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Interaction of levitating liquid microdroplets with intensive vapor flow near the contact line

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Abstract. In this research, interaction of liquid microdroplets with the air-vapor flow near the contact line (the three-phase solid - liquid - gas boundary) is studied. It is shown experimentally that the flight of levitating microdroplets from the wetted surface to the dry one is accompanied by a significant change in the levitation height, which proves the existence of a zone near the contact line with intense evaporation.

1 Introduction

Two-phase cooling systems represent the effective solution for removing high heat flux densities. Some applications, such as spray cooling [1], heat pipes [2], and film cooling systems [3-5], require a study of the processes taking place near the contact line, i.e., the line, where liquid contacts with the gas phase and heated surface. Recent studies have been dealing with droplet evaporation on the heated substrates [6-8]. It was found out that with decreasing droplet size, the specific evaporation rate increases, which can be associated with increased contribution of evaporation near the contact line to the total evaporation rate. The study of heat and mass transfer near the contact line is also important for the applied research in various fields, such as the study of heat transfer at fuel ignition [9-10]. In this paper, we study interaction of levitating liquid microdroplets with the air-vapor flow in the contact line region. It is shown that in this region, there is an area of intense evaporation, where the flight of microdroplets is accompanied by a significant change in the height of droplet levitation.

2 Experimental setup and research methods

In the experiments, the stainless steel working section with embedded copper rod of 10x10 mm^2 was used. The rod was heated using a nichrome spiral, with the current supplied from the power source. The substrate surface temperature was controlled by means of thermocouples installed at the surface of the copper rod. The scheme of experimental setup is shown in Fig. 1. The experiment was performed in the horizontal working section open to the atmosphere at the air temperature of around 25°C. The working surface of the test section was mechanically polished. The working surface morphology was studied using scanning electron microscope JEOL JSM6700F and atomic-force microscope Solver Pro

NT MDT. An image of the surface obtained using the electron microscope is shown in Fig. 2. The value of root-mean-square roughness of the working surface, obtained with the help of the atomic-force microscope, is RMS = 500 nm.

Distilled deionized nano-filtered water at the room temperature was used as the working liquid. The droplet diameter and height of droplet levitation were measured using the images obtained by the high-speed camera FASTCAM SA1.1 (5600 frames per second at resolution of 1024x1024 pixels). Optical resolution of the system was 0.78 μm/pixel.

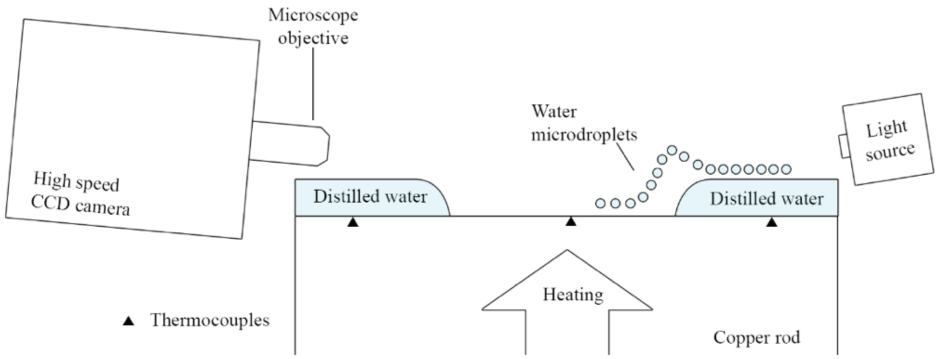

Fig. 1. Schematic of the experimental setup.

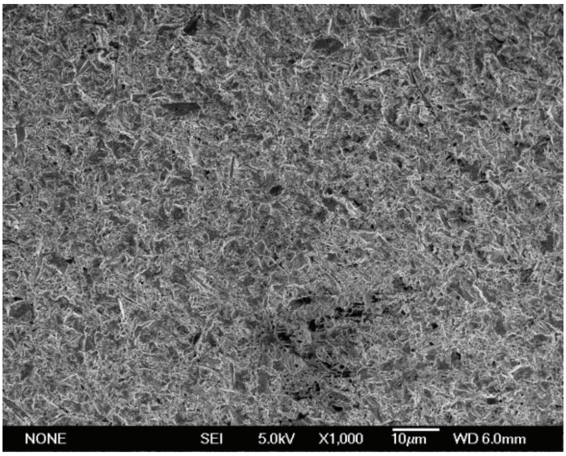

Fig. 2. The working surface image obtained using the scanning electron microscope JEOL JSM6700F.

3 Investigation results

Under intensive heating of a horizontal liquid film, a monolayer of microdroplets with ordered hexagonal structure is formed, levitating at a certain height above the free surface of liquid [11, 12]. If a dry spot is formed in the film, the droplets will "roll down" to the area of the dry spot. The picture of droplets moving towards the dry spot area and flying over the contact line is shown in Fig. 3. Possible scenarios of microdroplet flight are shown in Fig. 4. With the help of high-speed shooting, three possible scenarios of droplet flight over the contact line were distinguished: 1 – flight with a change in the height near the

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contact line; 2 – flight with a circular trajectory; 3 – levitating at a fixed location. All three cases are observed within the temperature range from 75°C to 100°C, however, the scenario No 1 is much more common. In the case of "normal" flight across the contact line, the droplet changes the height of levitation several times, when approaching the contact line. This means that in this area there is more intense evaporation, which throws up a droplet. Thus, we can conclude that evaporation intensity in the contact line area can be several times higher than evaporation intensity of liquid at a distance from the contact line. Droplet circular trajectory near the contact line (scenario No 2) can be connected with the vortex flow of the air-vapor mixture formed near the contact line. The most unlikely scenario is droplet hanging near the contact line (scenario No 3); in this case, the force of dynamic vapor pressure from the contact line balances the gravity force acting on the droplet.

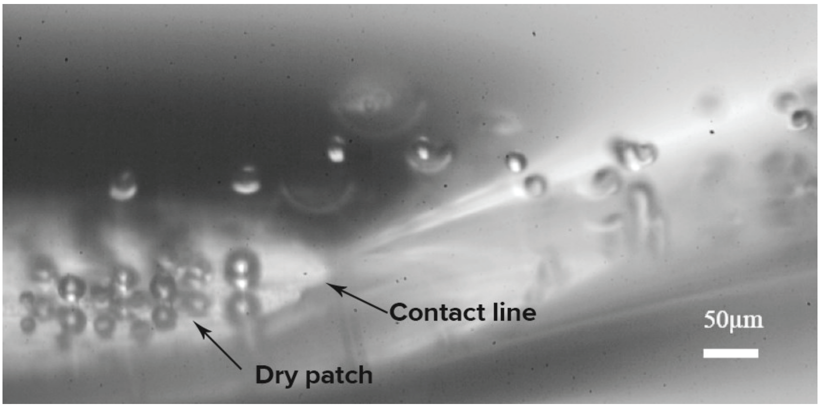

Fig. 3. The flight of liquid microdroplets across the contact line to the dry spot zone. Substrate temperature is 79°C.

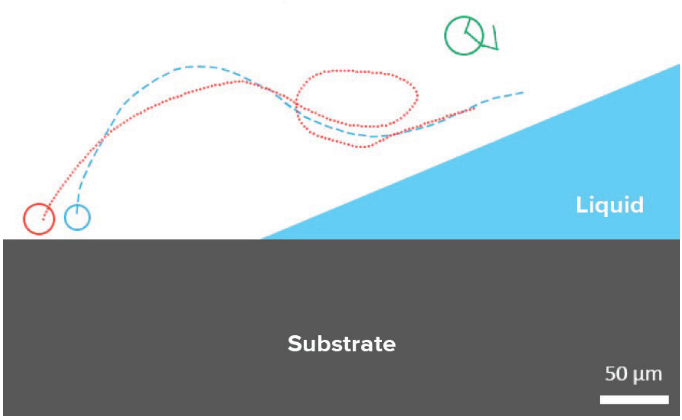

Fig. 4. Scenarios of microdroplet flight across the contact line: blue dashed line – with a change in the height near the contact line (substrate temperature is 79°C); red dotted line – with circular trajectory (substrate temperature is 81°C); green line – with levitation at a fixed location (substrate temperature is 97°C). Droplet size is in the scale.

4 Conclusions

Interaction of liquid microdroplets with the size of about 10 μm with air-vapor flow near the contact line was studied experimentally. It is shown that:

- transition of microdroplets from the wetted to the dry surface is accompanied by a change in the height of droplet levitation near the contact line, which proves the existence of the zone with intense evaporation near the contact line;
- three scenarios of microdroplet flight across the contact line are possible.

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