# Lowering of Acoustic Droplet Vaporization Threshold via a Non-uniform Focused Vortex

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## Background, Motivation and Objective

Acoustically sensitive nanodroplets composed of perfluorocarbon have shown great potential for advanced medical diagnosis and therapy but are limited by the required high acoustic droplet vaporization (ADV) threshold for clinical applications. Although the use of ultrasonic standing waves to aggregate nanodroplets has been shown to effectively reduce the ADV threshold[1], which may be attributed to the amplified acoustic negative pressure in the micron-sized aggregations due to the superharmonic focusing effect [2], it had limited maneuverability. This study experimentally validated the feasibility of a non-uniform acoustic vortex for lowering of ADV threshold.

## Statement of Contribution/Methods

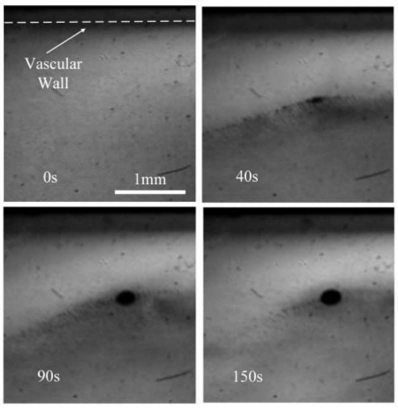
A transparent phantom with a wall-less vessel of 6 mm diameter was used to mimic a blood vessel in soft tissue, where disperse nanodroplets (mean diameter: 408 nm) were pumped into. A non-uniform acoustic vortex (PNP: 500 KPa) was generated by a 16-element focused transducer (center frequency: 645 KHz) via adjusting the power for each element, and its focus was positioned in the vessel. A focused 5 MHz transducer transmitted a 4 μs burst to initiate ADV. The processes of aggregation, ADV, and vaporized bubble dissolution were observed using high-speed photomicrography.

## Results/Discussion

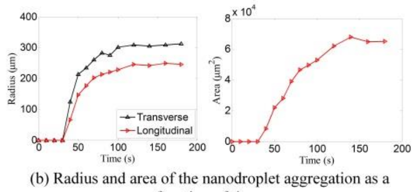
The images showed the disperse nanodroplets were aggregated into a micron-sized ellipse shape (long axis: 308 μm, short axis: 250 μm) under the action of vortex when flow was static (cf. Fig. 1). Also, the pressure in the upper left of the focal region was larger than that in other regions, indicating the generation of a non-uniform vortex, which was further simulated (cf. Fig. 2). Fig. 3 indicated the non-uniform distribution of the pressure was the key for the elliptical aggregation of nanodroplets, and it would locate in the upper left corner of the focal region, unlike microbubbles gathering in the center, which was in good agreement with the experimental results. Furthermore, the ADV threshold was significantly lowered after aggregation, while a similar size range of the microbubbles generated by disperse nanodroplets was maintained (cf. Fig. 4).

## Ref.

[1] S. Guo, et al., Appl. Phys. Lett. 111, 254102 (2017).
[2] O. Shpak, et al., Proc. Natl. Acad. Sci. USA. 111, 1697 (2014).




(a) Microscopic images of nanodroplet aggregation process.




(b) Radius and area of the nanodroplet aggregation as a function of time.

Fig. 1 Aggregation process of nanodroplets under the action of a non-uniform focused acoustic vortex. The initial concentration of the disperse nanodroplets was $1.64 \times 10^{10}$ droplets/ml.

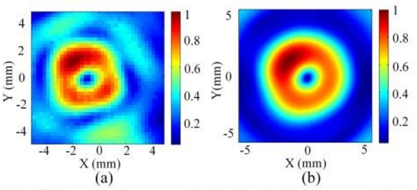



Fig. 2 Normalized pressure distribution in the (a) generated and (b) simulated non-uniformed acoustic vortex.

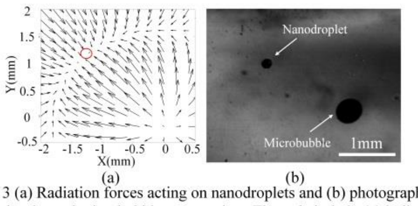



Fig. 3 (a) Radiation forces acting on nanodroplets and (b) photograph of nanodroplet and microbubble aggregations.The red circle in (a) indicates the predicted location of nanodroplet aggregation.

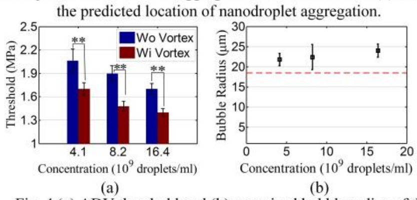



Fig. 4 (a) ADV threshold and (b) vaporized bubble radius of the nanodroplet aggregations as a function of concentrations. The red dotted line in (b) indicates the mean vaporized bubble radius of the disperse nanodroplets with a concentration of $1.64 \times 10^{10}$ droplets/ml.