

Study of heat transfer in the bubble meniscus with an array of temperature micro-sensors

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Abstract. Experimental setup has been designed and manufactured to study the evaporation processes in the bubble meniscus. New method for accurate measurements of local heat transfer has been proposed in collaboration with Kyushu University. Two side transparent coatings (thin film uniform heater and an array of temperature micro-sensors) are developed on sapphire substrates. Application of such substrate allows one to investigate heat transfer in the vicinity of the contact line. The shadow technique is used to define shape and contact angles of bubble.

1 Introduction

In recent years, progress in electronic technology resulted in increasing heat dissipation from semiconductor chips. Thus there is a strong demand for thermal management systems with higher performance compared with the existing ordinary convective air or single-phase liquid systems [1, 2]. The cooling by phase change attracts much attention for micro-electronics and space applications because of potentially high efficiency at low mass flow consumption [3, 4, 5]. It is known that heat transfer increases by reducing thickness of liquid film. The experimental work shows that heat transfer near the contact line is three times higher compared to average for sessile drop on electrically heated thin foil [6]. Some experimental works related to vapor bubble and its meniscus can be founded in the literature [7]. The goal of the present experiment is to study the boiling and condensation of vapor in the bubble, and also the process of evaporation at the meniscus, rupture of liquid layer, dynamics of receding contact line, under the control of the heating from the substrate. These studies are performed in collaboration with Kyushu University, where a unique technology of manufacturing micro-sensors (micro-heaters) have been developed that provides high accuracy of heat transfer measurements [8]. Micro-sensors create relief on surface, which may significantly affect the behavior of the contact line and the evaporation. Analysis of the effect of patterned and structured surfaces on contact line and its dynamic has been reviewed in [9].

2 Experimental setup

Experimental setup consists of three elements (Fig. 1): a transparent test cell with inner size of $60 \times 60 \times 8 \text{ mm}^3$, a pressure damper connected to the test cell and a transparent cover box with air fan electrically heated to control surround temperature. A pressure damper is mounted on a platform which

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allows changing hydrostatic pressure and equipped with Peltier elements controlling the temperature in a liquid.

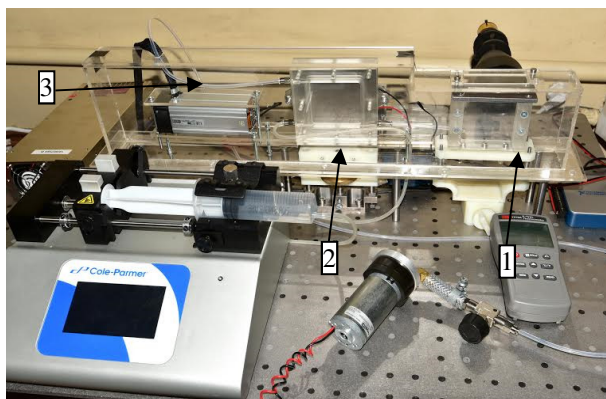


Figure 1. Photograph of experimental setup: 1 –test sell, 2 – pressure damper, 3 – transparent cover box.

The bubble shape is visualized from the top and from the side with the help of the schlieren technique and shadow technique with resolution of $6\ \mu\text{m}/\text{pix}$ respectively, (as shown in Fig. 2 and Fig. 3). The images from the side (Fig. 4) are processed in the Drop Shape Analysis software by KRÜSS using different methods including Young-Laplace method [10]. The result of the contact angle hysteresis (CAH) measurements of water on the uniform transparent heater (Fig. 5) is shown in Fig. 6. CAH on uniform transparent heater more than two times less compare surface without coating (15° compare 40° correspondingly). Using of fast cameras and infrared scanner is also expected.

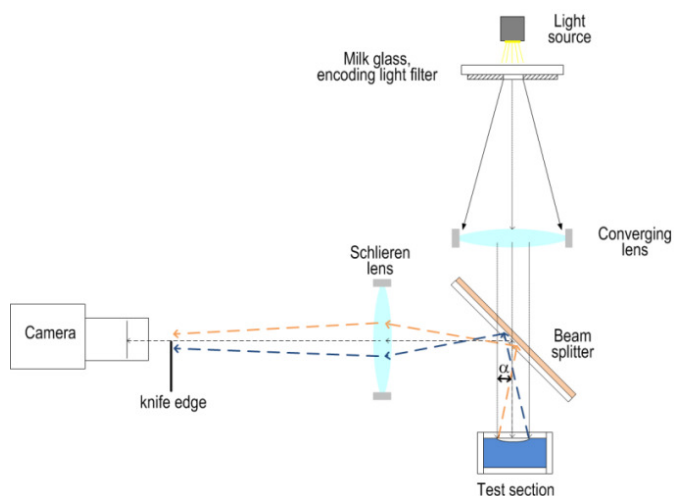


Figure 2. Schlieren method from the top.

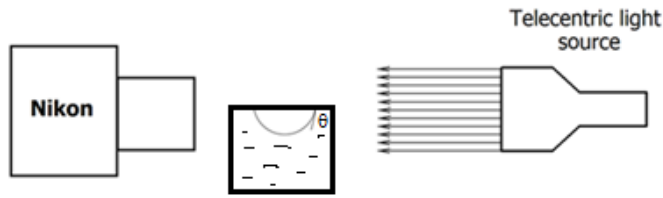


Figure 3. Shadow technique with optical resolution of $6\mu\text{m}/\text{pix}$ from the side.

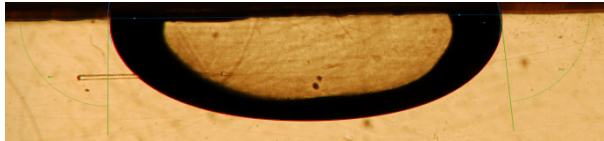


Figure 4. Photograph of the bubble in water on the transparent heater.

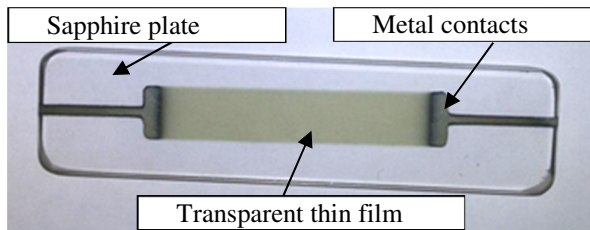


Figure 5. Photograph of sapphire substrate with thin film heater.

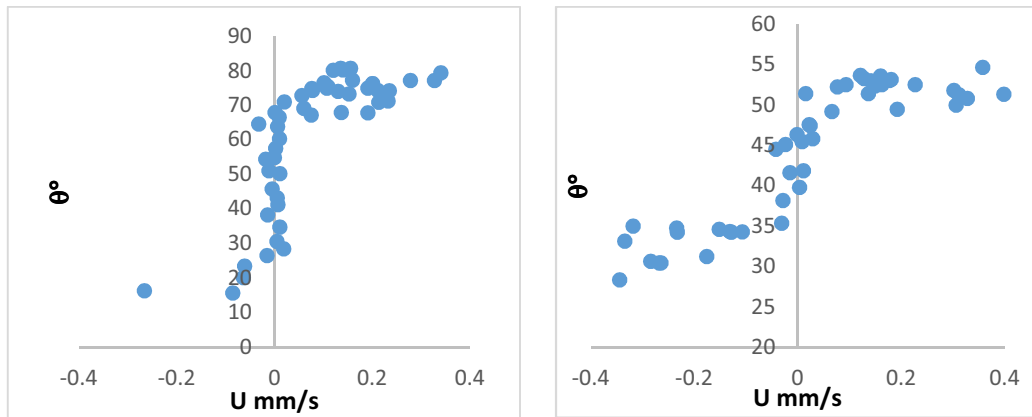


Figure 6. Contact angle hysteresis of water on the sapphire (left) and transparent heater (right).

Two types of substrates are used: 1) 3 mm thick sapphire plate with a uniform transparent thin film heater (Fig. 5) made of indium tin oxide (ITO). Thickness of the ITO layer is 1.1 micron, which has been coated by 450 nm silicon dioxide (SiO_2) layer to prevent electrolysis. Thin film heater stay in direct contact with liquid and it is considered that heat losses are negligible. 2) Substrate for local heat transfer measurements using temperature platinum micro-sensors is shown in Fig 7. The surface area of a single sensor is $3 \times 0.5 \text{mm}^2$. Distance between sensors is 0.1 mm. The temperature platinum micro-sensors stay in contact with a liquid and measure local surface temperature. Heat flux is known from electrical power, hence local heat transfer coefficient can be found from temperature surface and heat flux.

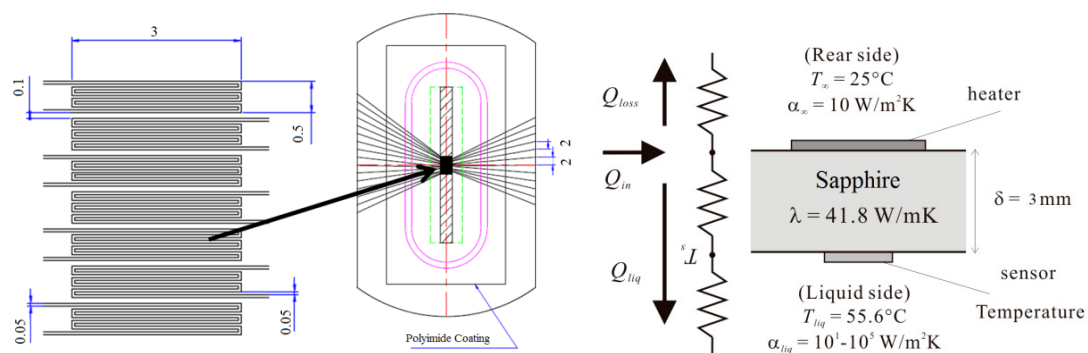


Figure 7. Scheme of substrate with an array of temperature micro-sensors for heat transfer measurements.

3 Conclusions

Manufactured experimental is used to perform wide investigations of vapor bubble meniscus. A unique technology of manufacturing micro-sensors (micro-heaters) has been developed that provide high accuracy of heat transfer measurements. Transparent substrate and test cell allows observed bubble from all sides using different optical techniques including infrared diagnostics.

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