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A MEMS micromachined low cost microheater platform for applications in thermal sensors

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Summary:

We developed a low-cost thin membrane based microheater platform (MHP) as scalable basic unit for thermal sensors. The MHP consisting of thin membranes supporting the microheater and temperature sensors is CMOS/MEMS compatible and features high performance characteristics such as controllable temperature distribution and low power consumption.

Keywords: membrane, microheater, thermal isolation trench, thermopile, microcalorimetric sensor.

Introduction

There is an increasing need for low cost microheater platforms (MHPs) for use in different thermal sensor systems such as gas sensors [1, 2, 3], thermal flow meters [4, 5], microreactors [6], radiation bolometers [7] as well as infrared emitters [8]. The focus of the work shown in this paper is to be develop a platform which is CMOS/MEMS-compatible and made of cost-effective materials for the carrier membrane, heating elements, temperature sensors and thermal insulation.

Sensor design

Preliminary simulation works yielded different approaches to chip design a selection of which is shown in Fig. 1. Based on these results, the design of the chips consisting of microheaters with different geometries and temperature sensors was derived and optimized.

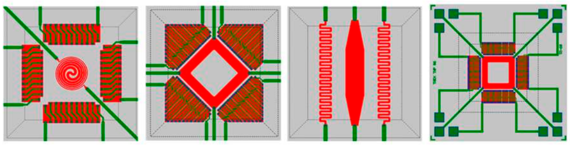

Fig. 1. Layouts of different microheater shapes, thermopiles, and thermistors for use as temperature sensors.

Simulations of the distribution of the heating voltage, current density and temperature show that our MHP have different thermoelectric properties that allow their use in diverse applications. The simulated temperature distribution on the membrane and the temperature profiles at the junction between the membrane and the silicon frame for two chips with two microheater geometries (square and spiral) are displayed in Fig. 2.

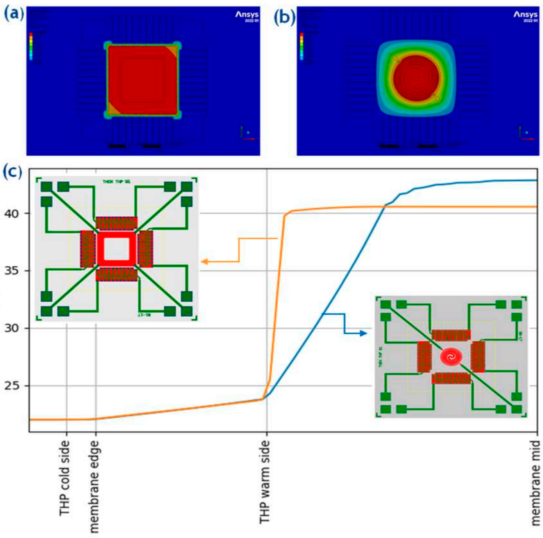

Fig. 2. Simulation of two MHPs with thermopiles and different heater geometries in terms of temperature distribution on the membrane and profiles at its edge.

Sensor fabrication and measurements

A technology for producing MHPs with closed as well as suspended membranes was developed. This is carried out with a process sequence consisting of the deposition of a dielectric layer stack made of silicon oxides and silicon nitrides, chemical vapor deposition of a polycrystalline silicon (Poly-Si) doped with phosphorus or boron, additional deposition of silicon nitride and silicon oxide layers, and magnetron sputter deposition of aluminum (containing 3% Si). Thermopiles and thermistors were chosen as temperature sensors because they have many advantages over other temperature sensors such as diodes [9].

Results

Fig. 1 shows some MHPs with suspended membranes.

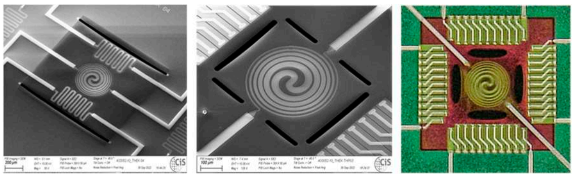

Fig. 3. Scanning electron microscope and 3D laser microscope pictures of the MHP showing isolation trenches.

The MHPs were characterized thermoelectrically at wafer level as well as using single chips mounted on PCBs. To determine the resistances and the corresponding temperature coefficients (TCR) of the heater and thermistors, calibration curves were determined upon varying the temperature. It was observed that, the heater resistance increases when the bias voltage changes from 0.1 to 10 V, which proves the Joule self-heating effect and thus the desired operation of the MHP. Regardless of the heater voltage, the heater resistance increases with the temperature, leading to TCR of 860 ppm/°C for the poly-Si used in our microheaters, thermistors and thermocouples. According to our measurements the Seebeck coefficients for the thermocouples made of poly-Si and Al (containing 3% Si), is about 100 to 103 μV/K.

The MHP was tested as calorimetric thermal flow sensor. Fig. 4 shows the thermoelectric voltage of four thermopile sensors (S1 to S4) symmetrically surrounding a square microheater in a diagonal arrangement (see inset) as a function of heating voltage. Fig. 4 (a) shows the output voltages depending on the heating voltage without air flow, causing the signals to overlap. This shows the existence of a symmetrical temperature field around the heater.

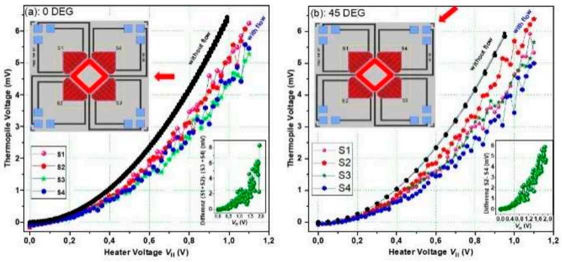

Fig. 4. Electrical self-Test applied to a microcalorimetric thermal flow consisting of a square heater and 4 thermopiles arranged diagonally to the heater. The arrows show the flow direction. The insets exhibit the difference between the downstream and upstream sensor signals.

When applying an air flow using pressurized air, the thermoelectric voltage of all four sensors decreases and the output voltage of the upstream sensors is weaker than the voltage of the downstream sensors. In Fig. 4 (b) it can be clearly seen that S4 is cooled down more than S2. This symmetry is thus disturbed. The resulting temperature difference serves as a measure for the flow velocity. Thus, the flow modulates the temperature distribution on the sensor membrane and demonstrating the calorimetric effect.

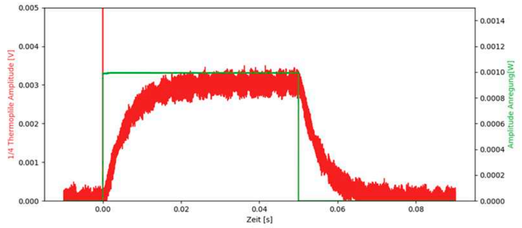

Fig. 5. Time response of electrically excited sensor.

Figure 5 shows the time response of a thermopile using power pulse of 1mW with a duration of 50ms. From this plot recorded directly from the measuring instrument, the heating time constant is about 8 ms. Thus, the MHP studied here achieves high heating power with a short response time.

Conclusion and outlook

Based on very extensive simulation and experimental work, low-cost and CMOS/MEMS compatible membrane-based microheater platforms with good performance could be designed and processed. Using the approach shown above MHPs for various applications can be fabricated.

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