Design and Implementation of a Flow Microsensor by using Silicon Microelectronics Technology

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Abstract

This work presents the design of a gas flow microsensor that was implemented by using silicon microelectronics technology. Its main features are a low power consumption (tens of mW) and the possibility of integration in flow microactuators. It was adopted a calorimetric device with free - standing microfilaments and thermoresistive sensor elements. Analytical and numerical modeling were developed for device analyses and design. The free – standing microfilaments were fabricated using surface micromachining. Characteristic curves, of output voltage vs. flow, were obtained by using a commercial flow sensor for calibration. A good agreement was obtained comparing the flow microsensor experimental characteristic curves with numerical simulation results.

1. Introduction

The miniaturization of sensor devices using semiconductor technology results in higher performance, as faster response, lower power consumption, and measurement of small flow [1][2][3]. Important applications of a flow sensor can be found in chemical, medical, automotive, and industrial areas [2]. Besides, there is the possibility of integration in flow microactuators, being the study on micro-domains needed to reveal the deviation from macro-scale field [4][5].

The microsensor presented in this paper is based on the calorimetric principle [3] and consists of three free – standing microfilaments fabricated by surface micromachining [6]. These resistors are aligned as showed in the Figure 1, where the central one works as a heater and the other two work as temperature sensors [3][7][8].

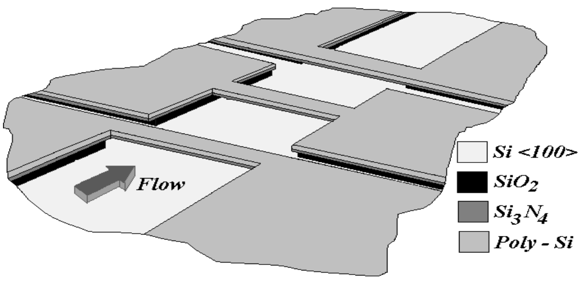


Fig. 1: Schematic illustration of the flow microsensor based on the calorimetric principle built in this work [8].

2. Analytical Model and Numerical Simulation

In previous works [7][8], we presented an analytical model, which allows determining a temperature distribution around the heater (central resistor in Figure 1) and its corresponding characteristic curves. This analytical result agrees qualitatively with previous results found in literature [1][2][3], as presented in the Figure 2. The sensor - heater distance could be found in the range of 100 μm.

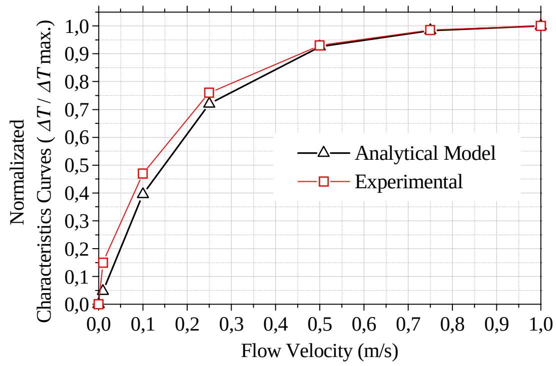


Fig. 2: Comparison between experimental results presented by Qio et al. [3] and the analytical model developed in this work [7][8].

With the results obtained by simulations, it is possible to achieve a better design optimization, to foresee possible experimental results and to explain possible device limitations [2][3][5]. The simulations were performed using the software package ANSYS®/FLOTRAN® version 5.4 (University Research). A two-dimensional model corresponding to the cross - section through the sensor and channel system was considered [7][8].

Figure 3 shows the characteristic curves obtained from simulation for airflow and heater temperature of 373 K. Different characteristic curves were obtained to determine the better distance between heater and temperature sensors.

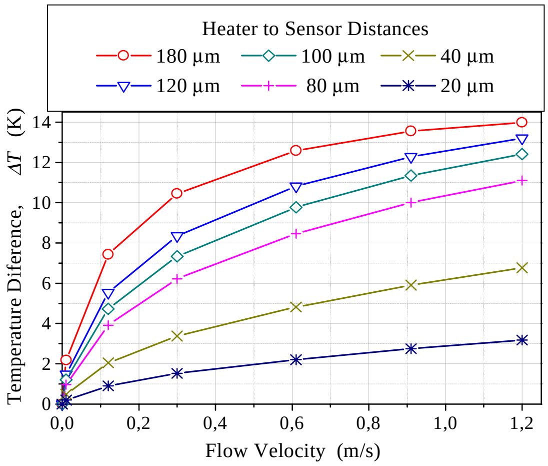


Fig. 3: Characteristic curves obtained from numerical simulation performed for different distances heater – sensors, used in the device design.

Through analytical model and the simulations, the better distance between heater and temperature sensors was determined as either 80 µm or 120 µm. High sensitivity was considered in this choice. The polysilicon resistors dimension, see Figure 1, are 200 µm long and with 10 µm wide.

3. Device Fabrication

Figure 4 shows the schematic cross - section of the main processing steps for fabrication of the flow microsensor [8]. Silicon wafers were used as substrate.

A layer of 0.6 µm of PECVD oxide was deposited in TEOS (Tetra-Ethyl-Ortho-Silicate) ambient [9]. Layers of Si_3N_4 and polysilicon were deposited by LPCVD, with thickness of 0.15 µm and 0.5 µm, respectively. The polysilicon doping was performed through phosphorus (PSG) diffusion after thermal step.

Plasma etching was performed for polysilicon electrical contacts and temperature sensors definition after photolithography. The aluminium layer was deposited by evaporation and patterned to form electrical contacts through wet chemical etching.

The wafers were cut for devices definition and the sacrificial layer removal was performed in DLV solution, $6NH_4F+1HF$ (25 °C).

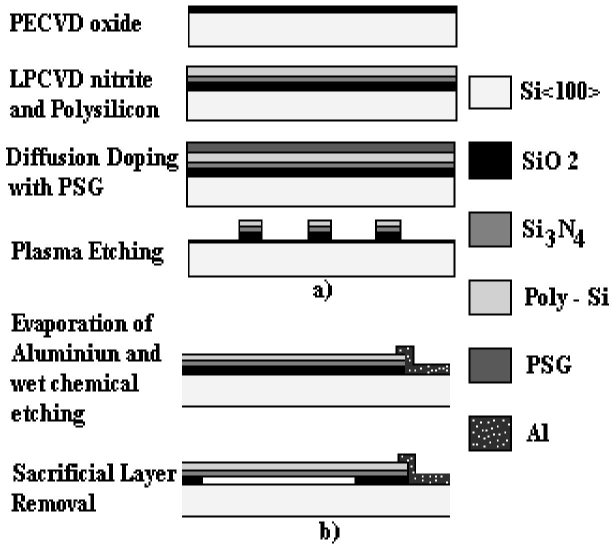
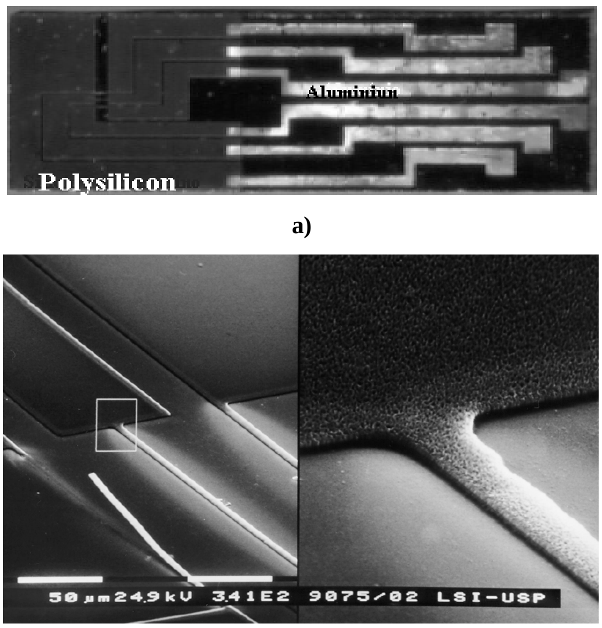


Fig. 4: Main process steps for fabrication of the flow microsensor for: a) transversal and b) longitudinal view of filaments.

Figure 5 shows micrographs of the fabricated microsensor. Figure 5b shows released filament details by electronic microscopy. The broken filament is curved due to stress.



a)

b)

Fig. 5: Microsensor micrographs: a) top view and b) Photo by Electronic Microscopy.

The device was glued in a plate and attached in tube with a diameter of the 3 mm, as shown in Figure 6, for the experimental measurements.

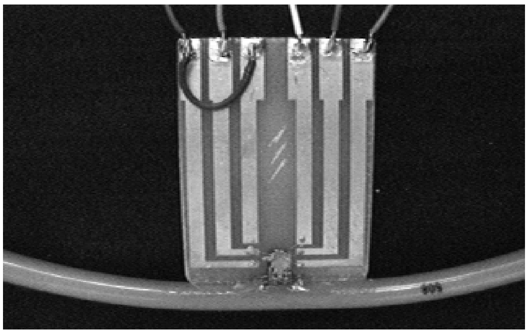


Fig. 6: Photo of the device attached in a tube, for tests.

4. Results and Discussions

The free - standing filaments obtained were tested through *i* x *v* curves. The red - light emission was observed only for free - standing filaments under voltage close to 11 V. Thus, becoming evident that the filaments were released [6].

Figure 7 shows the change in the electrical resistance due to temperature increase for released filaments (Joule effect) and the dotted line shows the *i* x *v* curve for a not released filament. This happens due to a lack of thermal isolation between filaments and substract.

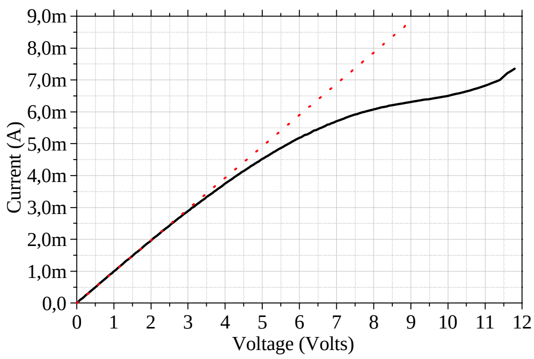


Fig. 7: *I* x *V* curves after sacrificial layer removal. Effect of the no removal of the sacrificial layer is shown in the *i* x *v* curve indicated through dotted line.

The power dissipation in the heater is close to 50 mW for an applied voltage of 6 V.

The fabricated device was installed in series with a commercial mass flow meter, as shown in the Figure 8. Thus, characteristic curves were obtained, i.e. output voltage of Wheatstone bridge as a function of the flow measured by means of mass flow meter [7][8]. With this aim, the microsensor (Figure 5a) was inserted in a tube with 3 mm of diameter and tested with nitrogen in a flow range of 0 to 500 sccm.

Characteristic curves were obtained for different heater voltages and comparated with numerical results, as shown in Figure 9. The characteristic curves obtained for heater – sensors distance of 80 µm showed smaller sensitivity than those obtained for 120 µm [8].

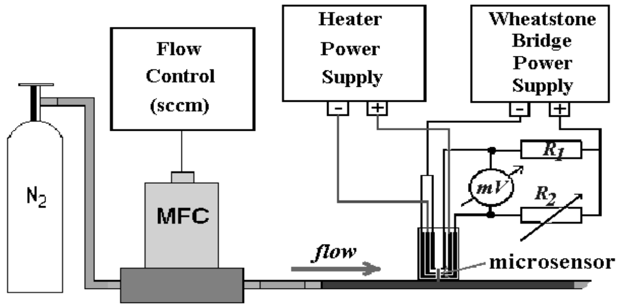


Fig. 8: Experimental set – up.

To make possible the direct comparison between numerical and experimental results, voltage was used instead of temperature. Thus, the temperatures obtained numerically were converted to voltage obtained in the Wheatstone Bridge output by considering linear dependence between electrical resistance of temperature sensors and temperature in conformity with the following equation 1 [8]:

$$R = R_o.[1 + \alpha.(T - T_o)] \qquad (1)$$

where R and R_o are electrical resistances of the device, respectively, at sensor temperature (T) and ambient temperature (T_o), and α is the temperature coefficient for doped polysilicon.

In conformity with the adopted assumptions, the best agreement between experimental and numerical results was obtained for the experimental characteristic curve obtained for an applied voltage V_{ht} = 6,12 V, in the heater resistor, as observed in the Figure 9, which corresponds to an estimated temperature of 115 °C.

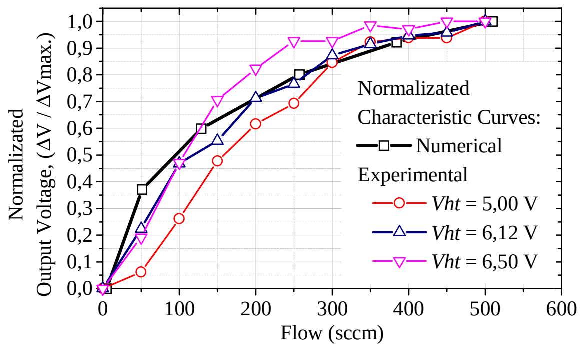


Fig. 9: Comparison between normalized characteristic curves obtained from numerical and experimental results for qualitative analysis.

Figure 10 shows the comparison between characteristic curves obtained for numerical simulation and experimental for distance heater – sensors of the 120 µm.

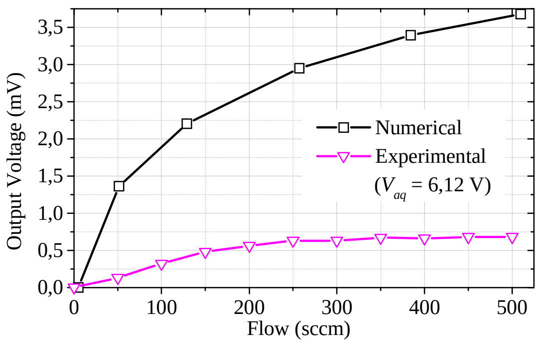


Fig.10: Comparison between characteristic curves obtained from simulation and experimental results for quantitative analysis.

The possibility of a partial removal of the sacrificial layer is pointed as the cause of the sensitivity decrease; in this way, only for simulation considerations, the filaments were made shorter. Thus, better qualitative results were obtained after new comparison between numerical and experimental results (Figure 11).

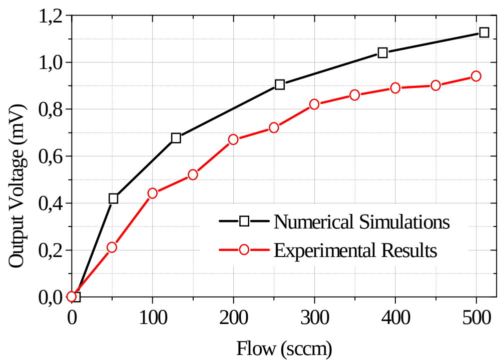


Fig. 11: Comparison between experimental and numerical curves after to consider, in the simulation results, filaments approximately 65 µm long [8].

5. Conclusions

A low power flow microsensor (50 mW) consisting of three free - standing microfilaments has been fabricated and tested. An analytical model and numerical simulations have been used to predict the experimental results through temperature distributions around the heater. The good agreement between analytical, numerical and experimental results obtained in this work shows the consistence of our design methodology.

The comparison between experimental and numerical results was performed through characteristic curves, of output voltage *vs*. flow.

The distance between the central heater and the sensor elements was determinate and resulted in the range of 120 µm.

Differences in the qualitative analysis between numerical and experimental results suggest that part of the filaments are in thermal contact with the substrate, what is probable due to both small thickness of the sacrificial oxide layer (0,6 µm) and stress in the polysilicon structures.

Acknowledgements

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