$GaPO_4$ Factsheet

FEATURES

- Thermal stability up to 970°C
- Outstanding electric resistance up to very high temperatures
- Twice the sensitivity of tourmaline and quartz
- No pyroelectricity
- Proven stability for 10 000 hours at 200°C, 90 bar mean pressure
- Guaranteed 100 000 000 pressure cycles 1 - 250 bar

DESCRIPTION

Piezoelectric sensing elements can be made of different materials. Common to all these materials is that they exhibit the piezoelectric effect, which transforms applied forces upon the material into electric signals. Some piezoelectric materials show, in addition, a pyroelectric behavior, and as such, deliver an electric signal whenever the temperature of the sensing element changes.

Gallium phosphate is the perfect pressure sensing element, as it does not show this thermal behavior and it can be used up to very high temperatures.

The industrial growth process ensures a constant material quality with intrinsic material sensitivity. This crystal has been used in technical applications such as pressure sensors since 1994.

Gallium phosphate shows excellent thermal stability of piezoelectric constants, phase transition at a temperature of 970°C (Fig. 1). Long term testing at 950°C showed no sign of structure changes.

An ideal sensing element does not show any signal variation when exposed to temperature changes. Piezoelectric materials that also have pyroelectric characteristics like Tourmaline or Piezoceramics produce a significant amount of charges due to temperature changes; an effect that is absent in the purely piezoelectric gallium phosphate or quartz (see Fig. 2).

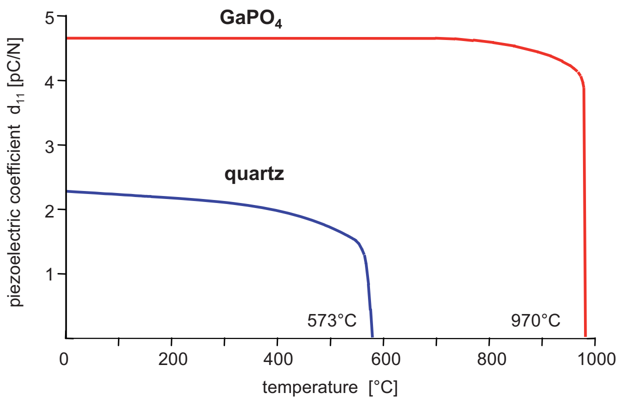

Fig. 1 : Comparison between the piezoelectric constant d_{11} of $GaPO_4$ and quartz. $GaPO_4$ is twice as sensitive as quartz and extremely linear over a large temperature range.

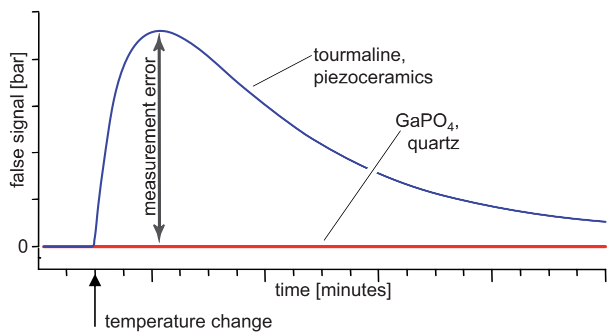

Fig. 2 : Comparison between the piezoelectric constant d_{11} of $GaPO_4$ and quartz. $GaPO_4$ is twice as sensitive as quartz and extremely linear over a large temperature range.

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Under real world conditions, sensors are exposed to temperature and pressure variations at the same time. This leads to signals that are a combination of both effects. In a pyroelectric material, it is not possible to extract the pure pressure portion of such superimposed signals (see Fig. 3).

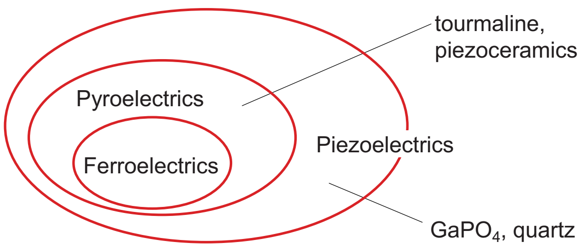

Fig. 3 : Classification of piezoelectric materials.

SPECIFICATIONS

General data

Point group	: 32 (D_3) (quartz-homeotype)
Lattice constants (25°C)	: a = 4.901 Å, c = 11.048 Å
Density (25°C)	: 3 570 kg/m^3

Piezoelectric constants

	25°C	500°C	700°C	950°C
$d_{11}^{a,b}$ [pC/N]	4.5	4.5	4.5	4.1^c
d_{14}^{a} [pC/N]	1.9	1.6	1.4^c	1.0^c

$$d = \begin{bmatrix} d_{11} & -d_{11} & 0 & d_{14} & 0 & 0 \\ 0 & 0 & 0 & 0 & -d_{14} & -2d_{11} \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Thermal expansion coefficients (at T_0 = 25°C, -253°C < T < 900°C)

	$\alpha_{ii}(T_0)$ [$10^{-6}K^{-1}$]	$T\alpha_{ii}^{(1)}$ [$10^{-9}K^{-2}$]	$T\alpha_{ii}^{(2)}$ [$10^{-12}K^{-3}$]	$T\alpha_{ii}^{(3)}$ [$10^{-15}K^{-4}$]
α_{11}	12.78	10.6	-16.1	12.3
α_{33}	3.69	5.0	-5.4	3.6

$$\alpha = \begin{bmatrix} \alpha_{11} & 0 & 0 \\ 0 & \alpha_{11} & 0 \\ 0 & 0 & \alpha_{33} \end{bmatrix}$$

$$\alpha_{ii}(T) = \alpha_{ii}(T_0) + \sum_{n=1}^{3} \left[T\alpha_{ii}^{(n)} \cdot (T - T_0)^n \right]$$

Thermal conductivity

	50ºC	70ºC	100ºC	130ºC	150ºC	180ºC	200ºC
$\lambda_{11}\left[Wm^{-1}K^{-1}\right]$	4.21	3.96	3.68	3.28	3.07	2.85	2.71
$\lambda_{33}\left[Wm^{-1}K^{-1}\right]$	6.66	6.14	5.66	5.00	4.78	4.27	4.02

$$\lambda = \begin{bmatrix} \lambda_{11} & 0 & 0 \\ 0 & \lambda_{11} & 0 \\ 0 & 0 & \lambda_{33} \end{bmatrix}$$

Electric resistivity

	25ºC	200ºC	300ºC	500ºC	700ºC	900ºC
$\rho\left[\Omega m\right]$	$>10^{15}$	$>10^{13}$	$>10^{11}$	$>10^{9}$	$>10^{7}$	$>10^{5}$

Relative dielectric constants (at T_0 = 25ºC, 1 kHz)

$\varepsilon_{11}{}^{T}$	6.1	$\varepsilon_{11}{}^{S}$	5.8
$\varepsilon_{33}{}^{T}$	6.6	$\varepsilon_{11}{}^{S}$	6.6

$$\begin{bmatrix} \varepsilon_{11} & 0 & 0 \\ 0 & \varepsilon_{11} & 0 \\ 0 & 0 & \varepsilon_{33} \end{bmatrix}$$

Elastic constants (at T_0 = 25ºC, -50ºC < T < 700ºC)

	c_{ij} [GPa]	$Tc_{ij}^{(1)}$ [$10^{-6}K^{-1}$]	$Tc_{ij}^{(2)}$ [$10^{-9}K^{-2}$]	$Tc_{ij}^{(3)}$ [$10^{-12}K^{-3}$]
c_{11}^E	66.58	-44.1	-28.5	-59.4
c_{12}^E	21.81	-226.7	-70.8	-205.7
c_{13}^E	24.87	-57.6	41.3	-109.9
$c_{14}^{E\,b}$	3.91	507.2	280.6	-99.9
c_{33}^E	102.13	-127.5	-18.3	-134.8
c_{44}^E	37.66	-0.4	-43.8	-37.1
c_{66}^E	22.38	44.9	-7.9	11.9

$$c = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & 0 & 0 \\ c_{12} & c_{11} & c_{13} & -c_{14} & 0 & 0 \\ c_{13} & c_{13} & c_{33} & 0 & 0 & 0 \\ c_{14} & -c_{14} & 0 & c_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & c_{44} & c_{14} \\ 0 & 0 & 0 & 0 & c_{14} & \frac{(c_{11}-c_{12})}{2} \end{bmatrix}$$

$$c_{ij}(T) = c_{ij}(T_0)\left[1 + \sum_{n=1}^{3} Tc_{ij}^{(n)} \cdot (T-T_0)^n\right]$$

	s_{ij} [$10^{-12}m^2N^{-1}$]	$Ts_{ij}^{(1)}$ [$10^{-6}K^{-1}$]	$Ts_{ij}^{(2)}$ [$10^{-9}K^{-2}$]	$Ts_{ij}^{(3)}$ [$10^{-12}K^{-3}$]
s_{11}^E	17.93	22.4	30.5	62.4
s_{12}^E	-4.82	-210.5	-0.1	-271.3
s_{13}^E	-3.19	181.6	78.2	322.2
$s_{14}^{E\,b}$	-2.36	482.2	315.5	7.9
s_{33}^E	11.35	147.9	14.1	261.5
s_{44}^E	27.04	18.7	54.7	52.0
s_{66}^E	45.51	-26.9	24.0	-8.3

$$s = \begin{bmatrix} s_{11} & s_{12} & s_{13} & s_{14} & 0 & 0 \\ s_{12} & s_{11} & s_{13} & -s_{14} & 0 & 0 \\ s_{13} & s_{13} & s_{33} & 0 & 0 & 0 \\ s_{14} & -s_{14} & 0 & s_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{44} & 2s_{14} \\ 0 & 0 & 0 & 0 & 2s_{14} & 2(s_{11}-s_{12}) \end{bmatrix}$$

$$s_{ij}(T) = s_{ij}(T_0)\left[1 + \sum_{n=1}^{3} Ts_{ij}^{(n)} \cdot (T-T_0)^n\right]$$

[a] signs according to standard IEEE 176-1987 for right-handed crystals; for left-handed $GaPO_4$ crystals the signs of d_{11}, and d_{14} are changed
[b] signs are changed according to IEC 60758 2004-12
[c] predicted value
[T] constant stress, [S] constant strain, [E] constant electric field

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