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Temperature Gradient Generation and Control

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Synonyms

Temperature control

Definition

In today's microfluidic technology, electrokinetic transport is used to perform many chemical and biological analyses in Lab-on-Chip devices, such as clinical diagnoses, DNA scanning, cell manipulation, cell patterning, and molecular detection. Due to the presence of an electrical potential gradient in electrokinetic transport, Joule heating is a ubiquitous phenomenon which may lead to an increase in the overall temperature and to temperature gradients in the transverse and longitudinal directions inside the channels. These generated temperature gradients and their control are crucial for the performance of the devices.

Overview

Simply, a temperature gradient can be generated by means of two temperature reservoirs at different temperatures at the inlet and the exit of a microchannel. However, in electrokinetic transport, Joule heating results in heat generation which can also result in temperature gradient generation in the longitudinal and transverse directions inside the microchannels due to

- the effect of the temperature reservoirs at the inlet and the exit of the channel (thermal end effects);
- the different thermal boundary conditions at the channel wall (thermostatted and thermostatted region along the channel wall);
- the cross-sectional area change along the channel; and
- the flow of two parallel streams having different molar concentrations.

These temperature gradients also affect the electrical field, flow field, and concentration field via temperature-dependent electrical conductivity, viscosity, and diffusivity. Large temperature gradients inside channels may cause band broadening and dispersion that leads to inefficient and low-quality separation for separation processes [1]. Effective dissipation of the heat generated by Joule heating is critical for reproducible and efficient separations in electrokinetically driven separation systems. These temperature gradients can also be useful for some applications such as isoelectric focusing (IEF) [2–4] and temperature gradient focusing (TGF) [5, 6]. Therefore, generation and control of the temperature generation inside the Lab-on-Chip are very important to enhance and optimize the performance of the device.

Xuan and Li [7] developed an analytical model to study Joule heating effects on electrokinetic transportation in capillary electrophoresis with thermal end effects by considering the temperature-dependent fluid viscosity and electrical conductivity. They derived closed formulas for steady-state temperature field, applied electrical potential field, pressure field, velocity field, and transient concentration field which provide fundamental understanding of effects of the temperature gradients on transport of heat, electricity, momentum, and mass species in capillary electrophoresis. They showed that Joule heating enhances the transport of samples which can provide a reduction in the analysis time for capillary electrophoretic separations. Despite the time reduction benefit, they also showed that Joule heating and thermal end effects increase the sample dispersion which leads to a lower separation efficiency. Xuan and coworkers [8, 9] also studied the same effects with temperature-dependent fluid properties, both numerically [8] and experimentally [9]. They used a caged-fluorescent dye-based visualization technique to measure the EOF velocity profile, and a fluorescence-based thermometry technique to measure the temperature profile inside the channel. They observed concave and convex velocity profiles due to distortion of the plug-like profile because of the induced pressure gradients resulting from the axial temperature gradient.

Non-uniform cooling across the length of the channels can be experienced by some thermostatted portion of the channel either by

1. forced convection of the channel or
2. cooling of the channel by optical infrastructure in the detection region.

This non-uniform dissipation also results in temperature gradients inside the channel. Xuan and Li [10] studied case (1.) and Sinton et al. [11] studied case (2.) for a microcapillary.

Temperature gradients along the channel can also be used to focus different species inside the microchannel. IEF and TGF are the two methods that use this concept for focusing. Temperature generation along the channel is achieved both by using two reservoirs at different temperatures [4, 5] and by using Joule heating by means of the variable cross-sectional area along the channel [2, 3, 5, 6]. Using two parallel flow streams with different molar concentrations also results in non-uniform Joule heating and hence a temperature gradient in the transverse direction as well as the longitudinal direction. Cetin and Li [12] studied the effect of these two streams on the temperature field inside a microchannel for the potential use of this gradient in cell manipulation.

Cross References

► Temperature Control in Microfluidic Systems
► Methods for Temperature Measurements

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Temperature Measurement, Methods

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Synonyms

Thermometry

Definition

Thermometry is the determination of a medium's temperature as inferred from properties of a probe whose characteristics are highly dependent on temperature.

Overview

There exists a growing demand for the development of advanced diagnostics for high-precision temperature measurements at the microscale. This demand is driven by the ever-increasing use of complex microfluidic devices such as micro-total analysis systems (μ-TAS) and μ-heat exchangers. Lab-on-a-Chip devices, which integrate multiple complex laboratory functions onto a single chip-sized substrate, often require precise temperature control to maximize the productivity of chemical operations like mixing, reactions and separations. Such control becomes especially critical when electrokinetic pumping is used for driving flow through these devices, as the current flowing through the buffer solution can result in significant internal heat generation, a phenomenon known as Joule heating. Since most microfluidic-based MEMS devices utilize very high heat and mass transfer rates, a thorough understanding of their thermal transport characteristics is paramount for optimizing their design for increased performance and reliability.

Several methods exist for measurement of fluid and/or surface temperature at both the macro- and micro-scale; however, the appropriate choice of methodology is tightly coupled to the specific application under consideration. Further, the capabilities of many techniques that are commonly implemented at the macroscale are greatly challenged in microscale applications where one wishes to