Electronic Supplementary Material (ESI) for Lab on a Chip.

Lab on a Chip
Supplementary Information

Title: Microwave temperature measurement in microfluidic devices

Authors: David Y. Wong[a]*, Gurkan Yesiloz*[a]*, Muhammed S. Boybay*[a, b]*, and Carolyn L. Ren*[a*]

a Department of Mechanical and Mechatronics Engineering, University of Waterloo,
200 University Avenue West, Waterloo, Ontario, N2L 3G1, Canada.

b Department of Computer Engineering, Antalya International University, Universite
Caddesi No:2, 07190 Antalya, Turkey.

S1. Hotplate correction

There is a need to account for the temperature difference between hotplate surface, which is accurately measured to ±0.05℃, and the working fluid. A thermal couple is inserted into a dummy chip with PDMS thickness equals to that of the actual test chip, in order to measure the channel temperature while being oriented in the inverted hotplate setup, as shown in Figure **1**. The resulted correction function is plotted in Figure **2**, and is subtracted from the hotplate surface temperature during experiment, in order to obtain the fluid temperature.

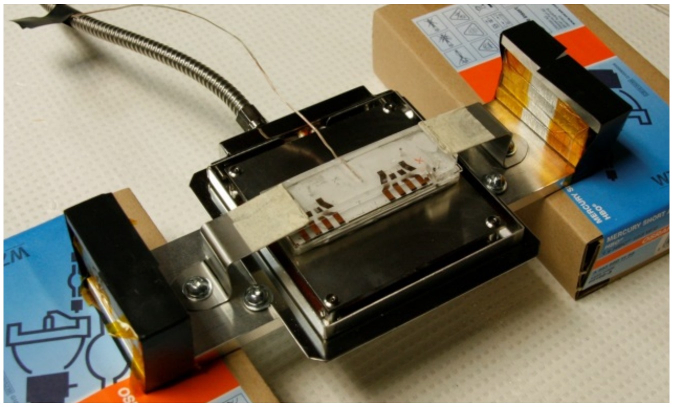


Figure 1. Inverted hotplate setup, currently flipped over for taking picture.

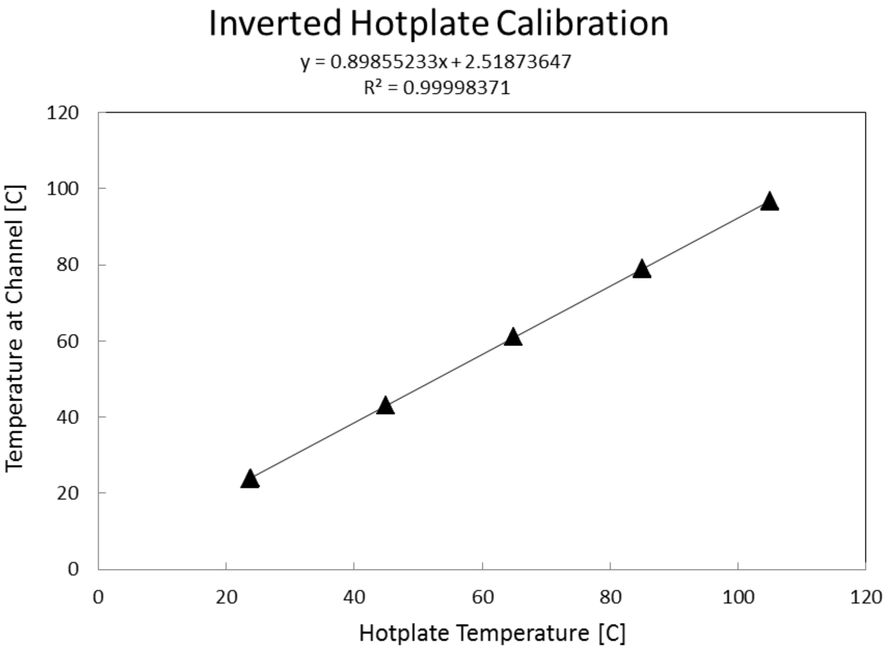
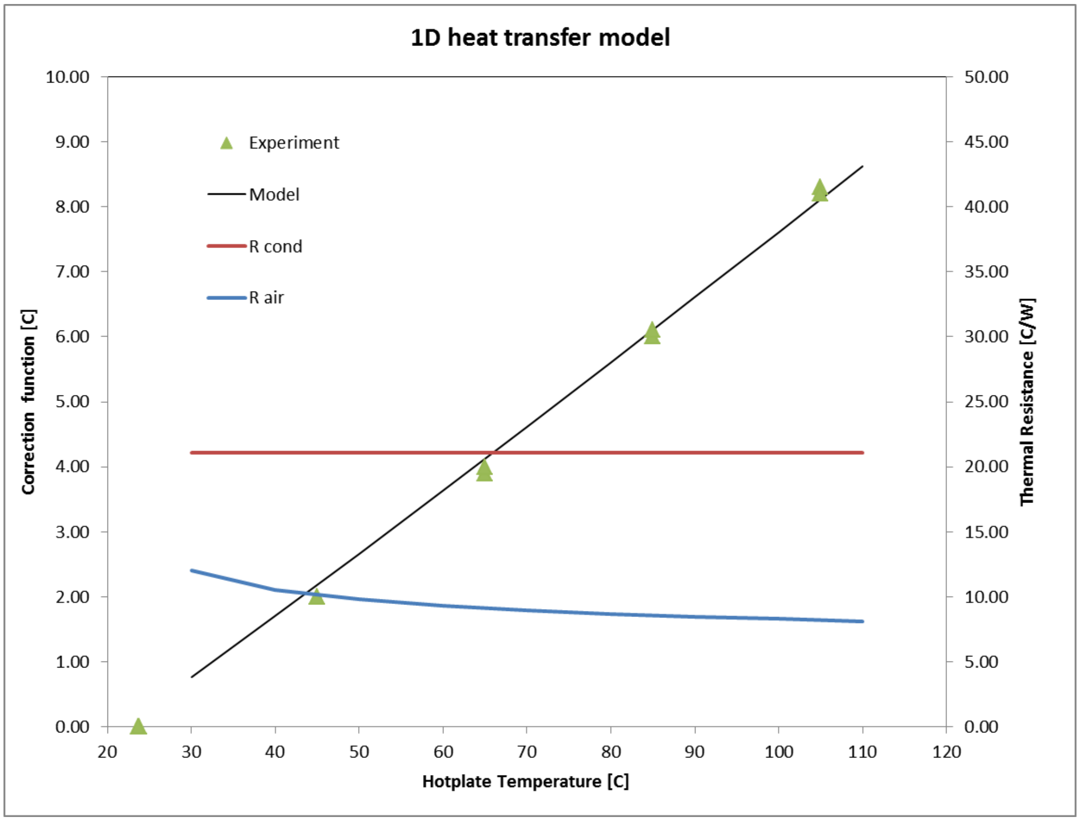


Figure 2. Correction function

S2. Error due to ambient temperature fluctuation

The correction function accounts for heat flow from hotplate into the surrounding atmosphere, and is therefore dependent on ambient temperature. To quantify such dependence, a 1D heat transfer model is created. The model is first validated to predict the same temperature difference as measured. Then, ambient temperature is perturbed by ± 1.5℃ to represent room temperature change observed in the laboratory. Finally, the correction function error induced by such perturbation is calculated to be < 0.1℃, as listed in Table 1 in the main article.



S3. Fluorescence Thermometry and RTD

Attempts were made to measure working fluid temperature directly. Figure **3** shows the intensity vs. temperature calibration obtained for a fluorescein and Tris-HCL solution. Fluorescence properties of fluorescein are pH dependent, while pH properties of Tris-HCL are temperature dependent, allowing temperature to be measured from its fluorescing intensities. However, local concentration difference, lamp intensity fluctuation, and CCD camera noise resulted in error in the range of ±3℃, which is higher than what the microwave sensor can achieve, and therefore is not suitable for calibrating the microwave sensor. In contrast, the hotplate correction method is much more accurate.

Resistance Temperature Detector was also considered for use in calibrating the microwave sensor in the single-phase experiment, Figure **4**, but fabricating both the RTD and microwave sensor on the same chip has proved to be problematic.

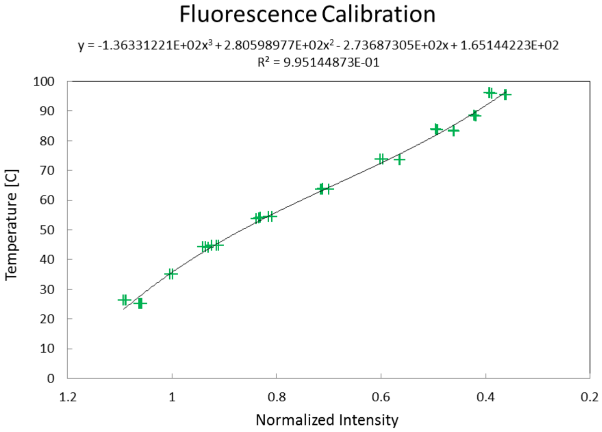


Figure 3. Fluorescence Thermometry using 100uM fluorescein and 10mM Tris-HCL buffer adjusted to pH 7.1 at 22 degC

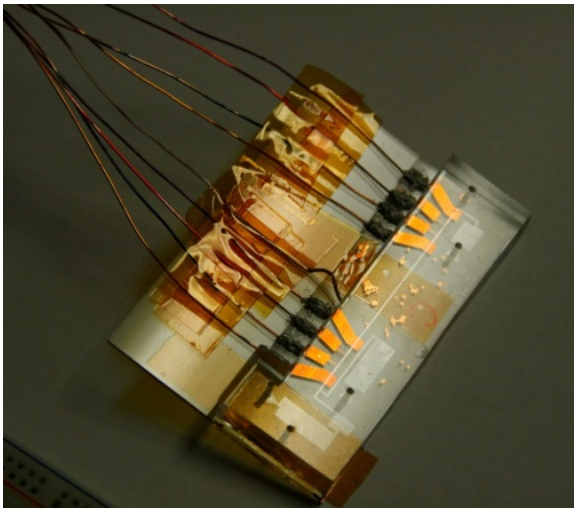


Figure 4. RTD sensor

S4. Raw data, Day-to-day repeatability

To investigate the repeatability of the microwave sensor, single-phase frequency sweep tests were performed on three separate days. Figure **5**, Figure **6**, Figure **7** shows raw data collected from those tests. Each step in the resonance frequency corresponds to a temperature set point, while each data point corresponds to a spectral S_{11} measurement, as described in Figure 2 in the main article. Data from all three days are used to produce the temperature calibration as shown in Figure 3 in the main article.

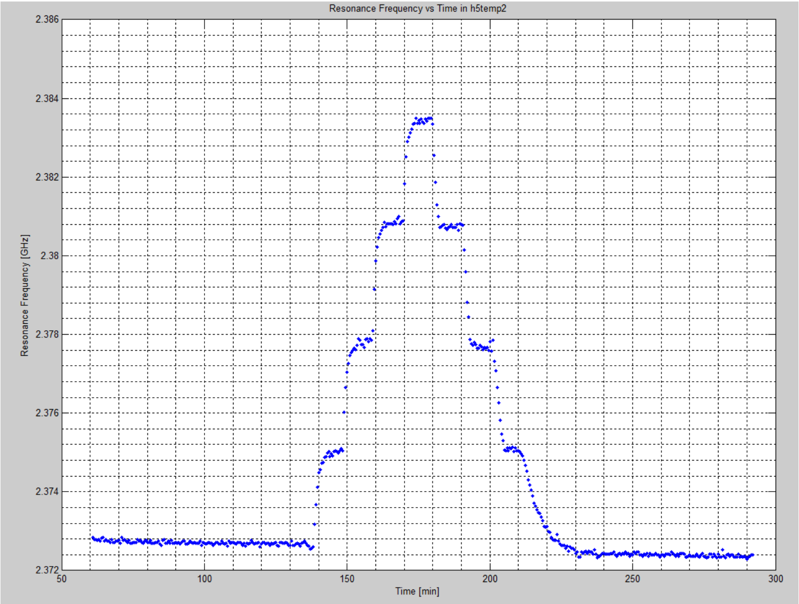


Figure 5. Resonance frequencies vs. time (Day One)

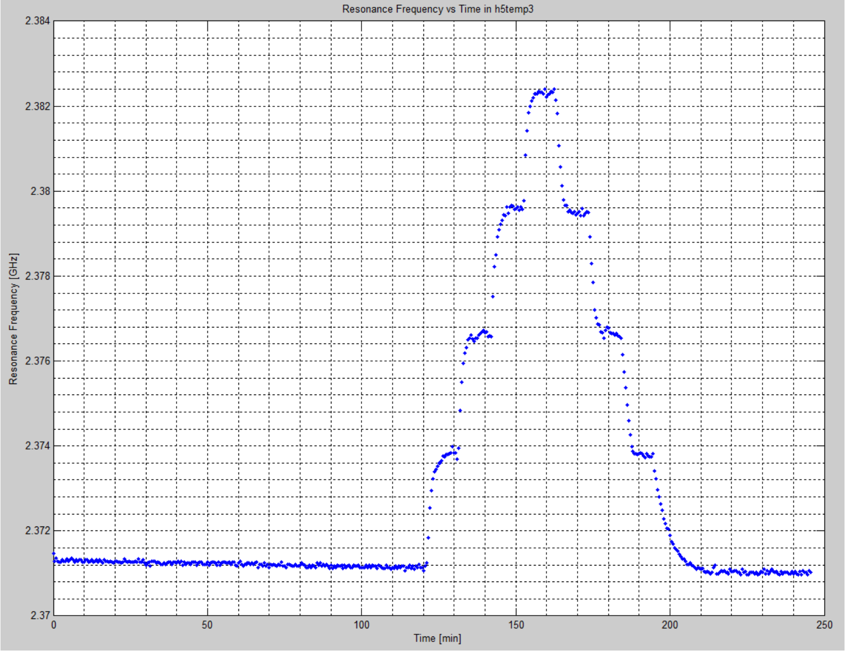


Figure 6. Resonance frequencies vs. time (Day Two)

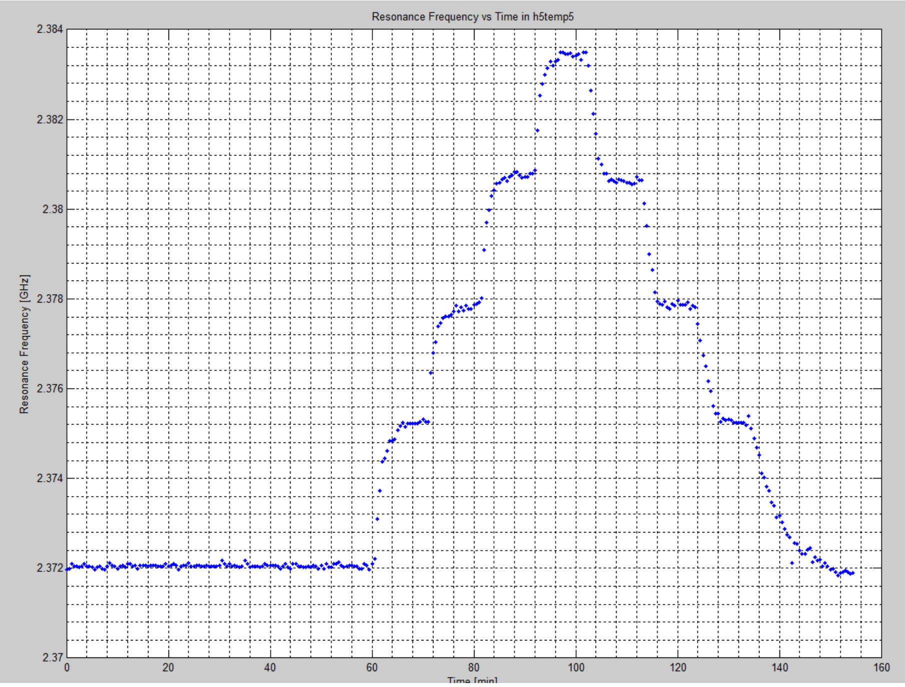


Figure 7. Resonance frequencies vs. time (Day three)

S5. Sensor Drift

It was observed that the resonance frequency would drift even in the absence of temperature change. The drift is very small, and increases with temperature, as shown in Figure **8**. Since temperature is calculated from frequency shift $(F - F_0)$ instead of absolute value of the resonance frequency, the sensor drift has no effect on the calibrations. Continuous water absorption into the PDMS chip was theorized to be the cause of sensor drift. By soaking the test chip in water prior to experiment, the drift can be greatly reduced, but not eliminated. Error incurred by the drift is calculated to be $0.25^{\circ}\mathrm{C}/hr$, as listed in Table 1 in the main article. In addition, sensor drift has no effect when measuring droplet temperature, as the hydrophobic channel walls and non-aqueous continuous phase prevents water from touching the PDMS.

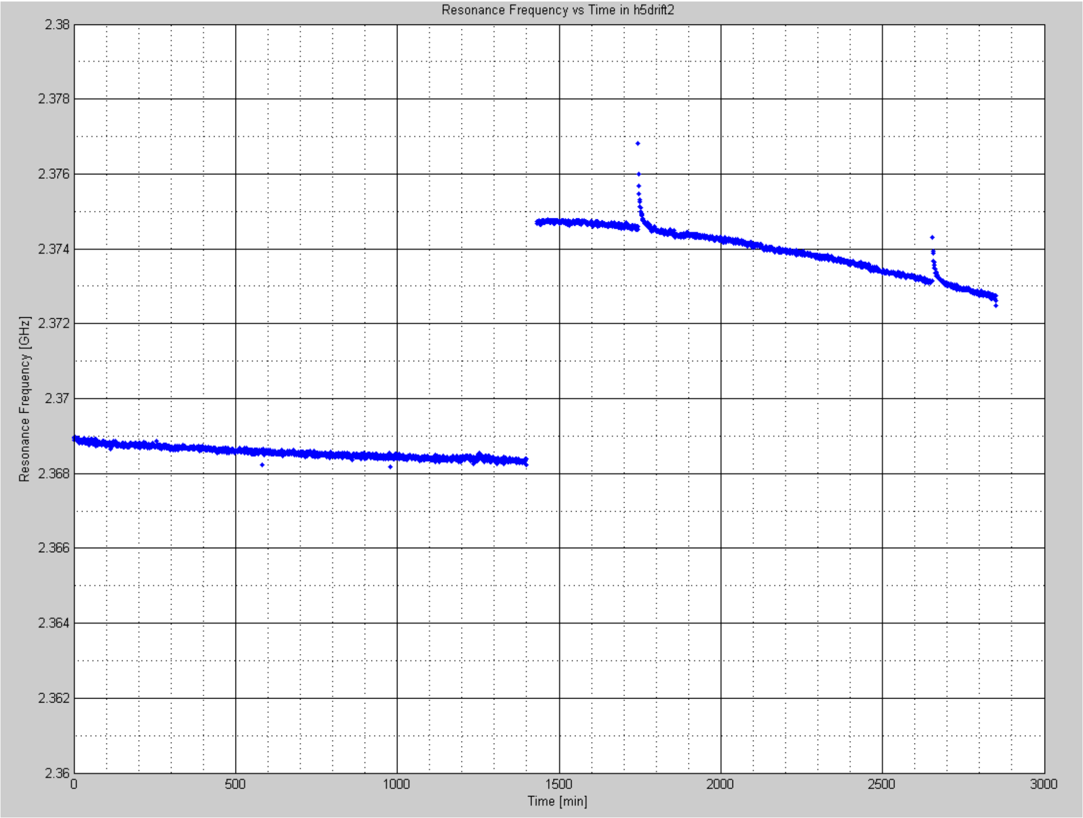


Figure 8. Resonance frequency drift over two days, first at 25degC, then at 50degC