Microfluidic cell for studying thermodiffusion in colloidal solutions

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Thermodiffusion (thermophoresis or Soert effect) is the phenomenon of the mass transport in a multicomponent system induced by a temperature gradient [1]. Mathematically the effect can be described by an equation similar to the Fick's law where an additional term containing the temperature gradient appears. For a dilute solution the flux $\vec{J}$ in the temperature gradient $\vec{\nabla}T$ is given by:

$$\vec{j} = -D\vec{\nabla}c - cD_T\vec{\nabla}T \quad (1)$$

where D is the diffusion coefficient, D_T – thermodifusion coefficient, c – concentration.

The effect has been used for characterization and separation of macromolecules and colloids (e.g TFFF - thermal field flow fractionation [2]), for separation of substances in thermo-gravitational column as well as for biomedical applications [3] and in semiconductor industry [4].

Currently used optical methods for investigation of the Soret effect such as thermal diffusion forced Rayleigh scattering (TDFRS) [5] or beam deflection method are often not suitable for the investigation of large colloids (with the radius bigger than 100nm) due to strong scattering or sedimentation. Additionally, both methods rely on the refractive index contrast, which typically limits the system to binary mixtures. Also, investigation of the effect requires relatively high temperature gradients. Therefore we developed a microfluidic cell which allows to observe thermal diffusion in the solution of colloids using a microscope. The device could be also applied for investigation of thermophoretic phenomena in biological systems such as cells and supported lipid bilayers.

The developed cell consist of three channels (Fig. 1 – A and B): two relatively big ones for providing high flow rate of hot and cold liquid and a small channel in between them which contains the sample to study. The cell is produced either from PDMS by molding on lithographically made Si/SU 8 master or by micromilling the Plexiglas block with a CNC machine. The central channel is made very flat (hight=30 um, width=100 um) to prevent convection.

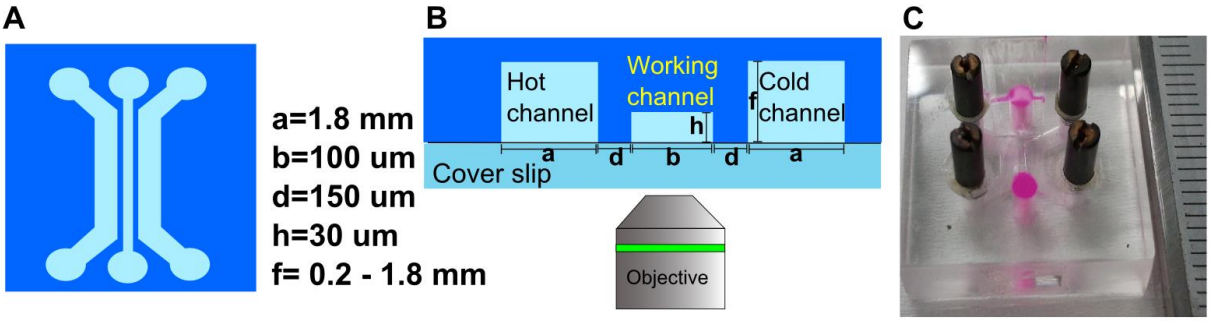

Figure 1. Schematic representation of the microfluidic cell (not in scale): top view and cross section (A and B respectively). Photo of the cell made of Plexiglas (C).

To characterize the temperature distribution in our cell we used fluorescence life-time microscopy (FLIM) [6] with Rhodamine B as a temperature sensitive dye. We applied hot water of 47°C and cold water of 22°C to the side channels of the cell. The measured temperature distribution in the central channel is shown in Fig. 2. The temperature difference across the central channel appeared to be around 2°C which is much smaller than the temperature difference between the hot and cold channel indicating high temperature drop in the walls of the cell. Nevertheless, the temperature gradient in the central channel appeared to be equal to $2 \cdot 10^4$K/m which is an order of magnitude higher the in e.g TDFRS method [5].

The cell was applied to investigate thermodiffusion of latex microbeads (sulfate modified, 0.5um) in water. The resulting distribution in equilibrium (Fig. 3) shows good agreement with the theoretical curve:

$$c = c_0 \exp(S_T \Delta T \frac{x}{L}) \qquad (2)$$

which follows from the Eq. 1 in the assumption of zero flux. In the formula $S_T = D_T/D$ is the Soret coefficient, L in the width of the channel, c_0 is the bulk concentration and x is the distance across the channel. From this fitted function one can extract the term $S_T \Delta T / L$ from which, knowing the width of the channel and the temperature difference one can calculate the Soret coefficient S_T.

The results obtained show the applicability of the developed microfluidic cell for studying thermophoresis of large colloids. At the same time small colloids (with the size not resoluble with the microscope) can be studied also if one takes the fluorescence intensity as a measure of the particle concentration. The microfluidic cell presented here, in our opinion, can be easily adapted for studying thermal diffusion in such interesting biologycal systems the supported lipid bilayer (which can be built on the bottom of the

central cannel) or in the biological cells cultivated in the central channel of the device.

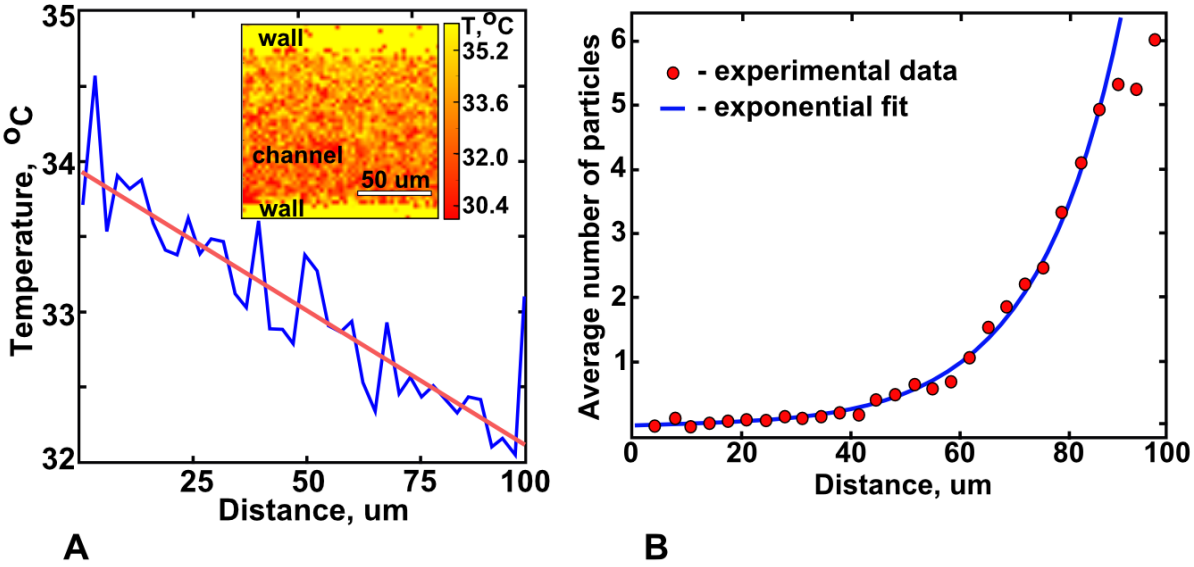

Figure 2. The average temperature profile across the central channel of the cell calculated on the basis of the lifetime of Rhodamine B measured with FILM (A). The inset in (A) shows temperature distribution in the channel. The distribution of the microbeads in the central channel of the cell (B).

References

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