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Miniature BAW Resonators and Filters Based on Single Crystals of Strong Piezoelectrics

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Using single crystals of "strong" piezoelectrics allows sizable reduction of BAW-resonators and filters. This paper reviews new information about development of microminiature BAW-resonators and monolithic filters fabricated from a single piece of quartz, LGS, LGT and lithium tantalate. The investigation results of wideband high-frequency (40-100 MHz) monolithic crystals filters using inverted mesa-technology are given. It is shown that these miniature resonators have considerable smaller values of aging, motional resistance and capacitance ratio in comparison with these parameters of quartz crystal units. The possibility of application of microminiature resonators (volume less than 0.02cm^3) of different new types TCXO's, VCXO's, wide-band filters and other devices is proved.

I. Introduction

Recent improvements in the technology of "strong" piezoelectric crystal growing have considerably cut production costs and increased single crystal's quality. On the other hand new design solutions and technologies have caused device microminiaturization. Moreover less piezoelectric material is spent on a resonator or a monolithic filter. It has made "strong" piezoelectric devices more competitive, their production has been increasing from year to year, new radioelectronic devices with properties and characteristics that couldn't be realized on quartz have appeared.

High Q factor, chemical stability, a high temperature of phase shift (or its absence) allow realizing BAW piezoelectric resonators at a wide frequency range from 10 kHz to 100 MHz excited at fundamental mode. Recently crystal blank orientations have been found that allow realizing resonators with zero values of temperature-frequency coefficients or low steepness coefficients.

If a piezoelectric designer needs to microminiaturize devices, increase long-term frequency stability and performance temperature, reduce motional resistance R_1 and capacitance ratio C_o/C_1 in resonators or widen a passband and lower load impedance in monolithic filters then he should consider LT, LGS or langatate as ideal candidates for wafers. These materials will allow him to design wideband filters and widen the tuning range of voltage controlled oscillators.

Recently Russian scientists have achieved a great success in the field of "strong" piezoelectric growth. A major contribution was made by the research of physical properties and the improvement of growing technologies that have been carrying out by Fomos together with faculties of the Institute of Crystallography of the RAS (IC RAS), Moscow State Institute of Steel and Alloys (MISA), Moscow State Academy of Information and Instrument-making, the International Academy of Information.

The high reproducibility of resonator electrical properties is achieved thanks to the quality of used single crystals. The research of growing technology effect on physical properties of single crystals has enabled to establish the reliable production of 3" langasite and langatate crystals. The main results were achieved due to raw material quality control, the optimization of initial charge synthesis and heat assembler design, etc.

II Lithium Tantalate Resonators and Filters

Ferroelectric single crystals of lithium tantalate have crystallographic orientations that allow manufacturing resonators with a zero first order temperature-frequency coefficient. That's why the crystals draw the attention of microminiature resonator and filter designers. The authors have been carrying out work aimed at setting up the production of lithium tantalate resonators that cover frequency range from 10 KHz to 100 MHz.

Low-frequency lithium tantalate resonators (10-800 KHz)

Resonators in 0.02-0.05 cm^3 micro-packages have been designed at frequencies from 10 to 40 KHz with piezoelements fabricated as fork, strip and bar (pillar) plates, flexibly vibrating in Y'Z' and XY' planes.

The main properties and characteristics of such resonators are listed in Table1.

Lithium tantalate resonators with face and thickness shear at frequencies 0,500 - 100 MHz

For a frequency range of 600 to 1500 kHz resonators with face shear vibrations have been designed. The resonators have electrodes that excite "parallel" field vibration (fluctuation). For a frequency range of 5-50 MHz resonators have been designed using X-cut crystal elements, operating at fast thickness shear mode. Electrodes were round shaped. The main properties of the resonators are listed in Table 2.

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TABLE 1

Crystal element shape	f_0, kHz	TFC, 10^{-8} C^{-2}	R_1, кOm	C_0/C_1	Q, k	Mode of vibration
Fork	15 - 40	8 – 10	0,5 - 50	40 - 80	5 - 40	Flexural
Bar (pillar)	20 - 120	7 – 9	0,1 -	29 - 30	10 - 80	Flexural
Strip	350 - 800	7 - 9	0,1 - 40	20 - 40	10 - 50	Extensional

TABLE 2

Crystal element shape	f_0, MHz	TFC, 10^{-8} C^{-2}	R_1, Ω	C_0/C_1	Q, k	Mode of vibration
Rectangular	0,5 – 1,5	6 – 9	50 - 200	30 - 100	15 - 100	Face shear
Rectangular Round, Ø4,5 mm.	8 - 50	10 – 12	10 - 80	12,5 - 20	1 - 6	Thickness shear
	50 – 100 3-th over.	-	25 - 100	140 - 220	0,6 – 1,5	Thickness shear

The properties of microminiature vacuum dual mode lithium tantalite resonators with a volume less than 0.02 cm^3 and thermodependant (at 9.4 MHz) and thermostable (at 10.6 MHz) modes are listed in Table 3. The temperature-frequency characteristics of such resonators are illustrated in Figure 1.

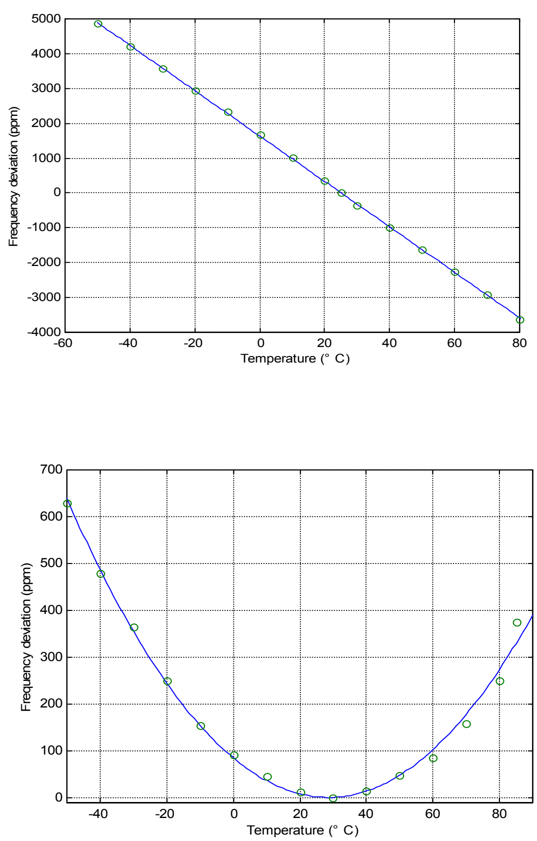

Fig. 1. Temperature-frequency characteristics of a dual-mode lithium tantalate resonator

TABLE 3

Excited mode	f_0, MHz	FTC type	Thermal coefficient	R_1, Ω	C_0/C_1	Q, k	Mode of vibration
Thermostable	10,6	Parabolic	(9 – 10) 10^{-8} C^{-2}	15 – 40	9,3 – 11,5	4 - 5	Thickness shear
Thermodependant	9,4	Linear	65,4 C^{-1}	25 – 50	97 - 107	7 - 12	Thickness shear

Lithium tantalate filters

At present a frequency range from 2.5 to 30 MHz has been mastered, while a relative pass bandwidth is 0.5-4.5% for some frequencies. The latter is achieved by using crystal elements fabricated from incongruous crystals. Moreover a high value of electromechanical coupling factor for thermostable cut allows using relatively small electrodes, that in its turn leads to wafer downsizing.

III LANGASITE MICROMINIATURE RESONATORS AND FILTERS

Both upgraded technologies and necessary equipment allow growing in Russia big-sized crystals with low density inclusion and reproducible physical properties. Single crystal treatment that is used now has improved greatly wafer surface quality that enables fabricating crystal elements with inverse mesa-structure at 100 MHz on fundamental mode.

Langasite resonators have been fabricated in DW-type packages using rotated Y-cut rectangular crystal elements with length along X and Z'-axis. Hermetical sealing is made in vacuum. Regardless of crystal element length's orientation the temperature-frequency characteristics of such resonators looks like quadratic parabola with steepness coefficient (5,9 – 6,3) 10^{-8} °C^{-2}. A temperature of extremum can be obtained at any temperature within the range of -30°C to +100 °C. Figure 2 shows extremum temperature dependence on crystal element cut angle.

Q-factor of resonators with length along Z'-axis is 15-20% higher then that of resonators with length orientation along X-axis, while the latter have motional resistance R_1 1.5 times lower and capacitance ratio C_o/C_1 - 20% lower. The key properties of these resonators are listed in Table 4.

Fork langasite resonators with capacitance ratio less than 350, motional resistance 10-40 kOhm and steepness coefficient (30-32)*10^{-8} °C^{-2} have been designed for viscosity sensors.

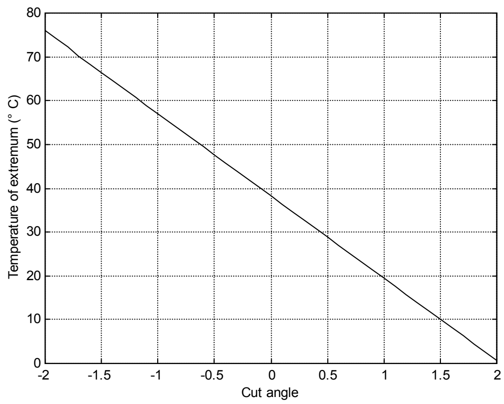

Fig. 2. Extremum temperature versus cut angle

TABLE 4

f_0, kHz	R_1 Ohm		Q k		L_1 mH	C_0 pF	C_0/C_1	Plate size, mm	
	min	max	min	max				X	Z’
11 800	10	30	20	40	5.5	3.7	110	1.0	4.5
13 100	5	20	11	37	3.1	4.5	90	4.5	1.0

Langasite monolithic filters

The use of langasite in filters with relative pass band 0.5-0.8% allows realizing them as 4-pole dual element sets. 10.7 MHz filter composed of two UM-5 package cans has been designed with group delay. Frequency and group delay responses of the filter are illustrated at Figure 3.

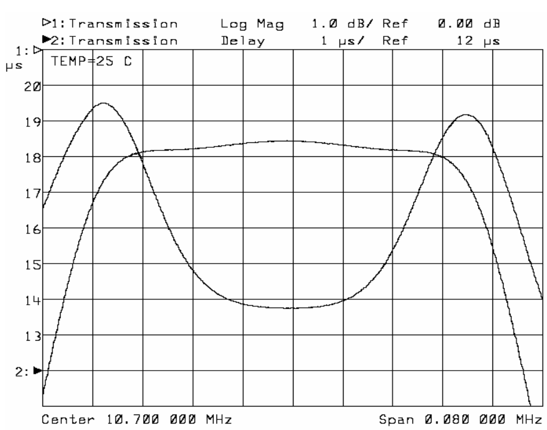

Fig. 3. Frequency and group delay responses of an LGS filter

Due to inverse mesa-structure technology langasite filters can be designed at a frequency range up to 100 MHz. While designing and fabricating a wafer with inverse mesa-structure the ratio between the thickness of buffer and operating zones has a great importance. A ratio of 2.9 to 3.1 is a critical one as additional spurious pass bands appear in frequency response when wafers with these parameters are realized. The characteristics of 91 MHz filter is shown at Figure 4.

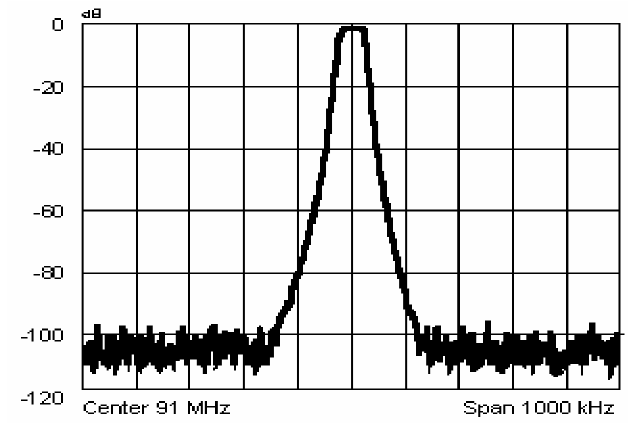

Fig. 4. Frequency response of a 6-pole LGS filter

IV. CONCLUSION

It is possible to make the conclusion that microminiature resonators with lithium tantalate and langasite crystal elements have advantages over the analogous quartz crystal units as far as their motional resistance value R_1, motional inductance L_1 and capacitance ratio C_0/C_1 are concerned. They can be also used for designing new models of miniature piezoelectric filters and microoscillators. The cost of these resonators can be close to the cost of analogous quartz crystal units.