INVESTIGATIONS TO DESIGN PIEZOELECTRIC RESONANCE SENSORS ON LANGASITE

V.V. Bezdelkin

State Research Institute For Heat Power Engineering Instrument Making
"NIITEPLOPRIBOR", Prospekt Mira, 95, Moscow, 129085, Russia: Fax: (095) 215-78-00

Abstract

The results of researches on development of piezoelectric resonance sensors of langasite designed for high-temperature transducers for measurement temperature and pressure are discussed here.

Introduction

Sensors for high-temperature transducers must ensure high sensitivity regarding measured parameter, stability and reproducibility of results within a wide temperature range. In many respects, these parameters depend upon proper selection of materials of the piezoelectric and design of the sensor. The results of some researches are discussed in this paper.

Selection of piezoelectric for high-temperature sensors

In high-temperature applications, the piezoelectric crystals must feature high temperature of phase transformation and high threshold of instability of electophysical properties. The following crystals: $GaPO_4$, $La_2Ga_5SiO_{14}$, $LiNbO_3$, $LiTaO_3$, $Li_2B_4O_7$ and some others may be considered to be among high-temperatures crystals.

The researches revealed that langasite is a promising material for application in high-temperature transducers. In langasite, there are crystallographic directions with both low and high values of temperature-frequency characteristic and load-bearing sensitiveness.

Research of high-temperature conductivity of langasite

When being heated up to temperature +300…+400^{o}C there took place increase in dynamic resistance 2-3 times as more. To find out the reason there were carried out researches of specific conductivity and dielectric permeability of langasite at high temperatures.

The measurements were performed in an open atmosphere on plates with X-cut (normal cut) and with Z-cut (face perpendicular cut) equipped with golden electrodes. Electrical characteristics of the sensor commence to degrade abruptly within the range of temperatures from +300 to +400^{o}C (see fig. 1-2). Within the range of higher temperatures, electrical characteristics degrade in accordance with exponential dependence.

Activation energy of conduction current carriers under conditions of rise in temperature is equal to ~0.6-0.7 eV. Doglegs of the curves at temperature near to +300^{o}C (see fig. 3) indicate the shift of mechanism of conductivity and increase in number of current carriers in the crystal.

Particulars in design of sensors

Bellow you may find the results of high-temperature measurements in an open atmosphere of thermal and load-bearing sensitive features of langasite on Y-cuts (face parallel cuts) of piezoelectric cells with resonance frequency being equal to 5 MHz. The measurements of tension sensitive features of langasite were performed on elements of rectangular shape with dimensions of 10x4 mm, stretched out along either X-axis or Z-axis. Gold was used as a material for electrodes. The sensors were made in accordance with technology of quartz resonators. Basic characteristics of thermal and load-bearing sensitive piezoelectric cells, measured by means of a Hewlett Paccard measuring instrument at a room temperature on air, are given in fig. 4 and in table 1.

Temperature sensors

Temperature-frequency characteristic of the sensors were measured in the temperature range from -80 to +1000^{o}C. The typical temperature-frequency characteristics of Y-cut of langasite sensors are shown in fig.5 At temperatures higher than +700^{o}C piezoactivity of the fell down practically down to zero mark, however, when being cooled, the sensors started up to operate again. Average slope of curve representing temperature-frequency characteristic of thermal sensitive cells in temperature range from +100 to +600^{o}C was amounted to ~160 Hz/^{o}C. While operating on the third harmonic the average slope in the stated temperature range was amounted to ~350 Hz/^{o}C, and while operating on the fifth harmonic the slope of temperature-frequency characteristics increased up to ~460 Hz/^{o}C. Temperature-frequency characteristic of the sensors for various temperature intervals are shown in table 2. When operating on harmonics the extremum of temperature-frequency characteristic of the sensors offsets into the realm of higher temperatures.

Load-bearing sensitive sensors

The results are of preliminary nature. In direct Y-cuts, load-bearing sensitivity of langasite reaches its maximal value along the direction of Z-axis. At a room temperature, the coefficient of load-bearing sensitivity of the sensors along the direction of Z-axis is equal approximately to 0.4 Hz/g. Frequency deviation at loading of 500 g while operating under tension conditions was amounted approximately to 200 Hz. Thus, relative load-bearing sensitivity of direct Y-cut of langasite cell turned out to be comparable with quartz and sufficient for practical application. Inferior of Q-quality and high resistance R_1 of the experimental sensor along the direction of Z-axis (see table 2) may be explained on the basis of by-side resonances, which may be eliminated by proper design selection.

It is worthy to make a note that at high temperatures within the cells without hermetic encapsulation there took place rapid destruction of golden electrode surfacing. The electrode surfacing became thinner and almost pellucid. Therefore, in further researches electrode surfacing of platinum was employed.

Temperature transducer based on sensor of langasite

The researches of experimental temperature transducers of langasite were carried out within the temperature range from -50^{o}C to +500^{o}C. Base model of the transducer consists of langasite thermal sensitive sensor located inside a hermetic metallic housing of 10 mm in diameter, protective shroud of steel of 12X18N10T grade and another housing with electronic circuit of oscillator inside. This electronic circuit transforms variation of resonance frequency of the langasite thermal sensitive sensor into a frequency output signal. The circuit operates safely when located at large distance from the sensor whose frequency and electrical characteristics vary greatly in an operating range of temperatures.

The resonance frequency of the sensor is 5 MHz. The length of the submersible portion of the sensor is 0.5 m. Operating performance of the sensor is well characterized by the following third-degree polynomial: $T = T_0 + A_1(F-F_0) + A_2(F-F_0)^2 + A_3(F-F_0)^3$, where T_0 is a reference value of temperature, F_0 is the value of frequency of the input signal, and A_1, A_2 and A_3 are the coefficients of operating performance of the sensor. The supply voltage of the sensor is 5V; consumption current is less than 0.01 A. Deviation of the operating performance of the sensor from this polynomial did not exceed ±0.5^{o}C, return to the original frequency after multiple heatings beginning from the melting ice temperature (zero degrees) till +500^{o}C did not exceed ±1^{o}C. Temperature-frequency characteristic of the sensor is shown in fig.7. Average temperature-frequency characteristic of the sensor in a temperature range from -50^{o}C to +500^{o}C was amounted to~160 Hz/^{o}C. Within the interval from -50 to 0^{o}C the temperature-frequency characteristic is equal to ~70 Hz/^{o}C, within the interval from 0 to +300^{o}C the temperature-frequency characteristic is equal to ~150 Hz/^{o}C, and within the interval from +300 to +500^{o}C the temperature-frequency characteristic is equal to ~270 Hz/^{o}C.

Conclusion

Langasite is a promising high-temperature piezoelectric for application in thermal- and load-bearing sensitive piezoelectric resonance sensors. Sensors made of langasite are not inferior to quartz ones in respect of thermal- and load-bearing sensitivity and superior to them in respect of upper temperature band.

Table 1. Basic features of high-temperature langasite sensors.

Sensor	F, MHz	$\Delta(f_p-f_a)/f_p$, %	Q	R_1, Ohm	L_1, Henry	C_1, pF	C_0, pF	P, μW
Thermo (Au)	~5.5	0.68	24000	7.1	$4.90x10^{-3}$	0.17	12.36	50.0
Tenso along X	~5.0	0.62	25000	16.6	$1.37x10^{-2}$	0.075	6.03	50.0
Tenso along Z	~5.0	0.36	6000	132.9	$2.52x10^{-2}$	0.041	5.71	50.0

Table 2. Temperature-frequency characteristics (CTF, Hz/ ^{0}C) of langasite sensors

Harmonic	Temperature range ^{0}C		
	100 – 300	300 – 600	600 – 700
1	100	200	1000
2	210	450	1600
3	350	530	3200

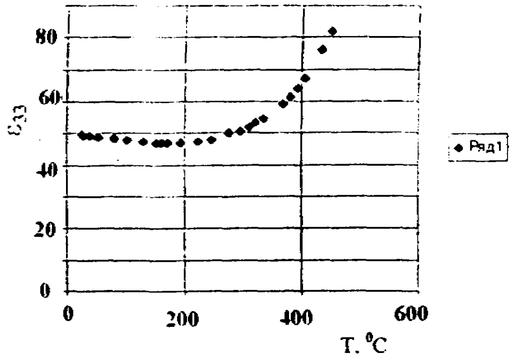
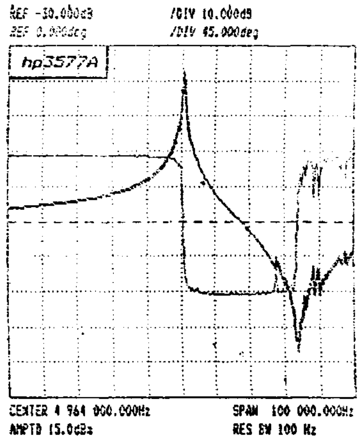


Fig. 1 Specific dielectric constants ε of Z-cut samples as a function of temperature



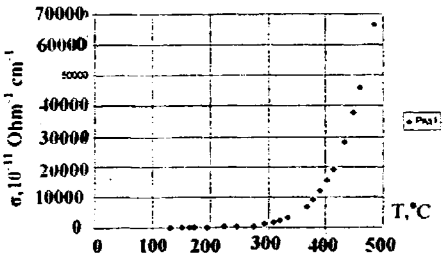


Fig.2 Specific conductivity σ, 10^{-11} Ohm^{-1}. cm^{-1} of Z-cut samples as a function of temperature

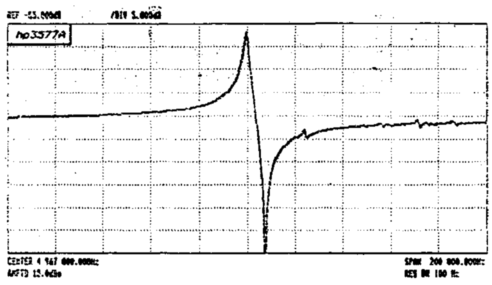


Fig.4. Amplitude-frequency responses of temperature transducers: 1 – Y-cut, 2 – reversed Y-cut.

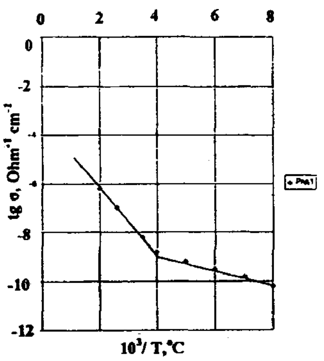


Fig 3. Specific conductivity of Z-cut langasite plates as a function of temperature

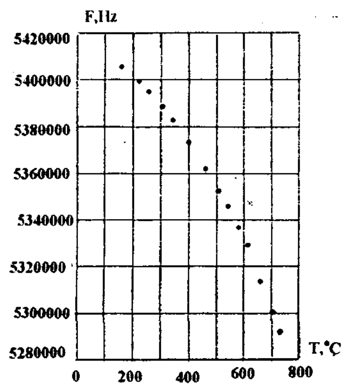


Fig.5. Temperature-frequency responses of temperature transducers (Y-cut).

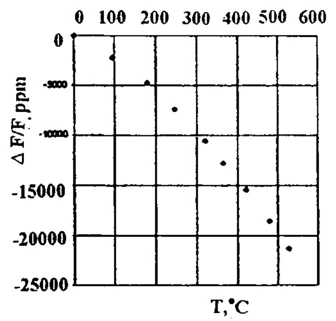


Fig. 6 Temperature-frequency characteristic of the sensor (reversed Y-cut).