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Housed Temperature Sensors Based on Piezoelectric Resonators for High-Temperature Applications

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Summary:
A housed temperature sensor based on piezoelectric CTGS ($Ca_3TaGa_3Si_2O_{14}$) single crystals is presented. Here, temperature data is derived from the shift of the resonance frequency, obtained from an analysis of the impedance spectra of resonators prepared from CTGS. The device is operated up to 900 °C, exhibiting nearly linear temperature dependence of the resonance frequency of about 180 Hz/K in the entire temperature range.

Keywords: piezoelectricity, temperature sensor, resonance frequency, CTGS

Introduction and Objectives

Piezoelectric devices based on high-temperature stable single crystals allow to create sensors for measurement of temperature as well as other physical properties. Thereby, the devices withstand harsh environments such as extreme temperatures or highly reducing or oxidizing atmospheres. The measured property is the resonance frequency which is governed by e.g. the temperature of the environment.

Commonly used piezoelectric materials such as quartz or lithium niobate are not suitable for high-temperature applications. Strongly increasing damping and destructive phase transitions or decomposition of the crystals limit their use up to about 400-500 °C. Catangasite ($Ca_3TaGa_3Si_2O_{14}$, CTGS) is a commercially available member of the so-called langasite family. The crystal structure of CTGS is the same as of quartz. CTGS does not undergo any phase transitions up to its melting point at about 1350 °C [1] and exhibits an ordered crystal structure, yielding low electromechanical losses [2,3].

This paper focuses on preparation and characterization of high-temperature stable resonators based on Y-cut CTGS crystals and their integration in a gas-tight package. The temperature dependence of the resonance frequency and loss of as-prepared resonators and housed devices is compared and discussed.

Experimental

Polished Y-cut CTGS blanks with a diameter of 10 mm are purchased from Shanghai SICCAS High Technology Corporation (Shanghai, China) and from FOMOS Materials (Moscow, Russia). The thickness of about 250 µm is chosen for a resonance frequency of 5 MHz. Keyhole-shaped electrodes with a diameter of 5 mm are deposited using pulsed laser deposition (PLD) and screen printing techniques. In case of the former, a Pt/Rh alloy is deposited, as it exhibits improved stability in harsh environments [4]. In case of the latter, standard Pt paste (Ferro, 64120410) is used.

The resonators are pre-characterized in air at a ramp of 1 K/min in temperature range from RT up to 850 °C and 1000 °C for PLD and screen printed electrodes, respectively. Thereby, the impedance spectra in the vicinity of the resonance frequency is measured using an Agilent E5100A network analyzer. From this data, the peak maximum and full width at half maximum (FWHM) of the real part of admittance are calculated.

Subsequently, the resonators are mounted in a housing made of Al_2O_3 (see Fig. 1). Thereby, the CTGS is glass-soldered with a support structure. The electrical contact between connector pads and the resonator is realized using Pt bond wires. Finally, a cap is mounted over the resonator and sealed using glass solder technique.

The complete device is characterized in a furnace up to 900 °C. Thereby, the analysis as done during the pre-characterization is repeated. The obtained frequency data and loss are compared with those of as-prepared Y-cut resonators.

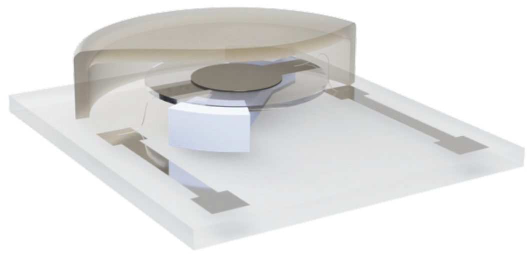

Fig. 1. Design of a temperature sensor based on CTGS.

Results and Discussion

The relative changes of resonance frequencies for as-prepared and housed resonators are shown in Fig. 2. Since the screen printed electrodes are fired in a furnace prior to the measurement, they introduce low mechanical strain to the resonator. In case of the PLD electrodes a small hysteresis of the resonance frequency is measured during first temperature ramp. The relative change of the frequency for two different crystal manufacturers is the same. The absolute data spreads by about 2 % between investigated samples. This is attributed to slight differences in the thickness of as-prepared blank Y-cuts.

The loss expressed in form of inverse Q factor [5] is shown in Fig. 3. Due to very narrow FWHM of the admittance peak, the calculated Q value at low temperatures exhibits large noise. The increase of Q^{-1} at 350-500 °C is attributed to anelastic relaxation of point defects [3]. At temperatures above 700 °C the loss is dominated by piezoelectric/conductivity relaxation [3]. As shown in Fig. 3, the loss measured for the housed device is nearly identical to those of an as-prepared SICCAS resonator. The FOMOS material exhibits significantly lower loss throughout entire temperature range.

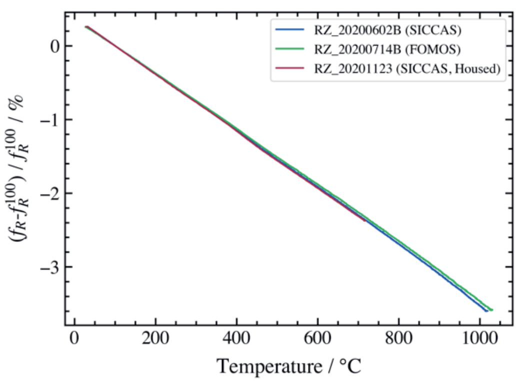

Fig. 2. Relative change of resonance frequency for CTGS manufactured by SICCAS and FOMOS as well as housed CTGS. Thereby, the housed resonator was annealed up to 700 °C only.

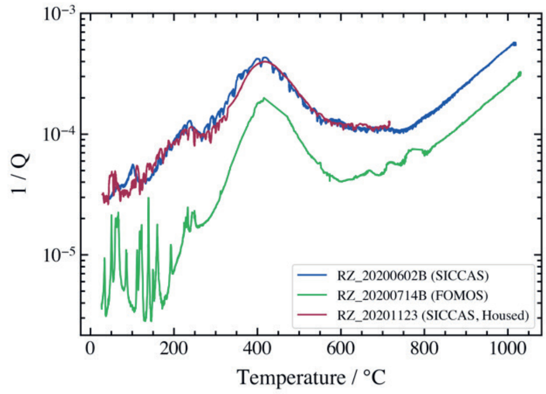

Fig. 3. Loss measured in CTGS samples and housed device as a function of temperature.

Conclusions

CTGS is a promising material for high-temperature stable sensor devices. Thanks to ordered crystal structure it exhibits low losses in comparison to some other members of langasite family. A nearly linear dependence of the resonance frequency from temperature of Y-cut CTGS simplifies the frequency to temperature conversion allowing to perform it even on low-cost microcontrollers. The housed sensor is tested up to 900 °C. The impact of the housing on resonators performance is negligible.

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