Model of a Microfluidic Thermal Cycler Activated By Means of Electro-Osmotic Micro-Pumps

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Abstract

Introduction: A microfluidic thermal cycler activated by electro-osmotic micro-pumps has been modeled. The main target of such device is the Polymerase Chain Reaction (PCR), a well known procedure in molecular biology able to amplify and simultaneously quantify a targeted DNA molecule. Sample has to be thermal cycled along three main temperature steps (368°K, 328°K, 345°K), enabling the denaturation of the strands, the annealing of the "primer" and the elongation of the new strand. Electro-osmosis is an electrokinetic phenomenon: when a polar fluid and a solid surface are brought into contact, the superficial charge, characterized by the zeta potential ζ [mV] induces the formation of a double-charged layer. The presence of an external electric field forces this layer to move, dragging the fluid in the channel and resulting in a flat velocity profile. Electro-osmotic pumps are then advantageous in microfluidic because of their compactness and the absence of moving parts [1,2]. Use of COMSOL Multiphysics: The parallel channel configuration has been selected for the design of electro-osmotic pumps. A set of pumps has been placed around a ring channel, connected to an external reservoir. The sample in the shape of a drop in buffer, is brought along the ring channel, flowing through three different temperatures. 3D model of different pumps configurations have been set (Figure 2a). An electro-osmotic velocity VEOF has been imposed to each wall, following the Helmotz-Smoluchowski equation: $VEOF=\varepsilon EEL\zeta/\mu$ with EEL the electric field generated by the potential V0 and V1 =10V, ε the permittivity, μ the fluid viscosity. ζ and μ are considered as functions of the temperature. The downstream pressure P1 is a function of the flow-rate and of the hydraulic resistance faced by the pump if connected to the ring. The flow-rates QEFF delivered by each configuration have been evaluated (Figure 3). QEFF is the effective flow-rate, defined as the vector sum of the electro-osmotic flow rates QEOF and the back-flow-rate QBFLOW induced by the downstream hydraulic resistance. The QEOF have been considered to define the boundary inlet in the model of the ring (Figure 2b). The ring with the pumping boundaries is a 2D model with the shallow channel approximation that considers the effect of the thickness of the channel by a proper volume forces term. A proper sequence of activation for couples of pumps has then been implemented in a time dependent simulation. Results: A number of configurations have been evaluated to recommend the pumping device to be integrated around the microfluidic ring. Number of channels, aspect ratio and different conditions of temperature have been considered to evaluate the effect of the change in zeta potential ζ and the efficiency of device. The six-channel-configuration has been selected and implemented into the 2D model: it shew the

highest QEFF = 1,8 µL/min and a time to cycle of ~50 s. Conclusion: Results of the simulations show a consistent performance of the micro-thermo-cycler in term of continuity in time and directionality. Priming volumes and times to cycle are compatible to the usual parameters characterizing a PCR protocol.

Reference

1. Wang, X., et al., Electroosmotic pumps and their applications in microfluidic systems. Microfluidics and Nanofluidics, 2009. 6(2): p. 145-162.
2. Brask, A., G. Goranović, and H. Bruus, Theoretical analysis of the low-voltage cascade electro-osmotic pump. Sensors and Actuators, B: Chemical, 2003. 92(1-2): p. 127-132.

Figures used in the abstract

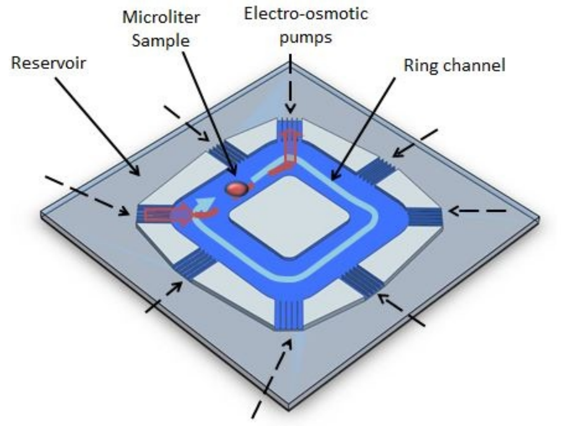

Figure 1: Sketch of the complete device: red arrows are the activated pump in a specific step.

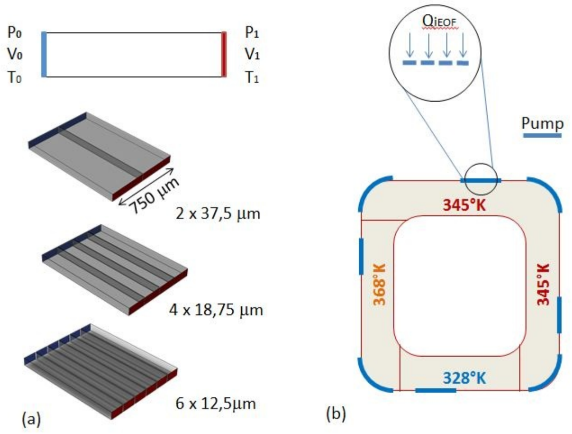

Figure 2: (a) Boundaries condition for each channel; multiple channel configurations (b) 2D model of the device: inidcated the position of the pumps an the temperatures zones. Pumps are activated in sequence, couple by couple

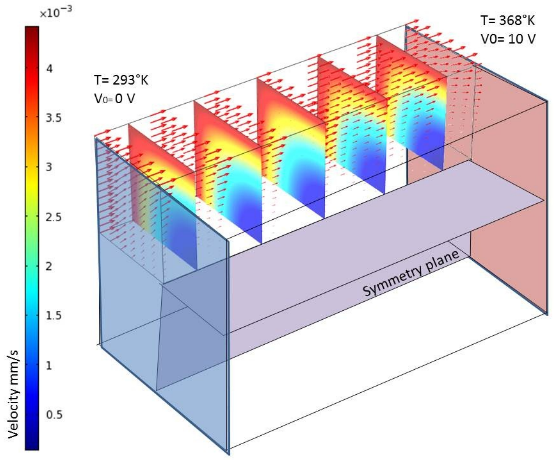

Figure 3: Velocity profile in a microchannel with a strong difference in temperature between inlet and outlet