

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 **CO₂** 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 1mm² 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

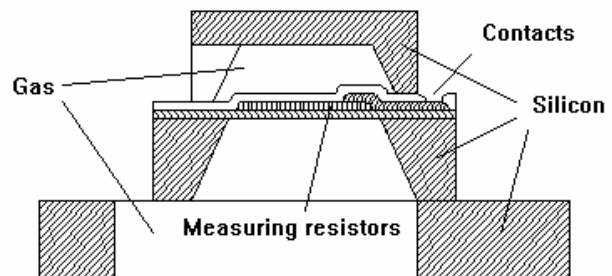


Fig.2 Cross section of the sensor

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 λ 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 ΔT 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 ϑ .

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 ϑ	-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	Ω
Resistances, R_{t1} , R_{t2}	220	240	275	Ω
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	Ω
α = 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
τ_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^3
Surrounding volume to be kept clear (see Fig.5)	---	100	---	mm^3

Base material Silicon, microstructured by anisotropic etching

Dimensions of sensor excluding base approx. 3mm x 3mm x 1mm
 including base approx. 13mm \varnothing x 15.4mm

Material of parts exposed to gas: Si, SiO_xN_y , gold, epoxy

Remarks: (1) Pressure data according to supplier specifications for properly supported device.
 (2) min. value of α 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

4.3 Recommended operating conditions:

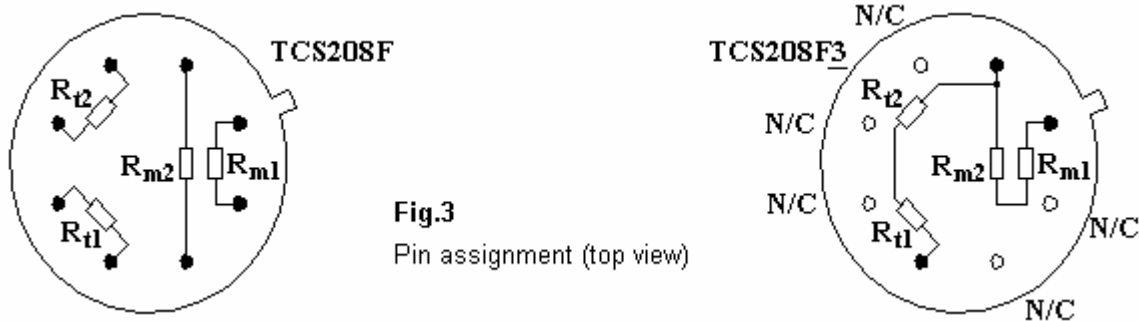
	min.	typ.	max.	units
Heating power $P(R_{m1}+R_{m2})$	---	---	5	mW
Membrane excess temperature $\Delta T = T_m - \vartheta$	(30)	50	70	$^{\circ}\text{C}$

The minimum ΔT for any application is determined by the resolution of thermal conductivity λ required in combination with the noise of the amplifier circuit used. A very low ΔT 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 ΔT 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 ΔT 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 λ of the gas in the sensor. The membrane excess temperature ΔT 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:

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

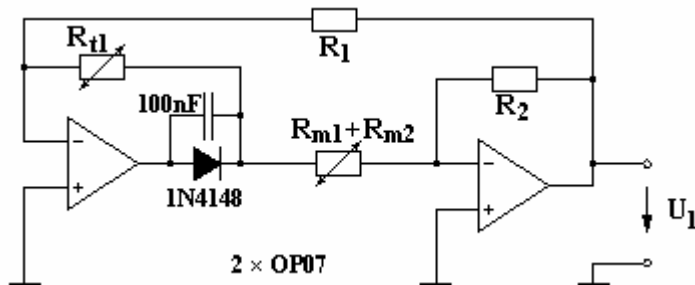


Fig.4a Application circuit for constant excess temperature operation

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°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.

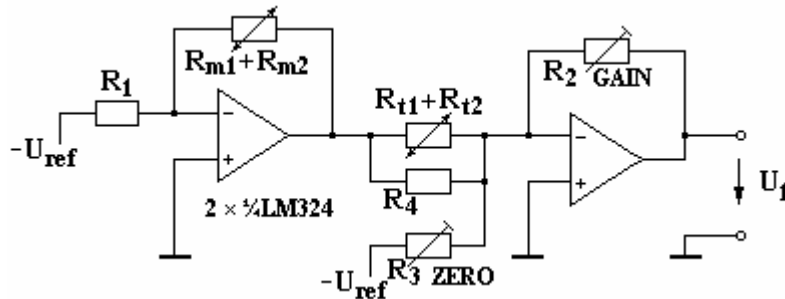


Fig.4b Application circuit for constant membrane current operation

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 CO_2):

$U_{\text{ref}} = 6.2\text{V}$; $R_1 = 1.5\text{k}\Omega$; $R_4 = 7.5\text{k}\Omega$ for N_2 ; $R_2 = 50\text{k}\Omega$; $R_3 = 10\text{k}\Omega$ (coarse) in series with 100Ω (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.

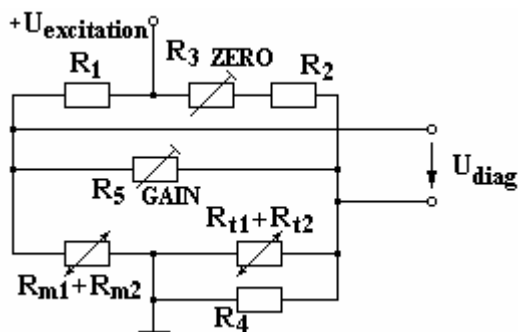


Fig.4c Application circuit for Wheatstone bridge operation

Typical dimensioning of this application circuit (i_m approx. 4mA ; not to be used for gases below the thermal conductivity of CO_2):

$U_{\text{excitation}} = 10\text{V}$; $R_1 = 2.7\text{k}\Omega$; $R_4 = 7.5\text{k}\Omega$ for 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_{diag} may be used as the input to a standard strain gauge meter (e.g. ATC Digtac® Indicator Model 3241 or Red Lion Controls® PAX-S) which also supply a stabilised 10V 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-

ponents can be determined by measuring the thermal conductivity. The concentration can be determined with higher precision if one of the following conditions is met:

- The gas mixture consists of only two components, e.g. measuring CO₂ in N₂, O₂ in N₂.
- The gas mixture consists of more than two components but the concentration of only two components changes.
- The gas mixture consists of more than two components, but the component of interest has a thermal conductivity that is very different from the other components (quasi-binary mixtures). e.g. H₂, He, or CO₂ in air.

Gas concentrations can also be determined in genuinely ternary gas mixtures if additionally to the thermal conductivity itself its temperature coefficient is determined. Due to the low thermal mass of the heating and measuring elements in the thermal conductivity sensor, this can easily be effected by modulating the heating power or alternatively by using two sensors at different membrane temperatures. The thermal conductivity can then be measured at two different gas temperatures. The gas concentrations can be calculated from the two measured values.

6. Dimensions

Fig.5 shows the dimensions of the sensor on its base. When handling or using it a cylindrical volume of 8mm Ø and 2mm thickness is to be kept clear above the base surface in all cases.

Warning: Touching the upper surface of the device will most likely damage the bond wires and destroy the sensor.

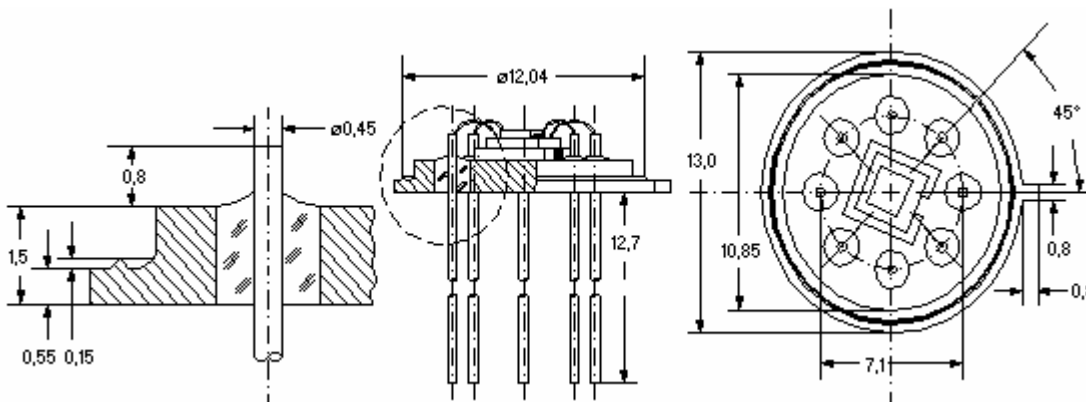


Fig.5 Dimensions

7. Ordering and price information:

Order text: "Thermal conductivity sensor TCS208F" or
 "Thermal conductivity sensor TCS208F3" for optional 3-pin version

qty per shipment	pcks for 6 pcs ea	TCS208F EUR	TCS208F3 EUR	All figures shown are indications of unit net list prices in EUR valid at the time of writing. Packing, freight and tax will be added as applicable. This product information in itself is not a commercial offer.
1 - 5	1	86,41	91,01	
6 - 42	1 - 7	77,72	82,32	
48 - 198	8 - 33	70,56	75,16	
204+	34+	67,49	72,09	

Please enquire to the address shown on the last page for a full quote. Packages for 6 sensors each will be charged at EUR 2,56 each. There is a full refund for any returned such packages.

(Mechanically protected sensor assemblies with pipe thread connectors for up to 160 bar rated pressure are available as well as instruments using this kind of sensor - data sheets on request!)

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.

Documentation, licences and industrial property rights

This product information leaflet has been carefully checked and is believed to be reliable, however, no responsibility can be assumed for inaccuracies that may not have been caught. All information in this leaflet is subject to change without prior notice. Furthermore, the supplier cannot assume responsibility for the use of any license under the patent rights of Hartmann & Braun (now ABB) or any third parties. Some of the applications of this sensor may be protected by third party industrial property rights (e.g. U.S. Patents 4,902,138; 5,333,591; and other German, U.S. and international patents). These components are currently manufactured in Germany by HL-Planartechnik GmbH under a valid license agreement with ABB including the use of the methods described in U.S. Patent 4,902,138 (temperature modulation). The handing over of this leaflet or the delivery of the sensor shall however not be construed as to be an act of granting a separate license.

Limited warranty

The supplier warrants the products he manufactures against defects in materials and workmanship for a period limited to six months from the date of shipment, provided the products have been stored, handled, installed, and used under proper conditions. The supplier's liability under this limited warranty shall extend only to the repair or replacement of a defective product, at the supplier's option. The supplier disclaims all liability for any affirmation, promise or representation with respect to the product. The customer agrees to hold the supplier harmless from, defend, and indemnify the supplier against damages, claims, and expenses arising out of subsequent sales of this product and based upon personal injuries, deaths, property damage, lost profits, and other matters which the customer, its employees, or sub-contractors are or may be to any extent liable, including without limitation penalties imposed by consumer product safety or warranty legislation in the customer's country. No warranties expressed or implied are created with respect to the supplier's products except those expressly contained herein. The customer acknowledges the disclaimers and limitations contained and relies on no other warranties or affirmations.

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 × 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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