Test Structures for Rapid Prototyping of Gas and Pressure Sensors

Martin Buehler and Li-Jen Cheng
Microdevices Laboratory
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
and
Dennis Martin
Halcyon Microelectronics, Inc.
Irwindale, CA

Abstract

A multi-project ceramic substrate was used in developing a gas sensor and pressure sensor, The ceramic substrate contained 36 chips with six variants including sensors, process control monitors, and an interconnect chip. The gas sensor is being developed as an air quality monitor and the pressure gage as a barometer.

introduction

The purpose of this paper is to describe the development of two sensors using a multi-project ceramic substrate approach to show how reliability problems are dealt at the outset of the effort.

The sensors are being developed for use in the space program. These sensors arc a part of an integrated instrument set in support of environmental quality and meteorological measurements.

Muti-project Ceramic Substrate

The multi-project ceramic substrate, show in Fig. 1, contains 36 chips with six variants including the sensors, process control and yield monitors, and interconnect chip A higher magnified view of the six variants is shown in Fig. 2. The substrate consists of eight layers including two metal and dielectric layers, a via, resistor, and pad layers. The chips were fabricated using screen printing techniques similar to the procedures used to process hybrid microelectronic thick-film co-fired ceramic substrates [1].

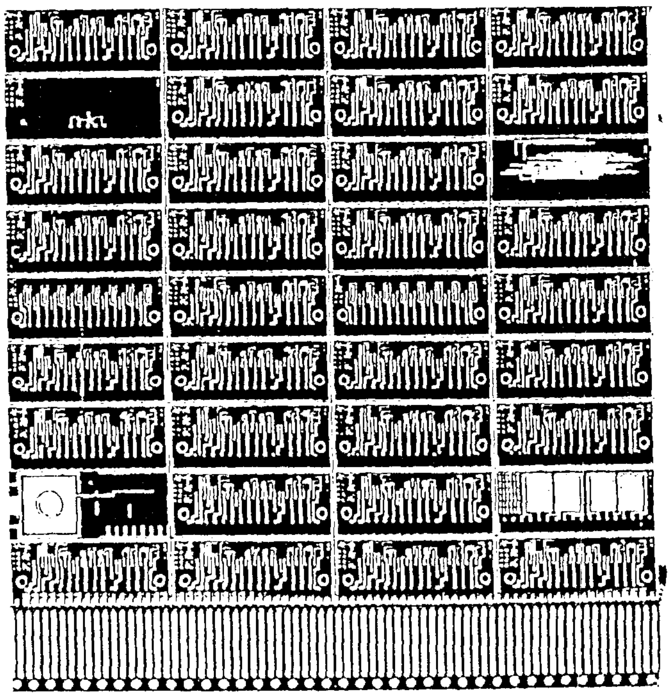

Figure 1 Multi-project co-fired ceramic substrate 9.0 cm x 9,6 cm with a row of electrical contacts shown at the bottom.

"The chips, found on the substrate shown in Fig. 1, were designed with six variants, The variants arc shown in Fig. 2. The chips arc (a) prototype gas SENSOR CHIP, (b) gas sensor TEST CHIP for gas sensor development, (c) YIELD CHIP for pinhole detection between layers and for via continuity tests, (d) ALPHA CHIP is a prototype pressure sensor, (e) PARAMETRIC chip for measuring metal layer sheet and via resistances, and (f) MUX chip for mounting two multiplexer circuits. The

TEST CHIP, was described at ICMTS 1996 [3] and was used to establish the baseline response for the polypyrrole gas sensing layers.

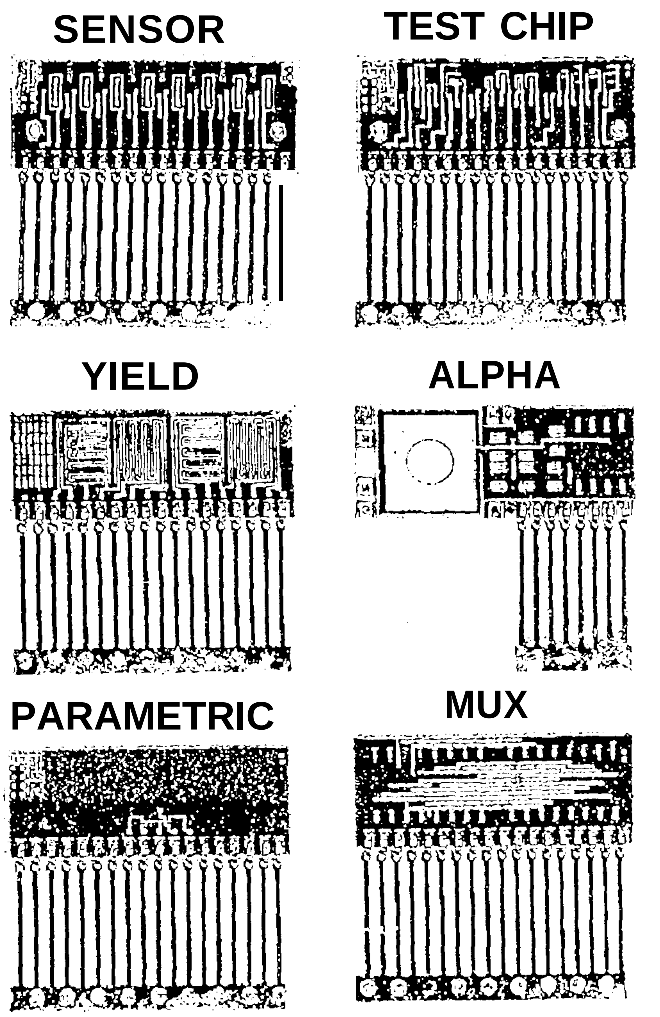

Figure 2. Six chips, 1.0 cm x 2.4 cm, found on the substrate shown in Fig. 1,

Simplified Circuit Diagram

The two sensors developed on this project are viewed as an interaction between the sensor heed with the surround electronics. An equivalent circuit for the surround electronics is shown in Fig. 3 where the sensor resistor is R_X. The extra resistors shown in the figure are potentially reliability problems in that they can detract from the sensor measurement.

The circuit, shown in Fig. 3, highlights several measurements issues that occur in varying edges with the two sensors under development. The characteristic feature of the circuitry is the presence of three nodes; a driven node, a virtual ground node and a ground node. The interfering resistors are: the contact resistor, R_C, the multiplexer (MUX) resistor, R_{mux}, the cross-talk resistor, R_{cross}, and the guard resistor, R_{guard}.

The measurement of R_X follows from $R_X = V/I_X$. This requires that R_C be much smaller than Rx: this was achieved by using Au or Pt electrodes. The MUX resistance, which is between 100 to 1000 Ω, can be neglected since it is small compared with the input impedance of the voltmeter, which exceeds 1 M Ω. The R_{cross} resistance can be ignored when the third terminal is grounded, Finally, the R_{guard} resistance can be ignored because the low impedance of the ammeter provides a low impedance path virtually grounds the virtual ground node,

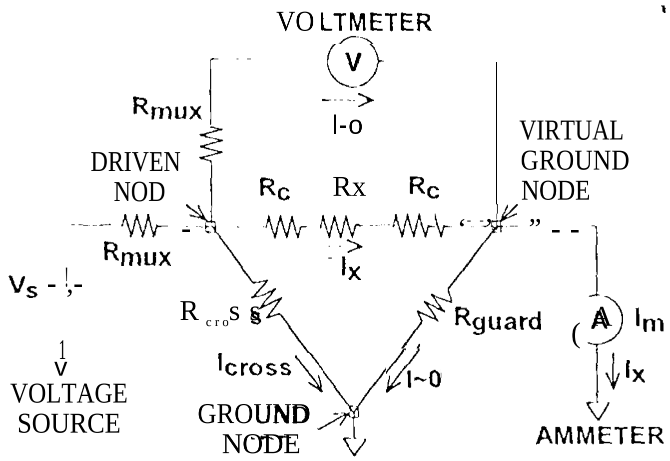

Figure 3. Simplified three-ternlinal circuit for a sensor denoted by R_X.

Gas sensor Development

The gas sensor is being developed as an air quality monitor for the Space Shuttle. The approach consists of fabricating an array of different polymers on a ceramic substrate, Each polymer has its own characteristic response to gases, Gas identification is accomplished by matching the response of the array to an unknown gas to the prerecorded response of the array to a suit of known gases [2].

The challenge in developing the gas sensor is found in the deposition of an array of different polymers, the elimination of the cross talk between the polymers, elimination of pinholes between conducting layers in the chips, reduction of the contact resistance well below the film resistance, and developing water insoluble insulators. The contact resistance is reduced by choosing a.metal such as Au for the electrodes. Pinholes between conducting layer were eliminated by using special processing and water insoluble insulators were designed especially for this application.

The development of the sensor chip is guided by the test chip [3] which consists of a number of electrode configurations as depicted in Fig. 4.

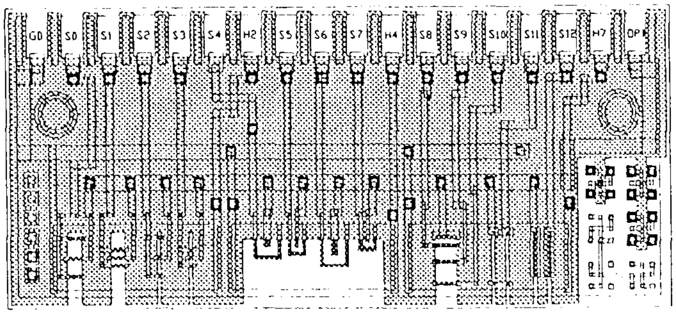

Figure 4. Gas sensor test chip consisting of 13 electrode configurations found at the botton of the chip, Electrical connections are made through the pads located at the top of the chip.

The response of the gas sensor, shown in Fig, 5, indicates (a) that the response is within 15 seconds of the onset of

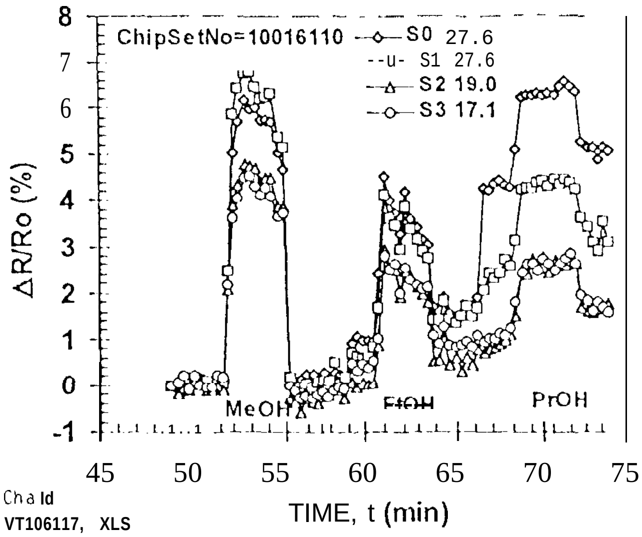

Figure 5. Typical gas sensor response for four sensors, S0, S 1, S2, And S3 seen in Fig. 4 exposed to methanol (MeOH), ethanol (EtOH) and propanol (PrOH) [3].

the gas exposure, (b) that there is a difference in response between the electrode configurations, and (c) that baseline drifts must be accommodated, Thus, the electronics is designed to measure the change in resistance of the films and to track baseline drift.

The gas sensor circuitry, shown in Fig. 6, is designed to measure film resistance changes in the ppm (parts per million) range, to eliminate cross talk between sensors, and to minimize pin count. The architecture of the gas sensor chip, shown in the shaded region of Fig. 6, indicates that one side of each sensor R_{xi} is connected to a common node which is connected to the input terminal of Op Amp U 1, The R_{cross} is eliminated by grounding the sensor nodes on either side of the sensor under test. The ppm detection is achieved by nulling the VSEN signal via V l and amplifying it via Op Amp U2. The signal is digitized via a 12-bit ADC.

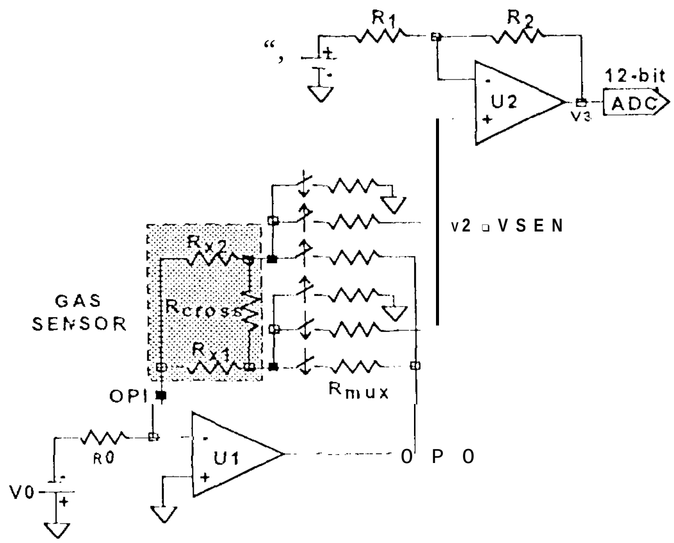

Figure 6. Gas sensor null and amplify circuit.

Pressure Sensor Development

The pressure sensor is being developed to measure the pressure on Mars where the atmosphere is 95 percent CO_2 and varies from 1 to 20 mb over a temperature range of -125 to 30°C. The approach consists of measuring the current from the ionization gage which is proportional to the gas density and hence the pressure at a given atmosphere temperature.

The challenge in developing the pressure sensor is found in measuring ion currents which are in the sub pA range, in developing a sensor to withstand a hard landing of 80,000 g's, and in determining the optimum size for the ion chamber.

The pressure gage, shown schematically in Fig 7, consists of a 1 -μCi Arm241 alpha source which ionizes the gas inside the chamber. The positively ionized gas is drifted to the cathode by an electric field resulting from a 5V potential placed between the anode and cathode. The ion current is fed directly into an Op Amp.

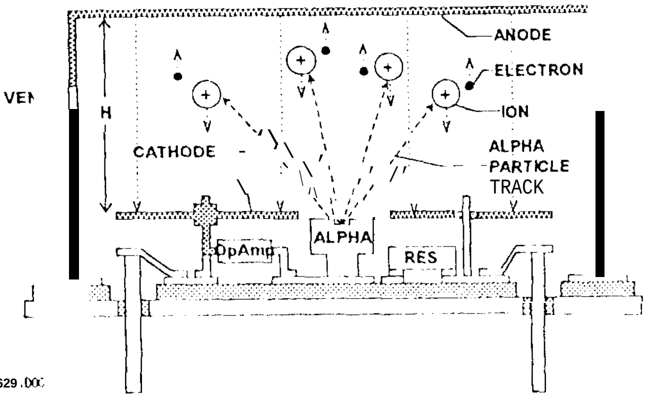

Figure 7. Configuration of the alpha-particle gas-pressure sensor where the distance between the anode and cathode is H [4].

Typical ion currents are shown in Fig. 8 where it is seen that the ion current is proportional to pressure, Note that the ion currents over the Martian pressure range are less than 0.4 pA.

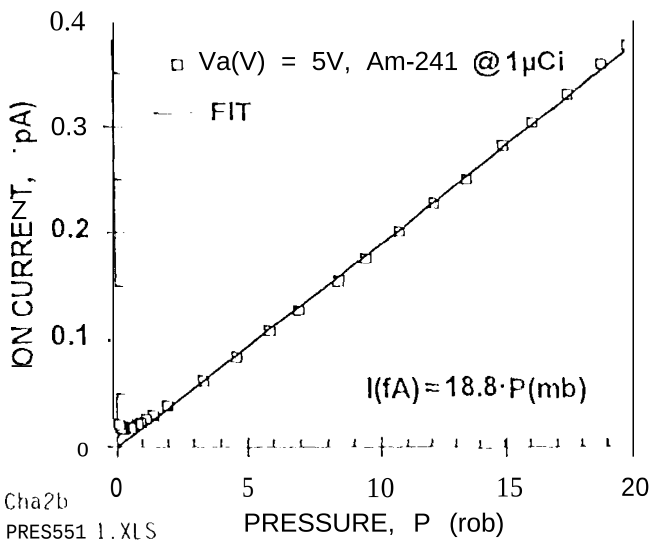

Fig. 8. Pressure gage ion current dependence on pressure where the gas in the chamber is N2 at room temperature [4]

in this effort the appropriate height, H, as seen in Fig. 7 of the anode above the cathode is determined to find the optimum performance for the chamber. in the experiment, the Am-24 1 source was raised (U}') anti lowered (DOWN) above the cathode, As seen in Fig. 9, the optimum height is about 5 mm for an air ambient at room temperature. Further experiments are under way to determine the optimum height for Martian pressures

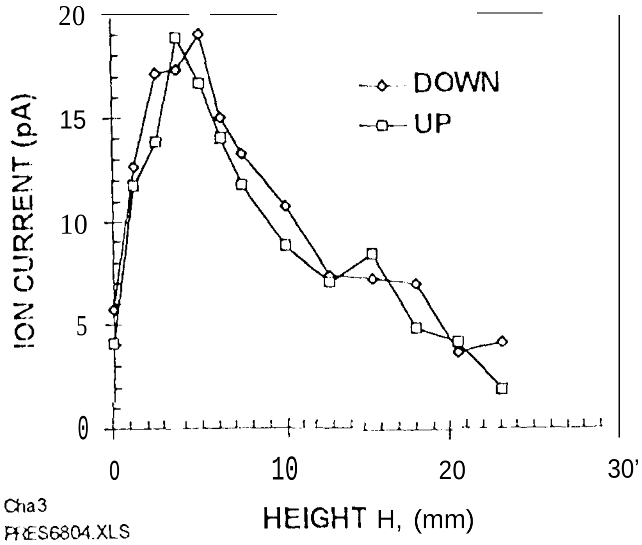

Figure 9. Pressure sensor response to height of Am-241 above the cathode.

The surround circuitry for the ion chamber is shown in Fig. 10. The ion chamber's cathode is connected directly to the input of Op Amp U I which has a very low input current and offset voltage. A T-network [5], composed of RI, R2, and R3, is used to amplify the input signal which is feed into the input of Op Amp U2 which is a follower with gain. The plus input to U2 contains a Sallen-Key 1-117, low pass filter [6] which reduces the random noise component of the ion current.

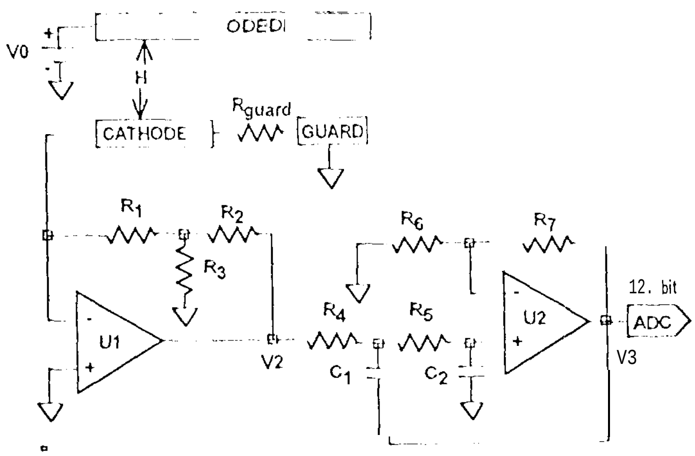

Figure 10. Pressure sensor circuitry showing the T-network is used to amplify the ion chamber current.

The circuitry is capable of measuring currents in the 10 fA range. The input to U 1 is guarded to maintain its 2 fA input current capability.

Conclusions

The development of the two sensors benefited from being simultaneously fabricated on the same multi-project substrate. This meant that the process control chips were in common between the projects and common problems such as pinholes and water soluble insulators were solved jointly. The surround circuitry, though different, had a common feature in the use of the third terminal to eliminate certain unwanted effects by grounding the ground node. In the case of the gas sensor, the third terminal was used to eliminate cross talk between sensors. in the case of the pressure gage, the third terminal was used to eliminate stray currents by guarding the input to the input Op Amp.

Acknowledgments

These efforts were carried out by the Center for Space Microelectronic Technology, Jet Propulsion Laboratory, California institute of '1'ethnology, and was sponsored by NASA Code UL and Code X. The authors are indebted to Dr. A. M. Ryan who is responsible for the chemistry of the gas sensor films. File: rapp6b29.doc

References

1, D. A. Deane and P. D. Franzon, eds. "Multichip Module Technologies and Alternatives: The Basics," Van Nostrand Reinhold (New York, 1993).

2. M. S. Fruend and N. S. Lewis, "A clinically Diverse Conducting Polymer-Based Electronic Nose," Proc. Natl. Academy of Science, Vol. 92,2.652-2656 (1995).

3. M. G. Buehler and M. A. Ryan, "Gas Sensor Test Chips," International Conference on Microelectronic Test Structures, Vol. 9, 105-110 (1996).

4. M. G. Buehler, 1.. D. Bell, and M. H. Hecht, "Alpha-l'article Gas-Pressure Sensor, " Journal of Vacuum Science and q'ethnology, Vol. A 14(3), 1281-1287 (May/June 1996).

5. J, G. Graeme, Photodiode Amplifiers, Op Amp Solutions, McGraw 1 lill (New York, 1996).

6. R. P. Sallen and E. I. Key, "A practical method of designing RC active filters," IRE Trans. Circuit Theory, Vol. CT-2, 74-85 (March 1955).