Increasing Heat Transfer in Microchannels with Surface Acoustic Waves

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Abstract

As the trend in electronics continues towards higher integration density and higher power devices, current remote cooling technology will not be able to handle the predicted levels of heat removal necessary. A new paradigm for embedded cooling is required. Microfluidic cooling holds potential promise for these thermal management challenges. In this numerical study, the effect on heat transfer in microchannels from surface acoustic waves (SAWs) is evaluated. SAWs are acoustic waves that propagate along an elastic surface and when these waves come in contact with a fluid medium, they can strongly couple with the fluid, driving fluid flow. This effect is known as acoustic streaming. To see if acoustic streaming can enhance heat transfer, numerical simulations were performed where SAWs were coupled with single phase flow to drive circulating and chaotic flow in a microchannel. The resulting circulating flow was shown to disrupt the thermal boundary layer, which increased heat transfer in the microchannel. The numerical simulation challenge is SAWs operate in the MHz range and behave with harmonic time dependence, but viscous effects in the fluid happen on a time scale of msec or slower, requiring a time-averaged response of the acoustic oscillations. To model the SAW/viscous flow interaction, perturbation theory is used, where acoustic motion to the first-order is solved [1]. Using first-order results, second-order perturbation theory is then employed to solve the conservation equations for fluid flow and heat transfer [1].

To simulate the acoustic streaming and the effects on heat transfer, a COMSOL Multiphysics® model was implemented. To determine the thermoviscous first-order equations that describe the ultrasound acoustics, the Thermoacoustics physics interface was used. Next, the Navier-Stokes and Energy equations were solved using the Conjugate Heat Transfer: Laminar Flow physics interface. Using the results from the first-order acoustic solution, source terms were added to the continuity and momentum equations, following a technique that was developed by Muller et al.[2]. Figure 1 shows the model geometry and boundary conditions used in the simulations. Figure 2a shows the steady-state results of streamlines and temperature contours for the condition with no SAW, only an inlet flow for Re = 1, and Figure 2b shows the results for SAWs coupled with an inlet flow of Re = 1. As the result clearly shows, the addition of the SAW disrupts the flow, creating rotating vortices within the microchannel, which enhance the heat flux. For the conditions simulated in Figure 2, there was a 3x increase in the average heat flux along the heated wall with SAW vs. no SAW. Figure 3 plots the average heat flux along the heated wall vs. Re for different SAW conditions. The results indicate that as the flow rate increases, the SAW influence on heat transfer is reduced. As the flow rate increases in the microchannel, the

advection term dominates the flow, overwhelming the ability for vortices to be generated. The results show that when the stream velocity is less than the SAW vorticity velocity, there is an enhancement in heat transfer from the SAW.

Reference

1. X. Ding, et al., “Surface Acoustic Wave Microfluidics,” Lab Chip, 13, 3626-3649 (2013).

2. P. B. Muller, et al., “A Numerical Study of Microparticle Acoustophoresis Driven by Acoustic Radiation Forces and Streaming-Induced Drag Forces,” Lab Chip, 12, 4617-4627 (2012).

Figures used in the abstract

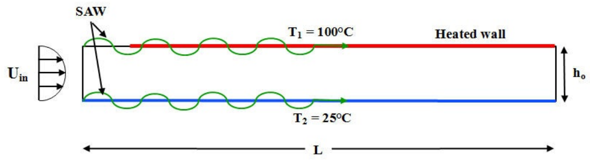

Figure 1: Geometry and boundary condition used for simulation. SAW launched on both sides of channel from the flow inlet side. Fully-developed inlet flow applied to end of channel. Constant wall temperatures were maintained. Channel height, ho = 100 µm, channel length, L = 1 mm, SAW frequency, f = 7.5 MHz, Inlet velocity, Uin – varied, SAW amplitude, do – varied. The fluid in the microchannel was modeled as water.

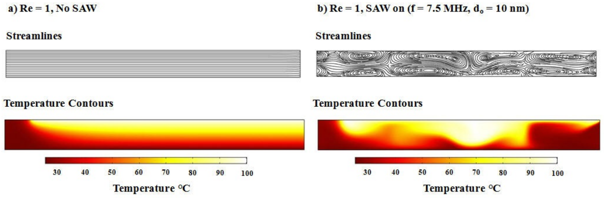

Figure 2: Simulation results showing steady-state streamlines and temperature contours though the microchannel. a) Results with only inlet flow (Re = 1), no SAW. b) Results with SAW coupled with an inlet flow (Re = 1); SAW: f = 7.5 MHz and wave amplitude, do = 10 nm.

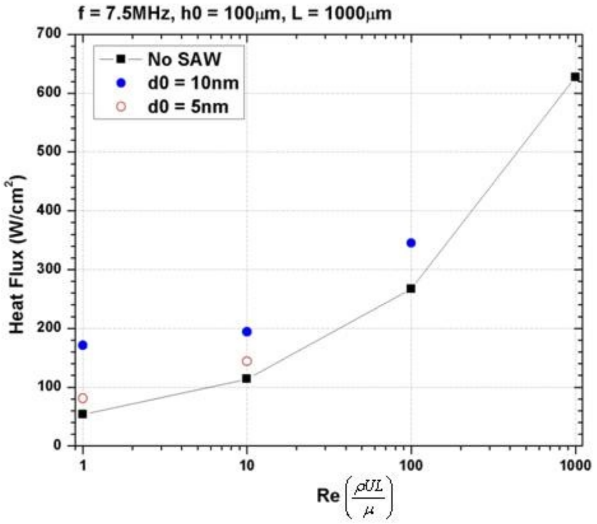

Figure 3: Average heat flux along the heated wall vs. Re. Solid line represents no SAW, only inlet flow. Data points represent coupled SAW and inlet flow for different SAW amplitudes.