MEMS Microhotplate Temperature Sensor BIST: Importance and Applications

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Abstract—**This paper describe the importance of temperature sensor built-in self test (BIST) for microhotplate-based sensors. It shows possible ways to implement BIST functionality for microhotplate temperature sensors, including resistance temperature detectors (RTD), microhotplate thermal efficiency, and Thermocouples. A calibration technique is discussed and conclusions are given.**

I. INTRODUCTION

Microhotplate platforms have the potential to support low-cost applications including combinatorial chemistry, matrix studies of thin film annealing, as well as temperature programmed sensing [1] of volatile organic compounds (VOC). The advantages of microhotplate platforms include easy monolithic array implementation, low-power consumption, and low thermal time constants (around 1 ms). Cavicchi et al. [1, 2] exploited the low thermal constant to identify different gas species from the response signature of a single microhotplate gas sensor during a series of rapid temperature steps. This technique provides tunable selectivity from a single microhotplate to complement other dimensions of selectivity available from the pattern of response obtained over an array of microhotplates having different gas sensor film compositions. But the potential of this technique can only be realized if the same temperature profile is used every time.

For system integration and mass production of microhotplate-based devices, BIST functionality will be a must to ensure reliable long-term operation. BIST usually validates critical system specifications during manufacturing and in the normal use of the system. In the case of microhotplate-based sensor systems, microhotplate temperature repeatability is a critical system specification. For optimum BIST functionality, two long-term stable microhotplate temperature sensors based on different thermoelectric mechanisms are required. In this case, microhotplate temperature-sensor BIST consists of comparing the temperatures reported by the two different sensors. As long as the absolute value of the difference remains below an application-specific threshold value, the average of the two temperatures will be considered reliable. But if the absolute value of the difference exceeds the threshold, the system will report an error. This paper describes three possible temperature sensors that can be integrated into microhotplate structures and shows how they can be calibrated and used to implement temperature-sensor BIST.

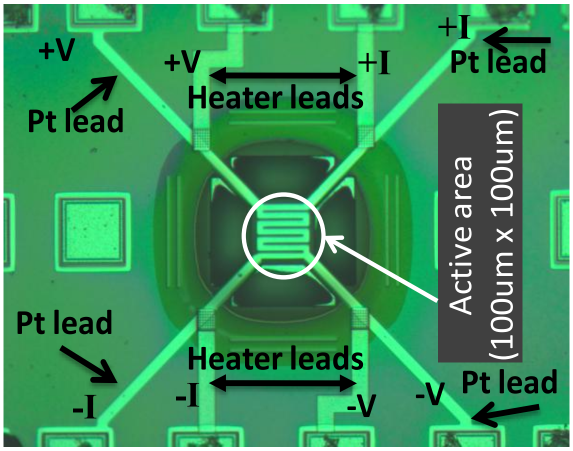

Figure 1. A micrograph of a microhotplate structure showing a four-wire serpentine platinum temperature sensor.

II. MICROHOTPLATE AND ITS TEMPERATURE SENSORS

Figure.1 shows a trampoline-type microhotplate structure of a type described in more detail in [3, 4]. It has four supporting legs to keep the microhotplate active area (100 um x 100 um) suspended to achieve high thermal efficiency. Here a four-wire platinum serpentine-structure over the active area defines a RTD–type temperature sensor with each wire occupying one leg, providing two current leads and two voltage leads. The active area of the microhotplate also has a four-wire polysilicon serpentine heater underneath it (not visible in Fig.1). The four-wire arrangement makes it possible to use the polysilicon as a heating element and also to measure the temperature of the platform portion of the microhotplate

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by measuring the voltage across the voltage leads. If a sufficiently small resistance-measurement current is used, the temperature of the microhotplate will be negligibly different from that of the chip in which it is located. Therefore it is possible to directly calibrate the microhotplate heater as a thermometer by heating the entire chip to a known temperature [5].

There are three types of independent temperature sensors that can be integrated into a microhotplate structure. These are based on: 1) a resistance temperature detector (RTD), 2) the thermal resistance of the microhotplate legs (thermal efficiency of the microhotplate), and 3) the thermal emf of a thermocouple. However, neither the thermocouple nor the thermal resistance of the microhotplate legs can be directly calibrated as a temperature sensor by heating the entire chip containing the microhotplate. Unlike the RTD, they respond to the temperature difference between the microhotplate and the substrate on which it is located.

III. TEMPERATURE SENSOR CALIBRATION AND RESULTS

The three types of temperature sensors, as mentioned earlier, require different calibration methods. The four-wire temperature sensor based on the RTD was calibrated by measuring the electrical resistance of the serpentine structure material (e.g. polysilicon or platinum) in the active area of the microhotplate by measuring the voltage at the voltage leads as a function of temperature in a custom oven with a 100 µA electrical current continuously injected into the RTD current leads. The oven temperature was increased in 10 ºC steps from 30 ºC to 220 ºC and measurements were made for each temperature step once thermal equilibrium was reached. A polynomial fit to the data was obtained.

The second type of temperature sensor (based on thermal resistance, which could not be calibrated directly) was calibrated by electrically heating the microhotplate polysilicon resistor from 30 °C to about 400 °C by applying known power levels to the polysilicon heater and measuring the resistance values of the active area of the microhotplate heater. The temperatures corresponding to the resistance values were then calculated using the polynomial fit obtained from the RTD calibration of the polysilicon or platinum calibration data. A polynomial fit to the microhotplate temperature vs. power was obtained as shown in Fig. 2. The thermal efficiency of this microhotplate device was 37 ºC/mW. For some types of microhotplate, the thermal efficiency is a suitable temperature sensor because it remains constant to within about a percent even after a long time operation at high temperatures (450 ºC).

To calibrate the third type of temperature sensor, based on the thermal emf of a thermocouple, a custom microhotplate [6] with a post-processed platinum-rhodium thermocouple junction in the active area was used. The calibration procedure for this type of temperature sensor is the same as that used for the thermal resistance temperature sensor. In this case, the thermocouple voltages were obtained as the microhotplate was heated from 30 ºC to about 400 ºC. A polynomial fit to the thermocouple voltage vs. temperature was obtained. In fact, the second and third type of temperature sensors for the microhotplate can be calibrated together in one step.

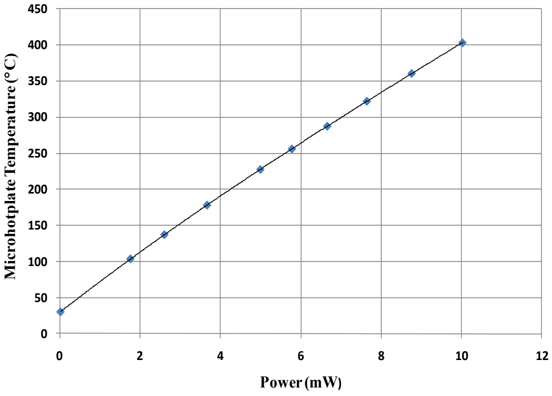

Figure 2. Microhotplate temperature as a function of the polysilicon heater power. This microhotplate efficiency was measured with an integrated Pt RTD temperature sensor.

IV. CONCLUSIONS

Based on our studies of microhotplate temperature measurements, we have concluded that polysilicon is not suitable for long-term reliable temperature measurements as its calibration drifts very substantially with time [6], but that it can be used to carry out the initial calibration of other more suitable temperature sensors. Specifically, it has been shown that a platinum-rhodium thermocouple temperature sensor or a four-wire platinum RTD sensor of the type described here can be used, and that the thermal efficiency of at least some types of microhotplates can also be used to implement temperature-sensor BIST functionality.

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