MICRODROPLET OPTICAL CAVITY SENSORS
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ABSTRACT
We describe the use of microdroplet optical cavities as sensors. By monitoring resonances of these cavities, we demonstrate precise characterization of the size of drops generated by a microfluidic flow-focusing nozzle (FFN), and the detection of nanoparticles inside the drops. This method should be useful for microfluidic droplet applications.

KEYWORDS: Microfluidics, Droplets, Whispering Gallery Modes, Optical Microcavities, Sensors

INTRODUCTION
In a micro-spherical cavity, light is confined by total internal reflections at the surface of the microsphere. Electromagnetic waves that meet the requirements for constructive interference form standing waves: they are the resonances of the cavity, and are called whispering gallery modes (WGMs).1 WGMs are sensitive to small perturbations in the size, shape, and refractive index of the cavity, and have been used to make label-free sensors, mostly made of silica.2 We and others have demonstrated enhancement of light and lasing in WGMs from microcavities made of droplets.3-6 WGM-based sensing in droplets is relatively unexplored. Motivated by recent developments in droplet-based applications,7 we investigate the use of WGMs for monitoring processes inside these droplets.

EXPERIMENTAL
We generated droplet cavities containing a solution of rhodamine in benzyl alcohol with water as the carrier fluid using a microfluidic FFN (Fig 1).6 Other liquids can also be used so long as the refractive index of the drop is sufficiently higher than the carrier. We excited the drops optically; the peaks in emission spectrum correspond to the WGMs of the drop (Fig 2). We have analyzed lasing spectra of 500 droplets. These drops possess an average radius ~17.4 μm.9 Clustering analysis identified ~5 major clusters of modes. The fluctuation in WGM positions was ~3 nm. Using the relation Δλ/λ = ΔR/R,3,4 the 3 nm-fluctuation in resonances indicates a variation of ~80 nm in the size of drops generated by the FFN (~0.5% dispersity). To our knowledge, this is the first in-situ characterization of size distribution of drops made by FFN at this level of sensitivity.

Fig 1a). Scheme of microfluidic flow-focusing nozzle (FFN) for generation of droplet resonators. b) Optical setup for excitation of drops and collection of emission from the drops.
Fig 2. Lasing spectrum of a droplet with radius ~ 17.4 μm.

To test if our method can sense the contents of the drops, we introduced Fe₂O₃ nanoparticles (size range 300-800 nm) at 1 μg-mL⁻¹ into the droplets. At this concentration, one particle would be present every 2 to 42 drops with radius of 20 μm. Although we cannot determine which drops contained particle(s), the lasing spectra from a large number of droplets should reveal two sets of spectra: one from the “empty” drops and one from those that contained the particles. Clustering analysis of lasing spectra from 2000 drops showed that spectra from ~30% of the drops formed a cluster at ~649 nm, and the rest of the spectra at ~657 nm. The presence of nanoparticles is known to cause blue-shifts in WGMs. Our result suggests ~30% of the drops contained nanoparticle(s); this corresponds well to the fraction of drops expected to contain particle(s). Sensing of single macromolecules, viruses, and cells should be possible with the same mechanism.

CONCLUSION

Droplets have mostly served as passive micro-compartments or reactors. We envision that they can also serve as built-in sensors to monitor internal biochemical processes.

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REFERENCES

[9] Average drop size is measured by dividing the flow rate of the disperse phase by the droplet generation frequency.

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