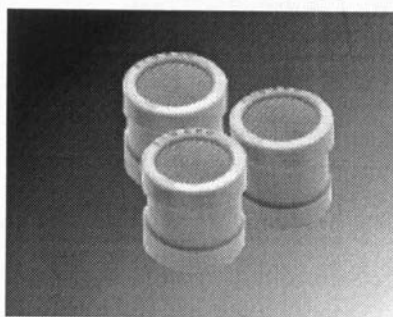


Technical Information for Carbon Dioxide Sensors

The TGS4160 is a new solid electrolyte type sensor which offers miniaturization and long life. The TGS4160 displays high selectivity to carbon dioxide. Also, the TGS4160 displays good long term stability and shows excellent durability against the effects of high humidity through the application of innovative technology in the sensor's electrode design.



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1. Specifications

1-1 Features

- * High selectivity to carbon dioxide
- * Low humidity dependency
- * Small size
- * Long life

1-2 Applications

- * Air quality control
- * Fermentation process control
- * CO₂ gas control for incubators

1-3 Structure

Figure 1 shows the structure of TGS4160. The TGS4160 is a hybrid composed of a carbon dioxide sensing element and an internal thermistor. The CO₂ sensing element consists of a cation (Na⁺) solid electrolyte formed between two electrodes together with a printed heater (Pt) substrate. The cathode (sensing element) consists of lithium carbonate and gold, while the anode (counter electrode) is made of gold. The anode is connected to sensor pin No.3 ("S(+)") while the cathode is connected to pin No.4 ("S(-)"). A Pt heater connected to pins No.1 ("H") and No.6 ("H") heats the sensing element. An internal thermistor connected to pins No.2 and No.5 detects the environmental temperature in order to compensate for the sensor's temperature dependency.

Lead wires are made of Pt at 0.1mm diameter, and these wires are spot welded to nickel pins. The sensor base is made of polyethylene terephthalate reinforced with glass fiber. The internal cover is a double layer of 100 mesh stainless gauze (SUS316). The cover is fastened to the sensor base with a nickel plated brass ring. External housing material consists of reinforced polyamide resin. A layer of 60 Mesh stainless steel gauze (SUS 304) is used for the outside cover. The space between the internal and outer covers is filled with adsorbent (zeolite) for the purpose of reducing the influence of interference gases.

1-4 Operation principle

When the sensor is exposed to CO₂ gas, the following electrochemical reaction occurs:

Cathodic reaction: $2\text{Li}^+ + \text{CO}_2 + 1/2\text{O}_2 + 2\text{e}^- = \text{Li}_2\text{CO}_3$

Anodic reaction: $2\text{Na}^+ + 1/2\text{O}_2 + 2\text{e}^- = \text{Na}_2\text{O}$

Overall chemical reaction:

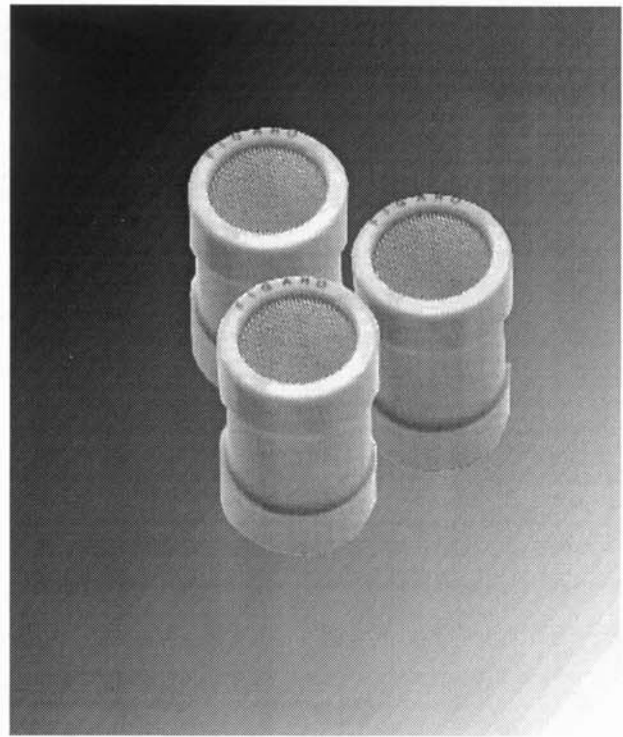


Fig. 1 - Sensor structure

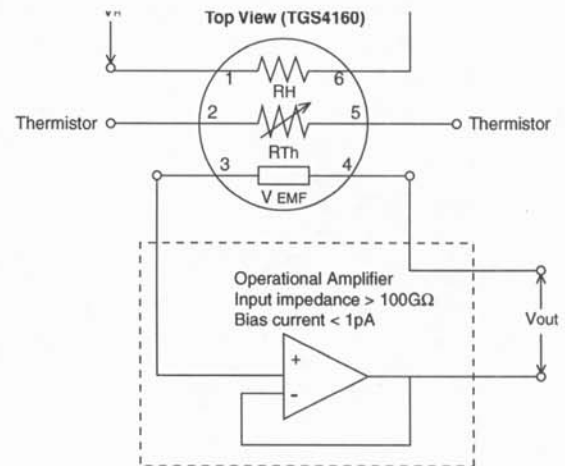


Fig. 2 - Basic measuring circuit

As a result of the electrochemical reaction, electromotive force (EMF) would be generated according to Nernst's equation:

$$EMF = E_c - (R \times T) / (2F) \ln (P(CO_2))$$

where

$P(CO_2)$: Partial pressure of CO_2 ,

E_c : Constant value R : Gas constant

T : Temperature (K) F : Faraday constant

By monitoring the electromotive force (EMF) generated between the two electrodes, it is possible to measure CO_2 .

1-5 Basic measuring circuit

Figure 2 shows the basic measuring circuit for TGS4160. The sensor requires that heater voltage (V_H) be applied to the integrated heater in order to maintain the sensing element at the optimal temperature for sensing. The sensor's EMF should be measured using an operational amplifier with high impedance (more than $100G\Omega$) and low bias current (less than 1 pA) such as Texas Instruments' model No. TLC 271. Since the solid electrolyte type sensor functions as a kind of battery, its absolute EMF value would drift using this basic circuit. However, the change of EMF value (ΔEMF) maintains a stable relationship with the changes in CO_2 concentration. Therefore, in order to obtain an accurate measurement of CO_2 , a special microprocessor for signal processing should be used with TGS4160. A special evaluation sensor module which performs the required signal processing (AM-4) is available from Figaro. See *Technical Information of AM-4* for further details.

1-6 Circuit & operating conditions

The ratings shown below should be maintained at all times to insure stable sensor performance:

Item	Specification
Heater voltage (V_H)	$5.0V \pm 0.2V$ DC
Heater resistance (R_H) - room temp.	$11.5 \pm 1.1\Omega$
Heater current	approx. 250mA
Heater power consumption	approx. 1.25W
Resistance of internal thermistor	$100k\Omega \pm 5\%$
B constant of internal thermistor	$3450 \pm 2\%$
Operating conditions	$-10^\circ C \sim +50^\circ C$, 5 ~ 95%RH
Storage conditions	$-20^\circ C \sim +60^\circ C$, 5 ~ 90%RH
Optimal detection concentration	300 ~ 5,000ppm

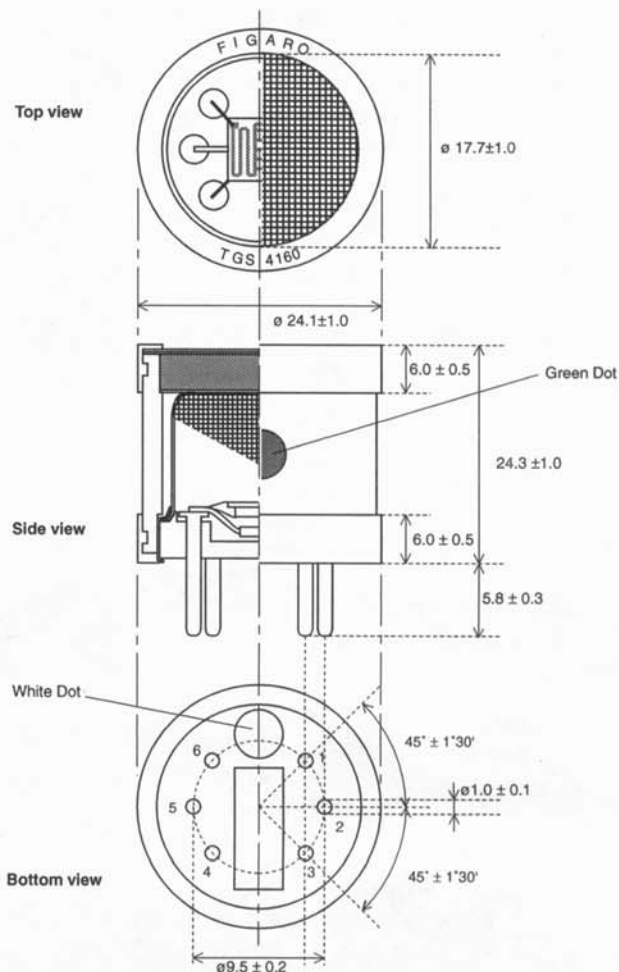


Fig. 3 - Sensor dimensions

NOTE: When the sensor is powered, the typical resistance value of the internal thermistor is around $8.0k\Omega$ due to heat radiated from the heater. Therefore, the change ratio of thermistor resistance (RT/R_{To}) should be used for compensating the temperature dependency of TGS4160 instead of using the absolute resistance value of the internal thermistor.

1-7 Specifications NOTE 1

Item	Specification
EMF in 350ppm of CO_2	220 ~ 490mV
ΔEMF	EMF (350ppm CO_2) - EMF (3500ppm CO_2)
	44 ~ 72mV

NOTE 1: Sensitivity characteristics are obtained under the following standard test conditions:

(Standard test conditions)

Temperature and humidity: $20 \pm 2^\circ C$, 65 \pm 5% RH

Circuit conditions: $V_H = 5.0 \pm 0.05V$ DC

Preheating period: 7 days or more under standard circuit conditions

Mechanical Strength:

The sensor shall have no abnormal findings in its structure and shall satisfy the above electrical specifications after the following performance tests:

Withdrawal Force - withstand force > 5kg in each direction

Vibration - frequency-10~55Hz, amplitude-1.5mm, repeating 1 min. sweep, duration-two hours, x-y-z direction

Shock - acceleration-100G, repeated 3 times, x-y-z direction

1-8 Dimensions (see Fig. 3)

2. Basic Sensitivity Characteristics

2-1 Sensitivity to various gases

Figure 4 represents typical sensitivity characteristics of TGS4160. The Y-axis is indicated as ΔEMF which is defined as follows:

$$\Delta\text{EMF} = \text{EMF}_1 - \text{EMF}_2$$

where

$\text{EMF}_1 = \text{EMF in } 350 \text{ ppm of CO}_2$

$\text{EMF}_2 = \text{EMF in listed gas concentration}$

As shown by Figure 4, TGS4160 exhibits a very good linear relationship between ΔEMF and CO_2 gas concentration on a logarithmic scale. The sensitivity curve to CO_2 shows a sharp increase in ΔEMF as CO_2 concentration increases. In comparison, sensitivity to CO and ethanol ($\text{C}_2\text{H}_5\text{OH}$) are very low as evidenced by the relatively flat slope and low ΔEMF values of the sensitivity curves for these gases.

2-2 Temperature dependency

Figure 5 shows the temperature dependency of TGS4160. These charts demonstrate that while the absolute EMF value increases as the ambient temperature increases, the ΔEMF remains constant regardless of temperature change (actually, ΔEMF changes according to Nernst's law, but the degree of change would be negligible in the operating temperature range of $-10 \sim +50^\circ\text{C}$). As a result, an inexpensive method for compensation of temperature dependency would be to incorporate an internal thermistor in the detection circuit.

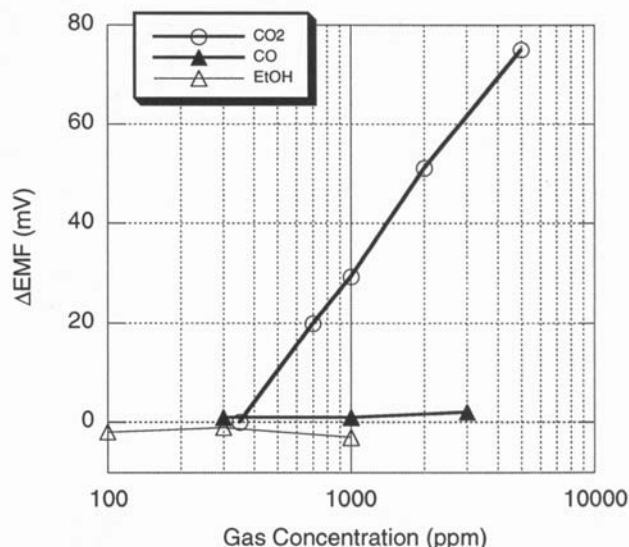


Fig. 4 - Sensitivity to various gases
($\Delta\text{EMF} = \text{EMF in } 350 \text{ ppm CO}_2 - \text{EMF in listed concentration}$)

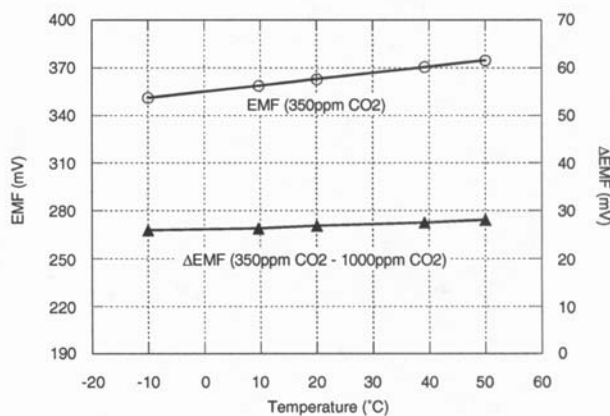


Fig. 5 - Temperature dependency
(Absolute humidity=7.4g H_2O /kg of air)

2-3 Humidity dependency

Figure 6 shows the humidity dependency of TGS4160. As this figure illustrates, the sensor shows very small dependency on humidity for both absolute EMF and Δ EMF values.

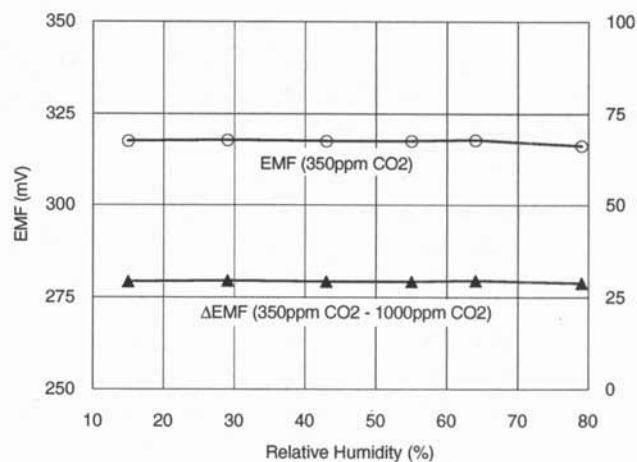


Fig. 6 - Humidity dependency (20°C)

2-4 Heater voltage dependency

Figure 7 shows the change in EMF at 350 ppm of CO₂ according to variations in heater voltage (VH).

Note that 5.0 ± 0.2 V as a heater voltage must be maintained because variation in applied heater voltage will cause the sensor's characteristics to be greatly changed from those shown as typical in this brochure.

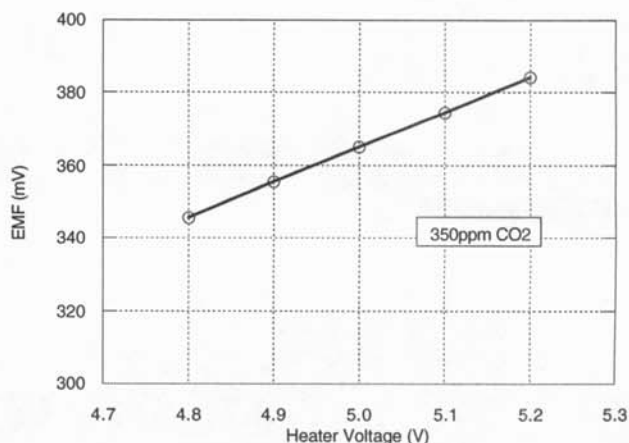


Fig. 7 - Heater voltage dependency

2-5 Gas response

Figure 8 shows the change pattern of absolute EMF values when the sensor is placed into 1,000 and 2,000 ppm of CO₂ for 10 minutes before being returned to normal air. The response time to 90% of the saturated signal level is around two minutes while recovery to 90% of the base level is within 4 minutes.

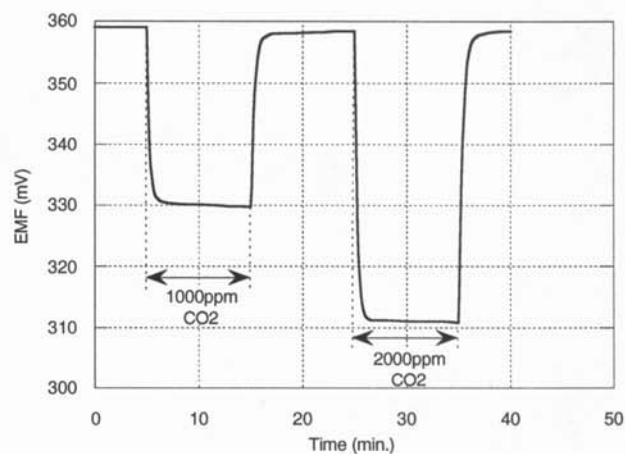


Fig. 8 - Gas response speed

2-6 Initial action

Figure 9 shows typical initial action of the sensor's EMF. For purposes of this test, the sensor was stored unenergized in normal air for two months after which it was energized in clean air.

After energizing, the sensor's EMF increases regardless of the presence of gas, reaching to 99% of its final value in less than 10 minutes. Since the sensor's EMF value is less than 99% of its final value during the first 10 minutes, a special signal processing method (such as that described in *Technical Information for AM-4*) should be incorporated into applications using TGS4160 in order to prevent faulty function of the user's device during this period.

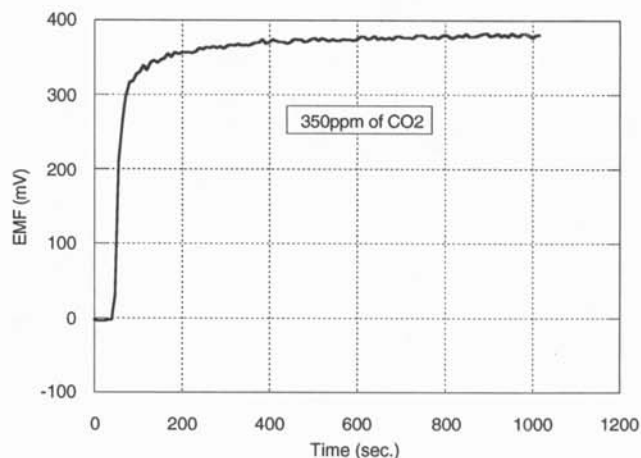


Fig. 9 - Initial action

2-7 Long-term characteristics

Figure 10a shows long-term stability data for TGS4160. The test samples were energized in normal air and under standard circuit conditions. These charts illustrate that while the absolute EMF values displayed a slight decrease over time, Δ EMF values show stable characteristics for more than 800 days.

Figure 10b shows the influence of unenergized storage on the sensor's long term stability. Test samples were stored unpowered in room air for more than 300 days. Sensors were intermittently measured under standard test conditions (20°C/65%RH) during the test. This chart also demonstrates that while absolute EMF values slightly decrease over time, Δ EMF shows stability for over 300 days.

As the charts presented in this section illustrate, Δ EMF shows stable long term characteristics.

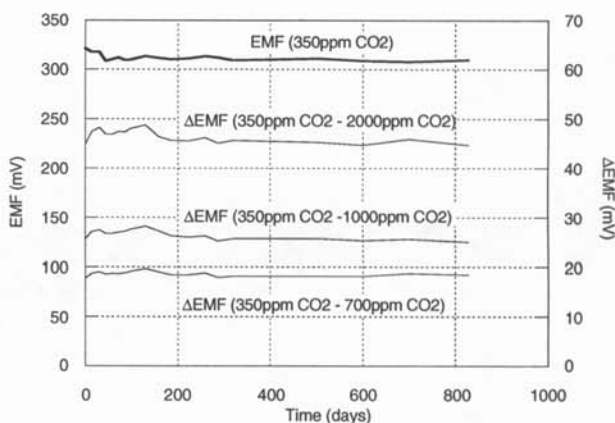


Fig. 10a - Long term stability

2-8 Life expectancy

The end of life for TGS4160 occurs when:

- Absolute EMF value in clean air drops to 100mV after energizing in clean air for 24 hours.
- Δ EMF (350ppm vs 3500ppm of CO₂) drops to less than 30mV regardless of absolute EMF in clean air.

The life expectancy of TGS4160 strongly depends on circuit and environmental conditions. By extrapolating the data in Figure 10a, the life expectancy of TGS4160 is approximately 2,000 days with continuous energizing at room temperature.

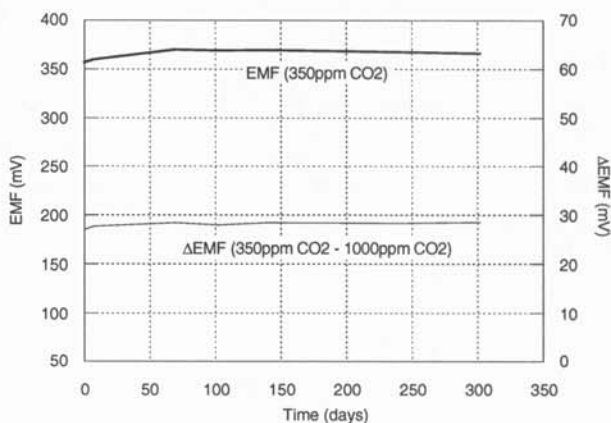


Fig. 10b - Effects of unpowered storage on long term stability

3. Reliability

3-1 Gas exposure test

Figure 11 shows the effect on sensor characteristics of various gases. Sensors were energized and the Δ EMF value (air vs 1000ppm of CO₂) prior to gas exposure was measured. After the exposure in gases in 100 ppm of the test gas for 24 hours, the sensor was removed from the test gas and energized in normal air. After one hour elapsed, the CO₂ characteristics was again measured.

As these tests demonstrate, care should be taken to minimize exposure to some kinds of gases (such as chlorine compounds) which lower the sensor's sensitivity.

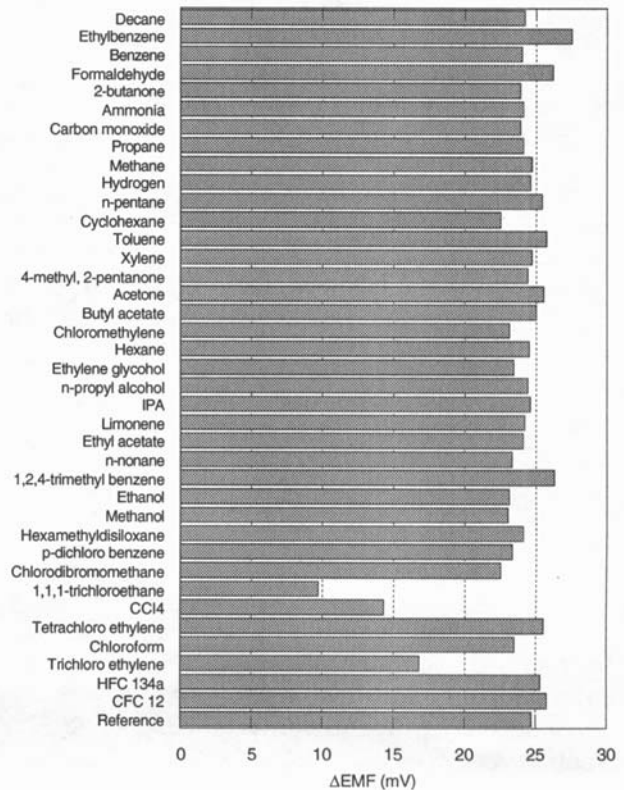


Fig. 11 - Effect on Δ EMF of exposure to other gases (Δ EMF = EMF (air - 1000ppm CO₂))

3-2 High temperature/humidity test

To show the ability of TGS4160 to withstand the effects of high temperature and humidity, the sensor was subjected to a test condition of 40°C/80%RH. Unenergized test samples were subjected this condition for 1000 hours and then samples were measured under standard test conditions (20°C/65%RH).

Figure 12 shows that the TGS4160 maintains stable characteristics even if the sensor is used in high temperature and humidity conditions.

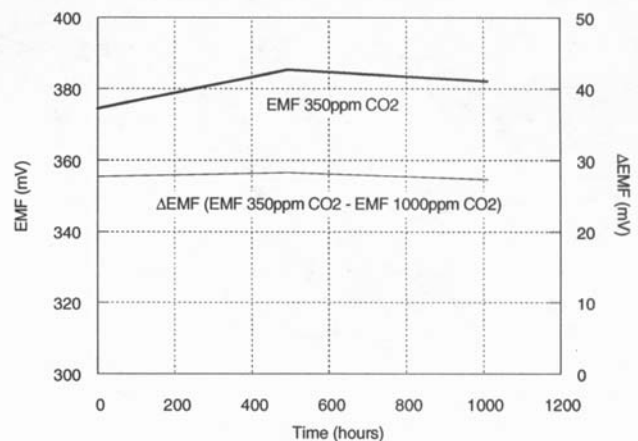


Fig. 12 - High temperature and humidity test

3-3 Heat cycle test

Figure 13 shows the effect of subjecting the TGS4160 to a heat cycle test. Unenergized sensors were subjected to a cycle of -25°C for 30 minutes followed by 85°C for 30 minutes, with this cycle being repeated more than 100 times. The sensors were intermittently measured under standard test conditions ($20^{\circ}\text{C}/65\%\text{RH}$) during the test.

As these test results show, TGS4160 has sufficient durability against the severity of heat cycle conditions.

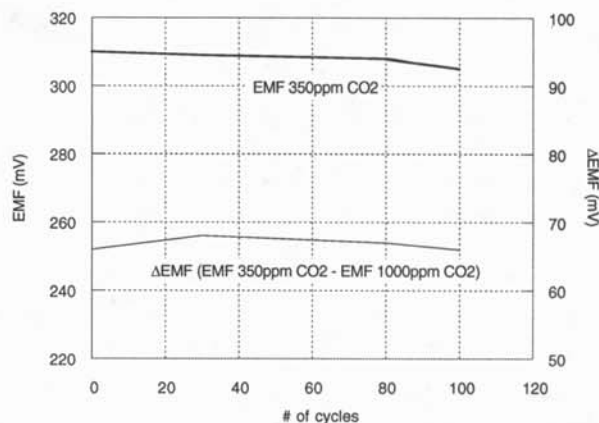


Fig. 13 - Effect of heat cycle testing

3-4 Low temperature test

Figure 14 shows the results of exposing TGS4160 to severe low temperature. Unenergized sensors were subjected to conditions of -20°C for 1,000 hours. Sensors were intermittently measured under standard test conditions ($20^{\circ}\text{C}/65\%\text{RH}$) during the test.

As these test results show that there is almost no influence by low temperatures on the sensitivity characteristics of TGS4160.

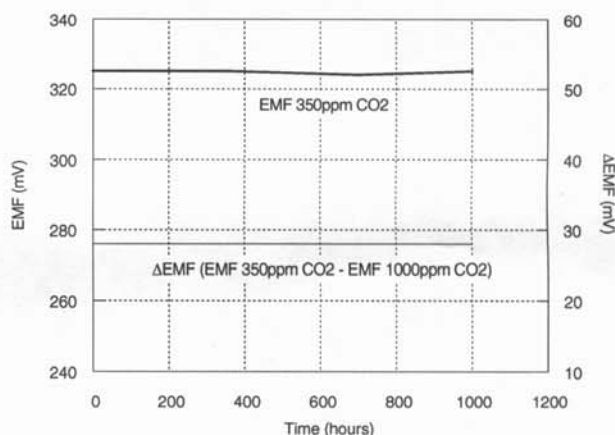


Fig. 14 - Effect of low temperature exposure

3-5 Heater on-off cycle test

If the TGS4160 would be used for indoor air quality monitoring or a portable CO₂ monitor, the sensor would be powered on and off frequently. To simulate such conditions, the sensor was subjected to a heater on-off cycle by applying the specified heater voltage (5.0V) to the sensor for 1 hour, then being powered off for 1 hour. Samples were subjected to this cycle 1500 times. Sensors were intermittently measured under standard test conditions ($20^{\circ}\text{C}/65\%\text{RH}$) during the test.

As Figure 15 shows, cycling the heater on and off demonstrates that heater on-off does not result in any appreciable change in the sensor's sensitivity characteristics.

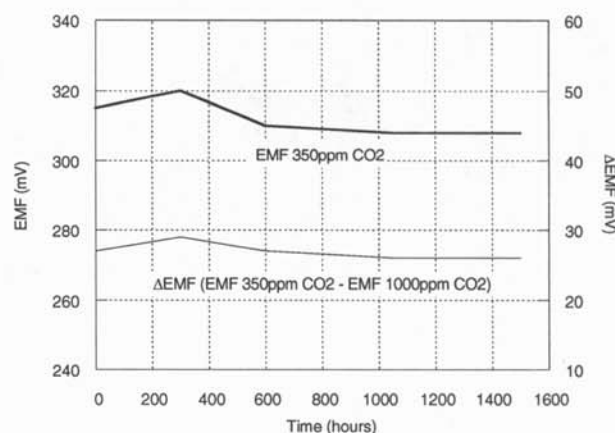


Fig. 15 - Effect of heater on-off testing

3-6 Ethanol exposure test

To eliminate the influence of interference gases such as an ethanol vapor, a zeolite filter is installed in the cap of TGS4160. To demonstrate the effectiveness of the zeolite filter, the sensor was exposed in 3% of ethanol gas for a period of 600 days. During this test, ΔEMF values of ethanol were measured. ΔEMF is defined as follows:

$$\Delta\text{EMF} = \text{EMF1} - \text{EMF2}$$

where

EMF1 = EMF in 350ppm CO₂

EMF2 = EMF in 350 ppm CO₂ and 300ppm EtOH

The results of the above test are shown in Figure 16. As the stable ΔEMF values show, the zeolite filter has sufficient ability to eliminate the influence of interference gases over an extended period of time.

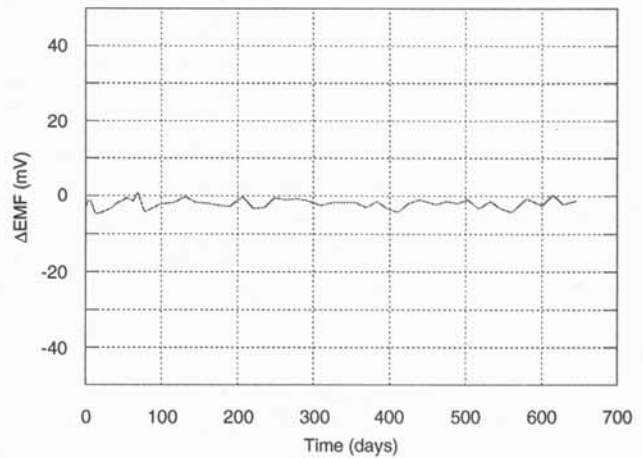


Fig. 16 -Effect of ethanol exposure

3-7 Effect of exposure to high CO₂ concentration

Figure 17 shows the sensor characteristics of TGS4160 in high concentrations of CO₂. This data suggests that TGS4160 can detect CO₂ in excess of 100000ppm. However, it should be noted that the ΔEMF values would likely deviate from their initial values after exposure to high concentrations of CO₂. This would occur due to a shift in the chemical equilibrium between the sensing electrode and CO₂ gas.

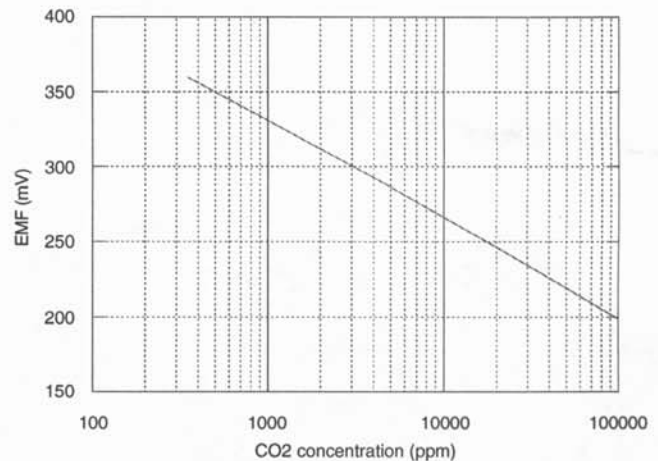


Fig. 17 - Effect of exposure to high CO₂ concentrations

4. Notes

The following cautions regarding storage and installation of TGS4160 should be observed to prevent permanent damage to the sensor:

- 1) Install/store indoors, avoiding dew condensation, silicone vapor, and exposure to alkaline metals (Na, Li, etc.).
- 2) Avoid places where vibration or mechanical shock may occur.
- 3) The sensor should not be stored in high humidity or temperature conditions. Sensors should be stored in an aluminum-coated sealing bag together with desiccant.
- 4) The sensor should be mounted on circuit board using manual soldering.

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