Visualization experiment of supercooled water in a microchannel using near infrared absorption imaging technique

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1. Introduction

Freezing phenomena at the microscales has been a topic of interest in various fields such as phase change valve for microfluidic devices, cryopreservation, and polymer electrolyte fuel cells [1]. Despite of a number of researches focusing on the above applications, there exists only a few studies on fundamental understanding of the phenomena.

Near-infrared (NIR) absorption imaging technique has been already used to visualize the temperature and concentration of water as well as aqueous solutions in microchannels. This imaging technique is a non-contact methods and thus this technique is advantageous for the visualization of the water freezing which can crucially influenced by impurities. Furthermore, the spectral characteristics of water highly depends on its state. Therefore, this technique can be utilized to visualize the state of water in microchannels as well as its temperature which is very useful to fundamentally understand the freezing phenomena at the microscales. This is our motivation of our study.

In this study, a set of experiments was implemented to visualize the water below freezing point in a microchannel having a depth of 500 µm using the NIR absorption imaging technique. During the experiments, the NIR absorption images of the (ν1 + ν2) absorption band of water were taken by a band-pass filter (BPF) having center wavelength of 1400 nm. The water in the channel was cooled by using a Peltier cooler and the surface temperature of the cooler was gradually changed, and the difference in the images at different temperatures are discussed.

2. Experimental methods

Figure 1 shows the schematic of the experimental setup. In the present study, an NIR LED light having a peak wavelength of 1450 nm was used. First, pure water was injected in the microchannel, followed by bonding it with two copper plates using thermally conductive adhesive where each copper plate has a 6-mm holes for photographing purpose. Then, the microchannel-copper-plate assembly was placed on the center of a Peltier cooler as shown in Fig. 1. The NIR light transmitted through the water in the microchannel was filtered by the BPF, and then the filtered light was captured by the NIR (InGaAs) camera. The temperature of the microchannel was changed by controlling the surface temperature of the Peltier cooler, Tp. Also, two K-type thermocouples were inserted in the assembly to validate the temperature difference between the cooling surface and thermocouple and it was found that the difference was to within 3 °C in the present experiment. Also, the humidity was measured to be about 15% during the experiment.

3. Results and discussion

In order to evaluate the temperature and phase-state dependences of water NIR absorption, the difference in the absorbance from reference value, ΔAν, was used, which is expressed as follows [2],

\[ \Delta A_\nu = -\log_{10}(I/I_0) \]  

In the above equation, I is the transmitted light intensity, and I0 is the intensity for reference condition (i.e., Tp = –0 °C).

Figure 2 (a) and (b) show the images of ΔAν for Tp = –15 and –17 °C, respectively, where the water in the microchannel is in liquid state or supercooled state. As can be seen in these figures, there are mainly two regions with mostly green and red colors in both figures, respectively. The former region shows the water in the microchannel transmitted from the 6-mm hole and the latter is the copper plate sandwiching the channel. Also, these figures present that the ΔAν distribution is almost uniform. Comparing the images for different Tp conditions, the ΔAν value for Tp = –15 °C is larger than that for Tp = –17 °C. This seems to be due to the temperature dependence of water NIR absorption. We have obtained similar images for the temperatures between 0 to –17 °C and found that the ΔAν value gradually decreased as temperature decreased.

When the experiment was conducted for the Tp-values lower than –17 °C, it was found that the freezing occurred at –18 < Tp < –21 °C. Figures 3 and 4 present the images of ΔAν when the water in the microchannel was frozen at Tp = –18 and –21 °C, respectively. It is observed from these figure that the range of the ΔAν value significantly differs from that in liquid state, which ranges –0.005 < ΔAν < –0.055 (see Fig. 2). For the case that the water was frozen at Tp = –18 °C, the magnitude of the ΔAν value ranges 0.25 < ΔAν < –0.17, and the ΔAν value is mostly positive as shown in Fig. 3. In contrast, for the case that the water was frozen at Tp = –21 °C, the range of the ΔAν value is 0.18 < ΔAν < –0.30 as can be seen in 4. Also, the region of negative ΔAν value in 4 is much larger than that shown in Fig. 3. This difference in NIR absorption image seems to be due to several factors involving phase change, refraction of light and frosting on the channel wall. In the current stage, however, the effect...
of frosting on the channel wall is probably the largest effect. The humidity was decreased to about 15% during the experiments as described in the previous section, which however corresponds to the saturated water vapor amount at about −20 °C, which might probably have caused frosts on the microchannel wall. Therefore, further modification of the experiment is required to obtain further reliability of experimental data at the frozen condition.

4. Conclusions

A set of experiments were conducted to visualize the water freezing in a microchannel having a depth of 500 µm using the NIR absorption image technique and the experimental results lead to the following conclusions.
1. The water in the microchannel was found to be in the supercooled state, and the degree of undercooling was up to 20.
2. The freezing occurred at different surface temperatures of the Peltier cooler below −17 °C, and the NIR absorption images were influenced by several factors, such as phase change, refraction of light and frosting on the channel wall.

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References: