INVESTIGATION ON BEHAVIOR OF BUBBLES GENERATION IN A DROPLET IMPINGING ON A HEATING SURFACE

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ABSTRACT

Cooling method in which fine water droplets are sprayed onto a high-temperature surface has been considered as a method that has a higher heat transfer coefficient than a cooling method in which cooling water is circulated over a high-temperature surface. The purpose of this study is to observe and clarify the mechanism of generation behaviors of bubbles in the center of droplet when a water droplet collided with a heating surface. A transparent sapphire was used as the heating surface in order to clearly catch the bubble which arises at the solid-liquid contact surface. Boiling behavior was photographed by a high-speed video camera from the backside direction of the surface. Bubbles' fluctuation was measured in order to determine the behavior during boiling process. Also, two different heating surfaces were used to determine the effect of surface wettability. Alas, the sapphire heated surface pretreated with hydrogen peroxide plasma had better wettability and increased bubble point density than the original sapphire surface.

Keywords: Droplet, Bubble Generation, Impingement, Heat Transfer, Fluctuation

1.0 INTRODUCTION

Researchers have spent decades delving into the phenomenon of droplet impingement to gain a comprehensive knowledge of the connections between mass, momentum, and heat transmission [1]. Research on droplet cooling of any surface such as metal surfaces are crucial for commercials and industries use such nozzle spraying and material quenching [2]. During heat treatment procedures like quenching, spray cooling is one of the important cooling techniques used to remove heat and alter the mechanical characteristics of materials. High heat flux is achieved by combining the phase change and convection modes of heat transmission with a liquid drop [3]. One of the best methods for improving heat transfer is the boiling process. Early bubbles expand and agglomerate inside a thin liquid film during spray cooling and drop down on a hot surface [4]. The essential behaviors and properties of nucleation, transition, and film boiling for single droplets and droplet-droplet combinations were investigated in most experimental phenomenological research. For each of the many boiling procedures, key distinctions were noted and explained.

The boiling phenomenon in solid-liquid contact between a droplet and heated sapphire occurs when the temperature of the heating surface reaches a certain range, resulting in the instantaneous generation of many microscopic bubbles, resulting in a black area that is thought to be caused by the coalescence and disappearance of these bubbles appears on the hot surface. There are several research had conducted experiment by observing droplet behavior from the backside of the heating surface such as quartz and sapphire, photos were taken of the generation behavior of the tiny vapor bubble that formed in the liquid—solid contact surface (wetting surface) at the beginning of the collision. The influence of the heating surface temperature and the amount of time that passed after the collision on the quantity of bubble creation was investigated in the temperature range of 180°C to 520°C [5-8]. In this study, it is focused on the behavior of bubbles generated in the center of the droplet by changing the temperature of the heating surface, and photographed the boiling phenomenon from the rear of the heating surface using a high-speed camera, and investigated the process and behavior of the black part. The purpose is to observe and elucidate the liquid supply mechanism to the hot surface. It also clarified the characteristic of changing the wettability of the surface by irradiating plasma onto the sapphire surface, causing boiling on that surface, and comparing it with the phenomenon that occurs on normal sapphire surfaces.

2.0 METHODOLOGY

Figure 1 shows an experimental setup for photographing the boiling phenomenon during droplet collision from the rear directions using a high-speed camera at a frame rate of 10,000 fps and a shutter speed of 1/120,000 sec. The experiment was carried out at the Department of Mechanical Science and Technology, Gunma University, Japan. The heating surface uses artificial white sapphire with a diameter of 30 mm and a thickness of 8 mm, and both end surfaces are polished into a lens shape. The sapphire was fitted into a copper block with a heater embedded in it and held horizontally. The heating surface temperature was adjusted by changing the voltage of the transformer. The heating surface temperature was measured by fixing K-type thermocouples to two locations on the heating surface using ceramic adhesive. The experiment was conducted with the initial heating surface temperature T_w in the range of 180°C to 320°C. Sufficiently degassed distilled water is used for the droplets, which are constantly dripped from a nozzle and caught by a shutter.

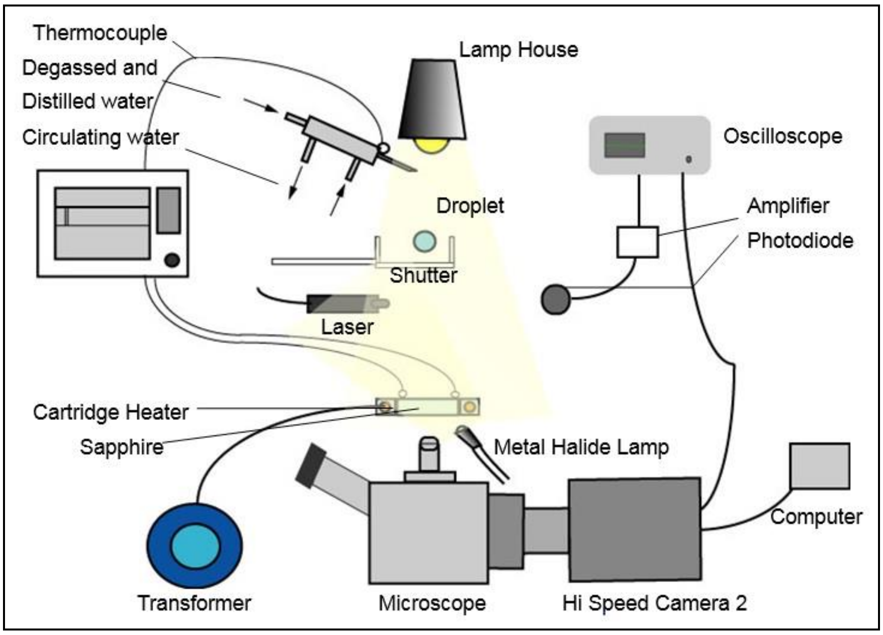

Figure 1: Experimental apparatus

Only during experiments, the shutter is moved to allow a single droplet to collide with the center of the heated surface. Tap water at a constant temperature was circulated around the nozzle to maintain the droplet temperature T_l at 18°C. The droplet diameter was set to 3.8 mm, and the droplet falling height was set to 65 mm. When considering a droplet collision system, the collision Weber number must be considered. The behavior of the droplet after falling differs depending on this value, and if the value is large, the droplet falling on the wall will break up. The collision Weber number is given by the following Equation (1):

$$We = \frac{\rho v^2 L}{\sigma} \tag{1}$$

where density, $\rho\left[\frac{kg}{m^3}\right]$, velocity, $v\left[\frac{m}{s}\right]$, representative length, $L[m]$, surface tension coefficient, $\sigma\left[\frac{N}{m}\right]$, Collision Weber number, $We = 70$.

A passing sensor was installed to capture the falling droplets, and the signal was sent to the camera, which then went through a pulse generator to adjust the timing of the start of the photo shoot. In addition, in order to change the wettability of sapphire, sapphire irradiated with hydrogen peroxide plasma (static contact angle; original sapphire: 45°, plasma-treated sapphire: 30°) was used. Bubble counts were performed using a manual counter.

3.0 RESULTS AND DISCUSSION

Figures 2 and 3 show the static contact angles of water droplets photographed on each surface used in this experiment. Here, the static contact angles of the original sapphire used in this experiment and the sapphire irradiated with hydrogen peroxide plasma are listed for reference. Distilled water was used as the water droplet, and the water temperature was room temperature, and the water was dropped from the same nozzle. Comparing each heated surface, the contact angle of normal sapphire is larger than that of sapphire irradiated with hydrogen peroxide plasma. This shows that sapphire that has been irradiated with hydrogen peroxide plasma on each heated surface is the easiest to wet. If the evaporation properties depend on the contact angle, then the one that is most wettable and has a large surface area that encounters heat should have good evaporation properties.

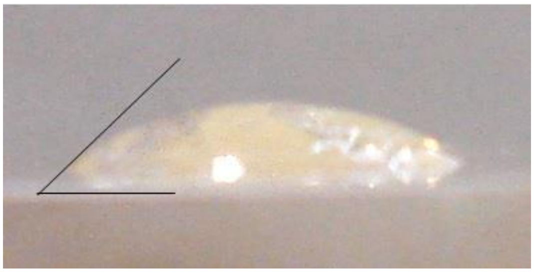

Figure 2: Static contact angles of droplet at 45^{o} on original sapphire

(a) Surface before heating (b) Surface after heating

Figure 3: Static contact angles of droplet at 30^{o} on sapphire irradiated with hydrogen peroxide plasma

Figures 4 and 5 show liquid images taken at a frame rate of 10,000 fps and a shutter speed of 1/120,000 sec for the case of original sapphire with a heating surface temperature of 280°C and the case of sapphire irradiated with plasma, respectively. This shows the bubble generation behavior on the heated surface immediately after droplet collision. It can be seen how the size and shape of the black part changes over time.

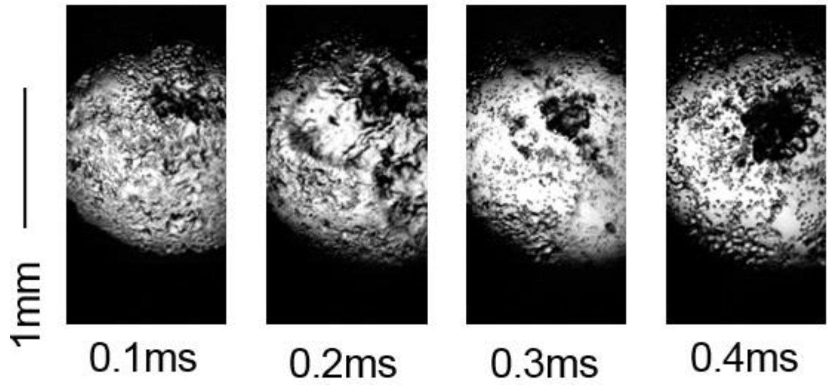

Figure 4: Bubbles behavior on original sapphire surface from backside at 280℃

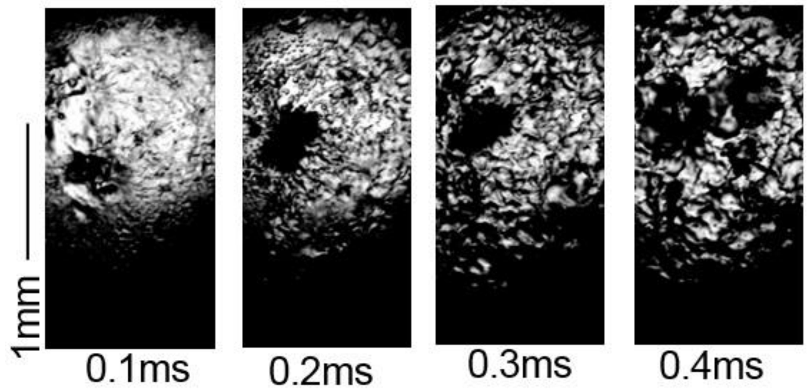

Figure 5: Bubbles behavior on plasma irradiated sapphire surface from backside at 280℃

Figure 6 shows the bubble point density at the initial stage of the collision. It showed a tendency to increase as the heating surface temperature increased. This can be said to be caused by the fact that the higher the temperature, the more intense boiling occurs, and the more bubbles are generated. When the heating surface was heated to 320°C, many bubbles were generated initially, and as time passed, the bubble point density became lower than that at other temperatures. It is conceivable that many bubbles are generated initially and coalesce as time passes. When the surface temperature was 260°C, the foaming point density reached its maximum value after a short period of time. This is thought to be because coalescence occurs frequently during early boiling, and the number of uncoalesced bubbles is still small.

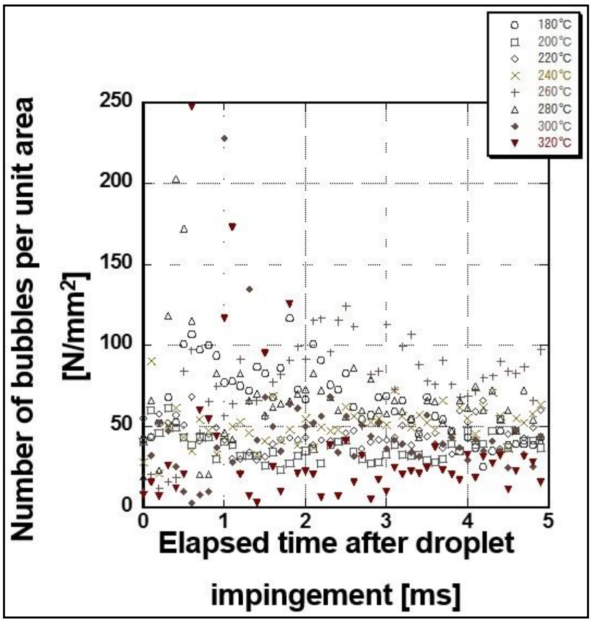

Figure 6: Bubble generation density for original sapphire

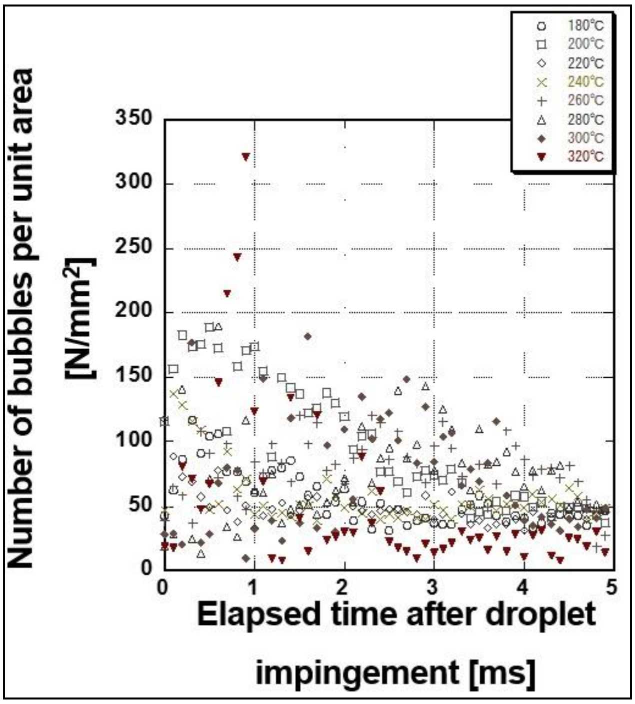

Figure 7: Bubble generation density for hydrogen peroxide plasma irradiated sapphire

Figure 7 shows the case of sapphire irradiated with hydrogen peroxide plasma, which showed the maximum bubble point density at the initial temperature of 320°C. A high foaming point density was obtained even when the heating surface temperature was 200°C. Overall, sapphire irradiated with hydrogen peroxide plasma showed a higher bubble point density. This is thought to be due to an increase in the contact area between the droplet and the sapphire due to increased wettability due to plasma irradiation. From the result, the phenomenon with the highest heat removal ability which is known as miniaturization boiling (micro-bubble emission boiling [MEB]) may play an important role in cooling techniques [9].

4.0 CONLUSIONS

The sapphire heated surface pretreated with hydrogen peroxide plasma had better wettability and increased bubble point density than the original sapphire surface. As a result, during the expansion and contraction behavior of the black area captured from the back of the thermal surface, at 260°C on normal sapphire, the foaming point density reached its maximum value after a short period of time. At the meantime, on sapphire irradiated with hydrogen peroxide plasma shows the maximum bubble point density at the temperature of 320°C.

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