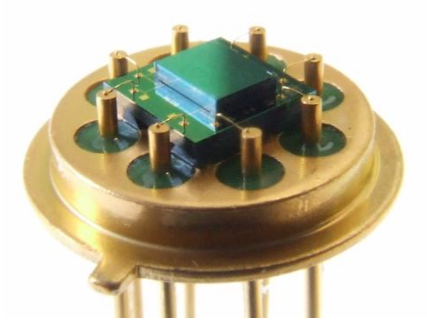
TCS205 [Thermal conductivity sensor]



- **Thermal conductivity sensor for gases**
- **Silicon micromechanics**
- **Very small dimensions**
- **Short time constants**
- **Measurement of very small gas volumes**
- **Gas exchange by diffusion**

DESCRIPTION

The sensor element consists of a silicon chip with a thin membrane approximately $1mm^2$ in size of a material with extremely good electrical and thermal insulating properties. On the membrane are two thin film resistors (R_{m1}, R_{m2}) which are both used for heating the membrane and for measurement of membrane temperature Tm. The resistors are passivated 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 comes 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 by gold wire bonding.

Due to the thermal conductivity l of the gas surrounding the membrane, thermal energy is dissipated from the membrane held at higher temperature Tm. Measured is the signal needed in a temperature stabilization circuit to keep the excess temperature of the membrane DT 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.

FEATURES

- Measuring hydrogen content thermal conductivity
- Analyzing binary gas by evaluating
- Determination of CO_2 vs. Methane
- Discrimination of natural gas
- Measurement of Helium or Xenon contents

APPLICATIONS

- Industrial application
- Monitoring of gas characteristic
- Determining gas concentration
- Landfill or digestor gas
- Different origin gas or compositions gas

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ABSOLUTE MAXIMUM RATINGS

Description	min.	typ.	max.	Unit
Heating power P (R_{m1} + R_{m2})			30	mW
Membrane temperature T_m			180	°C
Ambient temperature ϑ	-20		+85	°C
Gas pressure on base[1]				

SPECIFICATION

Description	min.	typ.	max.	Unit
Resistances R_{m1}, R_{m2} (T_{amb} @ 25°C)	92	100	115	Ω
Resistances R_{t1}, R_{t2} (T_{amb} @ 25°C)	220	240	275	Ω
Quotient R_{tx} / (R_{m1} + R_{m2}) | x ε {1,2}	1.13	1.2	1.27	
Resistance difference R_{m1} - R_{m2}	-2.00		+2.00	Ω
Temperature coefficient (R_m, R_t) | 20°C – 100°C (α)[2]	4800	5500	5900	ppm/K
Geometry factor (G)[3]		3.6		mm
Membrane thermal time constant (τ_m)		< 5		ms
Time constant for gas exchange ($\tau_{diffusion}$)		<100		ms
Drift (Rxy) | x ε {m,t} ; y ε {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

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

Mechanical stress tests have been performed on prototype sample devices for:

Vibration: in accordance with IEC 68-2-6 Appendix B (1982) 10 cycles; ±1.5mm; 20g; 10...2000Hz; 1octave/min

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

[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 specifications.
[3] The factor G is determined by the internal sensor geometry.

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RECOMMENDED OPERATING CONDITIONS

Description	min.	typ.	max.	Unit
Heating power P (R_{m1} + R_{m2})			5	mW
Membrane excess temperature $\Delta T = T_m - \vartheta$	(30)	50	70	°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.

NOTES ON USE OF THE SENSOR

Operation of the sensor

The four resistors R_{m1}, R_{m2}, R_{t1} and R_{t2} on the TCS205 sensor are connected separately to the eight pins on the TO5-style base. Fig.1 shows the pin assignments looking at the sensor side. To operate the sensor it is advisable 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.

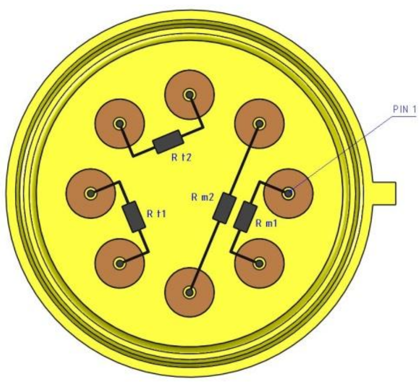

Fig.1: Pin assignment (top view)

Effect of ambient temperature

A given heating power in the membrane resistors produces an excess temperature 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}/°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.

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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)

$$\Delta T = \frac{1+\alpha\cdot\vartheta}{\dfrac{G\cdot\lambda}{i_m^2\cdot R_m}-\alpha}$$

Constant excess temperature operation

Fig.2 shows a temperature compensated application circuit for constant excess temperature operation (ΔT=const.) of the sensor. The membrane heating/measuring resistors R_{m1} and R_{m2} are connected in series between the two operational amplifiers. Also both ambient temperature measurement resistors R_{t1} and R_{t2} are connected in series and are 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(= $R_{t1}+R_{t2}$) 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)

$$\frac{R_1}{R_2} = \frac{R_{t1}+R_{t2}}{\left(R_{m1}+R_{m2}\right)\cdot\left(1+\alpha\cdot\Delta T\right)}$$

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)

$$U_1^2 = \frac{G\cdot\lambda}{\alpha}\cdot\frac{(R_{t1}+R_{t2})\cdot R_2^2-\left(R_{m1}+R_{m2}\right)\cdot R_1\cdot R_2}{\left(R_{m1}+R_{m2}\right)\cdot\left(R_{t1}+R_{t2}\right)}$$

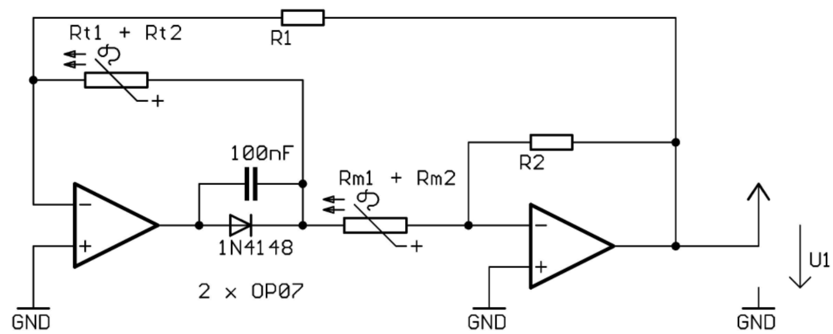

Fig.2: Application circuit for constant excess temperature operation

Example for dimensioning this application circuit:

Conditions:	ΔT = 36.4K	U_1 = 5.8V for l(N_2) = 0.0275 W/m*K (at 50°C)	
Results:	R_1/R_2 = 1.00	R_1 = 1.5 kΩ	R_2 = 1.5 kΩ
Sensitivity:	1% He in N_2 increases U_1 by approx. 140mV		

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Constant membrane current operation

Fig.3 shows a second order temperature compensated application circuit for constant membrane current operation (i_m=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.

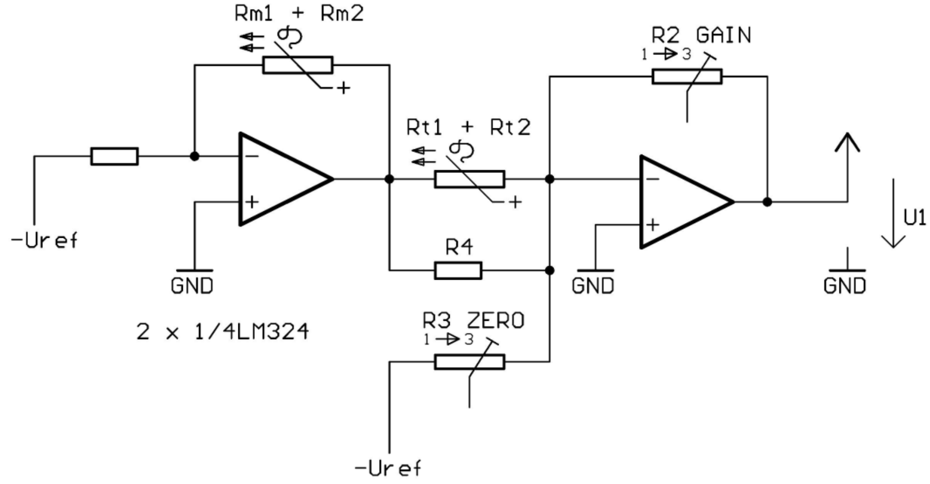

Fig.3: Application circuit for constant membrane current operation

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 = 4mA; not to be used for gases below the thermal conductivity of CO_2):
U_{ref} = 6.2 V; R_1 = 1.5 kΩ; R_4 = 7.5 kΩ for N_2; R_2 = 50 kΩ; R_3 = 10 kΩ (coarse) in series with 100Ω (fine); all trim resistors linear multiturn ceramic metal (e.g. Bourns® or Spectrol®)

Wheatstone bridge operation

Fig.4 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.

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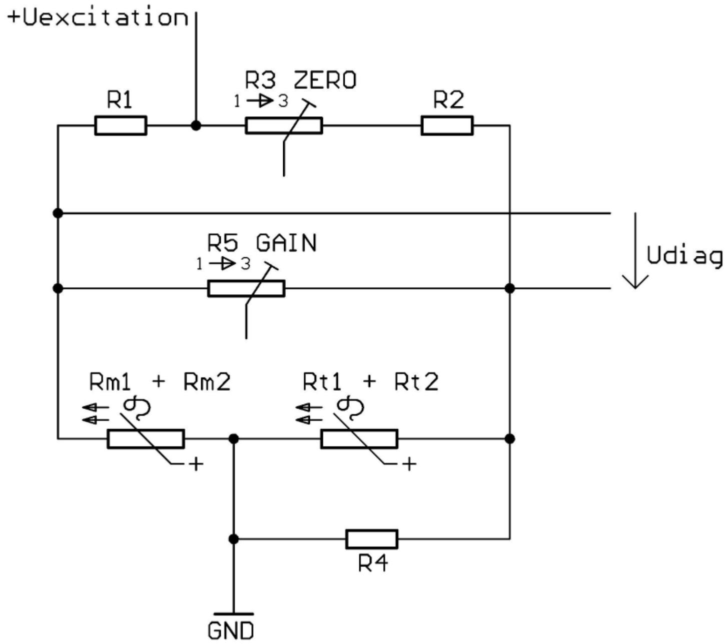

Fig.4: Application circuit for Wheatstone bridge operation

Typical dimensioning of this application circuit (im approx. 4mA; not to be used for gases below the thermal conductivity of CO2):
$U_{excitation}$ = 10 V R1 = 2.7 kΩ R4 = 7.5 kΩ for N2 R2 = 4.7 kΩ R3 = 2 kΩ R5 = 10 kΩ
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 Digitec ® Indicator Model 3241 or Red Lion Controls® PAX-S) which also supply a stabilised 10V excitation voltage.

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 components 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 CO_2 in N_2, O_2 in N_2.
- 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. H_2, He, or CO_2 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 affected 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.

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MECHANICAL DIMENSIONS

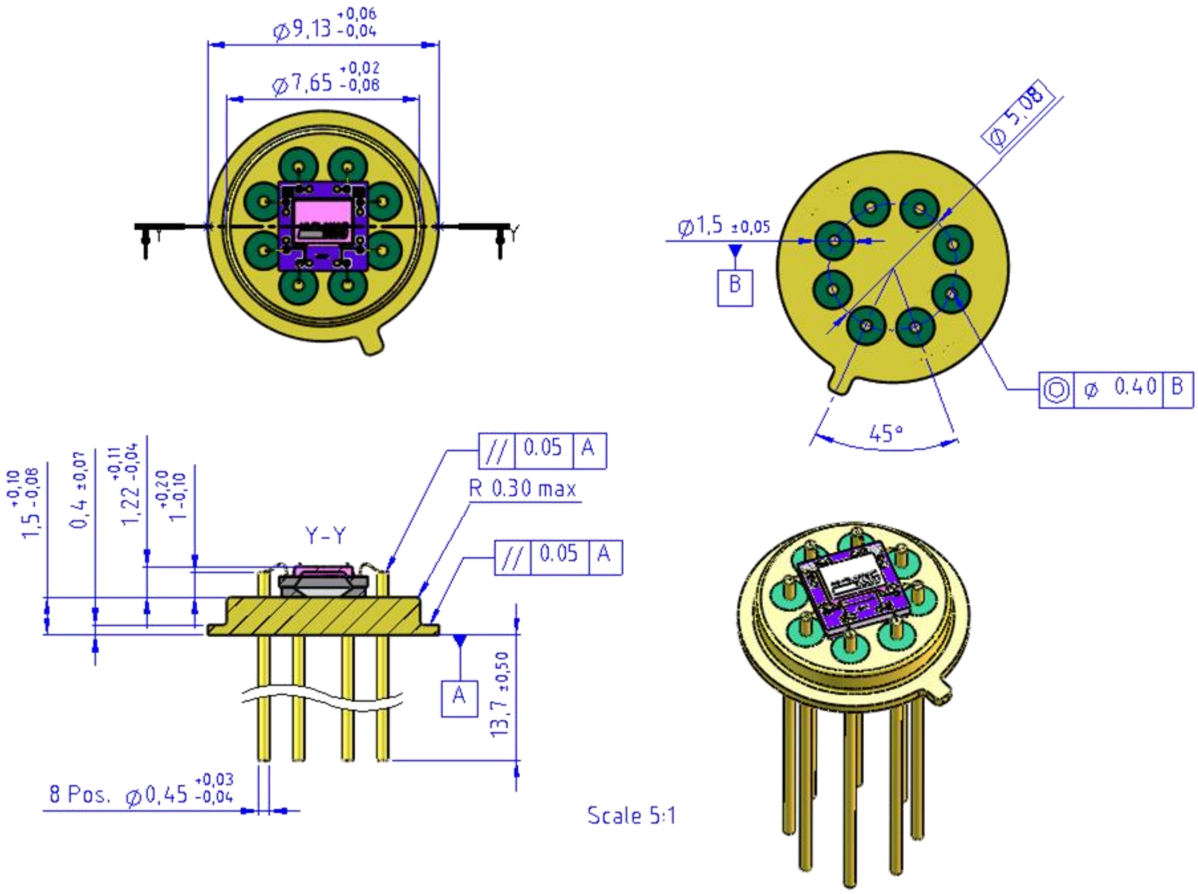

Fig.5: Mechanical dimensions (mm)

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