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Catangasite: piezoelectric single crystal for sensor applications at harsh conditions.

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Summary:
Material parameters of catangasite (CTGS) piezoelectric single crystal are derived in extremely wide temperature range from 4.2 to 1173 K. A temperature sensor on the base of Y-cut CTGS SAW resonator is demonstrated.

Keywords: piezoelectric crystal, catangasite, langasite family, BAW, SAW, HBAR, 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 over an extremely wide temperature range from cryogenic to very high temperatures (1000°C and higher). Materials for use under these harsh conditions should maintain their material parameters over the entire operating temperature range. 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 with ordered structure, demonstrates a combination of very attractive properties like relatively high piezoelectric coefficients, moderate dielectric constants, low acoustic loss and the absence of a structural phase transition up to the melting point of about 1450° C. In this communication, we present CTGS material parameters measured at 4.2 and 1173 K, an estimation of sound attenuation and viscosity tensor components 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 FOMOS Materials (Moscow, Russia) and Leibniz IKZ (Berlin, Germany) using the Czochralski technique. For the ultrasonic wave velocity and attenuation measurements, cube-like samples and plates of different crystallographic orientation were prepared. For GHz frequencies, AlScN thin film piezoelectric transducers were deposited on the samples to realize High overtone Bulk Acoustic Resonators (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 electrodes on top.

Experimental procedure

Measurements of the bulk acoustic wave velocities propagating along certain directions were carried out by means of RITEC RAM-5000 and UT340 ultrasonic systems. Results at GHz frequencies were obtained using Agilent E5071C Network Analyzer. 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 modes propagating along certain crystallographic directions considering dielectric constant ε_{ij} measured separately. 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 microwave 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+45^o-cut CTGS measured at room temperature.

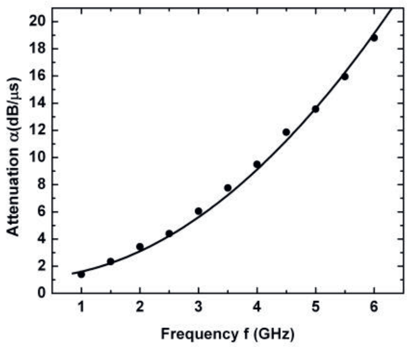

Fig. 1. Sound attenuation versus frequency for Y+45^o-cut CTGS (Quasi-Longitudinal mode). Symbols: experiment, solid line: function ~ f^2 for comparison.

Note the well-defined square dependence of the attenuation versus frequency, which is also valid for X, Y, Z and Y-45^o crystal cuts. Using the measured attenuation coefficients and elastic constants, the components of the dynamic viscosity tensor were derived in the 1-6 GHz frequency range. As for sound attenuation versus temperature, it was found to be low at 4.2 K while still reasonable at 1195 K. Fig. 2 shows as an example ultrasonic pulse-echo patterns for Y-cut CTGS at 298 and 1195 K, resp. The results were obtained using the intrinsic piezoelectric effect of the crystal for excitation and short (5 ns) ultrasonic pulses.

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 linear resonance frequency shift of the SAW device vs. temperature.

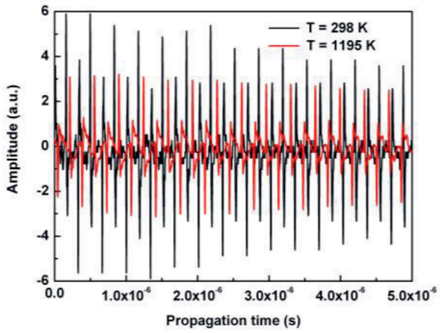

Fig. 2. Pulse-echo pattern for Y-cut CTGS single crystal at 298 K (black line) and 1195 K (red line).

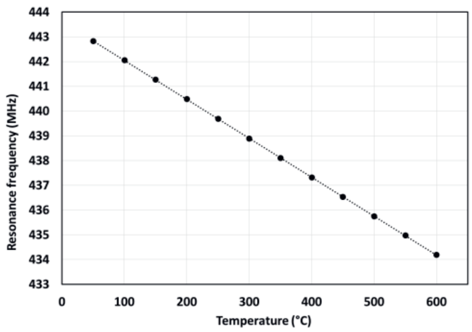

Fig. 3. Resonance frequency vs. temperature for SAW one-port resonator as temperature sensor.

Conclusion

Material parameters of CTGS single crystals were derived over extremely wide temperature range. Strong piezoelectric response as well as reasonable sound attenuation even in GHz frequency range predestine catangasite crystal as promising material for acoustic 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.

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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.