Chapter 24
Smart Multichannel Flow Sensor with Temperature and Pressure Compensation

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Abstract A compact sensor for measuring multiple gas flows has been designed and fabricated. The device consists in a single silicon chip where three independent flow sensing structures have been included. The sensing structures are differential micro-calorimeters, equipped with double heaters in order to perform drift-free offset compensation. The chip includes also a versatile electronic interface including a low noise chopper amplifier and an original closed loop heater driver capable of reducing the effects of pressure variations on the flow measurement. The chip has been designed using the BCD6s process of STMicroelectronics. A post-processing step, based on anisotropic etching, is required to complete the smart sensor fabrication.

24.1 Introduction

Microfluidic devices have received considerable interest for their wide field of applications. Wearable systems for autonomous drug delivery, microreactors for chemical synthesis [1] and miniaturized low cost instruments for biological analysis are among the most emerging applications requiring microfluidic devices. Integrated micro flow sensors have been among the first successful examples of Micro-Electro Mechanical Systems (MEMS). Nevertheless, very few commercial products based on integrated flow meters have been proposed so far. This is partly due to limitations still affecting existing devices, such as large intrinsic offset and

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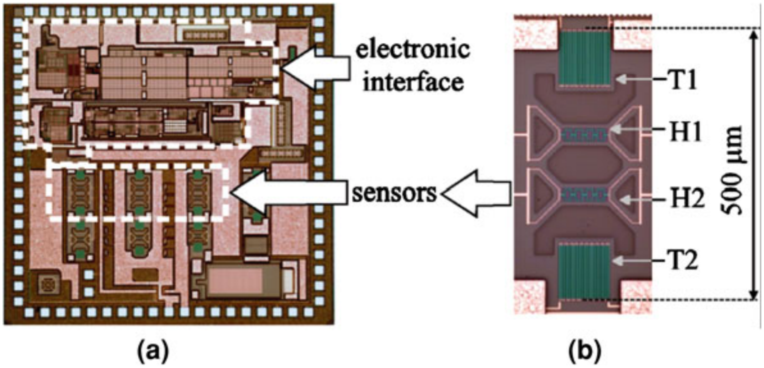

Fig. 24.1 Optical micrograph of the whole chip (**a**) and enlargement of one sensing structure (**b**) with the main elements indicated: H1, H2: heaters; T1, T2: thermopiles

pressure dependence. These aspects limits the potential capability of these sensors of detecting minimal flow rates, which is a critical operation frequently required in microfluidic systems that cannot be accomplished with traditional devices. An interesting example is represented by in the feed lines for ionic and cold gas thrusters, used for controlling the attitude of small artificial satellites [2].

In this work we propose the design and electrical characterization of a smart flow meter consisting of a single $3.8 \times 3.8\ \text{mm}^2$ silicon chip including three independent flow sensing structures and an electronic analog interface capable of driving the sensors, reading the signal and correcting the offset and pressure sensitivity of the sensors.

24.2 Device Description

Figure 24.1a shows an optical micrograph of the chip prior to the post-processing step. It is possible to recognize the electronic interface and the three sensing structures that can be connected to the latter through an on-chip four-way analog multiplexer. An optical micrograph of one sensing structure is shown Fig. 24.1b. These devices are composed by two temperature probes (thermopiles T1, T2) symmetrically placed across two heaters (polysilicon resistors H1, H2).

The output signal is the difference between the voltages produced by two thermopiles. The double heater structure allows offset compensation by introducing a proper power unbalance between the heaters [3].

The chip has been designed and fabricated using the Bipolar-CMOS-DMOS process BCD6s of STMicroelectronics. A micromachining step, based on selective anisotropic etching of the bulk silicon, is required to thermally insulate the sensor elements from the substrate. This step is identical to that applied to previous version of the device [4]. The position of the sensors has been chosen to facilitate

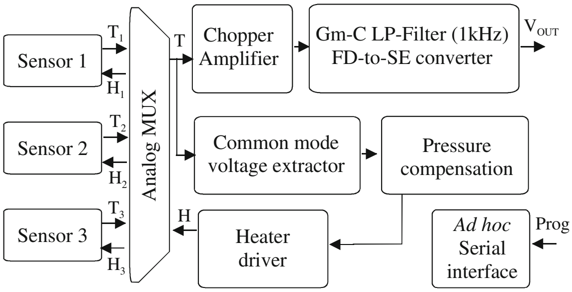

Fig. 24.2 Block diagram of the on-chip integrated interface

the packaging technique described in Ref. [5], successfully applied to the fabrication of two channel flow meters.

A simplified block diagram of the integrated electronic interface is shown in Fig. 24.2. As stated above, the sensors are connected to interface through an analog multiplexer, controlled by two selection bits. Alternatively, the interface can be connected to external pads for characterization or connection to an off-chip sensor. The sensor differential voltage, carrying information on the measured flow, is amplified by a chopper amplifier and filtered by a fully integrated low pass filter with 1 kHz roll-off frequency. The role of the filter is suppressing the amplifier output offset modulated by the clock signal. In addition to the differential voltage, also the thermopile common mode voltage is read, since it has been demonstrated [6] to be a useful indicator of the gas pressure. According to a recently introduced approach [7], the pressure variations can be extracted from the corresponding variations of the common mode voltage and used to modulate the heater power in order to cancel the effect of pressure on the output (differential) voltage.

The heater driver produces two currents feeding the two heaters of the sensing structures. The sum of the two currents is proportional to the input voltage while their difference (power unbalance) is digitally controlled in order to compensate for the sensor structural offset [3].

24.3 Readout Interface Characterization

The interface characterization has been performed on unprocessed chips that have been packaged into standard DIL28 cases and wedge bonded. The experiments have been carried out using a HP4145B parameter analyzer. The power supply voltage was set to 3.3 V and the total current consumption was 4 mA. The 32 bit internal register was programmed using a microcontroller Analog Devices ADuC847 connected to a Personal Computer via serial port. All the tests have been performed connecting the input of the interface to external pins through the analog MUX.

Figure 24.3a shows the response of the differential amplifier for different gain settings ranging from 160 to 1000. The output linearity spans by ±1 V wide

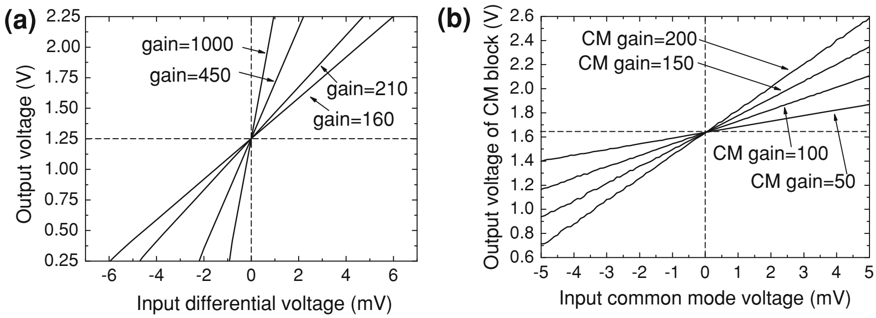

Fig. 24.3 Response of the differential amplifier (**a**) and common mode estimator block (**b**) for various gain settings

around the zero level. The latter has been set to 1.25 V, coinciding with the mid point of the ADuC microcontroller ADCs. The input referred offset voltage of the chopper amplifier was less than 2 μV. The correct operation of the common mode extractor and amplifier is proven by Fig. 24.3b. In this case, the zero level has been fixed to Vdd/2 for optimal interfacing with the pressure compensation block. The possibility of digitally varying the gains improves the adaptability of the interface with respect to a wide range of external sensors.

24.4 Conclusions

A smart sensor, including several flow sensing microstructures and a versatile electronic interface on the same chip, has been designed and fabricated. The interface incorporates several functions that, so far, were implemented only by means of relatively large printed board circuits. These functions were aimed at improving the precision and detection limit of the sensor, through drift free offset compensation and reduction of the sensitivity to pressure. A detailed characterization of the electronic interface has been performed, obtaining a complete agreement with the initial specifications. The devices will be completed by means of post-processing and packaging steps similar to those described in [4].

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