

# TCS208F

## TCS208F3

## Thermal Conductivity Sensor for Gases

Fig.1 Sensor with base

### 1. Features

- Thermal conductivity sensor for gases in **silicon micromechanics**
- Minimal power consumption, **low temperatures**
- Very **small dimensions**, short time constants
- Measurement of very **small gas volumes**
- Gas exchange by diffusion, **independent of flow**
- Integrated temperature compensation resistors
- TO8-style base, **shock proof**

### 2. Applications

**Determining gas concentrations** by measuring the thermal conductivity. **Monitoring of gas characteristics** that can be detected by changes in the thermal conductivity of the gas, e.g.:

- discrimination of **natural gases** of different origin or composition,
- determination of **CO<sub>2</sub>** vs. **methane** contents in **landfill** or **digester gas**,
- measurement of **helium** or **xenon** contents in mixtures with air

Reference should be made to the appropriate literature to determine the applicability of this gas analysis method.

### 3. Description

The sensor element consists of a silicon chip with a thin membrane approximately 1mm<sup>2</sup> in size of a material with extremely good electrical and thermal insulating properties (see Fig.2). Integrated into the membrane are two thin film resistors ( $R_{m1}$ ,  $R_{m2}$ ) which are used both for heating the membrane and for measurement of its temperature  $T_m$ . The resistors as well as the conductor tracks are passivated

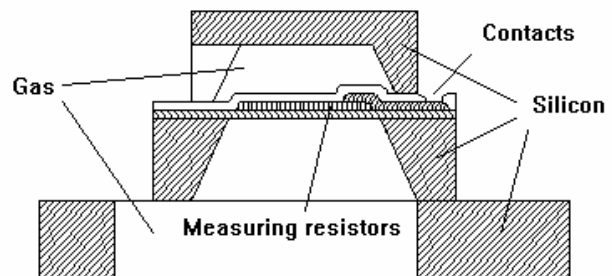


Fig.2 Cross section of the sensor

to protect them from the effects of the gas. The membrane is completely covered by a second small silicon chip with a rectangular cavity etched in. The hollow space thus formed above the membrane is the thermal conductivity section. The gas passes to the measuring section through a small lateral opening in the membrane cover by diffusion only, and not by flow.

The sensor chip and its cover are attached to a silicon support which also permits gas exchange to the lower side of the membrane. The sensor is electrically connected to an eight pin base (similar to TO8) by gold wire bonding.

Due to the thermal conductivity  $\lambda$  of the gas surrounding the membrane, thermal energy is dissipated from the membrane held at higher temperature  $T_m$ . Measured is the signal needed in a temperature stabilization circuit to keep the excess temperature of the membrane  $\Delta T$  constant.

On the solid part of the chip are two more resistors ( $R_{t1}$ ,  $R_{t2}$ ) to measure and compensate for the effect of the ambient temperature  $\vartheta$ .

#### 4. Technical data

(Measuring dry  $N_2$  at  $\vartheta=25^\circ C$  and  $\Delta T=50^\circ C$  unless otherwise specified)

##### 4.1 Absolute maximum ratings:

	min.	typ.	max.	units
Heating power $P(R_{m1}+R_{m2})$	---	---	30	mW
Membrane temperature $T_m$	---	---	180	$^\circ C$
Ambient temperature $\vartheta$	-20	---	+85	$^\circ C$
Gas pressure on base (1)	---	---	200	bar

**Warning:** Due to the short thermal time constant of the membrane, applying excessive heating power even for a short time can destroy the sensor.

##### 4.2 Specifications:

	min.	typ.	max.	units
Resistances, $R_{m1}$ , $R_{m2}$ ( at $T_m = 25^\circ C$ )	92	100	115	$\Omega$
Resistances, $R_{t1}$ , $R_{t2}$	220	240	275	$\Omega$
Quotient $R_{tx} / ( R_{m1}+R_{m2} ) \mid x \in \{1,2\}$	1.13	1.2	1.27	1
Resistance difference $R_{m1} - R_{m2}$	-2.0	---	+2.0	$\Omega$
$\alpha$ = Temperature coefficient ( $R_m, R_t$ ) $\mid 20 - 100^\circ C$	4.8 (2)	5.5	5.9	$10^{-3} \cdot K^{-1}$
G = Geometry factor (3)	---	3.6	---	mm
$\tau_m$ = Membrane thermal time constant	---	< 5	---	ms
$\tau_{diffusion}$ = Time constant for gas exchange	---	< 100	---	ms
Drift ( $R_{xy}$ ) $\mid x \in \{m,t\} ; y \in \{1,2\}$	---	0.001	0.01	% / week
Volume of diffusion chamber structure	---	0.2	---	mm <sup>3</sup>
Surrounding volume to be kept clear (see Fig.5)	---	100	---	mm <sup>3</sup>
Base material	Silicon, microstructured by anisotropic etching			
Dimensions of sensor (see Fig.5)	excluding base		approx. 3mm × 3mm × 1mm	
	including base		approx. 13mm Ø × 15.4mm	
Material of parts exposed to gas:	Si, SiO <sub>x</sub> N <sub>y</sub> , gold, epoxy			

#### Remarks:

- (1) Pressure data according to supplier specifications for properly supported device.
- (2) min. value of  $\alpha$  quoted only for applications to be compatible with a potential second source of lower specs. Product is constantly being improved to get closer to DIN 43760 specification.
- (3) The factor G is determined by the internal sensor geometry.

Mechanical stress tests have been performed on prototype sample devices for  
**vibration:** in accordance with IEC 68-2-6 Appendix B (1982) 10 cycles;  $\pm 1.5\text{mm}$ ;  
**20g; 10..2000Hz**; 1octave/min and for  
**shock:** in accordance with IEC 68-2-27 Amendment #1 (Oct.82) 10 shocks each  
 radial and axial; 100g; 7.5ms / 300g; 2.5ms / **900g**; 1.2ms

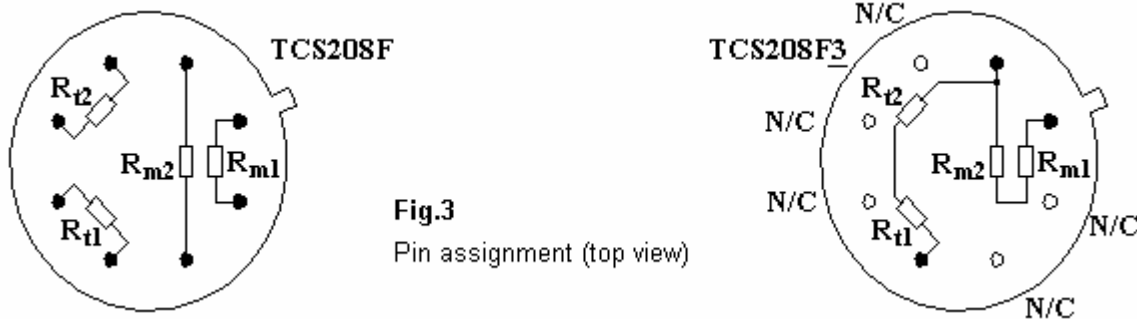
<b>4.3 Recommended operating conditions:</b>	min.	typ.	max.	units
Heating power $P(R_{m1}+R_{m2})$	---	---	5	mW
Membrane excess temperature $\Delta T = T_m - \vartheta$	(30)	50	70	$^{\circ}\text{C}$

The minimum  $\Delta T$  for any application is determined by the resolution of thermal conductivity  $\lambda$  required in combination with the noise of the amplifier circuit used. A very low  $\Delta T$  has advantages in terms of linearity, low drift and better long-term stability of the sensor.

## 5. Notes on use of the sensor

### 5.1 Operation of the sensor

The four resistors  $R_{m1}$ ,  $R_{m2}$ ,  $R_{t1}$  and  $R_{t2}$  on the TCS208F sensor are connected separately to the eight pins on the TO8-style base. On the TCS208F3 both  $R_{m1}$  and  $R_{m2}$  as well as  $R_{t1}$  and  $R_{t2}$  are connected in series. Fig.3 shows the pin assignments looking at the sensor side. To operate the sensor it is ad-



visible to apply approximately equal heating power to the two membrane resistors  $R_{m1}$  and  $R_{m2}$  to avoid temperature gradients on the heated surface. The power used to measure the ambient temperature via resistors  $R_{t1}$  and  $R_{t2}$  should not exceed the power dissipated in the resistors  $R_{m1}$  and  $R_{m2}$  to avoid heating the sensor chip.

### 5.2 Effect of ambient temperature

A given heating power in the membrane resistors produces an excess temperature  $\Delta T$  in the membrane compared with the solid part of the sensor chip which depends on the absolute ambient temperature only very little through the temperature coefficient of the thermal conductivity of the gases (typically  $10^{-3}/^{\circ}\text{C}$ ). The absolute resistance values however vary with the ambient temperature just as they do with changing thermal conductivity. Therefore in general temperature compensation will have to be implemented.

### 5.3 Recommended application circuits

Three application circuits are described. Whereas the first one uses a constant membrane excess temperature and is fairly safe against rapid changes in thermal conductivity over a very wide range the membrane can be destroyed by even very short interruptions of the  $R_t$  leads and the power up dynamics of the positive feedback loop have to be controlled. The other two circuits use a constant membrane current  $i_m$  (or a constant voltage with a relatively large series resistor). In all cases the

membrane excess temperature  $\Delta T$  is:

$$(eq. 1) \quad \Delta T = \frac{1 + \alpha \cdot \vartheta}{\frac{G \cdot \lambda}{i_m^2 \cdot R_m} - \alpha}$$

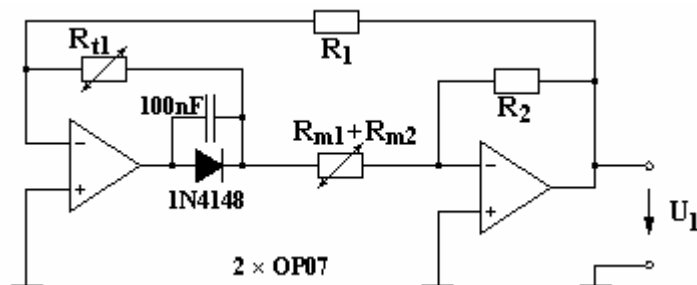
### 5.3.1 Constant excess temperature operation

Fig.4a shows a temperature compensated application circuit for constant excess temperature operation ( $\Delta T = \text{const.}$ ) of the sensor. The membrane heating/measuring resistors  $R_{m1}$  and  $R_{m2}$  are connected in series between the two operational amplifiers. One of the ambient temperature measurement resistor ( $R_{t1}$ ) is negative feedback for the first amplifier. The two amplifiers form a positive feedback loop. This loop will be in a stable state with a total gain of one determined by the nonlinear functions of current and voltage at both  $R_m (= R_{m1} + R_{m2})$  and  $R_t (= R_{t1})$  which in turn depend on temperature and thermal conductivity  $\lambda$  of the gas in the sensor. The membrane excess temperature  $\Delta T$  is determined by the quotient  $R_1 / R_2$  according to the equation:

$$(eq. 2) \quad \frac{R_1}{R_2} = \frac{R_{t1}}{(R_{m1} + R_{m2}) \cdot (1 + \alpha \cdot \Delta T)}$$

By electronically calculating the quotient  $(R_{m1} + R_{m2}) / R_{t1}$  within the loop the signal is first order temperature compensated. An additional external temperature second order compensation can be implemented using  $R_{t2}$ . The diode determines the polarity of the loop output voltage  $U_1$  the magnitude of which is defined by:

$$(eq. 3) \quad U_1^2 = \frac{G \cdot \lambda}{\alpha} \cdot \frac{R_{t1} \cdot R_2^2 - (R_{m1} + R_{m2}) \cdot R_1 \cdot R_2}{(R_{m1} + R_{m2}) \cdot R_{t1}}$$



**Fig.4a** Application circuit for constant excess temperature operation

Example for dimensioning this application circuit:

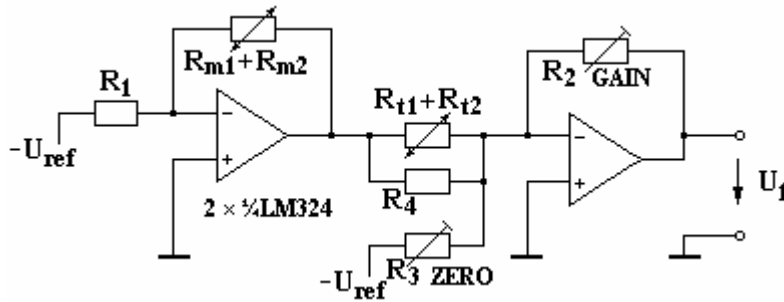
Conditions:  $\Delta T = 36.4 \text{ K}$ ;  $U_1 = 5.8 \text{ V}$  for  $\lambda(N_2) = 0.0275 \text{ W/m}\cdot\text{K}$  (at  $50^\circ\text{C}$ )

Results:  $R_1 / R_2 = 1.00$ ;  $R_2 = 1.5 \text{ k}\Omega$ ;  $R_1 = 1.5 \text{ k}\Omega$

Sensitivity: 1% He in  $N_2$  increases  $U_1$  by approx. 140 mV

### 5.3.2 Constant membrane current operation

Fig.4b shows a second order temperature compensated application circuit for constant membrane current operation ( $i_m = \text{const.}$ ) of the sensor. The two heating/measuring membrane resistors  $R_{m1}$  and  $R_{m2}$  are connected in series in the feedback of the first operational amplifier. A temperature compensated negative reference voltage  $-U_{ref}$  drives a constant current through  $R_1$ . The same current flows through the membrane resistors. The ambient temperature measurement resistors  $R_{t1}$  in series with  $R_{t2}$  between the two operational amplifiers provides first order temperature compensation.



**Fig.4b** Application circuit for constant membrane current operation

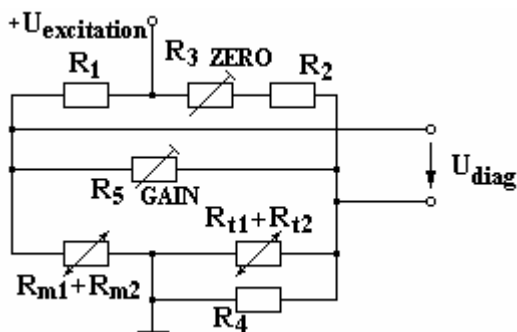
Offset and gain are controlled using the trim resistors  $R_2$  and  $R_3$  of the second stage. Attenuating the temperature dependence of the coupling between the two stages  $R_4$  introduces a second order temperature compensation. This resistor's value must be chosen according to the gases measured.

Typical dimensioning of this application circuit ( $i_m = 4\text{mA}$ ; not to be used for gases below the thermal conductivity of  $\text{CO}_2$ ):

$U_{\text{ref}} = 6.2\text{ V}$ ;  $R_1 = 1.5\text{ k}\Omega$ ;  $R_4 = 7.5\text{ k}\Omega$  for  $\text{N}_2$ ;  $R_2 = 50\text{ k}\Omega$ ;  $R_3 = 10\text{ k}\Omega$  (coarse) in series with  $100\Omega$  (fine); all trim resistors linear multiturn ceramic metal (e.g. Bourns® or Spectrol®)

### 5.3.3 Wheatstone bridge operation

Fig.4c shows an application circuit for use with a strain gauge amplifier. It operates the sensor in a Wheatstone bridge configuration. Due to the relatively large resistor  $R_1$  its characteristics are very similar to the constant membrane current operation as described above. Both membrane resistors are connected in series and divide the excitation voltage together with  $R_1$ . The temperature measurement resistors  $R_{t1}$  in series with  $R_{t2}$  are used in the other path for first order temperature compensation. Offset is controlled by balancing the bridge using the trim resistor  $R_3$ , gain by a resistive load on the diagonal voltage using  $R_5$ . The fixed resistor  $R_4$  introduces a second order temperature compensation by attenuating the ambient temperature influence on the right hand half bridge. Also in this case the value of  $R_4$  must be chosen fitting to the gases measured.



**Fig.4c** Application circuit for Wheatstone bridge operation

Typical dimensioning of this application circuit ( $i_m$  approx.  $4\text{mA}$ ; not to be used for gases below the thermal conductivity of  $\text{CO}_2$ ):

$U_{\text{excitation}} = 10\text{ V}$ ;  $R_1 = 2.7\text{ k}\Omega$ ;  $R_4 = 7.5\text{ k}\Omega$  for  $\text{N}_2$ ;  $R_2 = 4.7\text{ k}\Omega$ ;  $R_3 = 2\text{ k}\Omega$ ;  $R_5 = 10\text{ k}\Omega$ ; all trim resistors linear multiturn ceramic metal (e.g. Bourns® or Spectrol®)

The diagonal voltage  $U_{\text{diag}}$  may be used as the input to a standard strain gauge meter (e.g. ATC Digtect® Indicator Model 3241 or Red Lion Controls® PAX-S) which also supply a stabilised  $10\text{V}$  excitation voltage.

### 5.4 Determining gas concentration

The thermal conductivity of a gas mixture depends on the individual gas components and on their proportion in the mixture. Under certain conditions therefore the concentration of individual gas com-



**NOTES:****Safety warnings**

Without further testing and certification completely under the responsibility of the user this sensor is not to be used on explosive gas mixtures or in any area where such mixtures may occur. For measurements with toxic or flammable gases any instrument using this sensor must be tested for gas tightness by the user. Connection and placing into operation of any instrument using this sensor must only be made by personnel properly trained and licensed to work with the gases involved and the relevant equipment. When connecting to gas lines the pertinent regulations and guidelines of the individual national institutions and the regulations of the gas supply companies have to be observed strictly.

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**Changes from previous product information (TCS208) D/S dd 040996 [texte\TCSfaxDS.wri] and website data sheet**

- Lower bond posts (0.8mm instead of 1.2mm) to fit into smaller customer device cavity
  - but: required safety volume of 2mm x ø 8mm has not been modified in chapter 6
- Reduced maximum recommended operating temperature (70°C instead of 80°C) for increased long term stability
- Modified pin assignment for optional three pin version TCS208F3
- Additional application notes for constant current and Wheatstone bridge operation
- Formula (eq.2, ex eq.1) corrected
- Pricing information added
- Change of H&B company name in notes
- Country of origin added in notes

**Update history**

010199: Euro pricing in chapter 7 and minor re-formatting

150499: U.K. and e-mail addresses added

060600: conversion from MS Write to MS Word 97, partly re-formatted, PAX-S instrument added, F3 pin assignment corrected, change from H&B to ABB in notes, new U.K. phone number, mobile phone

200503: U.K. address and DEM pricing deleted, new Friedberg phone number, new e-mail address, conversion to .pdf

**Subject to change without notice**

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H&B/EGM/Wa/061290 last rev GRW/010198, 150499, 060600, 200503 (mydoc.\prodinfo\TCS208PI.doc - alternatively .pdf)