AC resistance thermometry for thermal characterisation sensing inside a microfluidic channel

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Abstract Summary: An AC resistance thermometer was integrated into a microfluidic channel and used to measure the flow of water at varying flow-rates. The ability to control the probing depth of the sensor has potential applications for laminar flow based experiments.

Introduction: AC resistance thermometry, also known as the 3ω method, is an established technique for the thermal characterization of thin films and other solid materials [1]. The measurement involves a resistance thermometer, which also acts as a heating source. The heater probes the thermal properties of the surrounding material and the temperature of the line is monitored simultaneously. Sweeping the electrical driving frequency of the heater allows the thermal transfer function of the material to be directly probed (at twice that frequency).

AC resistance thermometry has significant advantages over static/DC techniques in that the thermal penetration depth, and therefore the measurement depth, can be controlled using the driving frequency. These advantages can be extended to materials other than solids. Previously, the technique has been used to characterize small amounts of liquid material and biological samples [2,3]. In this paper we demonstrate how the technique can be used to measure flow rates in microfluidic channels.

Experimental: Microfluidic moulds were fabricated in Aluminium (6061 T6) using a CNC milling machine (Minitech 3-axis mill, Nakanishi Spindle). The channel design consisted of a 20 mm long, 725x725 μm square cross-section channel. PDMS (Sylgard 184) was then cast into the mould to form the microfluidic channel. A 200 nm thick Ti-Au resistance thermometer was patterned onto soda-lime microscope slides using standard photolithography lift-off procedure. The thermometers were characterized in terms of resistance and temperature coefficient of resistance, prior to being sealed in the channel using oxygen plasma bonding.

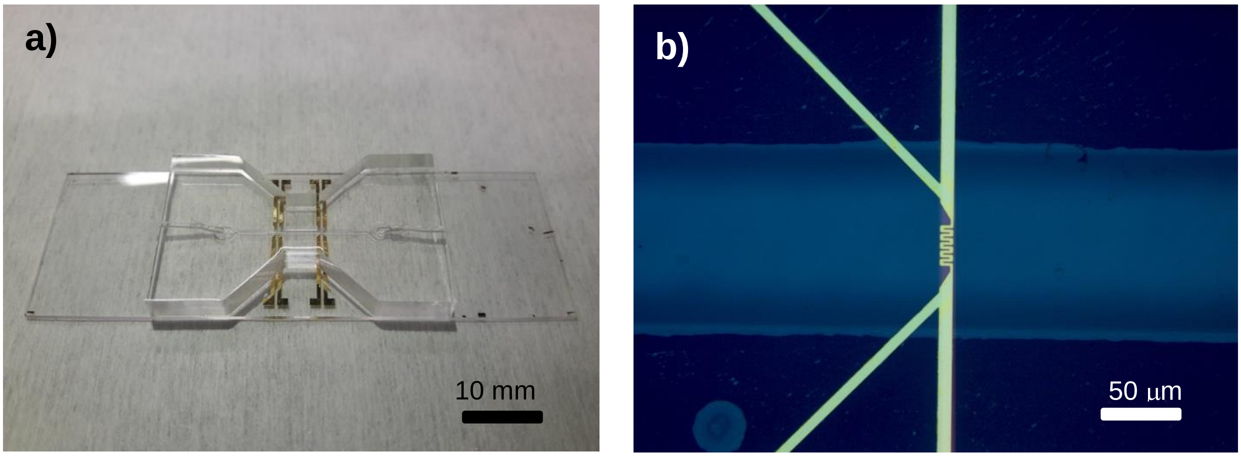

Figure 1: a) The PDMS chip bonded onto a microscope slide with electrodes patterned on the surface. b) The central resistance thermometer inside the microchannel. The thermometer was patterned as a serpentine to increase the resistance.

An electrical frequency sweep between 1 Hz- 1000 Hz was used to measure the thermal transfer function of the fluid in the channel. The thermal transfer function of water was obtained by a frequency sweep. The magnitude of this transfer function is effected on by the fluid flow via thermal energy transfer away from the resistance thermometer by the physical transportation of fluid, and therefore thermal energy, through the channel. Fluid flow was generated by a height difference between an open reservoir and the outlet of the chip. The signal was measured using a lock-in amplifier (Zurich instruments, MFLI). The results, plotted as a function of thermal wavelength and volume flow rate, can be seen in Fig 2 (a) and Fig 2 (a), respectively.

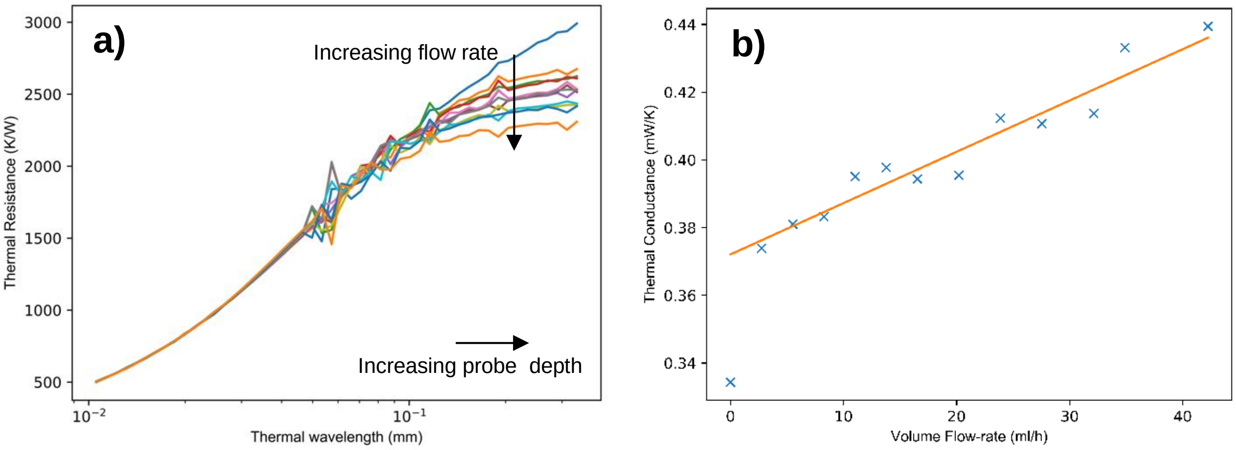

Figure 2: a) A frequency sweep (probing depth sweep) of water in the microfluidic channel. b) The thermal resistance measured at 1 Hz (electrical) vs the volume flow rate.

Measured data shows a linear fit in the fluid flow regime, however, a large difference between static fluid flow and the flow rate used was observed. The thermal wavelength is calculated using the textbook value of the thermal diffusivity of water (D = 0.014 cm^2/s). The thermal wavelength, $\lambda_{thermal}$, can then be calculated by

$$\lambda_{thermal} = \sqrt{\frac{D}{2\omega_{electrical}}} \tag{1}$$

where D is the thermal diffusivity of the water, and $\omega_{electrical}$ is the electrical radial frequency. The thermal penetration has been estimated to be between 2-5 wavelengths [4]. We expect that this control of thermal penetration depth can be used to measure flow profiles present in microfluidic channels if the optimal thermal wavelength can be found.

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