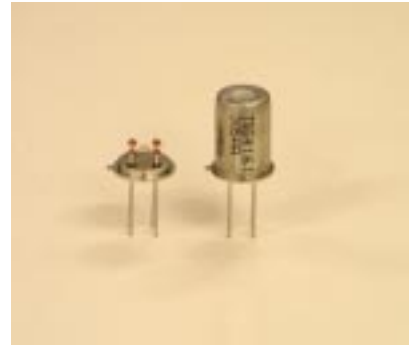


FIGARO

an ISO9001 company

Technical Information for Carbon Dioxide Sensors

The Figaro TGS4161 is a new solid electrolyte type sensor which offers miniaturization, low power consumption, and long life. The TGS4161 displays high selectivity to carbon dioxide. Also, the TGS4161 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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IMPORTANT NOTE: OPERATING CONDITIONS IN WHICH FIGARO SENSORS ARE USED WILL VARY WITH EACH CUSTOMER'S SPECIFIC APPLICATIONS. FIGARO STRONGLY RECOMMENDS CONSULTING OUR TECHNICAL STAFF BEFORE DEPLOYING FIGARO SENSORS IN YOUR APPLICATION AND, IN PARTICULAR, WHEN CUSTOMER'S TARGET GASES ARE NOT LISTED HEREIN. FIGARO CANNOT ASSUME ANY RESPONSIBILITY FOR ANY USE OF ITS SENSORS IN A PRODUCT OR APPLICATION FOR WHICH SENSOR HAS NOT BEEN SPECIFICALLY TESTED BY FIGARO.

1. Basic Information and Specifications

1-1 Features

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

1-2 Applications

- * Air quality control

1-3 Structure

Figure 1 shows the structure of TGS4161. The CO₂ sensing element consists of a cation (Na⁺) solid electrolyte formed between two electrodes together with a printed heater (RuO₂) 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.2 ("S(-)"). A RuO₂ heater connected to pins No.1 ("H") and No.4 ("H") heats the sensing element. Lead wires are made of Pt and are connected to nickel pins.

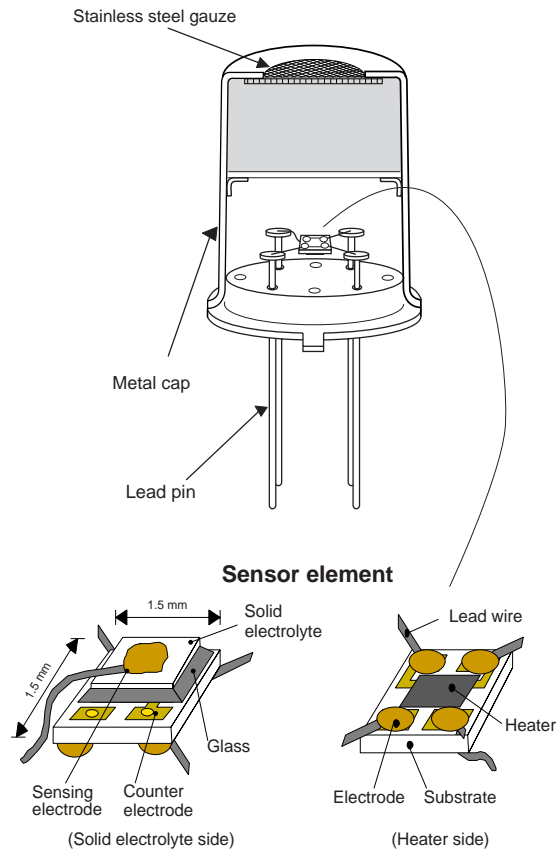
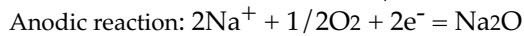


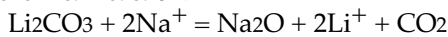
Fig. 1 - Sensor structure

1-4 Operation principle

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



Overall chemical reaction:



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

$$\text{EMF} = E_c - (R \times T) / (2F) \ln (P(\text{CO}_2))$$

where

P(CO₂): Partial pressure of CO₂,

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 CO₂.

1-5 Basic measuring circuit

Figure 2 shows the basic measuring circuit for TGS4161. 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

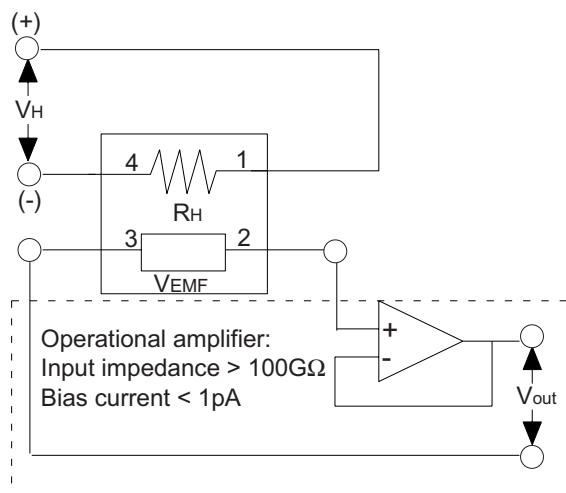


Fig. 2 - Basic measuring circuit

NOTE: Pins 1 and 4 must be connected as shown in the drawing because of the specific polarity of V_H.

measured using an operational amplifier with high impedance (more than 100GΩ) 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 (Δ EMF) maintains a stable relationship with the changes in CO₂ concentration. Therefore, in order to obtain an accurate measurement of CO₂, a special microprocessor for signal processing should be used with TGS4161. A special evaluation sensor module which performs the required signal processing (AM-4-4161) is available from Figaro. See *Technical Information of AM-4-4161* 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 (VH) | 5.0V ± 0.2V DC |
| Heater resistance (RH) - room temp. | 70±7Ω |
| Heater current | approx. 50mA |
| Heater power consumption | approx. 250mW |
| Operating conditions | -10°C ~ +50°C, 5 ~ 95%RH |
| Storage conditions | -20°C ~ +60°C, 5 ~ 90%RH (store in a moisture proof bag with silica gel) |
| Optimal detection concentration | 350 ~ 5,000ppm |

1-7 Specifications NOTE 1

| Item | Specification |
|----------------------------------|--|
| EMF in 350ppm of CO ₂ | 220 ~ 490mV |
| Δ EMF | EMF (350ppmCO 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 ± 2°C, 65 ± 5% RH

Circuit conditions: VH = 5.0±0.05V DC

Preheating period: 12 hours or more under standard circuit conditions

1-8 Dimensions (see Fig. 3)

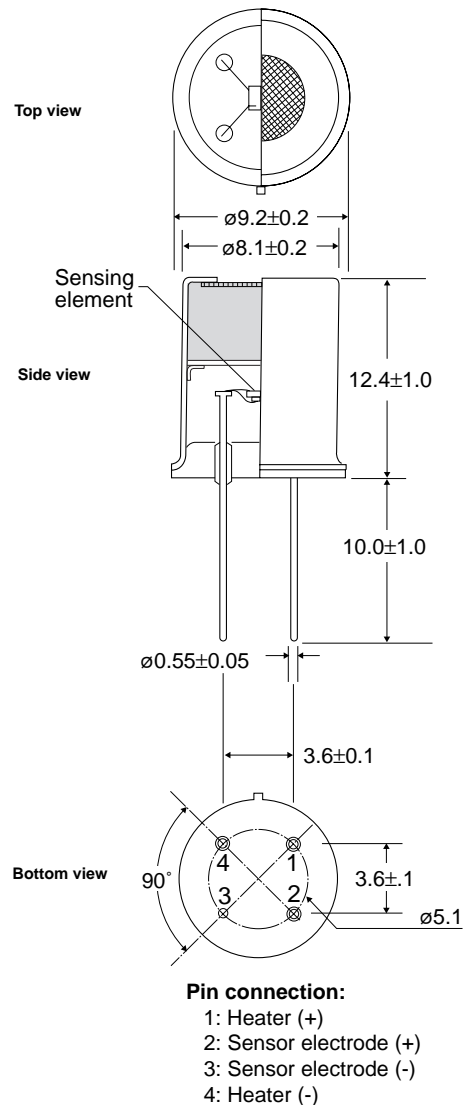


Fig. 3 - Sensor dimensions

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 of 5kg in each (pin from base) direction

Vibration - frequency-5~400Hz, amplitude-10mm, repeating 15 min. sweep, duration-two hours, x-y-z direction

Shock - acceleration-100G, repeated 5 times, x-y-z direction

2. Typical Sensitivity Characteristics

2-1 Sensitivity to various gases

Figure 4 represents typical sensitivity characteristics of TGS4161. The Y-axis is indicated as Δ EMF which is defined as follows:

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

where
 $\text{EMF}_1 = \text{EMF in } 350 \text{ ppm of } \text{CO}_2$
 $\text{EMF}_2 = \text{EMF in listed gas concentration}$

As shown by Figure 4, TGS4161 exhibits a very good linear relationship between Δ EMF and CO_2 gas concentration on a logarithmic scale. The sensitivity curve to CO_2 shows a sharp increase in Δ EMF 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 Δ EMF values of the sensitivity curves for these gases.

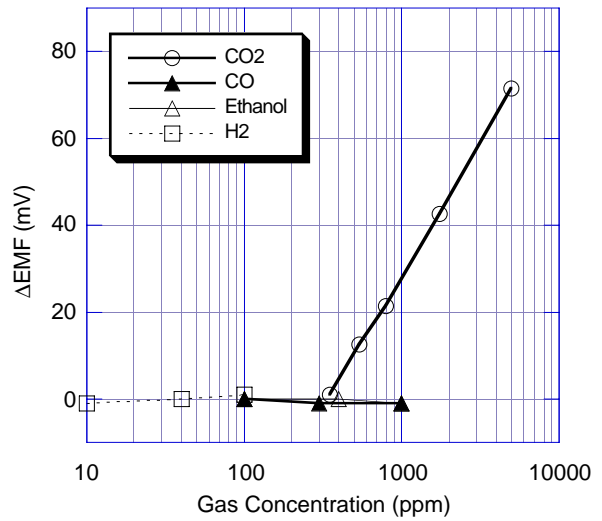


Fig. 4 - Sensitivity to various gases (Δ EMF = EMF in 350ppm CO_2 - EMF in listed concentration)

2-2 Temperature dependency

Figure 5 shows the temperature dependency of TGS4161. These charts demonstrate that while the absolute EMF value increases as the ambient temperature increases, the Δ EMF remains constant regardless of temperature change (actually, Δ EMF 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.

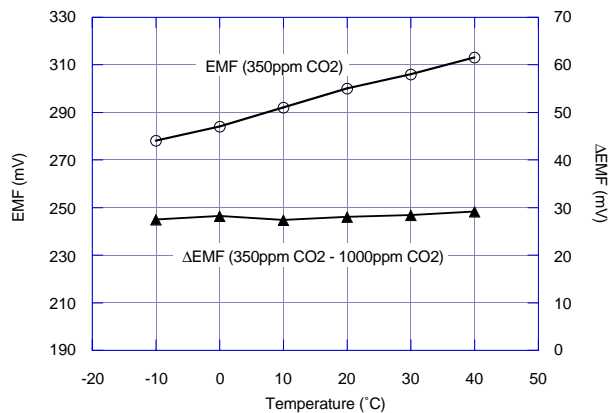


Fig. 5 - Temperature dependency (Absolute humidity=7.4g H_2O /kg of air)

2-3 Humidity dependency

Figure 6 shows the humidity dependency of TGS4161. As this figure illustrates, the sensor shows very small dependency on humidity for both absolute EMF and Δ EMF values.

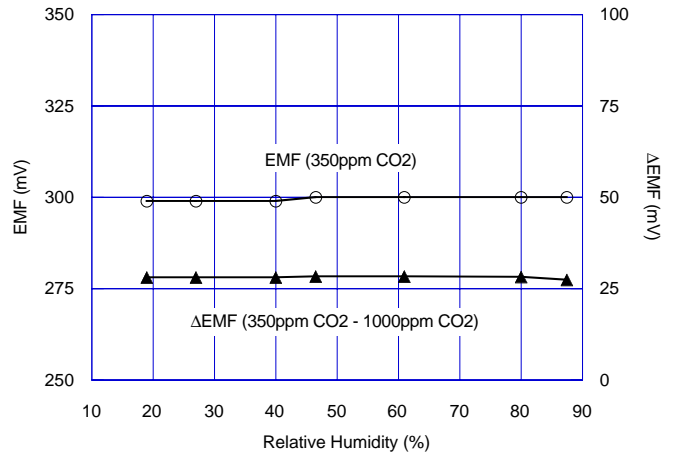


Fig. 6 - Humidity dependency (20°C)

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.

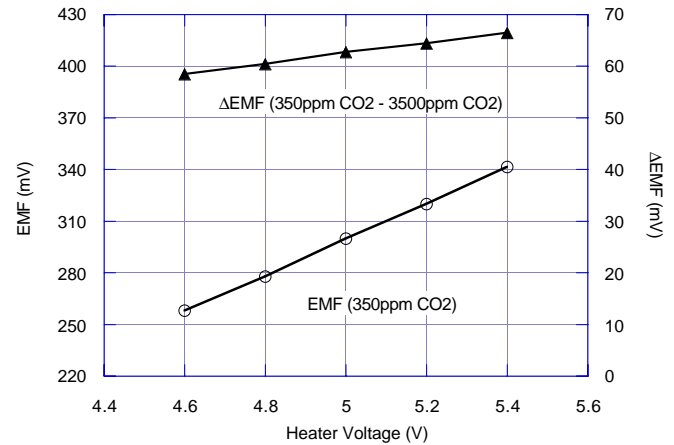


Fig. 7 - Heater voltage dependency

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 level of Δ EMF (350ppmCO₂-1000ppm/2000ppm CO₂) is around 1.5 minutes while recovery to 90% of the base level is around 2.5 minutes.

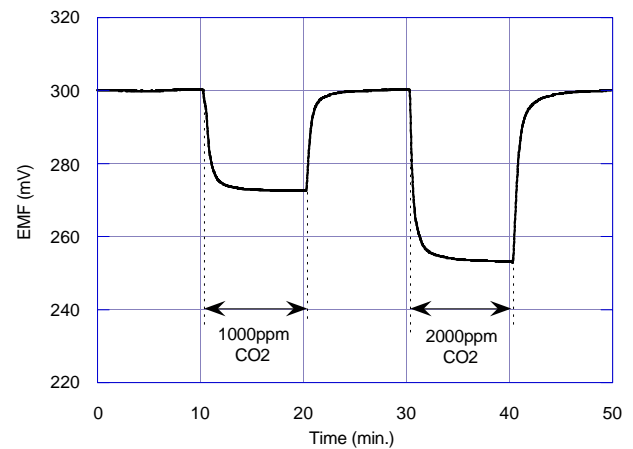


Fig. 8 - Gas response speed

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 one month 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 15 minutes.

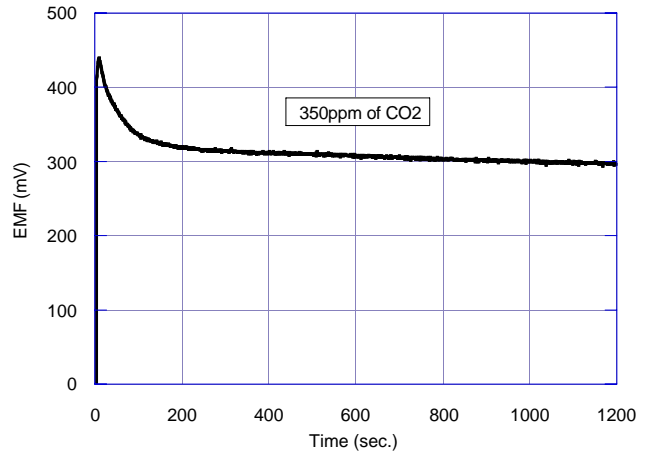


Fig. 9 - Initial action

2-7 Long-term characteristics

Figure 10a shows long-term stability data for TGS4161. 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 1000 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 150 days.

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

2-8 Life expectancy

The end of life for TGS4161 occurs when:

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

The life expectancy of TGS4161 strongly depends on circuit and environmental conditions. By extrapolating the data in Figure 10a, the life expectancy of TGS4161 is more than 10 years with continuous energizing at room temperature.

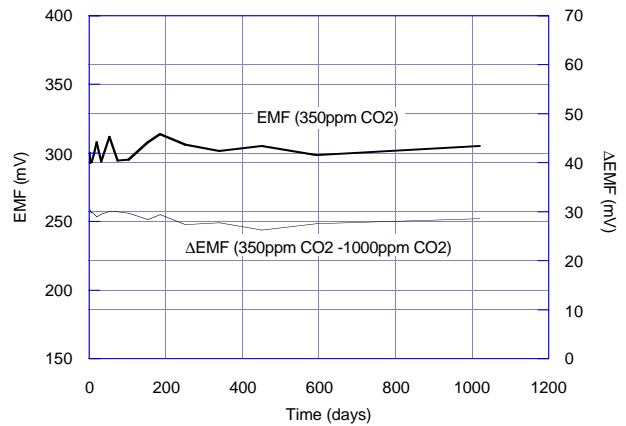


Fig. 10a - Long term stability

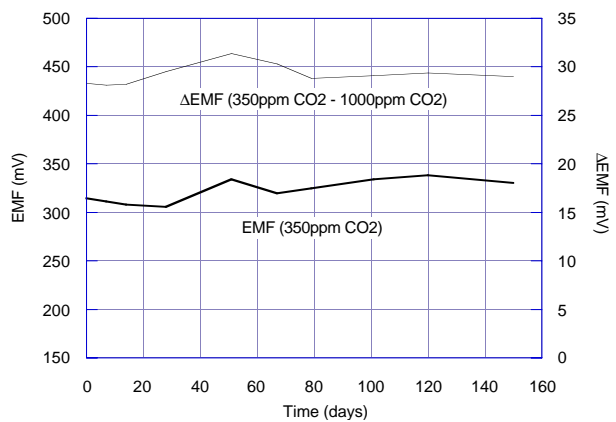


Fig. 10b - Effects of unpowered storage on long term stability

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.

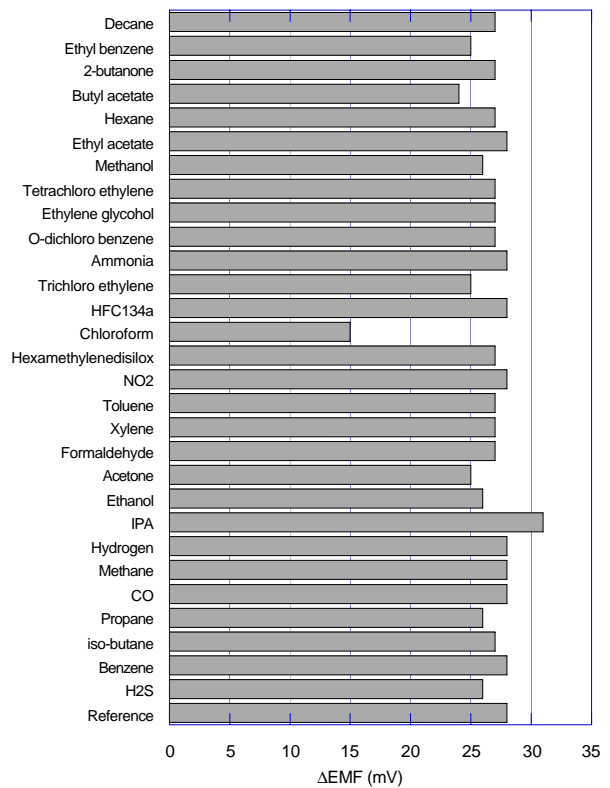


Fig. 11 - Effect on Δ EMF of exposure to other gases (Δ EMF = EMF (air - 1000ppm CO₂))

3-2 High temperature/humidity test

To show the ability of TGS4161 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 150 days and then samples were measured under standard test conditions (20°C/65%RH).

Figure 12 shows that the TGS4161 maintains stable characteristics even if the sensor is used in high temperature and humidity conditions.

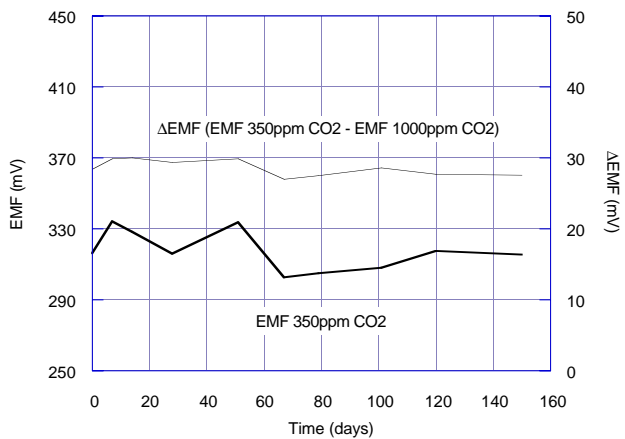


Fig. 12 - High temperature and humidity test

3-3 Heat cycle test

Figure 13 shows the effect of subjecting the TGS4161 to a heat cycle test. Unenergized sensors were subjected to a cycle of -30°C for 30 minutes followed by 80°C for 30 minutes, with this cycle being repeated more than 2000 times. The sensors were intermittently measured under standard test conditions (20°C/65%RH) during the test.

As these test results show, TGS4161 has sufficient durability against the severity of heat cycle conditions.

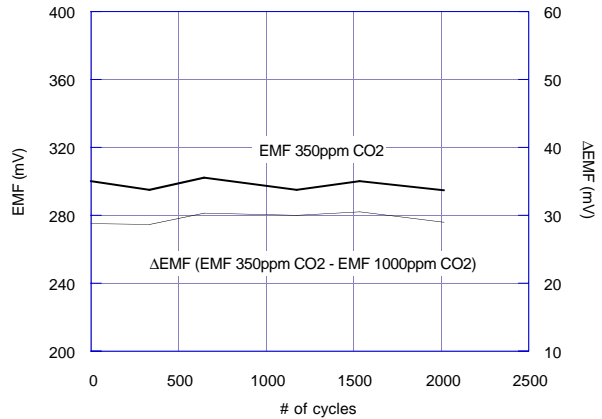


Fig. 13 - Effect of heat cycle testing

3-4 Low temperature test

Figure 14 shows the results of exposing TGS4161 to severe low temperature. Unenergized sensors were subjected to conditions of -40°C for 2,200 hours. Sensors were intermittently measured under standard test conditions (20°C/65%RH) during the test.

These test results show that there is almost no influence by low temperatures on the sensitivity characteristics of TGS4161.

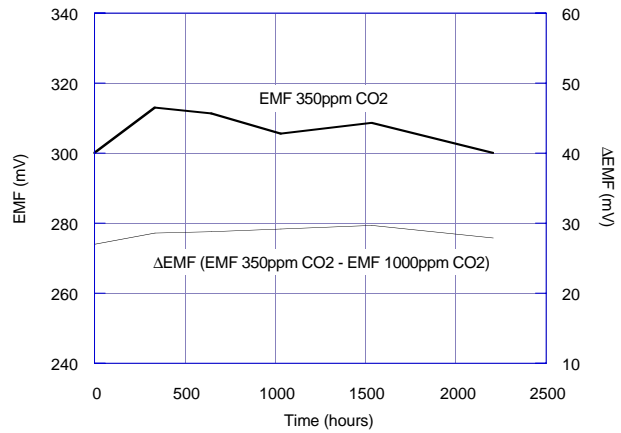


Fig. 14 - Effect of low temperature exposure

3-5 High temperature test

Figure 15 shows the results of exposing TGS4161 to severe high temperature. Unenergized sensors were subjected to conditions of 110°C for 2,000 hours. Sensors were intermittently measured under standard test conditions (20°C/65%RH) during the test.

As these test results show, stable CO2 sensitivity can be expected even if the sensor is exposed to high temperature extremes.

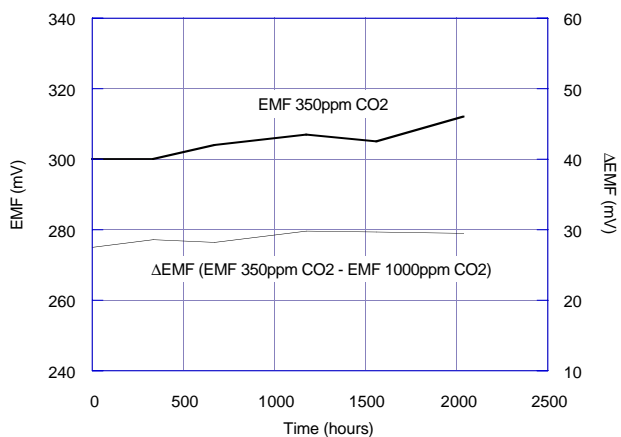


Fig. 15 - Effect of high temperature exposure

3-6 Heater on-off cycle test

If the TGS4161 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 minute, then being powered off for 1 minute. Samples were subjected to this cycle 30,000 times. Sensors were intermittently measured under standard test conditions (20°C/65%RH) during the test.

As Figure 16 shows, cycling the heater on and off demonstrates that while the value of EMF goes down a bit, the Δ EMF is minor and very stable. In addition, no breakage of the heater wire results from this test.

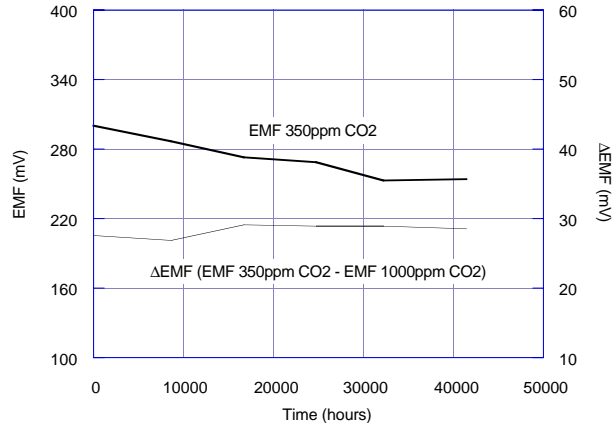


Fig. 16 - Effect of heater on-off testing

4. Cautions

4-1 Situations which must be avoided

1) Exposure to silicone vapors

If silicone vapors adsorb onto the sensor's surface, the sensing material will be coated, irreversibly inhibiting sensitivity. Avoid exposure where silicone adhesives, hair grooming materials, or silicone rubber/putty may be present.

2) Storage in high humidity conditions

A drift in characteristics such as a decrease in EMF and slower response speed may occur if the sensor is stored in a highly humid environment. The sensor should be stored in a sealed aluminum coated bag together with silica gel.

3) Water condensation

A drift in characteristics may occur if water condenses on the sensor's surface. If powered while condensation exists on the sensor's surface, sensor breakage may occur.

4) Usage of low impedance measuring device

The sensor functions like a battery when power is applied on the built-in heater. Accordingly, errors due to drop of output voltage can be expected if output is measured by a meter with low impedance. A buffer circuit with an op-amp, of which the impedance should be greater than 100G Ω , is suggested for measuring output (EMF).

5) Highly corrosive environment

High density exposure to corrosive materials such as H₂S, SO_x, Cl₂, HCl, etc. for extended periods may cause corrosion or breakage of the lead wires or heater material.

6) Contamination by alkaline metals

Sensor drift may occur when the sensor is contaminated by alkaline metals, especially Li. This may also happen if the sensor is exposed to inorganic elements.

7) Contact with water

The sensor's characteristics may drift if the sensor gets wet. If powered while wet, sensor breakage may occur.

8) Freezing

If water freezes on the sensing surface, the sensing material would crack, altering characteristics.

9) Application of excessive voltage

If higher than specified voltage is applied to the sensor or the heater, lead wires and/or the heater may be damaged or sensor characteristics may drift, even if no physical damage or breakage occurs.

10) Excessive exposure to organic solvents

If TGS4161 is exposed to high concentrations of organic solvents such as alcohol for a long period of time, the filter may become saturated. In this case, the sensor would show higher sensitivity to alcohol than that indicated in Figure 4.

4-2 Situations to be avoided whenever possible

1) Vibration

Excessive vibration may cause the sensor or lead wires to resonate and break. Usage of compressed air drivers/ultrasonic welders on assembly lines may generate such vibration, so please check this matter.

2) Shock

Breakage of lead wires may occur if the sensor is subjected to a strong shock.

3) Soldering

The sensor should be mounted on a circuit board using manual soldering.

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