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Abstract

Microfluidic Flowmeter Using a Single Hot Wire †

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Abstract: The objective of this study is the design and fabrication of a microfluidic thermal flow sensor using polymethylmethacrylate (PMMA) as a substrate. This enables the simple fabrication process of the channel structure and the sensor itself using a laser engraver/cutter machine and a solvent-based bonding process. A thin platinum wire called a Wollaston wire is directly integrated into the fluidic chip and acts as the only sensor element. The combination of this sensor and customized measurement electronics enables a measurement range at flow velocities from 4 mm/s up to 400 mm/s (volume flow rate range from 10 µL/min up to 1 mL/min).

Keywords: microfluidic flowmeter; flow sensor; hot Wollaston wire; polymer-based sensor

1. Introduction

Flow sensors in microfluidic devices are needed to precisely control fluid flow and handle tiny fluid volumes [1]. The majority of these sensors are based on different methods of thermal anemometry because this is quite a simple yet reliable principle [2]. Our sensor consists of a single tiny wire integrated into a polymer-based microfluidic platform; therefore, a simple integration in many different devices is possible through applications of lab on a chip. In this paper, we show the fabrication procedure for a demonstrator device, the working principle, and the underlying theoretical model, as well as discussing the results.

2. Materials and Methods

2.1. Fabrication

A channel (dimensions: length 40 mm, width 2 mm, and height 10 µm) is laser engraved into both a 4 mm (for top plate) and 2 mm (for bottom plate) thick polymethylmethacrylate (PMMA) plate. The structure is cut using a laser engraving machine (Speedy 300 flexx, Trotec Laser GmbH, Marchtrenk, Austria). Threads for connection with Luer fittings are cut into the top plate. A 6 mm long Wollaston wire (PT00-WR-000105, GoodFellow Cambridge Limited, Huntingdon, UK) is used as a hot wire and placed into the channel. Copper wires are soldered to each side (see Figure 1a). Anisole is used as a solvent for the bonding process of both parts. By injection of nitric acid (10% mass concentration) into the channel, the silver layer of the Wollaston wire is etched away within 20 min. The resistance over temperature curve of the sensor is measured using a four-wire resistance meter (DMM7510, Keithley, Tektronix GmbH, Koeln, Germany) and a climate chamber (WKL 100, Weiss Technik GmbH, Reiskirchen, Germany). In Figure 1b, the fabricated flow sensor is shown.

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(**a**) (**b**) (**c**)

Figure 1. (**a**) Etched Wollaston wire in the channel soldered to copper wires at each end; (**b**) fabricated flow sensor; (**c**) circuit to switch between two temperature levels.

2.2. Methods

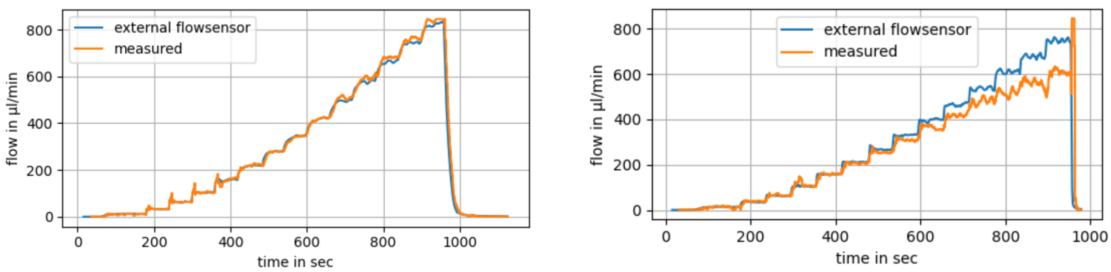
The temperature of the hot wire is periodically switched between two adjustable temperature levels using an adapted version of the circuit given in [3] (see Figure 1c), where the current and the voltage of the sensor are measured. Using the dynamic thermal energy balance equation [3], which is the linear fit of the resistance over temperature characteristics, the flow rate is obtained as

$$q = \left(\frac{U_{H,1} \cdot I_{H,1} - U_{H,2} \cdot I_{H,2}}{a \cdot \left(\frac{U_{H,1}}{I_{H,1}} - \frac{U_{H,2}}{I_{H,2}} \right)} \right)^{n} - b. \quad (1)$$

Here, a, b and n are constants, $U_{H,x}$ is the voltage, and $I_{H,x}$ the current of the hot wire at the temperature level x (equal to 1 or 2). The flow sensor is calibrated using an external flow sensor (SLI1000, Sensirion AG, Steafa, Switzerland).

2.3. Results

Figure 2 shows the flow rate measurements directly after calibration and two days later in comparison to the measurements with the external sensor. This and other measurements showed that the hot wire sensor deteriorates to a certain degree, supposedly due to material fatigue because of the flow-induced movement of the wire in the channel. However, the oxidation of the soldering joint and deposition of residues on the wire supposedly also play a role.



(**a**) (**b**)

Figure 2. Comparison of the measured flow rate with our hot wire sensor and the measured flow rate of an external sensor (**a**) directly after calibration and (**b**) two days after calibration.

3. Discussion

The results demonstrate the feasibility of this principle and technology. Because of the tiny size of the hot wire, an integration into many devices appears possible. The current drawback of deterioration because of material fatigue could be limited if the wire is strained during integration. Because the wire is very filigreed, this is not possible with the current manual integration procedure.

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