Temperature coefficient of the XEN-3880

The temperature coefficient (TC) of the output voltage U_{out} of the XEN-3880 (=XEN-TCG3880) depends on three factors. To get an idea of this Temperature Coefficient (TC) we will evaluate the output voltage U_{tp} (in V) of the XEN-3880 as given by the following formula:

$$U_{out} = U_{tp} = P_{in} \times N\alpha_s \times R_{th}$$

Here P_{in} is the input power in W. $N\alpha_s$ is the sensitivity of the thermopile in V/K (*N is the number of strips and α_s is the average Seebeck coefficient per strip*). And R_{th} is the thermal resistance in K/W between the hot junctions of the thermopile and the ambient. This in turn is determined by the thermal conductance of the membrane of the sensor G_{mem}, parallel to the thermal conductance of the surrounding gas G_{gas}, see Figs. 1 and 2. In the XEN-3880, effects of convection and radiation are generally negligible. All these three main factors are temperature dependent.

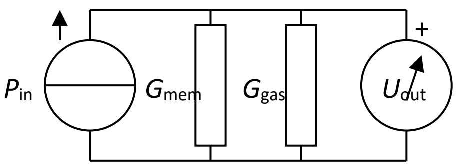

Figure 1: Discrete-element representation of the thermal characteristics of the XEN-3880, with input heating power P_{in} and thermopile output voltage U_{out}.

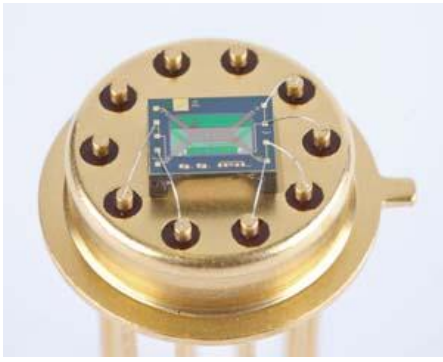

Figure 2: XEN-3880 on TO-5, showing the membrane with thermopiles going to the corners of the chip and the heater in the center.

TC of the power

The heating power P_{in} is supplied by biasing the polysilicon heating resistor R_h (≈ 600 Ω) in the center of the membrane. The temperature coefficient of resistance (TCR) of this heating resistor is about 0.1 %/K (≈0.6 Ω/K). If we bias with a temperature-independent voltage U_h, the heating power is equal to U_h^2/R_h and the temperature coefficient of the power is then –0.1 %/K, the inverse of that of the heating resistor. If we bias with a current I_h (or from a voltage source with a large resistance (>>600 Ω in series), the power is $I_h^2R_h$ and the TC is now +0.1 %/K, the same as the TC of R_h.
This allows us to vary the overall TC by ±0.1 %/K by using either voltage or current biasing, or something in between. By biasing from a voltage source with a series resistance equal to R_h the TC of the power becomes approximately zero.

TC of the thermopile

The thermopile sensitivity $N\alpha_s$ has a technologically determined TC, and for the XEN-3880 it is approximately +0.15 %/ ^oC at room temperature. This means that the thermopile output will rise approximately 0.15%/ ^oC with the ambient temperature, for a given temperature difference across the thermopile.

TC of the thermal resistance

The most complicated factor is the thermal resistance. The thermal resistance and its TC depend upon the use of the sensor.

In vacuum

At low pressures (*1 Pa or less*), the thermal resistance is almost completely determined by the membrane. For the XEN-3880, the thermal resistance of the membrane is determined largely by the (low-stress LPCVD) silicon-nitride. That means that the TC in vacuum is determined by that of the SiN (which is estimated to be +0.05 %/K).

Using the XEN-TCG3880 as gas type sensor

When using the TCG to determine gas type or gas mixtures, the situation is different.
For air at atmospheric pressure (100 kPa), the output voltage of the XEN-3880 is only 25% of the output voltage at 0 Pa. That means that the thermal conductance G_{th} to the ambient (*the inverse of the thermal resistance*) is determined for about 75% by gas conduction. Thus, the TC of the gas conduction will contribute for 75% to the TC of the thermal resistance. The TC of the thermal conductivity of gases is typically of the order of +0.3 %/K at room temperature, which means that the thermal resistance due to gas conductance will decrease with increasing temperature. For air, with a TC

of the conductivity of 0.29 %/K, assuming that the membrane resistance will increase at a rate of 0.05 %/K, this will give a TC of R_{th} of 0.25×0.05%/K + 0.75×-0.29%/K = -0.2 %/K.

When the sensor is immersed in pure helium, the situation becomes different again. The output is decreased by another factor of 4, because of the high thermal conductivity of helium. Now, R_{th} is almost entirely determined by the helium, and the TC of R_{th} also. The TC of the conductivity of helium is about 0.24 %/K at room temperature, so that the TC of R_{th} is now slightly larger at –0.24 %/K.

Overall Temperature Coefficient of the XEN-3880

Table 1 gives an overview of the various TCs for the different measurement situations. It is explained below.

Table 1: Temperature coefficients of the XEN-3880 in various situations

Situation	TC thermopile	TC power	TC thermal resistance	Overall TC
Vacuum sensor				
Heating voltage, 0 Pa	+0.15 %/K	-0.10 %/K	+0.05 %/K	**+0.10 %/K**
Heating voltage, 100 kPa	+0.15 %/K	-0.10 %/K	-0.20 %/K	**-0.15 %/K**
Gas type sensor (air)				
Heating voltage	+0.15 %/K	-0.10 %/K	-0.20 %/K	-0.15 %/K
Heating current	+0.15 %/K	+0.10 %/K	-0.20 %/K	+0.05 %/K
Heating voltage + 2 kΩ series resistance	+0.15 %/K	+0.05 %/K	-0.20 %/K	**0.00 %/K**

For vacuum sensor

The overall TC of the XEN-TCG3880 is now the sum of the components, we obtain for a vacuum sensor at 0 Pa a TC of +0.15 %/K (thermopile) +0.05 %/K (thermal resistance of membrane) ±0.10 %/K (power) = +0.10 to +0.30 %/K.
At 0 Pa, a near-zero TC is not possible. Biasing with a pure voltage is to be recommended, since the thermopile and the membrane both give a positive TC. Obtaining a near-zero TC for a vacuum sensor over the whole pressure range from 0-100 kPa is not possible by a simple biasing scheme, as can be deducted from the situation for the gas type sensor. Feedback of the output signal is required allowing the heating to be dependent upon output signal and temperature. Even then, measuring sub-atmospheric pressures of different gas types will lead to problems, as shown for the helium and air examples.

For gas type sensor

For a gas type sensor measuring air we obtain a TC of +0.15 %/K (thermopile) –0.20 %/K (thermal resistance) ±0.10 %/K (power) = -0.15 %/K to +0.05 %/K. Therefore, by heating from a voltage source with a series resistance of the order of 2 kΩ, a near-zero TC can be obtained.

RS PRODUCT SOLUTIONS
DISTRIBUTIEWEG 58 - 2645EJ DELFGAUW - THE NETHERLANDS
PHONE: +31639268377 - EMAIL: RENE@RSPRODUCTSOLUTIONS.NL - WWW.XEN5320.COM