Evaporation of microdroplet on a heated plate at 408 K

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Abstract. Droplet-based cooling systems require a detailed data on droplet evaporation at relatively high substrate temperature. We investigate the dynamics of water droplet evaporation on a heated sapphire substrate for the substrate temperature of 408 K. The stable (not boiling) evaporating droplet of 0.33 μl volume forms immediately just after boiling process when the temperature is still higher than boiling temperature of the liquid. Stick-slip motion is observed with the first depinning at 0.07 μl in volume. Total evaporation time is 1.13 sec.

1. Introduction
The droplet-based cooling system such as spray cooling is one of the most effective active cooling systems capable to remove more than 1 kW/cm² [1]. The heat transfer enhancement can be achieved through intensive evaporation near the contact line of sessile liquid droplets. It was shown that the temperature in the bulk of a sessile evaporating droplet substantially depends on the thermal properties of the substrate and the rate of evaporation [2]. The heat and mass transfer in FC-72 droplet impinging on a hot wall were investigated experimentally and numerically in [3]. The influence of three different ambient gases on the evaporation of the pinned droplet at reduced pressure was performed by Sefiane et al. [4]. Reducing the atmospheric pressure leaded to increasing evaporation rate due to the diffusion coefficient of water vapor in atmosphere increases. The droplet evaporation on different substrates under heating was investigated in [5] when the substrate temperature was about 337 K. The abrupt increase of the specific evaporation rate was clearly demonstrated at the final stage of the droplet evaporation. To our knowledge there is no data in literature about sessile droplet evaporation on a substrate at relatively high temperature, while such investigations are required for development of cooling systems.

Here we investigate the evaporation dynamics of 0.33 μl water droplet on a sapphire plate heated above the boiling temperature.

2. Experimental setup
An experimental setup is illustrated in figure 1. The detailed description can be found in [6]. A water drop of 10 μl in volume is generated to the surface using a Cole-Parmer syringe pump with a syringe of 10 ml. Ultrapure deionized water (MilliQ) is degassed and then used as a test fluid. Sapphire round plate of 40 mm in diameter is heated by round polyimide thermofoil heater (Minco) from the bottom part of the substrate. Advancing contact angle of water on sapphire plate is measured to be of 76.2 deg and receding contact angle is of 36.5 deg, therefore contact angle hysteresis is 39.5 deg. The measurement has been done by syringe-needle method at normal atmospheric conditions varying the
droplet volume from 2 to 10 μl. The substrate surface and air temperatures are controlled by type-K (Omega) thermocouples. Experiments are performed at the substrate temperature of 408±1 K. Air temperature at 10 mm up the substrate surface is measured to be 316±1 K. Therefore there should be air flow in the upward direction due to temperature difference. A high-speed camera Photron Fastcam SA 1.1 with a resolution of 1024×1024 pixels at the rate of 5400 fps is used to record the evaporation process from the side-view.

3. Results and discussion

Experiments are organized as follow. A water drop of 10 μl volume and of 296 K temperature is impacted under gravity to heated (408 K) sapphire plate. After impact and spreading, the expanded thin liquid disc breaks up into small droplets, which start to boil and can merge into one big boiling drop [6]. When the droplet base diameter reaches about 1.3 mm (the height of the droplet is about 0.43 mm), the boiling process stops, and the drop begins to evaporate without boiling (figure 2). We discuss here this stage of small droplet evaporation.

Image processing has been done using ImageJ software. Total errors (data processing and data between the runs) are ±0.35 mm for length scale and ±0.37 ms for time. The droplet lifetime is the time required for the contact diameter and/or contact angle, and consequently, its volume, to reach zero. Knowing the droplet lifetime and the time of droplet evaporation starts, we define (Time) as a real-time countdown to the moment of complete drop disappearance. Accordingly, zero time is the time of complete droplet disappearance.

Figure 2 demonstrates droplet evolution in time. The initial droplet volume is obtained using the spherical shape cap formula. The base diameter of 1.3 mm and the height of 0.43 mm give the initial volume of 0.33 μl. Evaporation starts from the pinned droplet evaporation mode. Then droplet depinned and the base diameter quickly decreased, while an apparent contact angle increased at the same time (figures 2 and 3).

The depinning is clearly illustrated in figure 3. The contact diameter quickly decreases and the droplet height increases (figure 3a). We find the contact angle using the spherical cap shape assumption. Receding due to evaporation contact angle evolution in time shows considerable increase just after depinning (figure 3b). However, the depinning angle (25 deg) is smaller than measured receding angle by the syringe-needle method for the unheated surface (36 deg). This may indicate both
Figure 2. Droplet evaporation in time. Scale bar is 0.2 mm on the first left figure. Substrate temperature is 408 K.

Figure 3. Evolution of droplet (a) base diameter and height (b) contact angle in time. Here 0 is time of complete droplet disappearance.

the effect of temperature on the receding angle and the effect of small volume, where the syringe-needle method can not be applied. The value of the initial contact angle for the beginning of evaporation process is close to the measured value of advancing contact angle. The stick-slip motion was observed during the evaporation (figures 2, 3). The first depinning is observed when droplet
became 0.07 $\mu$l in volume. The total time of droplet evaporation is about 1.13 sec. The dynamics of evaporation process is similar to the classical diffusion limited sessile droplet evaporation on a heated surface with pinning and depinning. But the droplet lifetime is much smaller than for unheated substrate.

Acknowledgments
This work was financially supported by the Federal Agency for Scientific Organizations (FASO Russia).

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