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

M. Y. Afridi1 J. S. Suehle2 M. E. Zaghloul3 J. E. Tiffany4 R. E. Cavicchi5

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 (SnO2).

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 SnO2 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 SnO2 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

1- Muhammad Afridi, The George Washington University (GWU/NIST) E-mail: afridi@seas.gwu.edu 301-975-5420
2- John Suehle, NIST, E-mail: john.suehle@nist.gov 301-975-2247, National Institute of Standard and Technology, Semiconductor Electronics Division, Gaithersburg, MD 20899
3- Mona Zaghloul, GWU, E-mail: zaghloul@seas.gwu.edu 202-994-3772,
4- J. E. Tiffany, NIST, E-mail: jason.tiffany@nist.gov 301-975-2847
5- R. E. Cavicchi, NIST, richard.cavicchi@nist.gov 301-975-3970

Contribution of the National Institute of Standards and Technology not subject to U.S. copyright.

III-381
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 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.

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.

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 gases 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.
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. 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 Interface circuit

In this section, an interface circuit for automatic sensor selection and conductance measurement is described. To measure the conductance of the SnO2...
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

Authors wish to thank David Berning for his valuable discussions.

References