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Investigation of the CTGS Single Crystals Potential for High Temperature SAW Devices

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***Abstract*—SAW resonators were patterned on CTGS wafers with different orientations at different propagation angles. Ir was used as a metal without additional adhesion layers. Resonator responses were acquired with a network analyzer. Resonance frequencies of the responses were measured and processed to obtain temperature behavior. For the cut with Euler angles (0, 90°, 0) almost linear behavior was observed with TCF close to –35 ppm/°C. The turnover point of the fitted parabolic curve gradually changed with propagation angle ψ (0, 90°, ψ) from negative temperatures up to about +550°C at (0, 90°, 90°). This also means that this material gives orientations (close to (0, 90°, 40°)) with the turnover point near the room temperature. Surrounding orientations should probably be same useful (the turnover point change is about 0.5°C with ψ angle change by 1' for these orientations). The coefficient at the quadratic term (with Ir metal) has a low value of about -30 ppb/°C^2. This value is several times lower than that of most langasite cuts and is close to that of ST-quartz. The material seems to be chemically stable at high temperatures. CTGS shows great potential and useful properties for devices operating in a wide temperature range. Similar to ST-quartz, CTGS can serve for temperature compensated resonators and filters at room temperature. It can also work in devices operating at temperatures up to several hundred degrees C.**

Keywords: CTGS, TCF compensation, high temperature, SAW, resonator

I. INTRODUCTION

High temperature operation is becoming increasingly attractive for SAW devices intended for wireless sensors. Beside already established materials such as LGS, LGT and LGN, new materials such as CTGS show new promising and useful features [1, 2].

We report on high temperature experiments with SAW resonators fabricated on 4" wafers produced by JSC Fomos-Materials from CTGS single crystals grown by Czochralski method.

II. SAW PROPERTIES OF CTGS

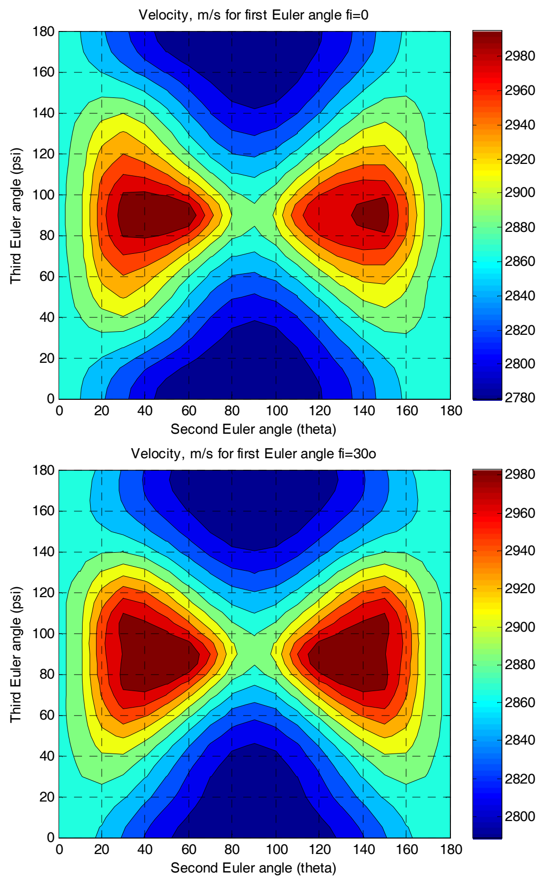

Figure 1. SAW velocity angular dependence

The constants of CTSG single crystals were measured at room temperature in [3]. Based on these constants and using modified VCAL free software contour maps of main SAW characteristics were calculated for the wave with lowest phase velocity (Figures 1-4). SAW velocity dependence is shown in Figure 1. SAW velocity varies from 2770 m/s to 3020 m/s, the total change does not exceed 2%. This is smaller than the velocity variation in commonly used piezoelectric crystals. Correspondingly, the power plow angle (PFA) is quite small (Figure 2). It does not exceed 5° for most orientations excluding small regions where the velocity change with propagation direction change is faster due to the wave type change. Propagation directions with PFA derivative reaching -1 (focusing properties) and smaller values exist in these regions as well. PFA derivative varies from -0.25 to 0.25 for most of orientations, so their diffraction properties are quite close to those of the isotropic case (Figure 3). Electro-mechanical coupling factor dependence is shown in Figure 4. It reaches 0.42% for the orientation close to YXl/-15° (Euler angles (0, 75, 0°)).

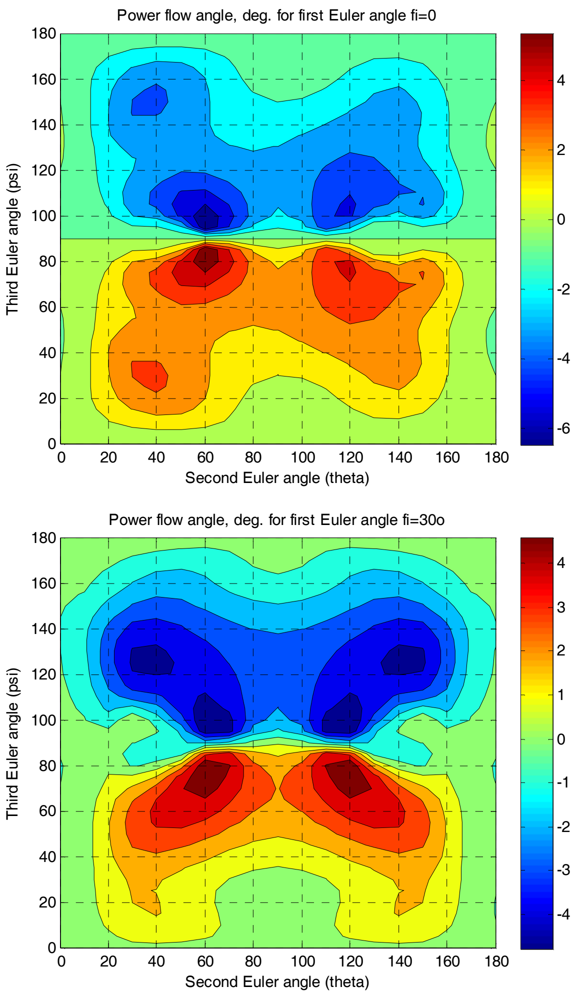

Figure 2. Power flow angle angular dependence

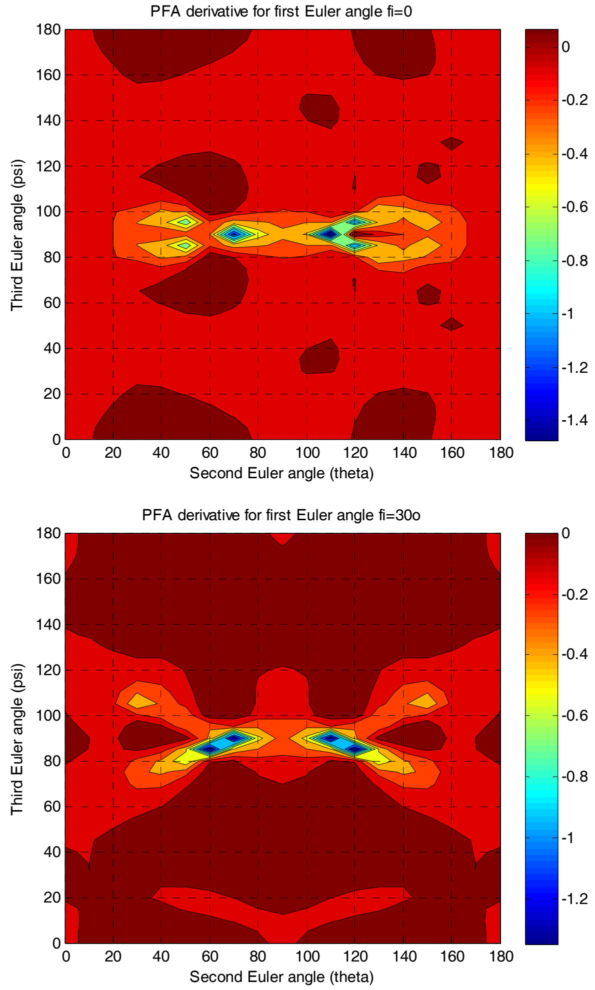

Figure 3. PFA derivative angular dependence

III. EXPERIMENTAL

A. Test sample preparation

We adopted two processes for sample preparation: lift-off (with either photo or e-beam patterning) and direct photolithography followed by ion beam milling. The latter looked more attractive because it does not require low temperature metal deposition and works well with noble metals deposited by magnetron sputtering. Ir served as metal coatings for SAW resonators patterns. No adhesion layers were present because magnetron sputtered Ir has enough adhesion strength for reliable patterning. Ir layer thickness was close to 100 nm. Synchronous single port resonators with 191 electrodes in the transducer and 50 electrodes in each short-circuited grating had the electrode pitch equal to 2.974 microns, the metallization ratio equal to 0.5, and the aperture of 300 microns. Thus, resonators obtained on various cuts of CTGS with different propagation directions had resonance frequencies between 420 and 490 MHz.

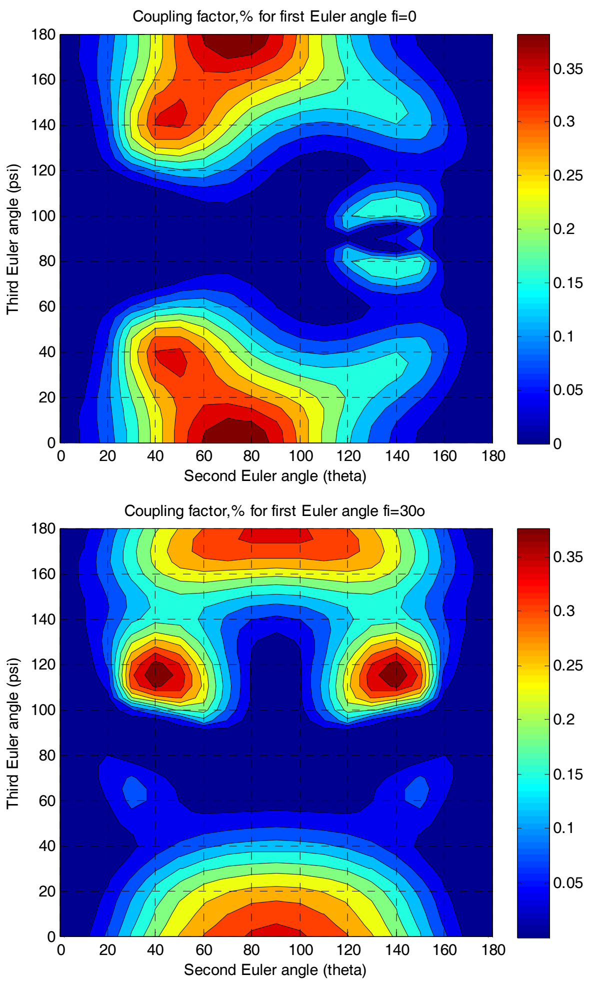

Figure 4. Electro-mechanical coupling factor angular dependence

B. *Testing results*

Resonators were on-wafer measured with calibrated Picoprobe™ SG tips by Agilent 5070A network analyzer.

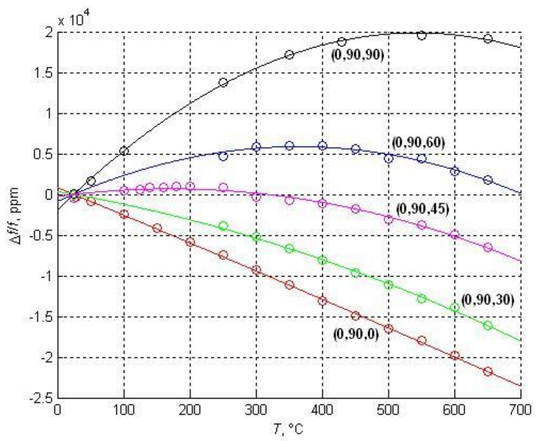

Figure 5. Temperature dependence of the resonance frequency on Y-cut CTGS versus propagation direction.

Measurements of frequency/temperature behavior were conducted in a furnace with ramping the temperature by 50°C. The results are shown in Figure 5.

The turnover point variation versus propagation direction together with the angular behavior of the coefficient at the quadratic term is presented in Figure 6.

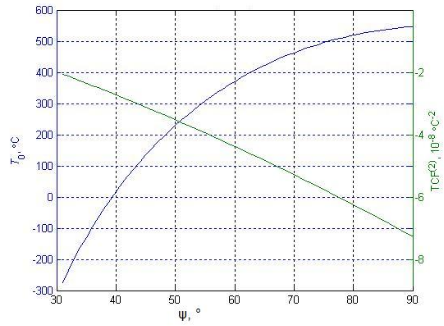

Figure 6. Turnover point variation versus propagation direction together with the angular behavior of the coefficient at the quadratic term

For the cut with Euler angles (0, 90°, 0) almost linear behavior was observed with TCF close to –35 ppm/°C. The turnover point of the fitted parabolic curve gradually changed with propagation angle ψ (0, 90°, ψ) from negative temperatures up to about +550°C at (0, 90°, 90°). This also means that following Fig. 6 this material gives orientations (close to (0, 90°, 40°)) with the turnover point near the room temperature. Surrounding orientations should probably be same useful (the turnover point change is about 0.5°C with ψ angle change by 1' for these orientations). The coefficient at the quadratic term (with Ir metal) has a remarkably low value of about -30 ppb/°C^2.

As we have mentioned in our earlier publications on Ir metallization for LGS substrates, the Ir annealing at about 500°C in air improves the conductivity and increases the resonance frequency [4]. In the CTGS case the frequency increases by about 0.5%. The sheet resistance of a 100 nm thick film has dropped after annealing from 2 to 1.66 Ohm per square. This value of resistivity is quite significant; however we could observe resonance with Q-factor above 4000.

Another important feature of using Ir electrodes was noticed. The reflection coefficients from 100 nm Ir strips on YX-cut of LGS and YX-cut of CTGS have opposite signs. Correspondingly the frequency response of CTGS-based synchronous resonators showed dominant resonance response on the left side of the Bragg band. In contrast to this the response of LGS-based resonators had the dominant resonance response on the right side of the Bragg band.

At the same time, the influence of the mass loading in lower density CTGS was much stronger, and the frequency scatter was many times higher than in our experiments with LGS [4]. Most of the resonators fabricated in laboratory conditions with contact printing photolithography were showing split resonances with several peaks of different forms, and the yield of usable test samples was quite poor. However we still could choose several good samples for measurements.

The frequency response of sensor unit built for a prototype of a wireless temperature measurement system is shown in Fig. 7. This sensor unit consists of two parallel-connected SAW resonators fabricated on a single substrate (Y-cut of CTGS) with different propagation directions. Synchronous single port resonators with 193 electrodes in the transducer and 437 electrodes in each short-circuited grating had the electrode pitch equal to 3 microns for the resonator placed along X-axis and 3.1 microns for the other resonator with propagation direction inclined by 10°. Thanks to low velocity variation, electrodes of inclined resonator could be placed perpendicular to the propagation direction. The Ir layer thickness was close to 100 nm, the intended metallization ratio was equal to 0.5 and the aperture was 357 microns.

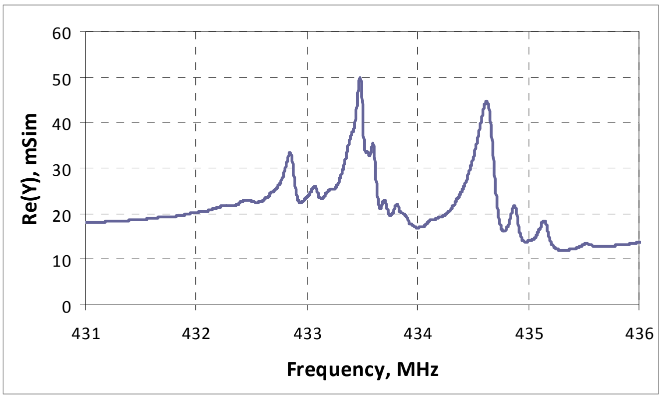

Figure 7. Frequency response of a sensor unit (real part of admittance).

Initial measurements of the sensor temperature behavior from room temperature to 100/°C revealed that the difference of the resonance frequency TCF values of the resonators is below 2 ppm/°C. This difference was slightly lower than expected. Detailed measurements are on the way.

IV. Discussion`

The turnover temperature range presents comfortable conditions for making sensors operating at different temperatures. The presence of temperature stable orientations near 20°C together with low quadratic term and relatively high electromechanical coupling coefficient promises good potential for moderate bandwidth filter applications with outstanding temperature stability.

However, technological issues related to the use of high-density metallization in IDT and reflector electrodes are noticeable. This feature needs to be taken care of in fabrication of high temperature devices where utilization of high-density materials (Ir or Pt) is unavoidable in order to obtain clean single resonance responses.

V. Conclusions

CTGS shows great potential and useful properties for devices operating in a wide temperature range. Similar to ST-quartz, CTGS can serve for temperature compensated resonators and filters at room temperature. It can also work in devices operating at temperatures up to several hundred degrees C.

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References

[1] D. Puccio, D. C. Malocha, and Mitch M. C. Chou, “Investigations of STGS, SNGS, CTGS, & CNGS materials for use in SAW applications,” IEEE Int. Frequency Control Symposium Proceedings, 2003, pp. 627-630.

[2] Yu.V. Pisarevsky, B.V. Mill, N.A. Moiseeva, and A.V. Yakimov, “Ordered $Ca_3TaGa_3Si_2O_{14}$ crystals: growth, electromechanical and optical properties,” Proceedings of EFTF, 2004, pp. 216-219.

[3] A. Sotnikov, H. Schmidt, M. Weihnacht, O. Buzanov, and S. Sakharov, “Material parameters of $Ca_3TaGa_3Si_2O_{14}$ single crystal revisited”, IEEE Int. Ultrasonics Symposium Proceedings, 2013, in print.

[4] S. Sakharov, A. Zabelin, S. Kondratiev, D. Richter, H. Fritze, D. Roshchupkin, A. Shvetsov, and S. Zhgoon, “Optimization of wafer orientation and electrode materials for LGS high-temperature SAW sensors,” IEEE Int. Ultrasonics Symposium Proceedings, 2012, pp. 1525-1528.