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CTGS: advanced piezoelectric single crystal for sensor applications over extremely wide temperature range.

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Summary:
Material parameters of CTGS piezoelectric single crystal were derived in extremely wide temperature range from cryogenic temperature to 1173 K. Temperature sensor on the base of Y-cut CTGS SAW resonator was demonstrated.

Keywords: piezoelectric crystal, bulk acoustic wave, SAW, langasite family, catangasite, temperature sensors

Introduction

Piezoelectric single crystals are key materials for microacoustic devices and sensors of various physical quantities. Of particular interest are crystals which possess a reasonable piezoelectric response i.e. high electromechanical coupling over extremely wide temperature ranges from cryogenic to very high temperatures up to 1000°C and higher. Materials for application under such harsh conditions should maintain their material parameters over this temperature range without noticeable deterioration. Among potential canidates, piezoelectric crystals of the langasite (LGS, $La_3Ga_5SiO_{14}$) family are very promising. For example, catangasite (CTGS, $Ca_3TaGa_3Si_2O_{14}$) crystal, a member of LGS family with ordered structure, demonstrates a combination of very attractive properties like relatively high electromechanical coupling, moderate dielectric constant, low acoustic loss and the absence of a structural phase transition in the entire considered temperature range. In this communication, we present CTGS material parameters measured at 4.2 and 1173 K, estimation of sound attenuation including measurements in the GHz range as well as the characteristics of a SAW temperature sensor based on Y-cut CTGS crystal.

Crystal growth and sample preparation

CTGS single crystals were grown by the Czochralski technique by FOMOS Materials, Moscow, Russia and Leibniz Institute for Crystal Grows, Berlin, Germany. For the ultrasonic wave velocity measurements of CTGS, cube-like samples were prepared. Attenuation measurements were carried out on the thin plates of 10 mm diameter and 0.5 mm thickness. For GHz frequencies, AlScN thin film piezoelectric transducers were deposited on the samples to realize High overtone Bulk Acoustic Resonator (HBAR). Finally, a demonstrator of SAW-based temperature sensor was realized by a one-port resonator chip comprising CTGS Y-cut crystal and advanced temperature stable electrode metallization system on top.

Experimental procedure

Measurements of the bulk acoustic wave velocities propagating along certain directions were carried out by means of a RITEC RAM-5000 System and UT340 Pulser Receiver. Results at GHz frequencies were obtained using Agilent E5071C Network Analyzer in combination with AlScN thin film transducer. All temperature measurements were carried out using a continuous flow cryostat, a Carbolite tube furnace and a Linkam HFS600E temperature stage, respectively.

Results and discussion

The elastic C_{ij} and piezoelectric e_{ij} constants were derived using a system of relations between bulk velocities of different characteristic modes propagating along certain crystallographic directions. As a result, elastic, piezoelectric and dielectric constants of CTGS single crystal at 4.2 K [1] and 1173 K are presented in Tab.1. Notice strong piezoelectric response of the crystal in a very wide temperature range including both cryogenic and high temperatures. Sound attenuation in GHz range is an important parameter, especially for SAW sensors usually operating at high frequencies.

Tab. 1: Material parameters of CTGS single crystal at 4.2 and 1173 K.

Material constant	4.2 K	1173 K
C_{11} (GPa)	159.8	136.2
C_{12} (GPa)	83.15	57.9
C_{13} (GPa)	70.6	68.5
C_{14} (GPa)	1.2	0.52
C_{33} (GPa)	218.3	180.7
C_{44} (GPa)	39.02	42.9
C_{66} (GPa)	38.3	39.15
e_{11} (C/m^2)	-0.36	-0.435
e_{14} (C/m^2)	0.62	0.646
$\varepsilon_{11}/\varepsilon_0$	19.7	17.2
$\varepsilon_{33}/\varepsilon_0$	34.4	22.9

Fig. 1 shows as an example obtained attenuation coefficient α as a function of frequency for longitudinal mode on Y-cut CTGS measured at room temperature.

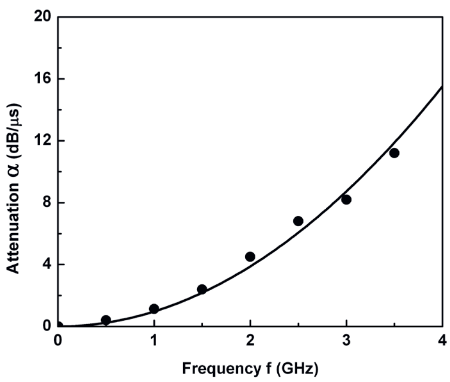

Fig. 1. Sound attenuation versus frequency for Y-cut CTGS (L-mode). Symbols: experiment, solid line: function ~ f^2 for comparison.

Note the well-defined square dependence of the attenuation versus frequency, which is also valid for X and Z crystal cuts. As for sound attenuation as a function of temperature, it was found to be low at 4.2 K while still reasonable at high temperature. Fig. 2 shows as an example ultrasonic pulse-echo patterns for Y-cut CTGS sample at 298 and 1195 K, resp. The results were obtained using very short ultrasonic pulses (5 ns); sound excitation and receiving here were done using the intrinsic piezoelectric effect of the crystal.

The temperature dependence of the resonance frequency of a SAW one-port resonator operated as temperature sensor in the range between 25°C and 600°C is depicted in Fig. 3. Note the very good linear frequency vs. temperature characteristics of the SAW device.

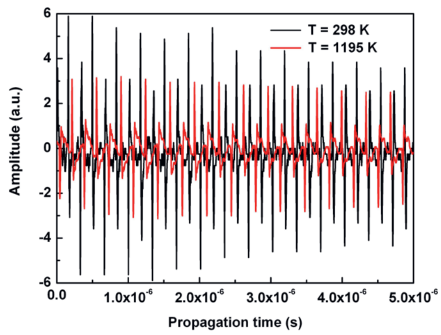

Fig. 2. Pulse-echo pattern for Y-cut CTGS single crystal at 298 K (black line) and 1195 K (red line).

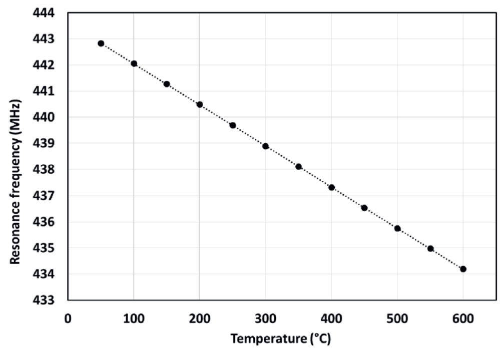

Fig. 3. Resonance frequency vs. temperature for SAW one-port resonator as temperature sensor.

Conclusion

Material parameters of CTGS single crystals were derived over extremely wide temperature range up to 1173 K. Strong piezoelectric response as well as reasonable sound attenuation even in GHz frequency range predestine catangasite crystal as promising material for sensors capable of operating in a very wide temperature range. Temperature sensor behavior on the base of Y-cut CTGS SAW resonator was successfully demonstrated.

Acknowledgements

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References

[1] A. Sotnikov, H. Schmidt, M.H. Haghighi, M. Gorev, Yu. Suhak, H. Fritze, S. Sakharov, Material parameters of $Ca_3TaGa_3Si_2O_{14}$ (CTGS) piezoelectric single crystal at extreme temperatures, *Proc. Joint Conf. Europ. Freq. and Time Forum and IEEE Int. Freq. Contr. Symp.,* 193-197 (2017); doi: 10.1109/FCS.2017.8088844.