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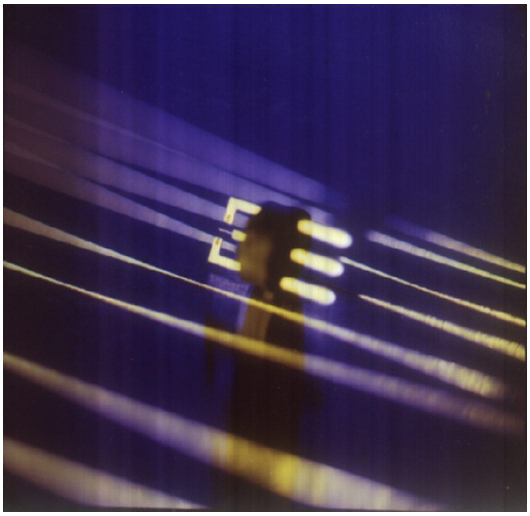
INFORMATION

RELIABILITY and TECHNICAL DATA of FIS GAS SENSOR

SB-42A-11 for Hydrogen Detection



Introduction

This technical information explains some basic technical background and related information concerning the reliability of FIS gas sensor SB series/SB-42A-11.

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FIS INTELLIGENT SENSORS

PART-1: General

1. Background

1.1. Structure

Fig 1 shows the structure of the SB series gas sensing element, gas sensor unit (internal housing), and the complete SB-42A-11 with external filter housing.

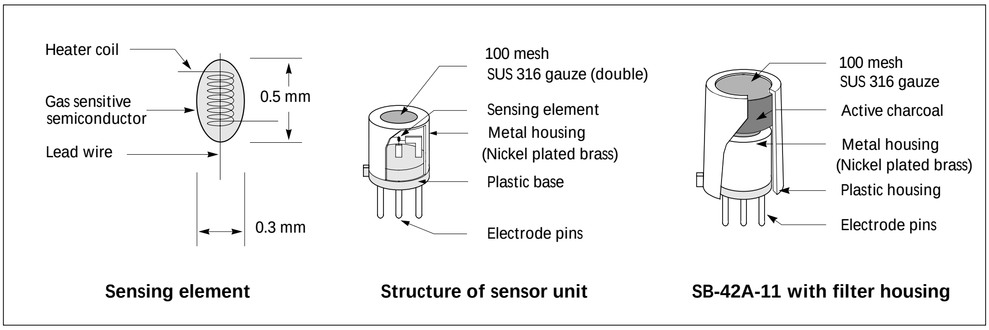


Fig 1. Structure of SB-42A-11 sensor **Fig 1b. SB series: Sensing element**

1.2. Tin dioxide gas sensor

The FIS SB series is a tin-dioxide (SnO_2) semiconductor gas sensor. In all models, a specially developed SnO_2 poli-crystal powder has been used. This special tin-dioxide material has various advantages as a gas sensing material as follows:

- Good stability in chemical and thermo-dynamical characteristics.
  - melting point: over 1600 ¡C
  - single crystal phase
  - low activity in the sintering of SnO_2 crystal
  - strong resistance against poisoning effects
- High activity in gas detection characteristics from low temperatures (below 450…C) with high sensitivity to gases without dopant.

Based on these characteristics, high reliability in gas detection is obtained over a long period. This is because changes in the basic characteristics of sensing material rarely happens.

Fig 2 shows some technical background such as microscopic structures and sensing mechanism of SnO_2 gas sensors.

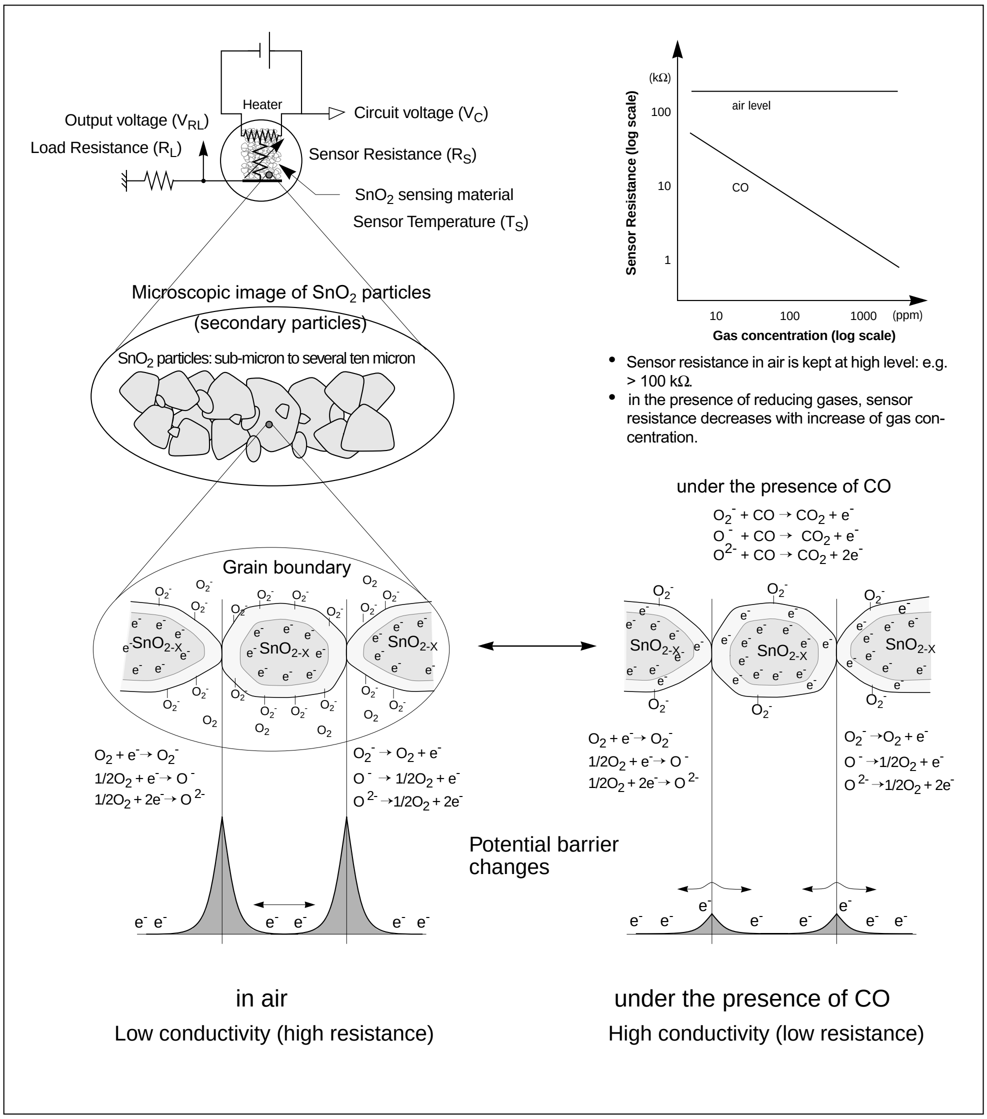


Fig 2. Schematic diagram

Background

1.3. Effect of additives

The sensitivity characteristics of SnO_2 gas sensors are controlled by adjusting the activity of sensing materials and by finding suitable combinations between the characteristics of sensing materials and operating temperature. To control the activity of sensing materials, small amounts of oxidation catalysers and/or other dopant have been applied (e.g. Pd, Pt, etc.). Fig 3 shows the different sensor temperature dependency of sensitivity characteristics curves between different sensing materials, with 0.1 wt% Pd and with 1.0 wt% Pd. As shown in these figures, the effect of added Pd reduces the sensitivity to oxidising gases. Based on this principle, the sensitivity of SnO_2 gas sensors increases (sensor resistance level decreases) if the activity of additives decreases for any reason. Therefore, the SnO_2 gas sensors have fail-safe characteristics in long term operation.

Each model has been developed to find optimum conditions of sensing material (production conditions of tin-dioxide, amount of additives, etc.) and operating temperature. The following parameters have been considered in the development of each model.

- Sensitivity characteristics
  - Sensor resistance
  - Sensor resistance change ratio
  - Cross sensitivity
  - Sensor temperature dependency
  - Response speed
- Initial action
- Long term stability

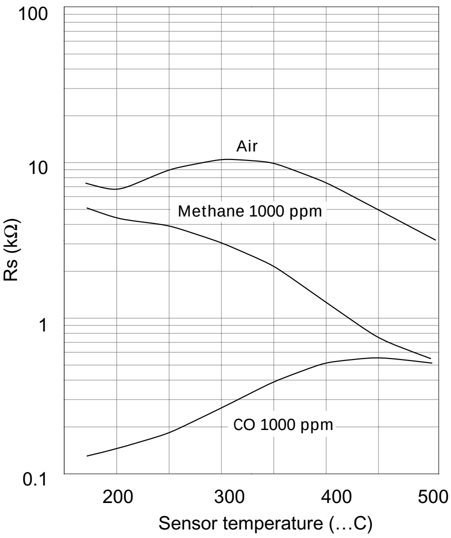


Fig 3a. SnO_2 + 0.1 wt% Pd

- Catalytic activity (for oxidation): moderate
- Sensor resistance level (in general): low
- Temperature dependency characteristics: broad
- Initial action speed: relatively slow
- Gas response speed: quick in responding to gas and slower in recovery

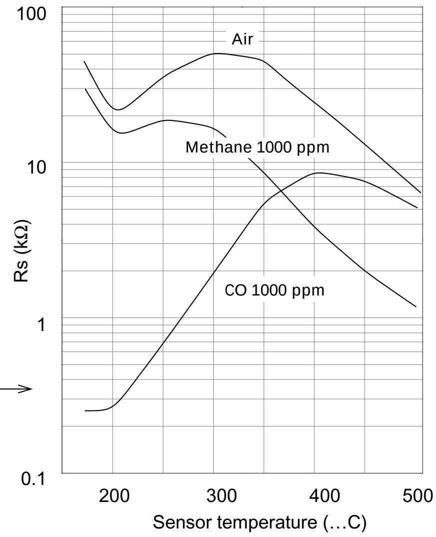


Fig 3b. SnO_2 + 1.0 wt% Pd

- Catalytic activity (for oxidation): active
- Sensor resistance level (in general): high
- Temperature dependency characteristics: sharp
- Initial action speed: quick
- Gas response speed: quick in both responding to gas and recovery
- Low sensitivity to alcohol, hydrogen,

1.4. Related factors to the gas sensitivity of SnO_2

There are several factors which are related to the sensitivity of SnO_2 gas sensors.

- Conditions of grain boundary of crystals
- Activity of additives
- Semiconductivity of SnO_2 (structural factor of SnO_2: number of free electrons, surface area, adsorption site of gases, etc.)
- Physical (mechanical) factors in the structure of gas sensors

The reliability of gas sensor depends on the balance of these parameters. The FIS SB series has been developed to achieve the most reliable gas sensors with effective gas sensing performance.

1.5. Expected life

In general, it is not easy to specify the life time of tin-dioxide semiconductor gas sensors. In terms of fundamental functions (sensor resistance changes according to the atmospheric conditions) of SnO_2, the life of FIS gas sensors can be extremely long at normal operating conditions (e.g. more than 100 years).

However, the actual life should be determined from the balance between the practical performance of gas sensors (including other parts) and the required performance of each application.

- Expected life (basic characteristic): more than 10 years
- Reasonable operation period in safety devices: more than 5 years

Also, it is important to note that the performance of applied products depends on the operating conditions and other factors.

1.6 Feature of the SB-42A

The gas sensing characteristics of the SB-42A-11 does not depend on the catalyst, and variation factors caused by catalyser is minimized.

Production process

2. Production process

Table-1 below indicates the basic production process and quality check method for the SB-42A-11 production.

Table-1: SB series production process chart

Items	Material	Flow chart	Process	Specifications and quality control			
				Equipment / Test method	Test items	Sampling	Specifications and instructions
1. Quality check (sensing material)	Gas sensing material		Production of sensing material	· X-ray diffract meter · X-ray fluorescent spectrometer · Other test equipment	· purity · composition · crystal size	· all batches	· FIS specifications for sensing materials
			Pre-production test	· Gas sensor test equipment	· sensitivity and long term stability	· all batches	
			Production test	· Gas sensor test equipment	· sensitivity characteristics	· all batches	
2. Heater, electrode assembly	Sensor Base			· Inspection data · micro-meter	· size (diameter)	· all batches · sampling test	· Specifications for sensor base
	Heater (Pt 20 ¿)			· Inspection data · Ohm-meter	· specific resistance · mechanical strength	· all batches · sampling test	· Specifications for Pt wire
	electrode (Pt 20 ¿)			· same as above	· same as above	· same as above	· same as above
			Coiling, insertion of electrode and spot welding	· Automatic coiling and spot welding machine	· number of turns	·	·
3. QC			Visual check	· CCD camera · Microscope (optical)	· width, shape of coil · number of coil turns · condition of spot welding		· Instructions
			Heater resistance check	· Ohm-meter	· heater resistance		·
			Strength of spot welding	· Electric balance (spring balance)	· mechanical strength (for disconnection)	· sampling test	·
3. Coating (for spot welding)	Coating material			· Inspection data	· composition	· all batches	· Specifications for sensing element
			Painting	· automatic dispenser	· amount of paint	·	·
			drying	·	·	·	·
4. Mounting of sensing material	Sensor material (paste)			·	· thickness of paste	· all products	·
			mounting	· sensor material mounting and drying system	· amount of sensing material	· all products	·
			drying	· sensor material mounting and drying system	· temperature · time	· all products	·
5. QC			Isolation between heater and electrode	· Ohm-meter · Micro-scope · CCD camera	· isolation · visual conditions	· all products	·
6. Calcination			Pre-calcination	· Digital multi-meter · Timer	· heater voltage · time	·	· Production instructions
	Binder		Binder deposition	· Automatic dispenser	· amount	·	
			Main-calcination	· Digital multi-meter · Timer	· heater voltage · time	·	

Table-1: SB series production process chart

Items	Material	Flow chart	Process	Specifications and quality control			
				Equipment / Test method	Test items	Sampling	Specifications and instructions
7. QC		◇	Visual check	· Micro-scope · CCD camera	· size, shape · surface conditions	· all products	
8. Capping	Sensor cap	▽		· Inspection data	· size	· all batches	
		▽	Fixing (3 points press)	· Automatic capping machine	·	· all batches	
		○	Assembly	· Angle · Pressure	· fixing condition	· sampling test	· FIS specifications
9. External filter	External filter housing	▽		· Inspection data	· size	· all batches	·
	Active charcoal	▽	Quantity check	· inspection data · weigher	· inspection data (particle size) · weight	· all products	·
		○	Assembly	·	·	· sampling test	· Production instructions
10. Aging (burn-in)		○	Aging	· Aging equipment	· operating conditions · time	· all products	· Production instructions
11. Sensitivity test		◇	Sensitivity test	· Gas sensor test equipment · Test gas	· sensitivity characteristics (details)	· sampling test (each production batch)	· FIS specifications for production lot judgement
		◇	Out going test	· Gas sensor test equipment · Test gas	· sensitivity characteristics · heater resistance · Insulation and short	· all products	· FIS specifications for out going test
12. Marking		○	Model and lot number	· Ink-jet printer	· position, visibility	· all products	· Production instructions
13. Final check		◇	Visual check Final check	· Visual · Ohm-meter	· surface conditions · heater resistance · isolation	· all products	
14. Packing		□	Quantity check				
		◇	Packing	· visual test	· package conditions	· all packages	
		▽	Shipping				

Remarks (symbol):

○: operation, ▽: storage, ◇: Check (QC), □: Check (production)

Test methods and test conditions: process control

3. Test methods and test conditions: Process control

3.1. Inspections for basic materials

- Gas sensing materials:
  - Purity and compositions:
    Method: X-ray fluorescent spectrometer, Gas-Liquid Chromatography, etc.
  - Crystal size:
    Method: X-ray diffractmeter
  - Sampling test: Sensitivity characteristics, Sensor temperature dependency, Long term stability test
    Method: Gas sensor test equipment
- Other materials: Heater and electrode wire
  - Purity, compositions, specifications, etc.
    Method: Inspection data from suppliers (for every production lot)
  - Characteristics
    Method: Sampling test by visual test, heater resistance check
- Structural materials: Sensor base, housing (including mesh), pins
  - Size, mechanical characteristics, conditions, etc.
    Method: Inspection data from suppliers (for every production lot) and sampling test
  - Mechanical strength of pins (pulling resistance):
    Method: Sampling test

3.2. Sampling test for gas sensing materials (pre-production test: details)

- Sensitivity characteristics
  - Sensor resistance level: at specific gas/concentration according to the model
  - Cross sensitivity
- Sensor temperature dependency (V_H-R_S characteristics)
  - Characteristics curves for standard gas/concentration
- Initial action
  - After different un-powered storage period: 1 month and 3 months
- Response speed
  - Specific gas/concentration
- Long term stability test: for at least 3 months
  - Continuous operation
  - Intermittent operation
  - Effect of long term storage
    Method: Gas sensor test equipment

3.3. Production test (gas sensors)

- Sensitivity characteristics
  - Sensor resistance level: at specific gas/concentration according to the model
  - Cross sensitivity
    Method: Gas sensor test equipment

3.4. Assembly of gas sensors

- Sensing element:
  - Size, shape and surface conditions:
    Method: Visual check using optical microscope and CCD camera + video monitor (all products)

- Sensor unit (sensing element + housing):
  - Bonding conditions of lead wires and condition of coating material:
    Method: Visual check (all products), sampling test by measuring the break off strength of connections
- Application of external filter housing (sensor unit + active charcoal + external housing):
  - Weight of active charcoal particles
    Method: automatic dispensing tool, calibration and sampling test (measuring the weight of active charcoal)

3.5. Mechanical strength

- Sensor material
  - Mechanical strength of sensor surface
    Method: Sampling test using a pincette and vibration/shock
- Mechanical strength of lead wire and lead wire connections
  - Mechanical strength of lead wire (Pt)
  - Spot welding of lead wires on the electrode pins
    Method: Sampling test by measuring the break off strength using a spring-balance

3.6. Outgoing test: SB-42A-11 for hydrogen detection (temporary specification)

1) Sensitivity characteristics: (all products)

- Sensor resistance
  - in hydrogen 1000 ppm: 0.8 kΩ to 5.0 kΩ
- Resistance change ratio: (all products)
  - R_S (hydrogen 5000 ppm) / R_S (hydrogen 1000 ppm): 0.40 to 0.60
- Sensitivity to hydrogen: (all products)
  - R_S (at 1000 ppm) / R_S (in air): > 0.015

Method: Gas sensor test equipment (REF: Test System/Equipment for FIS Gas Sensors; GTD05_Test System.pdf)
Conditions: Temperature: 20 …C – 2 …C, humidity: 65% RH – 5% (in clean air)
Circuit voltage (VC): 5.0 V – 1%
Heater voltage (VH): 900 mV – 1%
Load resistance (RL): 750 Ω – 1%

2) Heater resistance check: (all products)

- Heater resistance at room temperature
  Method: Digital ohm meter

3) Insulation and short test: (all products)

- Insulation between heater pins and electrode pins
  Method: Digital ohm meter

4) Visual test: (all products)

- Configurations, surface conditions (including dirt, marking, lot numbers, etc.)
  Method: Visual inspection

5. Development and quality control systems

Table 2 on the next page shows the process of development and quality control system of FIS.

- In general, FIS gas sensors are developed based on the general market demands (standard products).
- Also there are cases that the developments are carried out based on specific requirements from users or sub-contractors (new development or custom specifications).

The quality control system covers the steps of developing gas sensors, establishment of standard and/or special specifications, pre-production and mass production. In order to realise the most efficient

4. Reliability data

FIS tests various basic characteristics of each model, during the process of development or when any modifications in production process have been applied for improvement. These evaluation tests include the mechanical characteristics of gas sensor designs and gas sensors performances such as sensitivity characteristics, long term stability, etc. Through these tests, optimum production conditions have been developed and FIS applies them in mass production. This process ensures the performance and quality of FIS products.

4.1. Mechanical characteristics

- Mechanical strength of parts
  - Strength of heater/electrode wire
  - Contact between heater and sensing material
  - Wire bonding and spot welding
- Reliability and stability of heater
  - Continuous operation
  - Over heating (over heater voltage)
  - Heat cycle (heater voltage ON - OFF cycle)

4.2. Gas sensor performance

- Sensitivity characteristics
  - Sensitivity to target gases
  - Cross sensitivity
  - Response speed
  - Initial action
  - Sensitivity dependency to sensor temperature changes
- Long term reliability
  - Long term stability data at normal operating conditions
  - Long term stability data after un-powered storage period
- Resistance to over heating
  - Effect of applied high heater voltage
- Environmental tests
  - Effects of ambient temperature and humidity changes
  - Exposure to high concentrations of detection gases
  - Resistance to poisoning conditions

Details of reliability data and sensor performances are described in the following sections.

Appendix-1: Failure mode and FMEA table of the SB series: page 10, 11
Appendix-2: Mean Time To Failures (MTTF) of SB series: page 12
Appendix-3: Failure Rate Determination Results according to MIL-217 (F): page 13
Appendix-4: Mechanical performance: page 14
Appendix-4: Estimation for the long term stability: page 15

Actual gas sensing performances of the SB-42A-11 are shown in PART-2: pages 15 to 19

Development and quality control system

Table-2. Development and quality control system

Stage		Process	FIS organisation				
			Sales department	R & D (sensor)	R & D (application technology)	Quality assurance division	Production department
Basic technology			• Sales plan	• Sensor design • Sensing materials • Production process • Related technology	• Application software	• Basic study for quality assurance • Evaluation data	• Production technology • Engineering technology
Market requirements	users	Market research	Meeting: Development plan (stage-1)				
Planning		Development plan		• Provisional plan (Target specifications)			
		Provisional study		• Technical survey			
		Establishment of development plan		• Establishment of temporary specifications			
Development		Evaluation		• Evaluation of samples - basic characteristics		• Support for the development (evaluation)	
		Development of prototype	Meeting: Development plan (stage-2)				
Market survey	Users		• Sample supply to specific users	• Laboratory sample	• Study/development of software		
Feedback	Users	Information feedback	Meeting: Development plan (stage-3)				
Refine		Establishment of final specifications		• Refine • Establishment of final specifications • Sample production • Evaluation of performance, quality, reliability			
			Meeting: Production plan (stage-1)				
Pre-production		Small-medium scale production		• Final specification (standard specifications) • Production instruction		• Reliability test • Quality instructions	• Pre-production sample
Marketing-1		Test sales	• Preparation of technical information • Test sales				
Feedback	Users	Information feedback	Meeting: Production plan (stage-2)				
Production		Mass production	• Sales and marketing			• Reliability test • Quality check system controls • Measuring system controls	• Mass production • Process controls • Production facilities controls
Feedback	Users		• Market information	• Responding to claim and technical inquires			
Special requirements	Specific users	Information feedback	Sales / Development / Quality / Production meeting				
				• Technical study		• Technical backup	• Yield study
Special specifications		Establishment of special specifications	Sales / Development / Production meeting				
Production			• Sales and marketing			• Reliability test • Quality check system controls • Measuring system controls	• Mass production • Process controls • Production facilities controls

Appendix-1: Failure mode and FMEA table of the SB series

1. Failure mode

Fig 4 shows the possible sections which may produce any defects in the SB series gas sensor (A to E). There are two factors in the possible failures.

1) Heating system

- Heater material
- Lead wires, electrodes, electrode pins
- Contact between heater, electrodes, lead wires and electrode

2) Sensor signal system

- Sensing material
- Lead wires, electrodes, electrode pins
- Contact between sensing material, electrodes, heater/electrode, pins

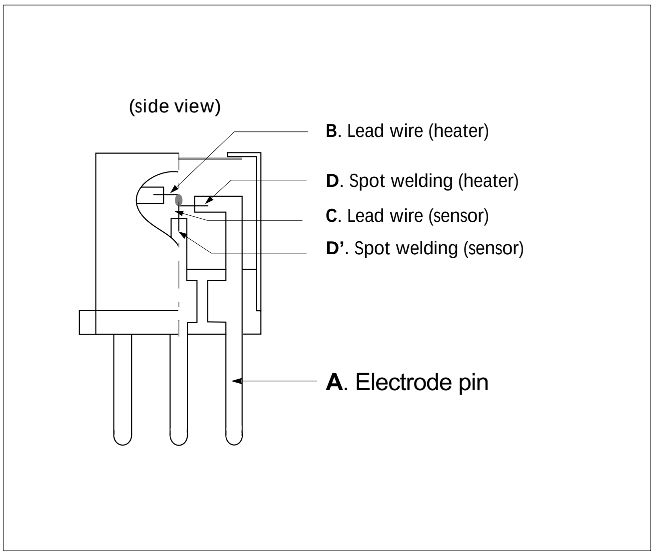


Fig 4a. Sensor unit

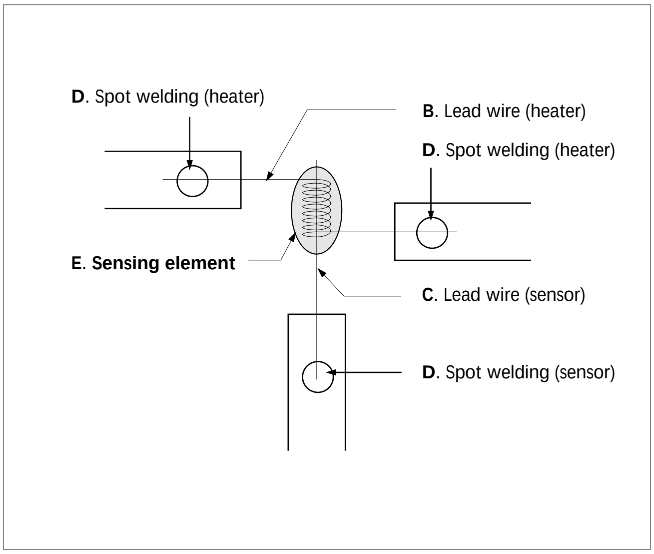


Fig 4b. Sensing element

2. FMEA table

Remarks

Category	Failure mode	Reasons of failure	Effect of failure	Probability	Degree of effect	Detection of failure	Remarks
Heater system	[A] loose of pins	· Mechanical impact · Drop of sensor unit	· disconnection of heater supply · Heater current off · Sensor resistance increases (initially) · Sensor resistance decreases gradually	2	5	1	
	[B] Cut off of lead wires in heater system	· Over current (Note-1) · Corrosion (Note-2)		4	5	1	Note-1: Miss setting of heater voltage, surge, etc. Note-2:
Sensor signal							

Detection of failure: 1: easy - 5: difficult to detect the failure

Degree of effect: 1: small effect - 5: serious effect in gas detection

Probability: 1: very rare - 5:- very often

Effect of failure: Occurring phenomenon in the event of failure

Reasons of failure: Possible reasons of failure

Failure mode: Kinds of failure

Category: Sections (parts, positions) of failure

Appendix-1: Failure mode and FMEA table of the SB series

Table-3: FMEA table of the SB-series

Category	[position] Failure mode	Reasons of failure	Effect of failure	Proba-bility	Degree of effect	Detection of failure	Total	Remarks
Heater failure	[A]: Loose of electrode pins	· Mechanical impact · Drops	· Disconnection in the heater power supply system · Heater current off · Sensor resistance increases (initially) · Sensor resistance decreases gradually	1	5	1	5	
	[B]: Heater coil break down	· Over current (1) · Corrosion (2)		2	5	1	10	(1): Miss setting of heater voltage, electric surge, etc. (2): Oxidizing and/or acidic gases (e.g. sulphur compounds, halogen gas) salt water, etc.
	[D]: Failure in the welding point	· Weak welding strength · Vibration, mechanical impact, drops		1	5	1	5	
	[B]: Low heater resistance	· Transitional over current flow · Corrosion · Heat shock	· Over heat of sensing element · Change in sensitivity characteristics	1	4	1	4	
	[B]: High heater resistance	· Corrosion	· Drop of sensor temperature · Change in sensitivity characteristics	1	4	1	4	
Sensor signal detection system	[A] Loose of electrode pins	· Mechanical impact · Drop of sensor unit	· Infinitely great resistance (V_{RL} output = 0)	1	5	1	5	
	[C] Cut off of lead wires in sensor signal electrode	· Over current (1) · Corrosion (2)		2	5	1	10	
	[D] Disconnection of spot welding contacts	· Weak welding strength · Vibration, mechanical impact, drops		1	5	1	5	
Active carbon filter failure (SB-50, SB-500, SB-95)	Contamination on filter	· Dust · Water	· Significant increase in sensor resistance (V_{RL} output becomes small)	1	2	5	10	
	Insufficient adsorption effect	· Saturation · Poisoning effect	· Increase of base signal level (in air) · Sensitivity increases	1	1	5	5	
[E]: Sensing material	Breakaway (peeling off) of sensing material	· Vibration, mechanical impact, drops · Heat cycle	· Infinitely great resistance (V_{RL} output = 0)	1	5	1	5	
	Crack, flaking, separation of sensing material	· Vibration, mechanical impact, drops · Heat cycle	· High sensor resistance (Low V_{RL} signal)	1	2	4	8	
	Decreasing of sensitivity (high sensor resistance)	· Over heating (1) · Poisoning (3)	· Low V_{RL} signal (High sensor resistance)	1	3	5	15	(3): High concentration of oxidizing gas, silicone compounds, etc.
	Increasing of sensitivity (low sensor resistance)	· Over heating (1) · Poisoning (3)	· High V_{RL} signal (Low sensor resistance)	1	1	5	5	

Appendix-2: Mean Time To Failures (MTTF) of SB series

SB Series: TECHNICAL NOTE

Long term stability and expected life of FIS gas sensor (example of the SB-11)

This TECHNICAL NOTES explains some basic information concerning the long term stability and expected life of the FIS gas sensors SB-11 (previous version of the SB-11A/SB-15).

1. Background

The FIS SB-11 is a tin-dioxide (SnO_2) semiconductor gas sensor. In general, the tin-dioxide has various suitable characteristics as a gas sensing material as follows:

- Good stability in chemical characteristics
- Good stability in thermo-dynamical characteristics (melting point: over 1600 ¡C, single crystal phase, low sintering activity)
- High activity in gas detection characteristics from low temperatures (low operating temperature, high sensitivity to gases without dopant)

The basic characteristics of the sensing material creates good stability in long term operation.

2. Expected life of SB-11

The SB-11 was developed in 1992 and actual long term stability data has reached to 4 years. From this data, the expected life of the SB-11 is calculated as follows.

3. MTTF Calculation

Since the failure rate during the long term test is ZERO , lower confidence limit has been calculated from the equation shown in the next column:

$$(MTTF)_L = \frac{2T}{\chi^2(2, \alpha)}$$

T: number of sample

X: duration of test

α: Level of significance

c^2 (2,a): c^2 distribution of the degree of freedom (2) and level of significant (a)

The relationship between (α) and k (a function of T: $0 < k \leq 1$) is given from the equation shown below:

$$k = \frac{\chi^2(2, \alpha)}{2}$$

Table 1 shows the values of α and k.

Table1: Relationship between α and k

α (%)	k
10	2.3
60	0.511

Using the data from Table 2 shown next page, $(MTTF)_L$ of each group have been calculated as below (days at confidence level is 90%):

¥ SB-11 (prototype)

$$T = 1410 \times 30 = 42300$$

$$(MTTF)_L = \frac{T}{2.3} = 18391$$

¥ SB-11 (production model)

$$T = 465 \times 60 = 27900$$

$$(MTTF)_L = \frac{T}{2.3} = 12130$$

4. Long term stability data

Figs 1 and 2 (next page) shows the long term stability data of the SB-11 (pre-production sample) in sensor resistance change: average of 30 pcs (15 pcs. of each group).

¥ The SB-11 has a good stability in the sensor resistance level at methane and iso-butane 3000 ppm over more than 1400 days (3.86 years)

¥ Virtually no tendency of increasing or decreasing of sensor resistance level is observed.

¥ From the sensor resistance variation range in this data, the variation range of alarm level is estimated as approx. – 70% from initial alarm level.

5. Conclusion

From these data, the $(MTTF)_L$ of the FIS SB-11 is calculated as 18391 days (50 years) and 12130 days (33 years).

¥ This calculation provides, more than 10 years in terms of basic function of the SB-11.

In terms of stability of gas detection performance, it is confirmed that the SB-11 has a good stability for approx. 4 years in the actual data.

¥ From this data, FIS suggest that **5 years** is a suitable period to specify the operation period of gas alarm devices using the SB-11.

Failure Rate Determination Results according to MIL-217 (F) SB Series Gas Sensor

This paper indicates the result of Failure Rate Determination which is specified by the MIL-217 (F) standard.

- The failure rate of electric components can be defined by the following relations:
  Total test period (components hours): ***T*** (number of sample ***(n)*** x duration of test ***(t)***)
  Number of failure: *r*
  Failure rate: $\lambda = r / T$ x level of reliability (***a***: Table-1)
- When the number of failure (*r*) is zero (0), failure t rate can be calculated by $\lambda = a / T$. In this case, the parameter ***a*** is defined as 0.92 (reliability level: 60%) or 2.30 (reliability level: 90%).

Table-1: Parameters for the limit of reliability level in failure rate calculation

Number of failure (r)	Level of reliability		Number of failure (r)	Level of reliability	
	60%	90%		60%	90%
1	2.02	3.89	6	1.22	1.76
2	1.55	2.66	7	1.20	1.68
3	1.39	2.23	8	1.18	1.62
4	1.31	2.00	9	1.16	1.58
5	1/26	1.85	10	1.15	1.54

- In the case of the SB series gas sensor, the following parameters are obtained by various long-term test data (laboratory tests and QC tests).

Table-2: Results of long term stability test for the SB series gas sensor

Item	Parameter	Value (unit)	Remarks
The Number of sensor sample	***n***	3420 (pcs)	based on the long term stability test results until September 20, 1997
Components Hours	***T***	57,172,252 (C.H.)	
Number of failure	***r***	0 (pc)	

As the number of failure is zero (0), using the 60% of the reliability level (0.92), the failure rate (λ) can be calculated as:

$$\lambda = \frac{0.92}{T} = \frac{0.92}{57{,}172{,}252}$$

$$= 1.61 \times 10^{-8} = 0.061 / 10^{6}$$

$$= 16.1 \text{ FIT } (10^{-9} \text{ hours})$$

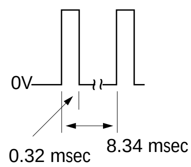
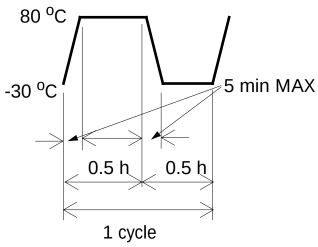
MIL-217 (F) Failure Rate = ***0.061***

This calculation is based on the 209 of long term stability test conducted with the SB series gas sensors.

Appendix-4: Reliability test- Mechanical performance

The Table below shows the results of reliability test for mechanical performance of the SB series gas sensor.

- Over voltage (over heat) test, mechanical test (vibration, shocks), soldering test and thermal shock test (ambient temperature) have been studied.

No.	Item	Conditions	Results /Data No.	Remarks
1	Over voltage test	* on/off cycle of VH:1.8 V for 3 sec. and 0 V for 7 sec. * n = 3 * at room temperature	Broken after 43,000 on/off cycles (120 hrs.)	Two times rated voltage (0.9 V)
		* on/off application of VH: 1.35 V for 3 sec. and 0 V for 7 sec. * n = 3 * at room temperature	Not broken even after 838,000 on/off cycles (2,328 hrs.)	One and half times rated voltage (0.9 V)
		* VH increased until heater broken * voltage kept for 10sec. * at room temperature * n = 3	Broken at 2.1 V	Rated voltage x 2.33
		* Dynamic Driving Method * pulse VH increased until heater broken * voltage kept for 10 sec. * at room temperature * n = 3	Broken at 12 V	Pulse VH 
2	Vibration test	* n = 3 * Acceleration:1.3 G * Frequency range: 5 - 500 Hz * Sweep method: Logarithmic * Directions: X, Y, Z * Sweep time: 40 min (half) * Ambient temperature: 60 °C * Duration: 66 hrs. for each direction	Satisfied the sensitivity specifications of each model.	
3	Drop shock test	* dropped from 75 cm height onto a hard p-tiled concrete floor. * Drop: 5 times * n = 10	Satisfied the sensitivity specification of each model.	
4	Soldering iron test	* contact a 60 W soldering iron to a sensor s electrode for 1 min. * n = 3	Satisfied the sensitivity specification of each model.	
5	Thermal shock test	*Test condition:  * Repeated 1000 cycles	Satisfied the sensitivity specification of each model.	

Appendix-5: Estimation for the long term stability (examples of SB-11A/SB-15)

Long term stability data with logarithmic scale and recursion method

In order to estimate the long term stability of gas sensors from actual data, it is effective to figure the X-axis (time axis) with logarithmic scale and using a recursion method . Figs 5a and 5b show the same data as FIg 8a and Fig 8b (page 19) with this expression. In these diagrams, each line indicates the tendency of sensor resistance changes. As shown in these diagrams, the SB-42A has good stability for approx 700 days. It is estimated that this stability will continue over a long period for much longer than 5 years.

Fig 5a. SB-42A-11, Long term stability data - Continuous operation (power ON continuously)

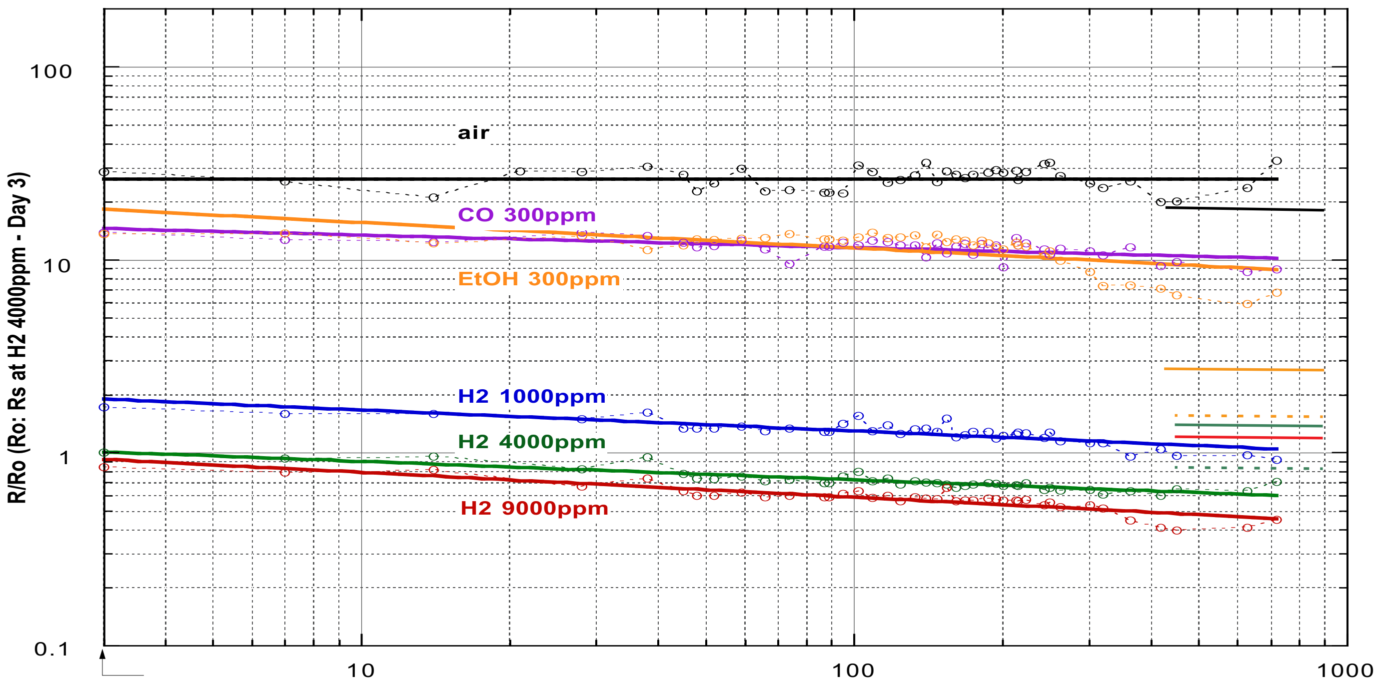
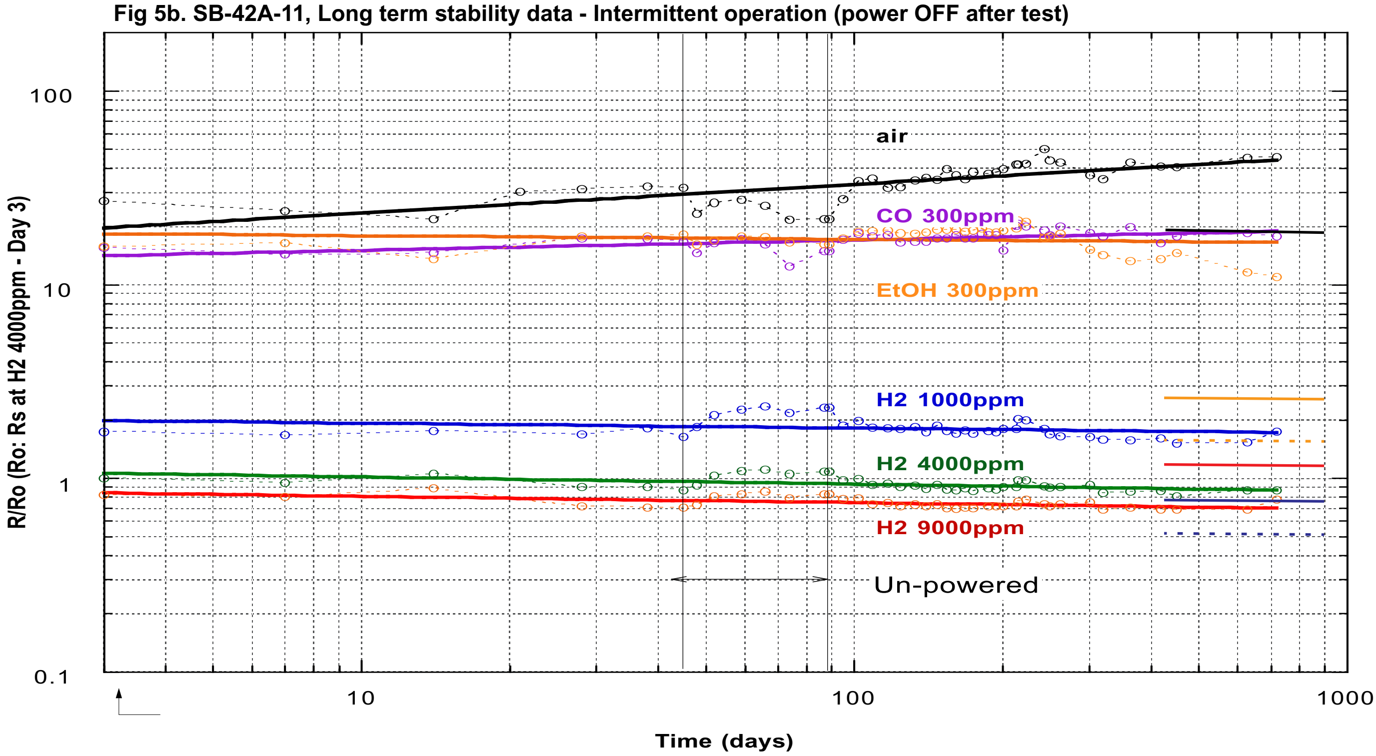


Fig 5b. SB-42A-11, Long term stability data - Intermittent operation (power OFF after test)

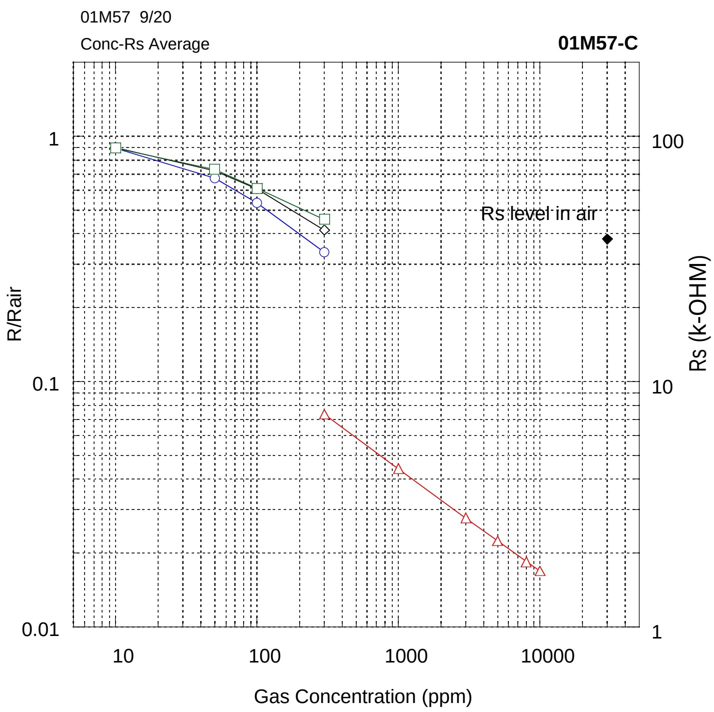


PART-2: Sensor performance

1. Sensitivity characteristics

Fig 6a shows the sensitivity characteristics of the SB-42A-11 (relationship between concentration and sensor resistance change ratio: R/Ro). Fig 6c indicates the change of output voltage using the standard circuit (Fig 6b).

Fig 6a. SB-42A Sensitivity characteristics



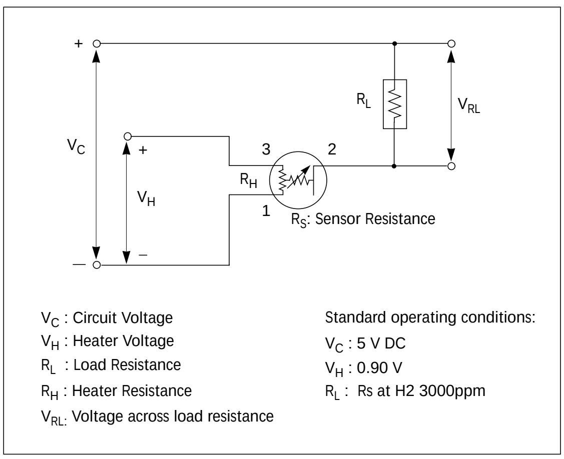


Fig 6b. Standard Circuit and operating condition

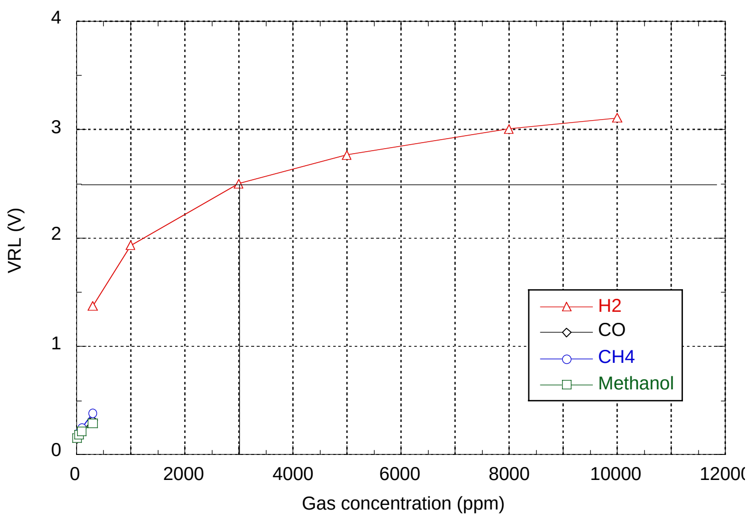


Fig 6c. SB-42A Sensitivity characteristics (Concentration vs. VRL output)

2. Response speed

Figs 6a to 6e shows the response speed of sensor resistance when the sensors are exposed to different gas concentration levels (from air -> 10ppm -> 50ppm -> 100ppm -> 300ppm for CO, CH4 and methanol (MtOH) and from air -> 300ppm -> 1000ppm -> 3000ppm -> 5000ppm -> 8000ppm -> 10000ppm for hydrogen.

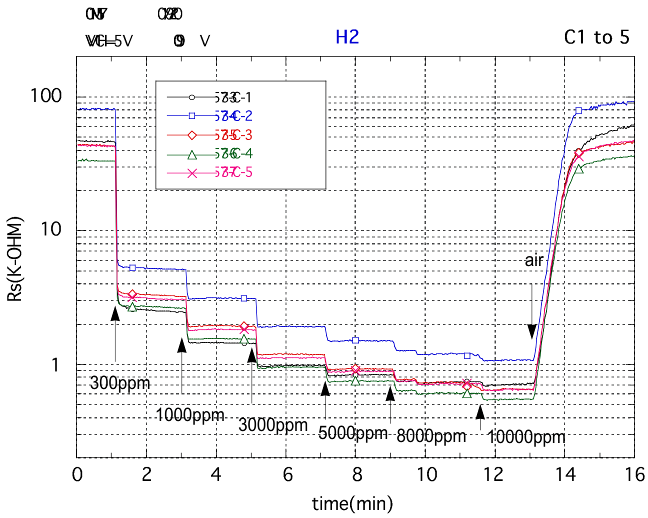


Fig 7a: Response to hydrogen

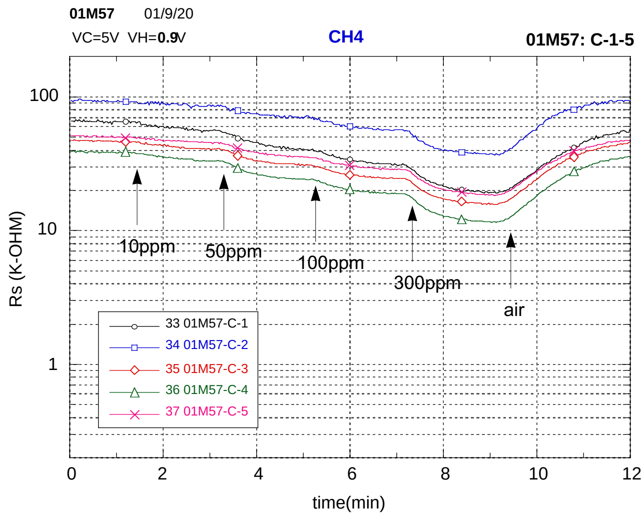


Fig 7b: Response to methane

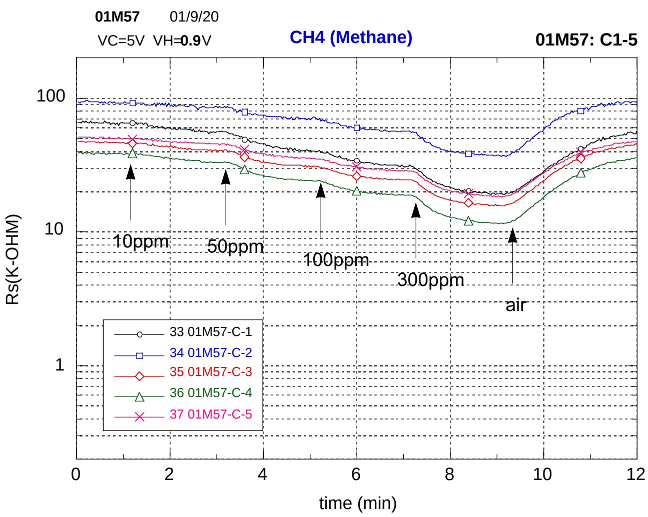


Fig 6c. Response to CO

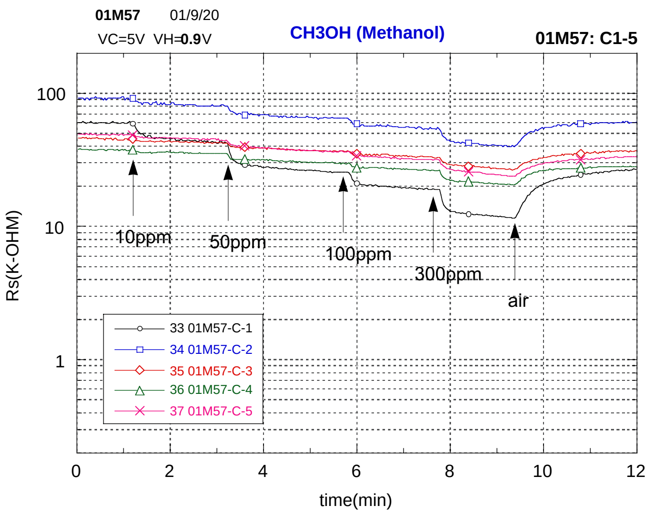


Fig 6d. Response to methanol

Temperature and humidity data

Figs 7a shows the sensitivity characteristics at different temperature and humidity conditions.

Fig 7b shows the temperature dependency of sensor resistance in hydrogen 5000 ppm at 55%RH. In this diagram, the resistance change is normalised by the sensitivity at 20…C 55%RH.

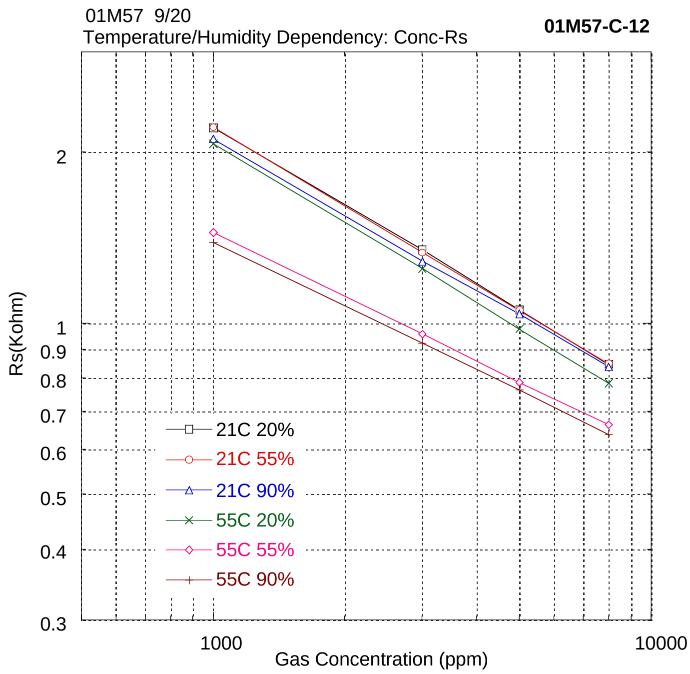


Fig 7a Temperature and humidity data

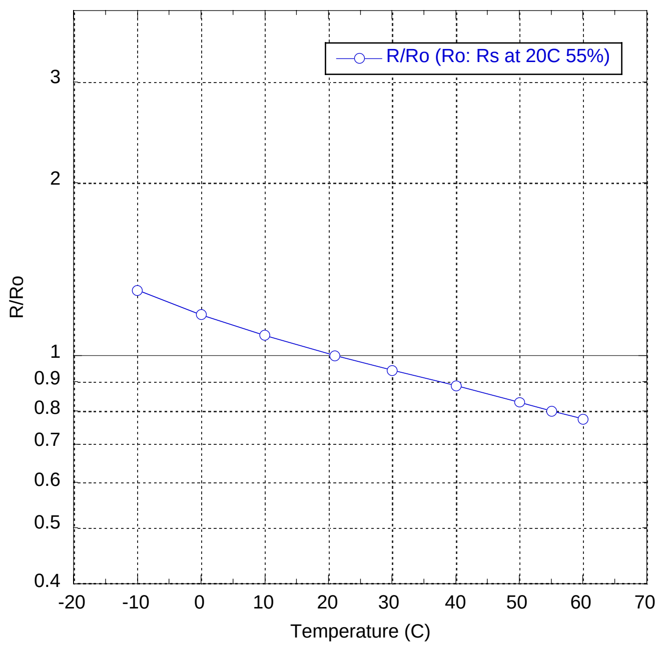


Fig 7b. Temperature dependency data (H2 5000ppm) (at 55%RH: above 0…C)

Long term stability data

Figs 8a and 8b show the long term stability of the SB-42A-11 with continuous operation and intermittent operation. These figures indicate the sensor resistance change (Average, Maximum and Minimum of 5 pcs.).

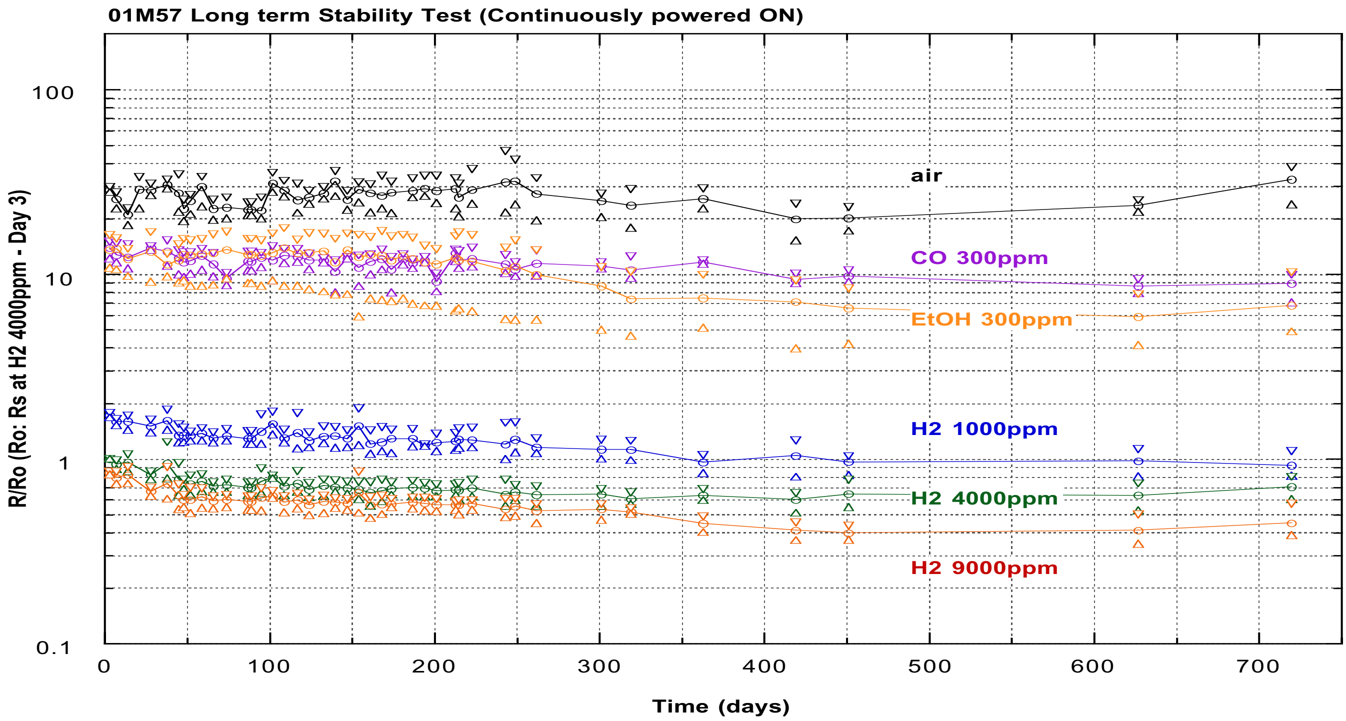


Fig 8a. Long term stability data: continuous operation

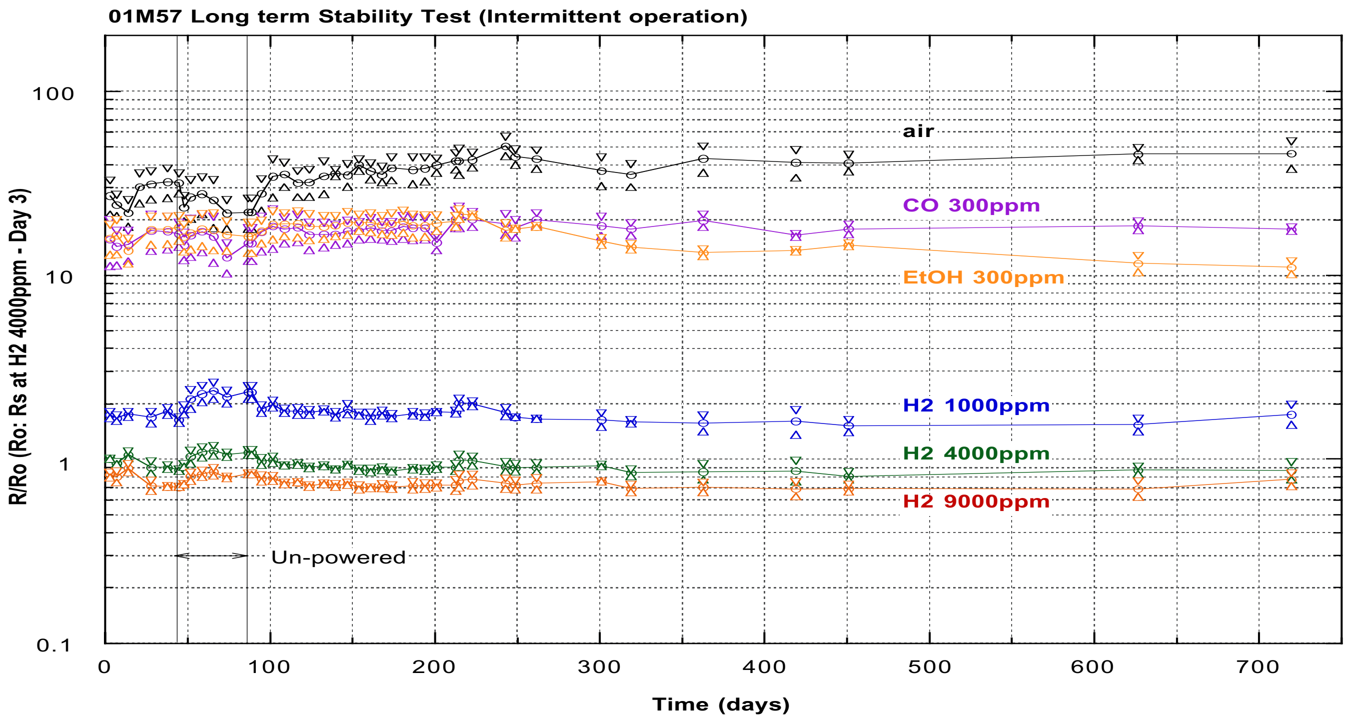


Fig 8b. Long term stability data: intermittent operation

Specifications

SB-42A-11 Specifications (Mar, 2002)

A. Standard Operating conditions

Symbol	Parameter	Specification	Conditions etc.
VH	Heater voltage	0.9 V ± 5%	AC or DC
V_C	Circuit voltage	Less than 5 V	AC or DC
R_L	Load resistance	Variable (> 350 Ω)	P_S < 10 mW
R_H	Heater resistance	2.8 Ω ± 0.2 Ω	at room temperature
I_S (H)	Current consumption (high)	132mA ± 15mA	VH=0.9V (Dynamic Driving: 26mA)
I_S (L)	Current consumption (low)	59mA ± 10mA	VH=0.2V
Ps	Power dissipation	Less than 10 mW	

B. Environmental conditions

Symbol	Parameter	Specification	Conditions etc.
Tao	Operating temperature	-20 °C to 50 °C	Recommended range
Tas	Storage temp	-20 °C to 70 °C	
RH	Relative humidity	Less than 95% RH	
(O_2)	Oxygen concentration	21% ± 1% (Standard condition)	Absolute minimum level: more than 18%
		The sensitivity characteristics are influenced by the variation in oxygen concentration.	

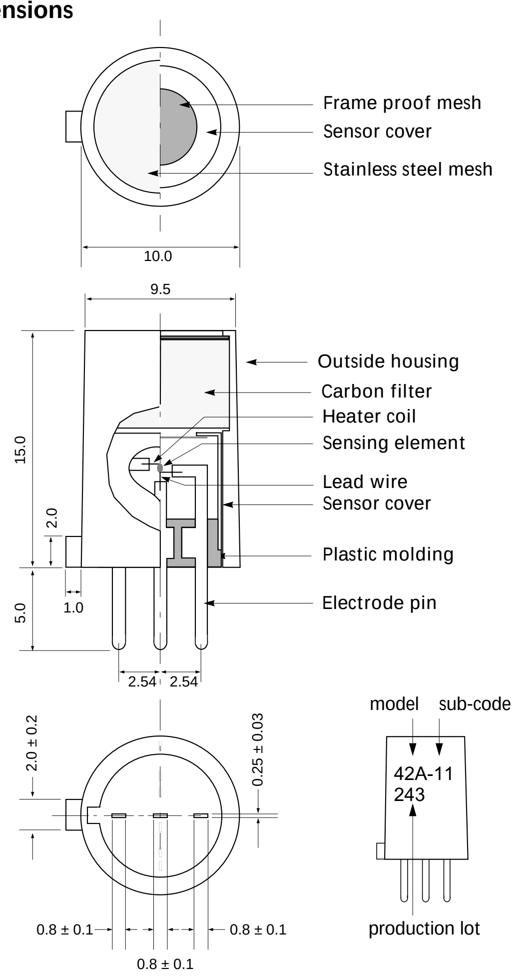
C. Sensitivity characteristics (provisional)

Model	SB-42A-11		
Symbol	**Parameter**	**Specification**	**Conditions etc.**
R_S	Sensor resistance	0.8 kΩ - 5.0kΩ	at 1000ppm of H2/ air
β	Concentration slope	0.40 to 0.60	Rs (H2 5000 ppm) / Rs (H2 1000ppm)
R/Rair	Sensitivity	> 0.015	Rs (H2 5000 ppm) / Rs (air)
Standard Test Conditions:		Temp: 20 °C ± 2 °C Humidity:65% ± 5% (in clean air)	V_C : 5.0 V ± 1% V_H : 0.9 V ± 1% R_L : 750Ω ± 5%
		Pre-heating time: more than 2 days	

D. Mechanical characteristics

Items	Conditions		Specifications
Vibration	Frequency: Vertical amplitude: Duration:	100 cpm 4 mm 1 hour	Should satisfy the specifications shown in the sensitivity characteristics.
Shock	Acceleration: Number of impacts:	100 G 5 times	

Dimensions



Scale: mm

E. Parts and Materials

No.	Parts	Materials
1.	Sensing element	Tin dioxide
2.	Heater coil/ Lead wire	Platinum
3.	Stainless steel mesh	SUS 316 (100 mesh, single)
4.	Carbon filter	Activated carbon
5.	Outside housing	Nylon 6 (UL94 V-0)
6.	Flameproof mesh	SUS 316 (100 mesh, double)
7.	Sensor cover	Nickel plated brass
8.	Plastic moulding	PBT (polybutylene telephtalate)
9	Electrode pins	Iron-chrome alloy

In the interest of continued product improvement, we reserve the right to change design features without prior notice.