Separate effects of surface roughness, wettability and nano-porosity on the Leidenfrost point temperature of water

Hyungdae Kim [a*]
[a]*Nuclear Engineering Department, Kyung Hee University, Yongin, Gyunggi, Korea*
[*]*Corresponding author: hdkims@khu.ac.kr*

1. Introduction

Quenching phenomena play a key role in LWR safety, particularly in the reflood phase of a large-break LOCA. It is well known that quenching phenomena are affected by the physico-chemical characteristics of the hot surface, such as surface roughness, wettability and porosity. However, while some general qualitative trends are known, there is a lack of quantitative data on the relative importance and magnitude of these effects. Therefore, we conduct water-droplet Leidenfrost Point (LFP) tests using custom-fabricated surfaces for which roughness, wettability and porosity were controlled accurately and separately at the nanoscale.

2. Methods and Results

2.1 Preparation of test surface

Surface roughness height was controlled by fabricating cylindrical posts of 15 μm height and 5 μm diameter on a nano-smooth silicon wafer (R_a < 0.5 nm; thickness 380 μm). The posts were fabricated with a deep reactive-ion etching process, and were arranged on a square array of large pitch (500 μm), to prevent secondary effects, such as capillarity. Next, the surface intrinsic wettability was controlled by depositing a nano-smooth thin layer of gold (100 nm thick) or silicon oxide (20 nm thick) with a sputtering technique; the resulting contact angles for de-ionized water droplets were found to be 83° on the gold surface and 19° on the silicon oxide surface. Note that the presence of the micro-posts does not affect wettability, which was expected, given the large pitch of the post array. Finally, to explore the effect of nano-porosity, we used a thin nano-porous layer (about 600 nm thick) made of silicon oxide nanoparticles (23 nm), deposited according to the layer-by-layer nanoparticle coating technique. The nano-porous layer causes a further enhancement in the apparent wettability (the contact angle decreases to ~0°) with respect to the smooth silicon oxide surface (19°). This is due to the well-known Wenzel effect. On the other hand, the roughness height change due to the nano-porous layer is negligible (≤ 0.016 μm). In summary, using a combination of spaced-out micro-posts, and smooth and nano-porous layers we were able to control surface roughness height, wettability and nano-porosity independently.

2.2 Measurement of LFP

A common technique used for determining the LFP consists in measuring the evaporation times of liquid droplets over a heated surface. A schematic of the experimental apparatus is shown in Fig. 2. The test surface is sandwiched between two independently heated and controlled copper blocks. The upper block has a through-hole in the shape of an inverted cone to place a droplet on the silicon wafer and keep the evaporating droplet on the silicon wafer. The temperature difference between the two blocks was controlled to be less than 1 K during the experiments. A water droplet of ~2.9 mm in diameter is released on the test surface from a height of 1.5 mm using a syringe, and the evaporation time is measured with a stopwatch.

2.3 Results

The data obtained from the droplet experiments for the surfaces without micro-posts and with the highest posts of 15 μm are displayed as droplet evaporation time vs surface temperature in Fig. 2. In this curve, the temperature corresponding to the longest evaporation time is the LFP. The LFP on the smooth gold surface without micro-posts is ~264°C, reasonably closed to the values found in the literature. The LFP is slightly higher (~274°C) for the smooth silicon oxide surface without micro-posts, but is significantly higher (~359°C) for the porous silicon oxide surface without micro-posts. This result suggested that nano-porosity has a significant effect, rather than intrinsic surface wettability, on the LFP.

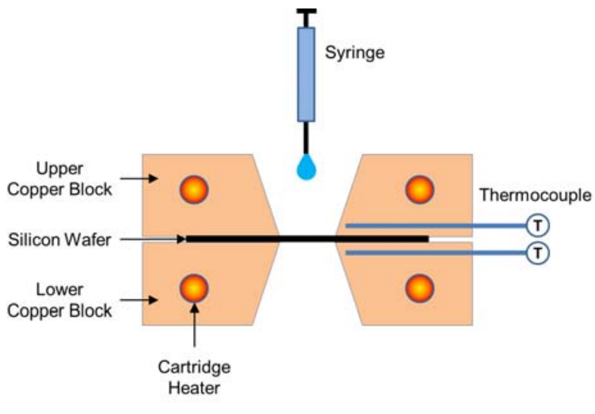

Fig. 1 Schematic of sessile droplet experimental setup

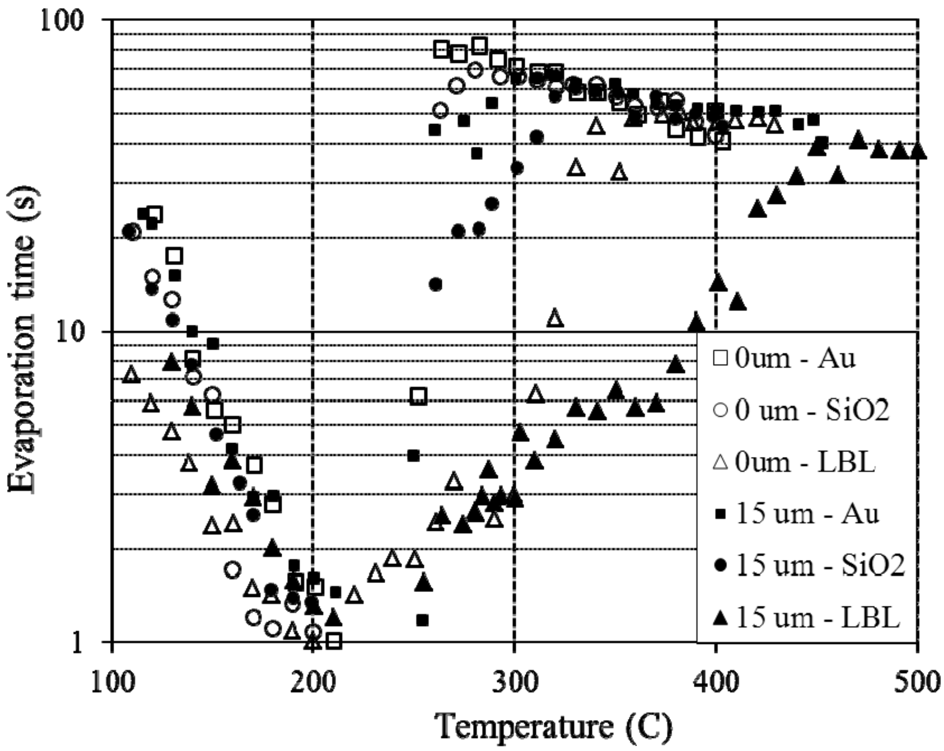

Fig. 2 Water droplet evaporation time vs surface temperature. The nominal uncertainty in the measurement of the LFP temperature was found to be less than ±5 °C.