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CHARACTERIZATION OF THIN INDIUM TIN OXIDE (ITO) COATED SAPPHIRE SENSOR FOR APPLICATIONS IN SIMULTANEOUS OPTICAL IMAGING AND NON-INTRUSIVE SURFACE TEMPERATURE MEASUREMENT OF GAS MICROFLOWS

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IR Sensor, Non-intrusive temperature reading, Gas microflow

ABSTRACT

Increasing computational capabilities of smaller, more highly integrated electronic and optoelectronic systems is pushing the need for miniaturized cooling techniques [1]. In this context, the use of a phase-change heat transfer mechanism in microchannels is an attractive solution for thermal management due to its high levels of thermal performance [2]. In this situation, it is important to understand the non-continuum transport behavior of vapor in microchannels for designing compact and effective micro-cooling system. In particular, there is an experimental need to access full-field temperature measurements to interrogate the nature of vapor microflow in microgeometries, while providing simultaneous optical imaging as vapor flow may condense or evaporate from the walls of the microflow geometry.

The majority of relevant studies in the literature rely on numerical and analytical techniques to understand gas microflows [3]. Moreover, reported experimental studies typically provide only point measurements or deploy intrusive method such as PIV [4], [5]. To address this issue, we are developing a non-intrusive and reliable infrared sensor/heater allowing for simultaneous optical imaging and full field surface temperature measurement in gas microflows. The key challenge is to calibrate this optically grey infrared sensor/heater so that accurate temperature data can be extracted under relevant experimental conditions.

The sensor was fabricated on IR transparent (>85% transmission in 2-5µm range) sapphire substrate (100mm diameter, 650µm thickness, University wafers, USA) and the sensing element was made of a thin film of ITO of sheet resistance 100 Ω/□ coated on it (Diamond Coatings, UK). Our goal was to characterize the IR sensor such that signals from sensing element ITO could be reliably read using IR Camera (FLIR SC5000, USA). Essentially, it was important to estimate the range of temperature over which the apparent emissivity of sensor is stable. To quantify this, a portion of the sapphire substrate was covered with a black tape of known emissivity, $\varepsilon \approx 0.96$ (Super 88, 3M, USA) to function as a calibration reference. A schematic of experimental setup is shown in Fig. 1A, where a voltage source (CPX 400D, AIM TTI, UK) is connected to the ITO thin via copper tape to induce joule heating. The experiments were performed over a range of electrical power input and the apparent temperature was measured at two neighboring points on the substrate. One of the points was positioned on

ITO/sapphire covered with black tape and the other on the uncovered area as shown by points A and B in Fig. 1A.

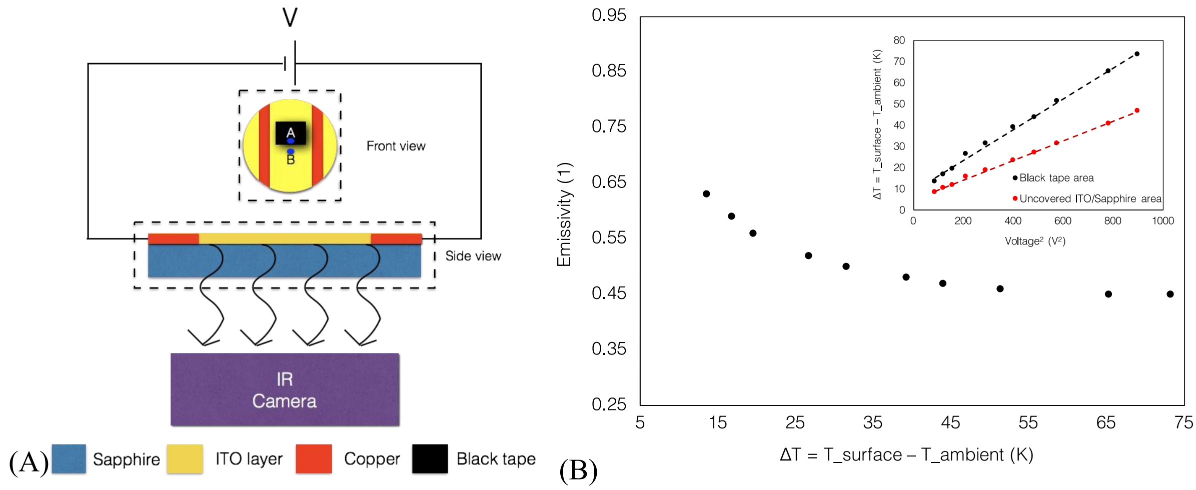

Figure 1. A. Schematics of experimental setup for reading the temperatures from ITO coated sapphire. B. Effect of temperature on emissivity of ITO coated sapphire sensor

The temperature reading from black tape area was greater as its emissivity is higher than the apparent emissivity of uncovered ITO/sapphire area as shown in inset plot of Fig. 1B. Using the known emissivity of the black tape, the apparent emissivity of the exposed ITO/sapphire area was estimated by adjusting the emissivity in camera software (Altair, FLIR USA) until the camera read the same temperature for both points A and B (Fig. 1A). The values of apparent emissivity obtained for ITO/ sapphire at different temperatures above the ambient (ΔT = T_surface – T_ambient (K)) is presented in Fig. 1B. We observe that the apparent emissivity of ITO-coated sapphire is higher at temperatures close to the ambient temperature, which we attribute to contributions from surrounding objects emitting at ambient temperatures. However, the apparent emissivity value starts saturating as the temperature of ITO heater reaches ~43 K above the ambient background. Furthermore, it was found that the apparent emissivity of ITO remains about ~0.45 over a wide range of temperature from 43 - 73 K above ambient. These initial results provide encouraging evidence that the ITO-coated sapphire sensor can be reliably used for experiments performed in this range. Ongoing efforts include the development and validation of a grey radiation model for the experimental setup that will be used in the design of gas-flow microchannel heat transfer experiment.

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References

[1] G. Hetsroni, A. Mosyak, Z. Segal, and G. Ziskind, "A uniform temperature heat sink for cooling of electronic devices," *Int. J. Heat Mass Transf.*, vol. 45, no. 16, pp. 3275–3286, 2002.

[2] L. L. Vasiliev, "Micro and Miniature Heat Pipes," *Microscale Heat Transf.*, no. September 2005, pp. 413–428, 2005.

[3] S. Colin, "Gas Microflows in the Slip Flow Regime: A Critical Review on Convective Heat Transfer," *J. Heat Transfer*, vol. 134, no. 2, p. 20908, 2012.

[4] H. Weng, "Combined Forced and Thermocreep Convection through a Long Horizontal Microchannel," *Micromachines*, vol. 7, no. 2, p. 33, 2016.

[5] P. Perrier, I. A. Graur, T. Ewart, and J. G. Méolans, "Mass flow rate measurements in microtubes: From hydrodynamic to near free molecular regime," *Phys. Fluids*, vol. 23, no. 4, 2011.