Design of Temperature Sensing and Heating for Disposable Lab-on-Chip Microsystems

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temperature controller, lab-on-chip, fluid analysis, gas sensors

Abstract

In this document a new approach for sensing and controlling temperature in lab-on-chip systems is presented. It is utilized in disposable flow-through microsystem with optical detection for measurement of creatinine concentration in urine and postdialysate fluid and hydrogen sensors. Heating system was realized as a ceramic based thick-film resistor with controlled temperature behaviour, designed specifically for ensuring uniform power distribution through the system.

Introduction

The rapid development of lab-on-chip microsystems for chemical or biochemical analysis have taken place for last years. Many of analytical reactions should be carried out at defined temperature so they need temperature stabilization. The microsystems for biochemical analysis of human fluids should be disinfected thoroughly or used only once. Some gas sensors are contaminated just after single application. The disposable parts of microsystem need to be very simple, cheap and environment friendly because of the large number of these components applied and disposed, for example microsystems for dialysis monitoring. The aim of this work was to elaborate very simple, cheap and environment friendly system for temperature stabilization of disposable postdialysate fluids analysis microsystem and for disposable parts of hydrogen detectors based on palladium doped carbon films.

Temperature measurement method for lab-on-chip application

In typical temperature control applications two separate elements are used – heater and temperature sensor. The disadvantage of such approach in microsystem technology is necessity of applying two different layer deposition processes with use of different materials and space requirements for that two elements and possibly reduction of power density of heating element. In presented work, different approaches were utilized. The main concept of proposed temperature controller it to use single layer (conductor or resistor) that can act as a heating element and as a temperature sensor simultaneously. Such approach needs incorporating heater materials with high and predictable resistance temperature coefficient.

The schematic diagram of this concept is given in Fig.1. The heater is driven by a controlled current source, with known current value. The voltometer senses voltage drop across heating element (Kelvin measurement technique). Current and voltage values are calculated into resistance. The temperature value can be obtained from R=f(T) analytical or tabular function. The information about the temperature is utilized for current source regulation.

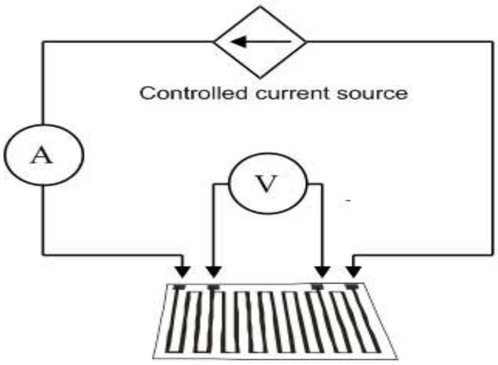

Fig. 1. Schematic diagram of a temperature controller.

Controller application

The proposed current regulator was used in lab-on-chip system. The substrate of heating element was a standard Al_2O_3 96% ceramic plate, 0.635 mm thick. On the top side of the substrate the polymer (PDMS) layer was attached. Between the polymer and the substrate the microchannels ware fabricated. On the bottom side of a substrate the heating and sensing element was situated. There was no possibility of attaching temperature sensor on the top side of a ceramic plate, because this side was occupied by a microfluidic channel, therefore the temperature had to be measured through ceramic plate. Schematic view of the designed system construction is shown at Fig.2. This system was used as flow-through microsystem with optical detection for measurement of creatinine concentration in urine and postdialysate fluid. The temperature stability of a fluid in microchanels is essential for proper function in such application. In this particular system the specific temperature 37^{o}C with the maximum ±0.5^{o}C deviation should be kept. Since heater construction is crucial to ensure proper thermal parameters its design was essential for building described system.

The first design of a heater/sensor which is presented in Fig.3A. contained screen printed lead-free PdAg thick-film (P-202 Pbf) by ITME deposited on alumina substrate. The meander design was applied to obtain the greatest total length of the conducting patch possible. The paths with 0.5 mm spacings and 2.75 mm width were applied resulting in the total number of

200 squares. The paths on the edges were thinned down to 2.25 mm to obtain higher heating power on the edges of the plate to compensate heat losses on uncovered ceramic areas.

The sheet resistivity of the layer was 20 mΩ/□. The PdAg compromises significantly lower cost than platinum with high resistivity to oxidation at room temperature range.

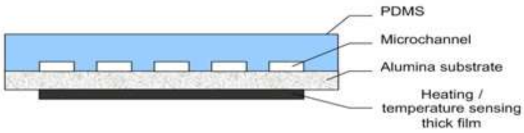

Fig. 2. Schematic cross-section of lab-on-chip.

Such a high sheet resistivity allowed to obtain suitable total path resistance 4 Ω from the only 200 squares. Four connection pads were placed on the edges of sample. The two outers for current supply and the two inners for voltage readout. The voltage was collected from the whole conductor on sample for sensing the average temperature of the plate. The sample was connected to the temperature regulator from Fig.1. The heating power was sufficient and the long term stability of resistance was very good. The main disadvantage was a low TCR (Temperature Coefficient of Resistance) at around 430 ppm/K. In consequences, the ability of sensing temperature was insufficient. With the use of this concept, the precise, low temperature drift electronic have to be used to meet requirements for the temperature stability.

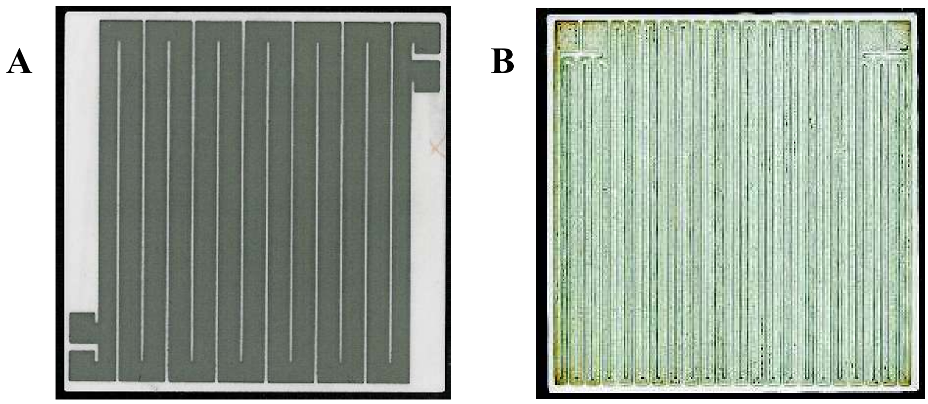

Fig. 3. View of the heater/sensor element A) first generation and B) second generation.

The second design of a heater/sensor which is presented in Fig.3B. incorporates screen printed lead-free Ag thick-film (P-120 Pbf) by ITME deposited on alumina substrate. The 0.5 mm line with and spacing were used. The sheet resistivity of the layer was 2 mΩ/□. The paths were redesigned to achieve 3500 squares. The 7 Ω resistance of the whole heater was achieved. That resistance value allowed to use lower current and higher efficiencies than the previous PdAg design. However the voltage on the whole sample exceeded measurement capabilities of applied voltmeter. Therefore the inner terminations were connected to the middle part of the conductor in order to collect voltage from the centre area of the sample only. The main advantage of this concept was a high and linear TCR at around 3800 ppm/K.

The temperature sensing abilities were improved nearly 10-times compared to the first design.

In the next step cost optimization was considered. The computer simulation was conducted to find the maximal spacing of heating lines that are sufficient for temperature uniformity across surface of heated plate on the side of microreactor. The width of a conductive path was assumed to be 0.5 mm. The 7 W heating power was calculated and assumed, that is necessary for heat-up whole microreactor from ambient temperature 15°C up to desired 37°C, and 3.6 W from 25°C ambient temperature accordingly. The results of the simulation, which are presented in Fig.4, lead to the conclusion that 5 mm is the maximal possible line spacing that provides temperature non uniformity below required 0.5°C for ambient temperature 15°C.

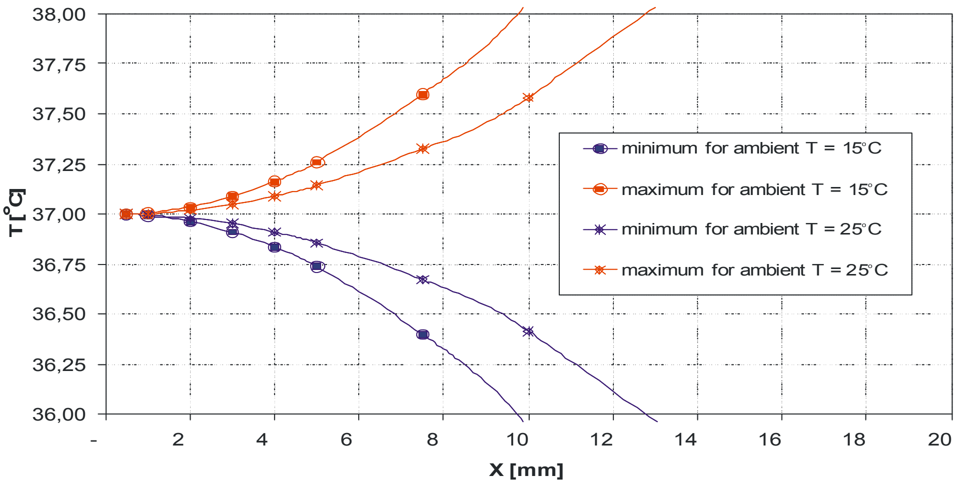

Fig. 4 Temperature deviations on microchannel side of the ceramic plate for different spacing X of heating paths.

Conclusions

The novel very simple, cheap and environment friendly system for temperature stabilization of disposable postdialysate fluids analysis microsystems was elaborated. The system consists of sophisticated control unit and cheap disposable conductior (resistor) that is applied as heater and temperature sensor. The system was constructed and tested. The temperature stability is better then +/-0.5˚C. Such stability is sufficient for postdialysate fluids analysis. The system can be applied for hydrogen detectors based on palladium doped carbon films.

References

[1] Ilona Grabowska, Michal Chudy, Artur Dybko, Zbigniew Brzozka, “Determination of creatinine in clinical samples based on flow-through microsystem”, Analytica Chimica Acta, 540 (2004), 181-185.

[2] M. Chudy, P. Prokaryn, W. Wróblewski, A. Dybko, Z. Brzózka,” Temperature controlled microfluidic PDMS reactor”, (TAS 2003, Squaw Valley, California, USA, 5–9 October, 2003,p. 171

[3] J. Cooper McDonald, George M. Whiteside, "Poly(dimethylsiloxane) as a Material for Fabricating Microfluidic Devices", Acc. Chem. Res., Vol. 35, 2002, pp 491–499