Contact line dynamics on a substrate coated with a fluoropolymer

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Abstract. This work investigates the dynamics of the contact line during the propagation of a dry spot in a water layer on a solid substrate. The substrate is coated with fluoropolymer by using a hot wire chemical vapor deposition method. The dry spot is generated using a thermocapillary mechanism caused by the heating of the substrate from below by the laser. By analyzing schlieren images, the dependence of the velocity of the contact line during the propagation of a dry spot was obtained for various initial thicknesses of liquid films.

1. Introduction

Currently, the problem of removing high heat fluxes at given temperature conditions limits the development of many branches of technology. Promising cooling technologies include those based on the evaporation of thin liquid films. Thus, the creation of highly efficient heat transfer systems is directly related to processes in thin liquid films, whose study is complicated due to the small scale and a large number of parameters of the gas-liquid-solid system.

Dry spots can appear in thin liquid films due to various mechanisms, and thus form a contact line of the three phases. Some studies \cite{1-4} have shown the presence of super intense evaporation in the vicinity of the contact line, which is explained by the small thickness of the liquid layer in this microregion. In this case, the local heat fluxes in the area of the contact line can significantly exceed the average heat fluxes, thereby making a significant contribution to the total heat transfer. However, large non-removable dry spots, on the contrary, worsen heat transfer, since the non-wetted area is too large in comparison with the formed contact line. Dry spots that impair heat transfer can form due to rupture of the liquid layer caused by thermocapillary convection, which occurs due to the dependence of surface tension on temperature and leads to deformation of the free surface of non-isothermal liquid films. There are several pioneering studies devoted to the thermocapillary breakdown of liquid layers under various conditions \cite{5-9}. In \cite{10}, different working liquids and coatings are used to investigate the effect of substrate wettability on the rupture of the nonisothermal falling liquid film.

2. Experimental equipment and methods

The test section (figure 1) is a cuvette with a working liquid (milli-Q water). The silicone plate is fixed in the cuvette so that a liquid film forms over it. The thickness of the liquid film was measured using an IFS2405-3 confocal sensor.
The silicon plate has a thickness of 0.5 mm and a diameter of 25 mm, and is covered by fluoropolymer by using a hot wire chemical vapor deposition method [11-13] to obtain a more hydrophobic surface. The substrate wettability was measured using a KRUSS DSA 100 system. The advancing contact angle for water was 141 ± 7°, and the receding contact angle was 58 ± 4° (figure 2).

The temperature of the liquid around the substrate is kept constant by means of a copper tube immersed in the cuvette through which water of a given temperature is pumped. The cuvette has a hole into which the continuous laser is directed to heat the substrate from below. The laser beam has a diameter of about 3.5 mm. The cuvette is connected to the tank with working liquid as communicating vessels. The dry spot spreading process was recorded by a Photron Fastcam camera at a shooting speed of 3000 frames per second. The image resolution was 1024×1024 pixels, with a field of view of 25×25 mm. The temperature and relative humidity of the ambient air during the experiments was 24-25 °C and 50-60 %, respectively.

3. Results and discussion

Figure 3 shows images demonstrating the propagation of a dry spot in the course of thermocapillary rupture of a horizontal layer of water located on a silicon substrate coated with a fluoropolymer. The optical schlieren method allows visualization of flat horizontal areas of the free surface and inclined ones using shades of gray in the image (darker areas correspond to a more inclined surface). A dry spot forms in the so-called residual film (light area in the center of the image) [14, 15]. Further, a single dry spot rapidly spreads over almost the entire surface of the silicon wafer. The substrate without liquid is practically white in the images, since it reflects the incident light well, while the

![Figure 1. Test section.](image1)

![Figure 2. Measurements of the contact angle on a silicon substrate coated with a fluoropolymer.](image2)

Advancing contact angle (left image), receding contact angle (right image).
contact line is black since it is inclined with regard to the substrate. Thus, the position of the border of the dry spot (i.e. contact line) due to good contrast can be clearly defined. The average velocity of the contact line was determined using image processing as the difference between the radii of the dry spot in time. The method for determining the velocity of the contact line is described in more detail in [16].

Figure 3. Dry spot dynamics (the time is indicated from the nucleation of a dry spot).

Figure 4 shows the dependence of the contact line velocity on time for a silicon wafer coated with a fluoropolymer at different thicknesses of the water layer at the beginning of the experiment. It was found that with an increase in the height of the water layer, the initial velocity of the contact line increases. This result is consistent with [16] and is most likely explained by the higher temperature in the center of the silicon wafer before breaking for thicker water films. Also, at different initial heights of the water layer, contact line velocity manifests a different tendency in changing during the propagation of a dry spot. For less thin layers (about 300 μm thick), the maximum velocity is observed sometime after the initiation of the dry spot, and then the velocity significantly decreases. With an increase in the initial layer height (about 450 μm), the contact line velocity is slightly higher at the initial moment and does not significantly decrease with the growth of a dry spot. With a further increase in the height of the water layer, the contact line velocity is maximum at the initial moment and sharply decreases with an increase in the size of the dry spot.

Figure 4. The contact line velocity during the growth of a dry spot.

4. Conclusion
An experimental study of the dynamics of the contact line on silicon wafers coated with a fluoropolymer has been carried out. The contact line was formed by a layer of water and a substrate with an area without liquid, that is, a dry spot that appeared due to thermocapillary convection caused by local heating of the substrate by a laser. It was revealed that at different initial heights of the water
layer, contact line velocity manifests a different tendency in changing with the growth of a dry spot on the surface of a silicon wafer with a fluoropolymer coating.

It was also confirmed that with an increase in the height of the water layer, the initial velocity of the contact line increases.

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