Acoustofluidic Interfacial Fluid Dynamics: From nanoscale confinement and capillary-wave turbulence to directional transport in porous materials

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Abstract:

Megahertz-order acoustic waves offer versatile fluid control, driving liquid through nanometer confinement, destabilizing capillary waves, organizing streaming, and transporting solutes in porous materials. These phenomena depend on how acoustic momentum interacts with fluid-solid and fluid-air interfaces. This talk explores interfacial fluid dynamics across scales, highlighting measurement methods, nonlinear mechanisms, and transducer designs. W first examine Miz-driven capillary waves captured via ultra-high-speed holographic microscopy at up to 120,000 fps with nanometer sensitivity. Masure-ments reveal transitions from wave turbulence to strong nonlinear turbulence before atomization. Results show Miz-driven atomization involves nonlinear feedback altering the acoustic field, unlike conven-tional Faraday-wave instability. W use the same approach to measure fluid height and menisci in 7 and 25 nm nanoslits, resolving evapo-ration-driven dewetting and 39.7 Miz surface-acoustic-wave-driven transport at 0.12 ms1. Nmofluidic devices use acoustogeometric streaming to overcome capillary resistance, enabling rapid manipu-lation of -200 tL droplets in 100 nm channels. Depending on interest, we can also briefly discuss the mechanisms underpinning sonogenet-ics through this method as well, where cell imaging can be used to characterize ultrasound interactions with live cells.

We then explore distributed forcing with a floating-electrode unidi-rectional transducer (FEUDT), creating streaming up to 18 mm s 1 at 0.54 WUnlike conventional designs, FEUDT deposits momentum across a broader area, enabling controlled unidirectional flow and enzyme-free detachment of cells. Finally, FEUDT forcing transforms porous materials into activetransport platforms, achieving direction-al flow through prewetted media at 0.6 mm s1 . In porcine dermis, it drives tracer transport along and through the tissue, suggesting applications in biological matrices.

These findings link interfacial geometry, acoustic fields, and nonlin-ear feedback to diverse acoustofluidic behaviors useful for a broad variety of medical and industrial applications.

Biography:

James Friend is the Stephen F. and Camilla T. Brauer Distinguished Professor of Mechanical Engineering and Chair of Mechanical Engi-neering and Materials Science at Washington University in St. Louis. His research explores acoustic phenomena at small scales, especially for biomedical applications and emerging technologies. Before join-ing Washington University, he held faculty positions in Japan, Austra-lia, and at UC San Diego, where he was appointed in engineering and surgery. He has authored more than 350 peer-reviewed publications, holds 30 granted patents, and has secured research funding from NSF, NIH, DARPA, and industry.