Implementation of CMOS Compatible Conductance-Based Micro-Gas-Sensor System

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***Abstract* – A CMOS compatible micro-gas-sensor system was designed and fabricated in a standard CMOS process through MOSIS [1]. The chip was post-processed to create microhotplates using bulk micro-machining techniques. Tin-oxide-sensing films were grown over post-patterned gold sensing electrodes using a low-pressure chemical vapor deposition (CVD) technique. The thermal properties of the microhotplates include a one-millisecond thermal time constant and a 10°C/mW thermal efficiency. The microhotplate operates at temperatures between 20°C and 450°C. Tin-oxide-sensing films were isothermally characterized using different gas molecules and concentrations. This paper describes the fabrication, characterization, and design of interface circuitry of a novel CMOS integrated micro-gas-sensor system.**

1 Introduction

Current trends in chemical sensing suggest the future use of arrays of micro-sensors where each sensor has different sensitivity and selectivity to a wide range of gases or mixtures of gases. Large arrays of micro-sensors require an efficient method for acquiring data from each element of the array. In most of the conductance-based gas sensors [2], the sensing mechanism utilizes a thin film of metal oxide; typically tin oxide (SnO_2).

Tin oxide in its purest form is a semiconductor. The conductance property of the material is due to oxygen vacancies which act as donors [3]. The SnO_2 film conductance depends upon its surface structure and the gas molecules in contact with it. The main objective of a gas sensor of this type is to measure the change in film conductance for each element of an array precisely and efficiently. In this paper, we describe an interface circuit that is designed to obtain the change in conductance from a sixteen-element gas sensor array, implemented in CMOS technology.

The circuit has both analog and digital components. To address each sensing element of the gas array, a 4-to-16 digital decoder is used. The outputs of the decoder are used to drive pass-switches, which places the desired sensing element in the feedback path of an inverting operational amplifier. The gain of the operational amplifier is modulated by the changing conductance of the sensing element.

2 CMOS Conductance-based Gas Sensors

The CMOS microhotplate [4] is the foundation on which this conductance-based gas sensor is fabricated. A maskless CVD process is used to deposit a thin film of SnO_2 over the microhotplate sensing area. Elevated temperatures are used for activation of the CVD process [5]. To achieve uniform temperature over the entire sensing area, an aluminum plate is sandwiched between the poly heater and sensing film. The microhotplate operates in a temperature range of 20°C to 450°C. A layout of a microhotplate-based gas sensor array is shown in Fig. 1. All of the major parts of an array element are shown Fig. 2.

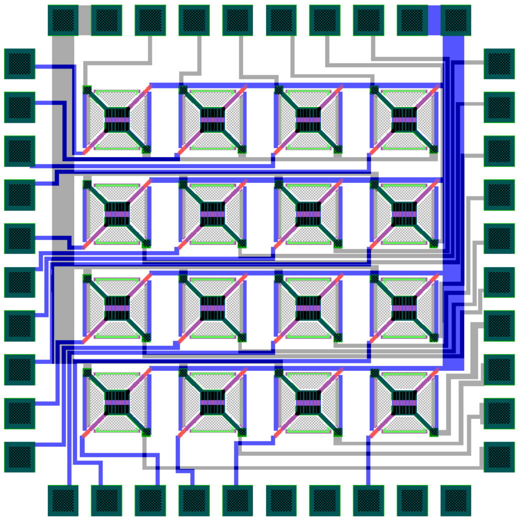

Fig. 1: Sixteen-element gas array layout

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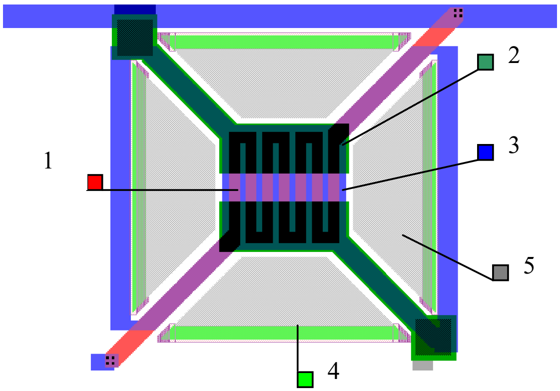

Fig. 2: A gas array element

1. Poly silicon heater
2. Gold sensing electrode (post process)
3. Aluminum hot plate
4. Etch stop
5. Open area

A CAD program was used to design the array layout. The design was submitted to the MOSIS foundry service for fabrication using a standard 2-micron CMOS process. A mask was prepared to pattern 300-nm thick Au electrodes over each microhotplate sensing area. 20-nm thick chrome was used as an adhesive for the gold layer. Before putting the chrome and Au on the chip, the chip was *in-situ* [6] sputter cleaned with argon to remove aluminum oxide from the open aluminum pads that make contact with the Au electrodes.

A silicon etchant was used to etch silicon in the open area. All other areas of the chip were protected by the passivation layer. Figure 3 shows a micrograph of a 16-element sensor array.

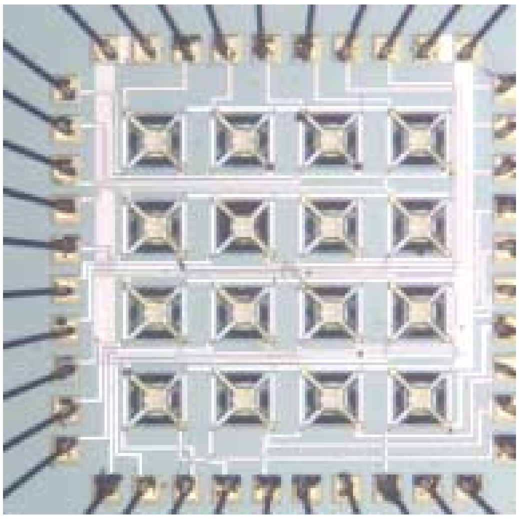

Fig. 3: Sixteen-element gas array in CMOS

2.1 Microhotplate characterization

The thermal efficiency of the microhotplate's poly silicon heater was characterized and found to be 10°C/mW. Figure 4 shows the measured thermal efficiency of the microhotplate and demonstrates its linearity. The microhotplate has a thermal time constant of about one millisecond.

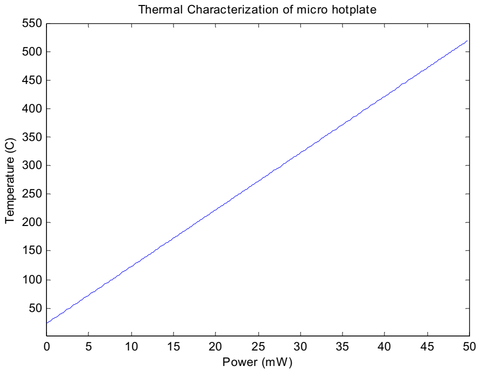

Fig. 4: Microhotplate thermal efficiency

2.2 Sensing film characterization

The SnO_2 film was isothermally characterized. The microhotplates were held at a constant temperature of 400°C by applying the appropriate heater power. Sensors were subjected to different gasses at different concentrations and the conductance was recorded as a function of time. The gases used in this test included hydrogen, methanol, ethanol, and acetone at 50ppm, 75ppm, and 100ppm. Gases were turned on for 300 seconds and then turned off for 300 seconds. Typical response curves for hydrogen and methanol gas species at concentration levels of 100ppm and 50ppm are shown in Figs. 5-8. These graphs show that the SnO_2 film conductance depends on the gas species and its concentrations, and furthermore exhibits complex time-dependent behavior.

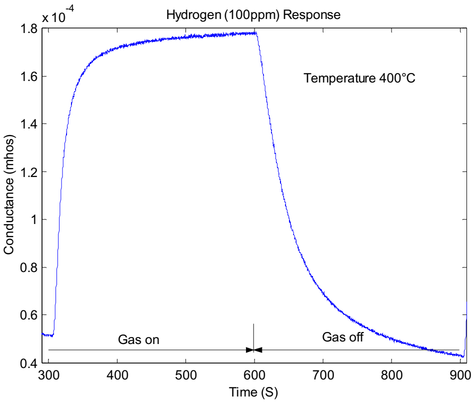

Fig. 5: Hydrogen response 100ppm gas

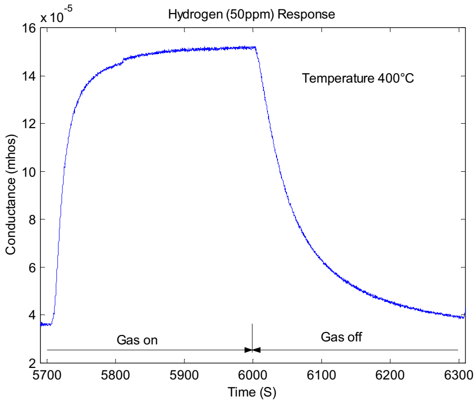

Fig. 6: Hydrogen response 50ppm gas

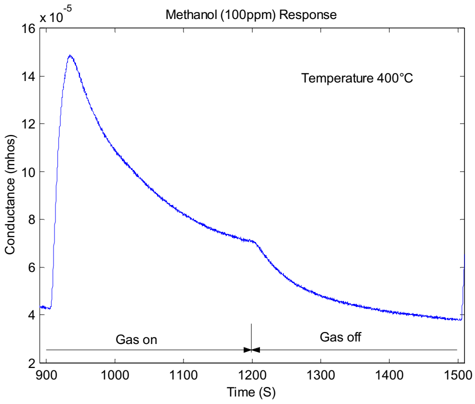

Fig. 7: Methanol response 100ppm gas

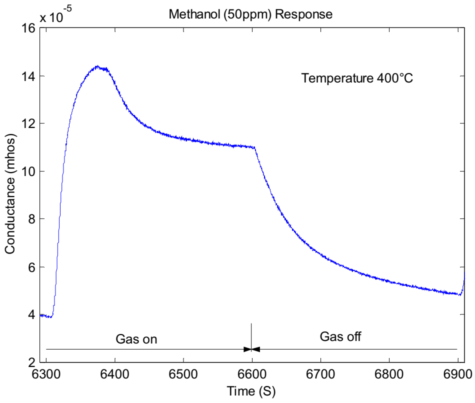

Fig. 8: Methanol response 50ppm gas

3 Interface circuit

In this section, an interface circuit for automatic sensor selection and conductance measurement is described. To measure the conductance of the SnO_2 sensing film, an inverting operational amplifier configuration is be used, where the sensing film is in the feedback loop of the amplifier. Figure 9 shows the interface circuit, which contains both a selectable sensor array (S1, S2, … , S16) with measurement amplifier, and a selectable heater array (H1, H2, … , H16). A 4-bit decoder activates a given sensor along with a corresponding heater for that sensor. Pass-switches are used for the activation as shown. Vh is the heater voltage that is common to any activated heater. Only one heater-sensor pair is activated at a time.

Due to the very large open loop gain and high input resistance, the closed-loop gain of the inverting amplifier depends only on Rref, and the sensor's resistance. The output of the amplifier thus reflects the conductance of the selected sensor element. The resistance of the pass-switches is known, and the output can be calibrated to compensate for this added resistance.

The advantage of this scheme is that only one operational amplifier and one decoder is needed to measure the change in conductance of the entire gas array. Furthermore, uncertainties in Vref, Rref, and amplifier offset and gain will remain constant for all sensing elements.

3.1 Interface circuit design and layout

The digital portion of the micro-gas-sensor system, comprised of a 4-bit decoder, was designed and implemented using a standard CMOS gate cell library. The layout of the 4-bit decoder was automatically generated by the CAD program. The layout of pass-transistors was done manually to insure low on-state resistance. The analog part of the circuitry, which includes an operational amplifier, was designed using a standard three-stage configuration scheme [7]. This scheme includes an input differential stage, a gain stage, and an output buffer stage. The layout for the operational amplifier was also done manually to maximize device matching and to obtain optimum performance. The operational amplifier is designed to operate with a supply voltage of plus and minus 3V.

Figure 10 shows a test chip with integrated electronics. The figure annotates the main parts of the gas sensor system. This test chip was simplified to include only four elements of a 16-element gas array system. The BJT pass-switches indicated in Fig. 10 implement heater switching, and the MOS pass-switches implement sensor array switching. BJTs were used for heater switching because of the higher voltage and current requirements. MOS pass-switches were used for sensor array switching because of their small dc-offset.

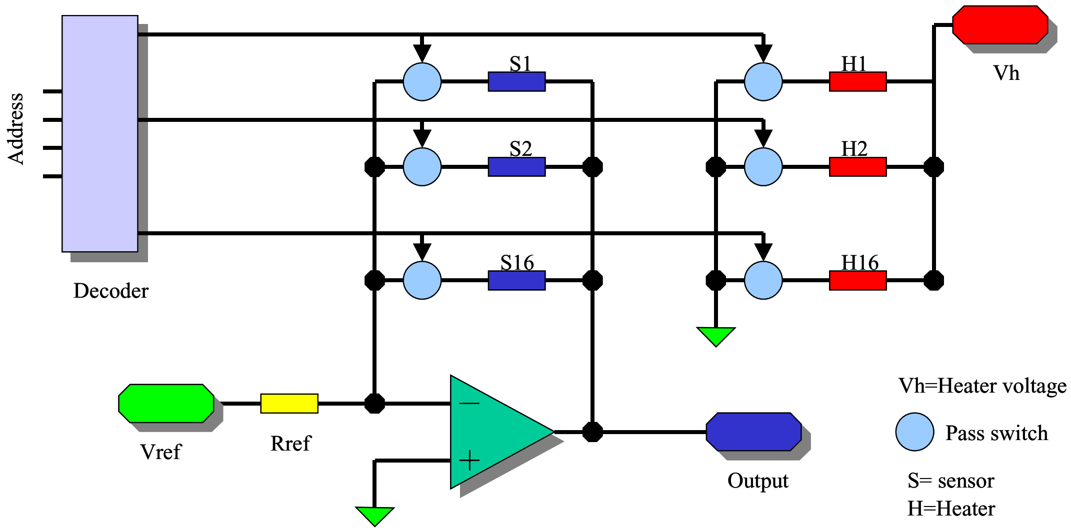

Fig. 9: Interface circuit

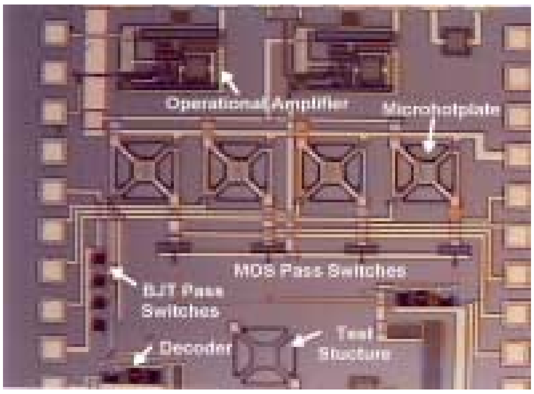

Fig. 10: Gas sensor test chip illustrating integrated electronics

4 Conclusions

In this paper, we presented the fabrication, characterization, and interface circuitry design for a CMOS compatible micro-gas-sensor system. An efficient on-chip circuit was designed to select and measure the conductance of each element of a microhotplate-based micro-sensor array. A prototype interface circuit is being tested at the present time.

Acknowledgement

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