NONDESTRUCTIVE INVESTIGATION OF 4-INCH LANGASITE WAFER ACOUSTIC HOMOGENEITY

S. A. Sakharov*[1] , A. N. Zabelin[1], O. A. Buzanov[1], A. V. Medvedev[1], V. V. Alenkov[1], S. N. Kondratiev[2] and S. A. Zhgoon[3]

[1]Fomos, 16, Buzheninova, 107023 Moscow, Russia

[2]Temex SAW, Puits Godet 8, CH-2000 Neuchatel, Switzerland

[3]Moscow Power Engineering Institute, 14, Krasnokazarmennaja, 111250 Moscow, Russia

Abstract - This paper reports an investigation of the free-surface SAW velocity homogeneity of 4-inch langasite wafers. The technique employed is fast, cheap, and non-destructive. The method is based on the determination of the SAW propagation time between two interdigital transducers (IDT), separated by a fixed distance. The measurement setup consists of an acoustic system comprising a sensor, the piezoelectric substrate under investigation, and a vector network analyzer HP-3577A. The sensor is fabricated on a non-piezoelectric substrate, with two split-electrode IDTs. The piezoelectric substrate to be studied is placed in intimate contact with the transducer system. The complex frequency response of the acoustic system measured by the vector network analyzer is the product of the input and output IDT responses including the phase. It is then possible to determine the impulse response of the acoustic system accurately with the help of the Fourier transform. The total error (data processing and acoustic system imperfections) amounts to 35 ppm of the measured velocity. The method described was used to carry out an inspection of the SAW velocity uniformity of quartz, langasite and lithium niobate substrates. SAW velocity measurements on 3” and 4” langasite wafers have shown that the mean square deviation of SAW velocity is less than 120 ppm. Information on the velocity variation over the area of 3” and 4” langasite wafers has been used to improve the in-house manufacturing process for the growth of large-size langasite crystals in batch production. A filter employing slanted fingers was designed and fabricated on wafers of LGS. This device required very small IDT dimensions and displayed exceptional repeatability of performance. The advantages of langasite devices are discussed.

I. INTRODUCTION

The introduction of new generations of substrate materials increases the number of market niches for SAW technology. Among these new materials langasite (LGS) has already found an established field of application in IF filters. Advances in crystal growth and wafer processing technology have resulted in the realization of the medium scale production of 4" LGS wafers fabricated in Fomos that demonstrate sufficiently good repeatability of relevant physical parameters across the wafer area.

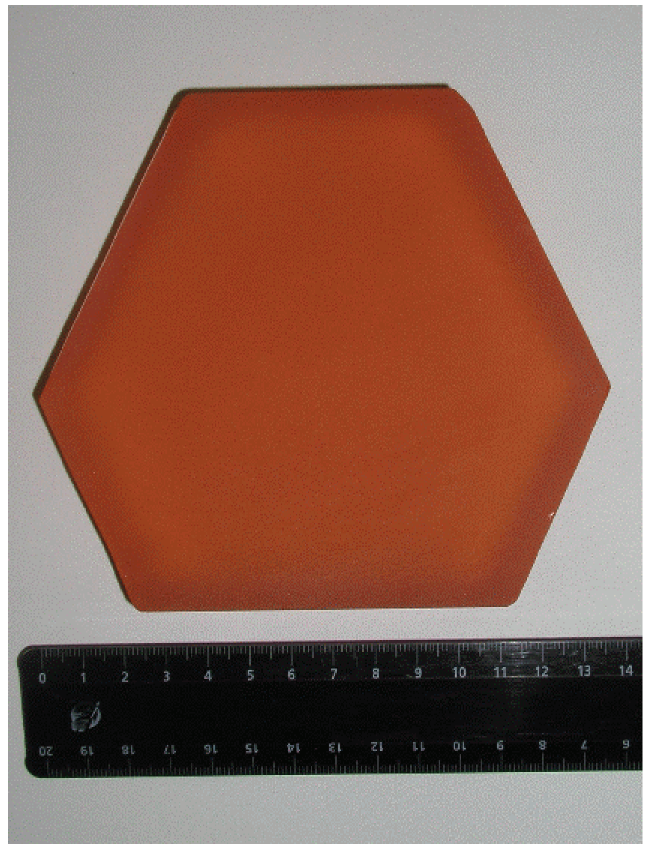

Fig. 1 Cross-section of an LGS crystal grown in <0 1. 1> direction.

II. CRYSTAL GROWTH PROCESS DEVELOPMENT

We have reported on langasite single crystal growth in the <0 1. 1> direction in detail in [1]. The fabrication of 100 mm wafers with orientation yxlt/48.5°/26.6° requires substantially larger crystal dimensions compared to those described earlier [2]. A cross-section of such a crystal is shown in Fig. 1. We have developed a process for the growth of large langasite single crystals with mass exceeding 7 kg. In order to improve the acoustic homogeneity of langasite crystals simultaneously with increased dimensions, growth conditions that are close to equilibrium are required. Reduction of axial and radial temperature gradients together with the reduction of crystal growth speed result in good facet development. Mirror flat planes (0 2. 1), (0 1. 0) and (0 0. 1) were observed. The increase of crystal size requires a disproportionate increase of all crystallizer dimensions. Additional optimization of the gas phase composition was carried out in comparison to that described in [1].

III. SAW Velocity Measurement Apparatus

The purpose of the SAW velocity testing method developed is to monitor the acoustic characteristics of langasite crystals at an early stage of wafer preparation. Reference wafers are fabricated from each crystal grown for acoustic homogeneity assessment. The decision on further substrate-production is taken based upon the results of the reference wafer inspection.

This method of monitoring also enables us to evaluate the influence of the crystal growth conditions on the acoustic properties. Introduction of this monitoring in the technological process guarantees the high acoustic quality of fabricated wafers.

The method is based on the evaluation of the SAW propagation time between two uniform interdigital transducers (IDT) separated by a fixed distance. A similar approach was described in [3].

The test setup structure presented in Fig.2 contains an acoustic system that is formed by the sensor and the wafer under inspection. The sensor is built on a non-piezoelectric substrate provided with two thin-film interdigital structures with split electrodes. Electrode widths and gaps are 7 microns, the aperture is 4 mm, and the distance between transducers is 14 mm.

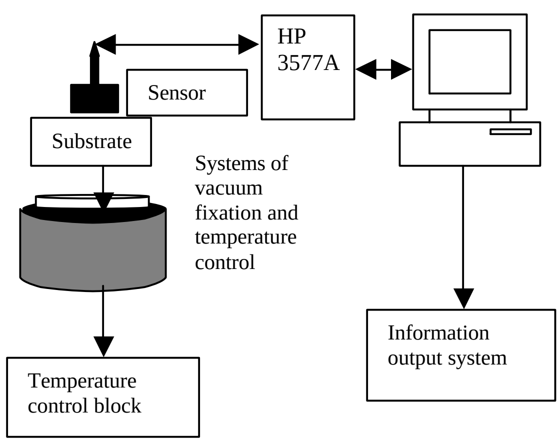

Fig.2 Structure of the SAW velocity test setup.

A vector network analyzer is connected to the input and output transducers of the sensor. When the sensor is pressed against the wafer under test the signal frequency response associated with the propagating surface acoustic wave is recorded. The amplitude of the resulting delay line frequency response corresponding to the product of two transducer responses is presented in Fig. 3.

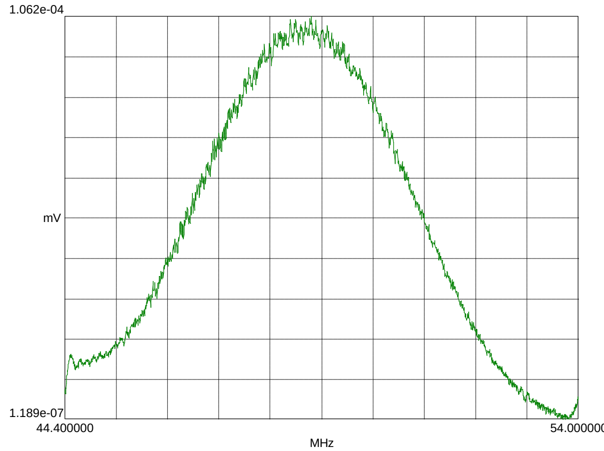

Fig. 3. Amplitude frequency response of the delay line. Langasite yxlt/50°/25°.

The measured complex frequency response is used for impulse response evaluation by use of the Fourier transform. As the impulse response results from the convolution of the input and output IDT responses it takes the form of a sinusoidal signal with a central frequency f_0 and a triangular envelope with total duration 2θ. Fig.4 illustrates the impulse response h(t) of the system computed from the frequency response [H(f)] of Fig. 3.

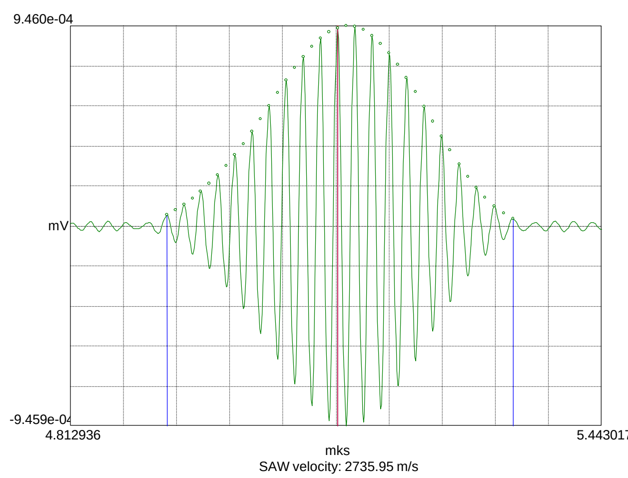

Fig. 4. Impulse response of the delay line. Langasite yxlt/50°/25°.

The complex frequency response H(f) is related by the Fourier transform to the impulse response h(t). Hence we can determine h(t) from a measurement of H(f).

$$h(t) = \int_{-\infty}^{+\infty} H(f) e^{iwt} df \quad . \qquad (1)$$

The impulse response reaches a maximum at time τ+θ. The propagation distance l, transducer period d, and number of electrodes N thus determine the SAW velocity:

$$V_R = \frac{(N-1)d + l}{t + q} \, . \qquad (2)$$

where the distance, l, and time τ correspond to propagation between the inner edges of the transducers.

IV. Wafer Inspection Results

As at constant temperature the distances between electrodes are fixed and can be measured precisely. Equation (2) shows that the error in delay time determination introduces the main contribution into the error of the SAW velocity:

$$\Delta V_R = V_R \frac{\Delta(t + q)}{t + q} \, . \qquad (3)$$

A computer program that evaluates the SAW velocity introduces an additional error of 1 ppm.

The reproducibility of the velocity measurements and their variation across the wafer have been evaluated experimentally. Measurements were taken 60 times at one point with alternate lifting and pressing of the sensor to the wafer. The standard deviation of the SAW velocities measured at one point is 7 ppm.

The wafer testing was performed at 25 points, 5 times at each point. Statistical processing has shown that the empirical distribution is well described by a normal distribution. The repeatability of measurements over 25 points corresponds to ±5ppm of the average value.

The results of the velocity evaluation error demonstrate that this method can successfully be used in the production of piezoelectric crystals and substrates. Figure 5 illustrates typical results of 4" langasite wafer investigations; they show a SAW velocity deviation over the wafer of less than 120 ppm. The data was taken at 25 different points over the wafer area. This data confirms the possibility of large-scale wafer production for the fabrication of SAW devices.

V. Practical Device Performance

Figures. 6 and 7 illustrate the performance of a slanted finger SPUDT filter realized on LGS.

The center frequency is about 80 MHz, and the 3 dB bandwidth is 6.8 MHz (8.5% of the center frequency). The insertion loss of this filter under matched conditions is about 16 dB, the chip size is 2x8 mm, while the amplitude ripple is about 1 dB and the ultimate rejection is better than 40 dB.

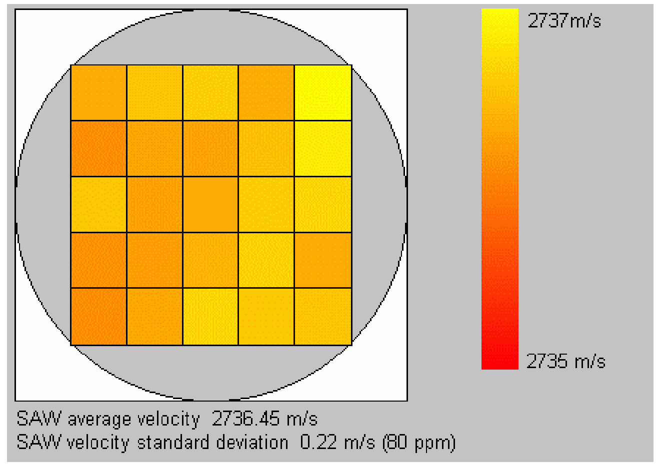

Fig.5 SAW velocity distribution over a 4" wafer area.

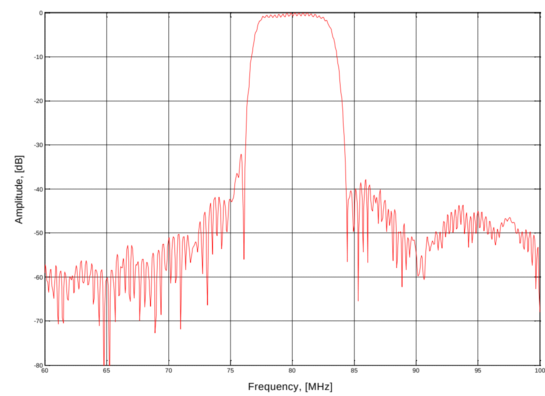

Fig. 6. The response of a slanted finger SPUDT filter on langasite.

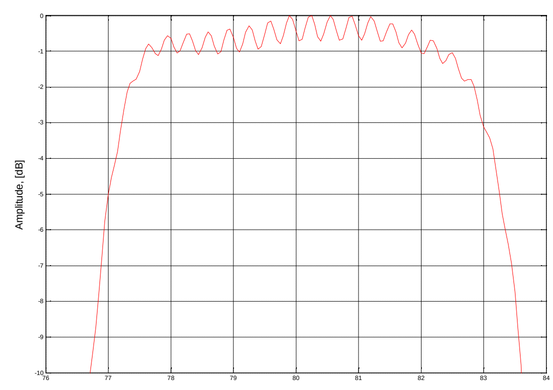

Fig. 7. Detailed response of the slanted finger SPUDT filter.

As the filter has a relatively large bandwidth no acoustic inhomogeneity was evident over the 4" wafer area. This result points to the most interesting application niches for this material – physically small IF filters with moderate bandwidth and demanding specifications.

VI. Discussion

It is probable that LGS based devices cannot force quartz devices out of the specific market of narrow band devices. For example quartz has a very strong position in the transversely coupled resonator filter (TCF) market because the bandwidth of TCF filters is very small (0.01…0.08 %). At the same time there is a wide market for SAW filters that are based on other design principles: transversal filters, coupled resonator filters (CRF), SPUDT, slanted finger SPUDT and RSPUDT filters with 0.1…5% bandwidth. The main applications of these filters are as IF filters for CDMA, base station filters and so on.

Table 1 Frequency shifts associated with the preparation and operating conditions of filters on quartz and LGS.

	Quartz	LGS	Comments
Frequency Shift in temperature range ±50°C, ppm	80	170	TC_{SiO2}=-0.032ppm/°C^2 TC_{LGS}=-0.068ppm/°C^2
Frequency Shift due to metal Thickness Variation, ppm	305	100 [4]	-
Frequency Shift due to metallization ratio Variation, ppm	90	25 [4]	-
Frequency Shift due to Phase Velocity variation, ppm	50	120	-
Total Frequency Shift, ppm	525	415	-

Because of its practical importance we have estimated the total frequency shift associated with temperature and process tolerances as well as with the phase velocity variation for quartz and LGS devices. Table 1 shows the result of this estimate for devices with the following parameters: electrode thickness 2 % of wavelength (λ), while thickness and metallization-ratio variations are ±2 % [4].

Table 1 demonstrates that filters realized on LGS are even better than their counterparts made on quartz under mass production conditions because of the lower limit of the total frequency shift.

The second advantage of SAW devices realized on LGS is their small size. For example, LGS resonator type SAW filters occupy four times smaller area than quartz devices due to the lower velocity and higher coupling coefficient.

The third advantage of SAW devices realized on LGS is the use of their perfect diffraction characteristics and of their natural directivity A SAW filter based on slanted finger design can have a bandwidth up to 10 % together with an insertion loss less than 20 dB [5]. Therefore LGS SAW devices will probably occupy the current market niche of 112-LT SAW filters.

VII. Conclusion

Langasite wafers are now being produced in the standard 4" size that is adopted by the SAW device industry. The SAW velocity variation over the wafer area is reliably controlled in the fabrication process. The value of 120 ppm is routinely obtained in batch production.

The method of testing the acoustic homogeneity has proved to give reliable results that are consistent with data obtained in the preparation of practical SAW devices.

The results presented demonstrate that the processes used in the fabrication of langasite wafers have matured greatly, are now suitable for large-scale repeatable production, and that there are no technological obstacles to the wide application of filters on this substrate.

VIII. Acknowledgments

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IX. References

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*Sergei Sakharov e-mail: saharov@fomos-t.ru