SAW Symposium 2020 KEYNOTE talk

A fourth type of acoustic streaming mechanism supports the dynamic wetting of nano-channels in the presence of surface acoustic waves

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Background, Motivation and Objective

To date we are familiar with three types of acoustic streaming mechanisms which, along with acoustic radiation pressure, are responsible to the array of flow phenomena observed under acoustic excitation. These are the Eckart (1948), Schlichting (1932), and Rayleigh (1884) streaming. Here we use experiment and theory to report a newly found type of acoustic streaming mechanism, which we observe in nanochannels under the excitation of MHz-frequency surface acoustic waves (SAWs) of the Rayleigh type. It originates from an interplay between SAW induced nanometer deformations in the channel's geometry and the leading order acoustic pressure in the liquid. The corresponding forcing term is capable of displacing liquid menisci in nanochannels againt a Laplace pressure of 1 MPa, which is typical in nanochannels. In comparison, the forcing term in the case of the Eckart, Rayleigh, and Schlichting streaming may resist an external pressure of up to approximately 1 KPa.

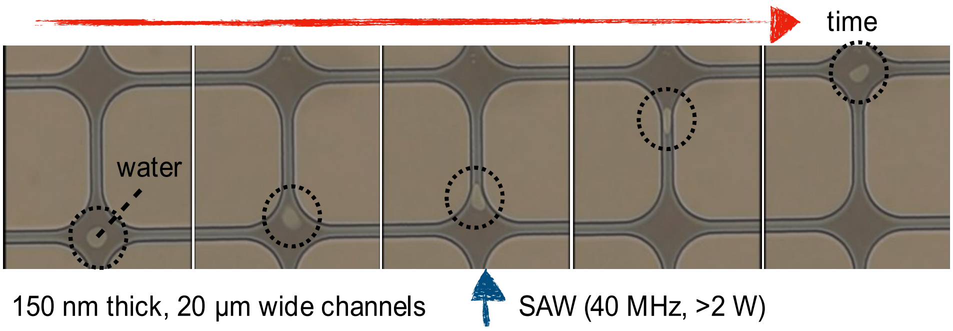

Fig 1: A water paddle translates through a 150 nm thick and 20 mm wide constriction under the action of a propagating SAW against a Laplace pressure of 0.96 MPa.

Statement of the Contribution/Methods

We report experimental observations of SAW induced dynamic wetting of nano-channels. In addition, we will suggest a corresponding acoustic streaming mechanism, which may support the dynamic wetting of nanochannels and show quantitative agreement between theory and experiment.

Results/Discussion

The newly found streaming mechanism is a reminiscent of a peristaltic pump, albeit with acoustic contributions. In parituclar, the characteristic amplitude range of the leading order and periodic pressure in water under SAW excitation, $|p| = \rho|\boldsymbol{u}|c_l = 0.01 - 1$ MPa, is comparable in magnitude to the Laplace pressure in submicron channels, when accounting for the magnitudes of the liquid density, ρ, and the particle and phase velocity of sound in liquid, $\boldsymbol{u}$ and c_l, respectively. An interplay between $|p|$ and the nanometer deformation, which the SAW generates in the nanochannel geometry, results in a ratchet type motion of the liquid at the net velocity,

$$< u >= |p||\boldsymbol{u}|/(\mu|\boldsymbol{u}|/h) \times |\boldsymbol{u}|/c_s \times f(h/\delta), \quad (1)$$

where μ, δ, c_s and h are the liquid viscosity, SAW viscous penetration length into the liquid, SAW phase velocity, and the channel thickness. Moreover, $f(h/\delta) = 1/8$ and 0 for small ($h \ll \delta$) and large ($h \gg \delta$) channel thicknesses, respectively. The theory in eq. 1 shows quantitative agreement with experiments, were we used 40 MHz-frequency SAW to wet and de-wet channels that are $h = 100 - 150$ nanometer in thickness with water and organic solvents (See Fig 1 for example).