, D. Psaltis, and G. M. Whitesides, "A multi-color fast-switching microfluidic droplet dye laser," Lab Chip. **9,** 2767-2771 (2009).