Integrated Raman Thermometry And COMSOL Modeling To Probe Heat Transport During Evaporation

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Abstract

Understanding heat transfer at the microscale during evaporation is critical for advancing thermal management technologies. In this work, we present an integrated experimental-numerical framework that combines spatially-resolved Raman thermometry with multiphysics modeling in COMSOL to investigate temperature distributions within microscale evaporating systems. Evaporation experiments are conducted on microstructured silicon substrates uniformly heated to steady state heat fluxes, where Raman spectroscopy is used to non-invasively extract local temperatures at the micropillar top surface and near the three-phase contact line. While Raman thermometry provides submicron spatial resolution temperature measurement close to the three-phase contact line, it only allows discrete point measurements.
A three-dimensional COMSOL model enables further quantification of subsurface temperature fields beyond optical access, offering insights into heat transport pathways and thermal gradients influencing phase change at the interface. The COMSOL model used herein, accounts for conduction through silicon microstructures and water (Figure 1) along with the evaporation at the L-V interface (Figure 1). To incorporate evaporation at the L-V interface, the COMSOL model employs a temperature-dependent heat transfer coefficient (HTC in Figure 1). The temperature-dependent HTC is optimized such that the water meniscus temperature near the three-phase contact line (Figure 1) in our COMSOL model is consistent with the Raman thermometry measurements.
The COMSOL model is then solved for a range of microstructure geometry by varying micropillar diameter and spacing between micropillars. Our modeling results show that there is an optimum microstructure geometry that provides the lowest surface temperature and hence bests heat transport performance. This combined approach establishes a platform for quantitatively linking microscale thermal behavior with interfacial phenomena, and can be extended to study nanostructured surfaces, alternative fluids, or transient heating conditions.

Figures used in the abstract

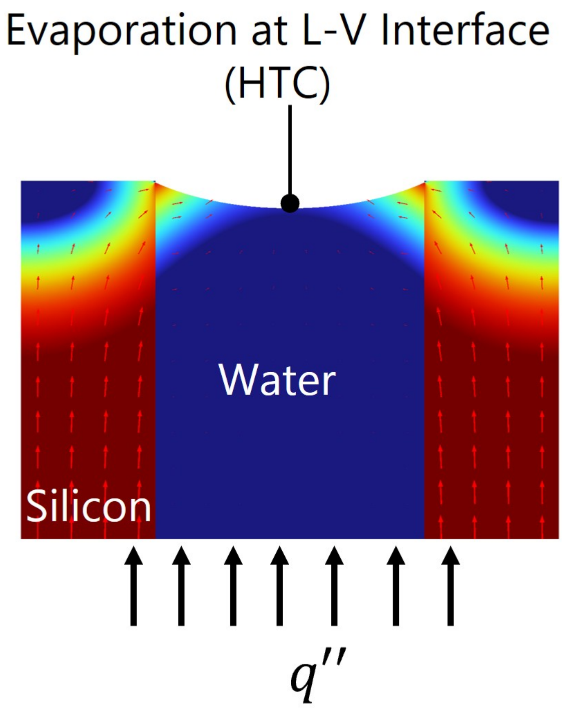

Figure 1 : Slice plot of a 3D COMSOL model for thin film evaporation within silicon micro-structured surface.