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Research Paper

Noninvasive temperature measurements of RLIF and nPIT in DI water flow microchannels

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HIGHLIGHTS

- The thermal slip and temperature jump still seem to be observable, but not clearly.
- It is found at $Re = 2$ that the present flow can be thermally fully developed.
- The local Nusselt number results are still a little higher than previous studies.

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ABSTRACT

Experiments were performed herein to examine the near-wall water flow/thermal characteristics and bulk flow behavior in a 20 mm long microchannel with a height of 45 μm (thermal) and a width of 200 μm, through the noninvasive optical measuring techniques of nPIT and RLIF. The corresponding streamwise wall temperature distribution (45 μm channel) was measured. It was found that at $Re = 2$, the flow can be fully developed thermally. In addition, both the local heat transfer coefficient and the corresponding Nusselt number were obtained via the RLIF and traditional thermocouple measurements. When compared to the results of previous studies our results are in good agreement.

1. Introduction

Over the past several decades, studies on the near-wall characteristics of fluid flows have received a lot of attention due to the emergence of micro/nanofluidics. Fluid-surface interfacial phenomena are important, as they can affect the conventional/traditional concepts, such as the no-temperature jump at the boundary condition, which has long been accepted for most macroscopic flows, but which may not be appropriate at a micro/nanoscale. As micro/nanofluidic applications are widely used in electronic, biomedical and energy technologies, it is essential that the thermal transport characteristics in micro/nanosystems be better understood. In particular, the interfacial behavior of the liquid and wall due to the wettability of the liquid, can influence the energy exchange at a micro/nanoscale and result in a temperature jump at the solid wall [1].

Intrusive measurement techniques using thermocouples in the micro/nanochannels have usually been limited to measuring the bulk fluid temperatures at the inlet and outlet of a channel and the channel wall. As for the local temperature measurements, although microchannels can be fabricated with integrated temperature resistance sensors, of a size in the order of a few microns embedded in the substrate, the often complicated fabrication processes have restricted their application. Furthermore, while these sensors are easy to use for measuring surface/wall temperatures, they do not provide direct measurement of the local temperature. In addition to being intrusive, these probes often suffer from spatial temporal resolution.

One of the most commonly used methods for non-intrusive temperature measurements at a micro/nanoscale is laser-induced fluorescence (LIF) [12–14], for which a temperature-sensitive fluorescent dye (either Rhodamine B or Sulfo Rhodamine 101) is dissolved in the fluid of interest and the dye is excited to fluorescence with an illumination source [2]. However, it has been found that a variation of ±2 °C in the measurement accuracy cannot be avoided because the intensity of the illumination source varies with the local fluid temperature change. In addition, the spatial resolution of O (10–100 μm) has been reported [3]. The most reliable way to overcome the above-stated difficulty is to normalize the fluorescence intensity of the temperature dye with a

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temperature-independent dye (Rhodamine 110), which is termed as ratiometric LIF/RLIF [4].

Although LIF/or µLIF has been used to measure liquid temperatures in channel flows, evanescent-wave fluorescence thermometry (EFT) has recently been employed [3] to measure the near-wall/or surface (<0.3 µm) temperature distributions via the fluorescent emissions of an aqueous solution by evanescent wave illumination generated by the TIR technique. The above method, an nPIV technique for temperature measurements using the Brownian motion of a seeded particle and known as nPIT (nanoparticle image thermometry), was first developed by Anoop and Sadr [5] to measure the near-wall temperature profile.

In the present work, the nPIT and RLIF techniques were used to quantitatively examine the temperature fields on a near-wall in a microchannel. RLIF was employed to measure the bulk fluid temperature with RhB and Rh110 for an asymmetrical heating flow microchannel with a constant heat flux and a height of 45 µm. The convective heat transfer coefficient was calculated and the

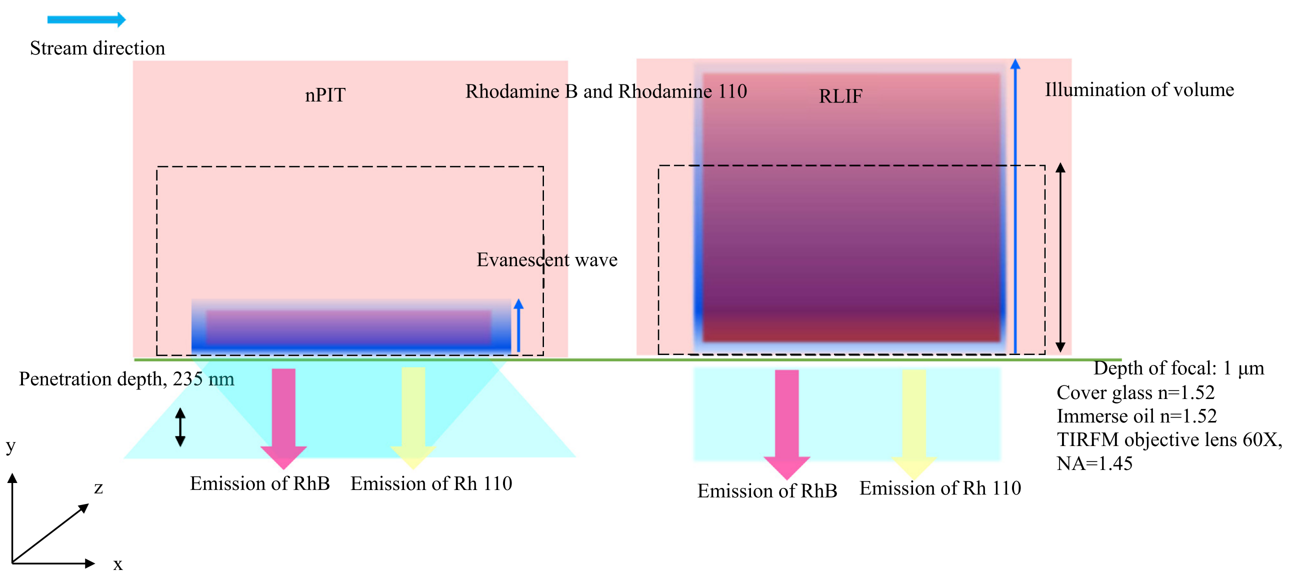

Fig. 1. Schematic of TRIFM of RLIF/nPIT system.

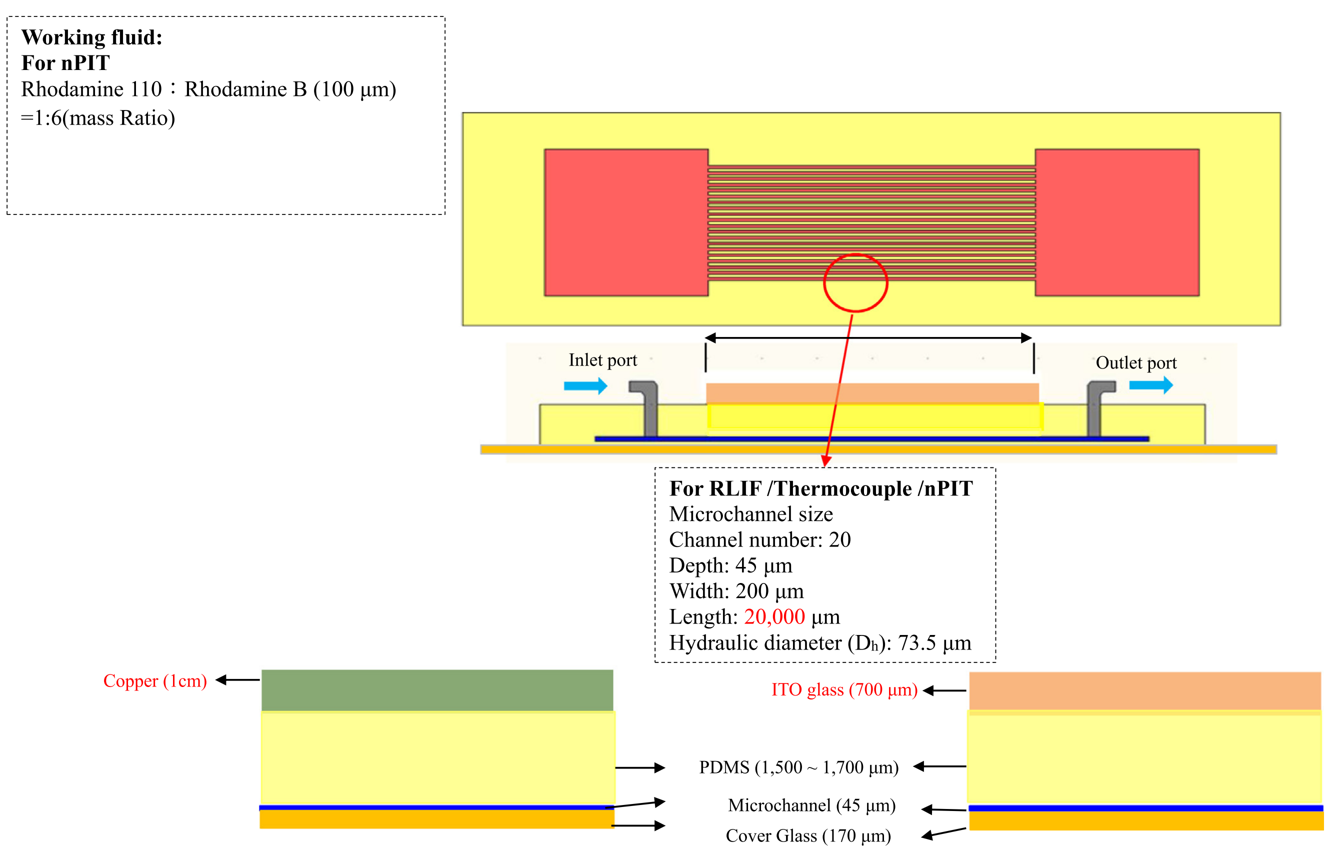

Fig. 2. Geometry of microchannel with nPIT measurement.