THREE-DIMENSIONAL IN SITU TEMPERATURE MEASUREMENT IN MICROFLUIDIC SYSTEM USING BROWNIAN MOTION OF NANOPARTICLES

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ABSTRACT

We report an *in situ* method for temperature measurement in microfluidic systems using Brownian diffussion of nanoparticles. This method is superior in its reproducibility and reduced systematic errors as measuring Brownian diffusivity does not rely on fluorescence intensity or lifetime of fluorophores. Three-dimensional temperature mapping was achieved using a simple videomicroscopy setup in combination with software analysis that enables selective tracking of nanoparticles. In addition, we successfully demonstrated the capability of this method as an *in situ* noninvasive temperature measurement tool for biological samples.

KEYWORDS: *in situ,* temperature, Brownian, nanoparticle

INTRODUCTION

Miniaturization and integration of functional components on-chip offer great advantages, including fine manipulation of samples and precise control of microenvironment. For many applications, the ability to measure and control the temperature inside microfluidic devices during their operation is critical, as temperature affects biological processes and temperature variations could perturb such processes. For instance, rate of embryonic development is a strong function of temperature [1]. In addition, temperature variation can be a side-effect of some microfluidic techniques, *e.g.* dielectrophoretic cell handling where Joule heating leading to hyperthermic cell damage [2]. Thus, reliable methods for on-chip temperature measurements are required to design and operate microsystems effectively. Many spectroscopic methods for temperature measurement in microfluidic devices have been developed, taking advantage of temperature-dependent properties of chemicals. Rhodamine-B intensity measurement has been broadly used because of the relative simplicity [3], although intensity can be affected by environmental factors. Ratiometric fluorescence techniques, including fluorescence lifetime imaging, complement intensity measurement techniques, particularly when coupled with multi-photon optical sectioning. However, there is still a need for simple, inexpensive, noninvasive technique for biological samples without potential toxicity effects from dyes. Here, we present for the first time 3D temperature measurements in microfluidic systems using the Brownian motion of nanoparticles in the presence of live biological samples.

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RESULTS AND DISCUSSION

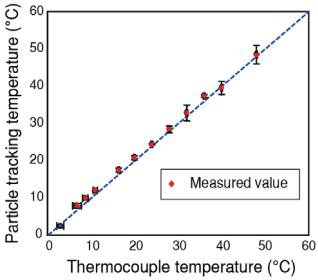

Figure 1. Comparison of temperature data from particle tracking with simultaneously measured thermocouple temperature.

Our technique takes advantage of the well-defined thermal correlation of Brownian motion, which can be described by the Stokes-Einstein equation

$$D = d\kappa T / 6\pi\mu(T)r \qquad (1)$$

(where D is the Brownian diffusivity, d dimension factor, κ the Boltzmann constant, T the absolute temperature of the fluid, $\mu(T)$ the dynamic viscosity of the fluid, and r the particle's radius) [4]. Because the kinetic energy of small particles and fluid viscosity are both functions of temperature, by measuring the Brownian diffusivity of suspended particles of known sizes, the surrounding liquid temperature can be determined. We measured the mean-squared displacement (MSD) of 500-nm fluorescently labelled polystyrene particles (Invitrogen) for temperatures ranging from 1°C to 50°C. The temperature calculated from particle mobility shows excellent agreement with the temperature measured simultaneously by a thermocouple inserted into the sample chamber (Fig. 1). Since particle tracking of nanoparticles does not rely on absolute values of fluorescence intensity, MSD measurements are not affected by variations in the power of the incident light, spatial variation of excitation, concentration artefacts, and photobleaching. Therefore, this method is superior in its reproducibility and insensitive to many systematic errors.

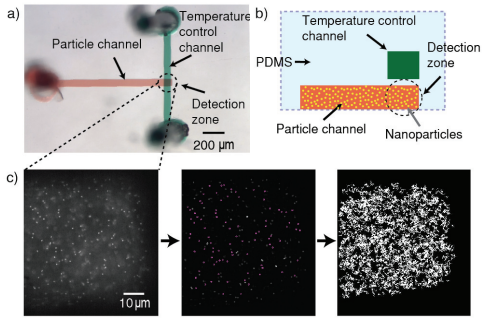

Figure 2. a) Optical micrograph of a temperature measurement device: particle channel (red), temperature control channel (green). b) Cross-sectional view of the device. c) Particle tracking algorithm: raw image, processed images showing the identified particles within the focal plane, trajectories of tracked particles for a duration of 49.5 seconds (1500 frames).

To demonstrate the capability of this method as a 3-D temperature mapping tool, we obtained a Z-stack of images of nanoparticles in a temperature controlled microfluidic channel (Fig. 2a, b). Nanoparticles outside the focal plane can easily be discarded by the image analysis algorithm (Fig. 2c), thereby achieving excellent optical sectioning without an expensive multiple-photon scanning setup. In Fig. 3a, we show the results of these spatially resolved temperature measurements with a resolution of ~ 4 µm in the out-of plane direction. The mapped 3D temperature

profile in the channel was in good agreement with numerical simulations in COMSOL.

Finally, we used this method for temperature measurement in the presence of *C. elegans* (a nematode). *C. elegans* and nanoparticles were suspended in a buffer solution together and introduced to the temperature-controlled sample channel (Fig. 4a). Images of nanoparticles and worm neurons expressing green fluorescence protein were obtained simultaneously (Fig. 4b) and the trajectory of particles were analyzed (Fig. 4c) thus allowing temperature measurement.

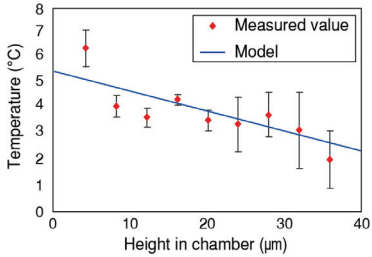

Figure 3. 3D temperature mapping of the detection chamber: Distribution of temperature as a function of location (height) in chamber, showing good agreement with the numerical model.

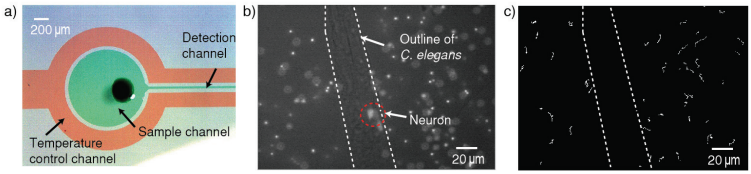

Figure 4. a) Optical micrograph of a heat-exchange microdevice showing particle and sample channel (green), temperature control channel (red). b) Raw image showing nanoparticles and C. elegans in the detection channel c) Processed image showing trajectory of particles.

CONCLUSIONS

We have developed an inexpensive and versatile method for three-dimensional *in situ* temperature measurement in microfluidic system using the Brownian motion of nanoparticles. This method will be applicable for many biological applications requiring 3D temperature mapping in the presence of live biological samples.

REFERENCES

[1] Lucchetta, E. M., J. H. Lee, et al. Dynamics of Drosophila embryonic patterning network perturbed in space and time using microfluidics. Nature, 434, 1134 (2005)

[2] Seger, U., M. Panayiotou, et al. Temperature measurements in microfluidic systems: Heat dissipation of negative dielectrophoresis barriers. Electrophoresis, 26, 2239 (2005).

[3] Ross, D., M.Gaitan, et al. Temperature measurement in microfluidic systems using a temperature-dependent fluorescent dye. Analytical Chemistry, 73, 4117 (2001).

[4] Hohreiter, V., S.T. Wereley, et al. Cross-correlation analysis for temperature measurement. Measurement Science & Technology, 13, 1072 (2002).