Thermal Circuit Analysis of Droplet Evaporation on Hot Microstructured Superhydrophobic Surfaces

Abstract

In this presentation, we report a thermal circuit model developed by us to analyze the evaporation dynamics of a water droplet dwelling on the hot surface of micro-structured superhydrophobic substrates. Droplet evaporation is divided into two distinguish parts: evaporation at the droplet top spherical cap liquid-vapor interface and evaporation at the droplet base. Evaporation at the droplet base around the micropillar top surface leads to decrease of the average temperature at the droplet base surface, which accounts for the decaying onset of nucleate boiling for water droplet on hot microstructured substrate over 100°C. Evaporation process of the water droplet can be ascribed to the constant contact radius (CCR) mode, the constant contact angle (CCA) mode and the hybrid mode of CCR and CCA. Evaporation flux ratio of the spherical cap surface and the droplet base is calculated during the evaporation process. Thermal resistances from the substrate to the droplet spherical cap interface are calculated by synthesizing the thermal resistance of the substrate, the micropillars, and the water droplet itself. Conduction thermal resistance of the water droplet is calculated by dividing the water droplet into infinite water layers and integrating all the thermal resistance of the layers. Temperature difference of water droplet top and bottom surface causes the surface tension gradient and density gradient of water, which lead to the internal flow of the water droplet. Convection thermal resistance inside of the water droplet is taken into account by employing the effective conductivity coefficient which relays on the droplet Peclet number. Temperature distribution from substrate to the water droplet top surface is obtained in the form of contour plot based on the thermal circuit model. Substrates with difference pillar array microstructure are used for the droplet evaporation and the substrates are heated for a large range of temperature (from 40 °C to the onset boiling temperature around 120 °C). The variations of the droplet spherical cap surface temperature on different microstructure substrates and with different substrate temperature are obtained by our analytical approach and matches well with the experimental results. Evaporation flux ratios of the droplet top and bottom surface on different microstructure substrates and with different substrate temperature are predicted. Our model indicates that the water droplet temperature increases during the evaporation process on a certain hot substrate and large periodicity distance of the substrate micropillar arrays leads to a higher onset boiling temperature of the water droplet. The evaporation flux ratio of the droplet top and bottom surface decreases with the rise of the substrate temperature and increases during the evaporation process on a constant temperature substrate.