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INVESTIGATIONS ON THE LANGASITE RESONATORS BY X-RAY TOPOGRAPHY

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Abstract - **In this paper the results of electrical measurements of the mass-loading influence on Y-cut langasite resonator parameters are compared with those obtained by X-ray topography analysis of the same resonators. Based on the Ballato's transmission-line analogs of the trapped-energy resonators vibrating in thickness-shear mode [1], the mass-loading effect on resonator characteristics was studied. The effective mass-loading, motional inductance and quality factor of langasite resonators were computed.**

Sawyer plan-parallel polished Y-cut langasite resonators with 14mm diameter, 5 MHz resonant frequency, Au electrodes of 7 mm diameters and various thickness were used in experiments.

X-ray topography measurements were performed by conventional transmission Laue setting using the white beam synchrotron radiation on fundamental, third and fifth overtones. The results are in agreement with those obtained by electrical measurements.

The comparison of X-ray diffraction topography images previously performed on AT-cut quartz resonators with X-ray topographs on langasite resonators pointed out that the Y-cut langasite resonators are less influenced by the mass-loading than the AT-cut quartz resonators.

I. INTRODUCTION

Langasite crystal is one of the promising materials for applications in acoustoelectronic and piezoelectric devices. The larger coupling coefficient of langasite, in comparison with quartz, allows obtaining filters with larger bandwidth. Also, the main characteristics of the langasite crystals compare favorably with those of quartz: the absence of phase transitions up to the melting point and low acoustic wave propagation losses. Y-cut langasite plates vibrating in thickness-shear mode, exhibit a good thermal stability, low values of the equivalent motional inductance and series resistance and high electromechanical coupling coefficient. The sizes of LGS devices are smaller by 30% than that of quartz devices.

The theoretical and experimental investigations of mass-loading effect on thickness-shear AT-cut, SC-cut quartz resonators and Y-cut langasite resonators, using the Ballato's transmission-line analogs [1], have shown that the harmonic dependence of electrical parameters is influenced by the electrodes [2, 3]. The studies are based on the assumption of non-uniformity of the vibratory motion over the electrode area of the crystal, due to the coupling of the thickness-shear with thickness-twist modes of vibration and to the stresses at interface electrode-piezoelectric plate. Using the Tiersten's analysis [4] of the trapped-energy resonators vibrating in coupled thickness-shear and thickness-twist modes, a correction of the mass-loading and coupling coefficient relations was performed [5], in order to account for the non-uniform distribution of motion found in practical plate resonators.

Experimental results for AT-cut resonators [6] with various electrode parameters, mode of electrode deposition and polishing degree of the blanks, were in good agreement with the theory for large electrode diameter and thin electrodes.

Based on the previous studies and on Steven and Tiersten's analysis of the trapped-energy SC-cut resonators [7], Zelenka [8] has performed the theoretical computation of the effective mass-loading, effective coupling coefficient and dynamic capacitance of the trapped-energy resonators for coupled thickness-shear and thickness-twist modes.

A comparison between theoretical and experimental results on SC-cut resonator [8] with various electrode diameters and thickness was performed. The conclusion is that at low frequencies, thin electrodes and large electrode diameter, the non-uniform distribution of motion is done by the coupling of the thickness-shear with thickness-twist modes, while for higher frequencies, thick electrodes and small electrode diameter it is done by the stress related effects at electrode-substrate interface.

The comparative study of the behavior of the AT-cut and SC-cut resonator characteristics for various electrode parameters [9] pointed out a strong influence of the effects associated to the electrode deposition (stress and inertial effects) on harmonic dependence of electrical parameters of quartz resonators. SC-cut resonators present a very small stress effect (stress-compensated cut) and the inertial effect prevails. In the case of the AT-cut resonators the stress and inertial effects are present and one of them becomes more important with the change of electrode diameter.

The experiments were performed on the AT-cut and SC-cut quartz resonators with 5MHz fundamental frequency, 14mm diameter of the blanks and Ag, Au electrodes with diameters 4.6 and 7mm and 100,300,500nm thickness. Based on these results one can conclude that the non-uniform distribution of motion, depending on electrode geometry, could be ascribed to the coupling of the thickness-shear and thickness-twist modes and to the effects associated to the electrode deposition.

The experimental electrical investigations of the mass-loading effect on the plan-parallel Y-cut langasite resonators, with various electrode diameters and thickness were performed [10]. The comparison between the result of

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the electrical measurements on AT-cut quartz resonators and Y-cut langasite resonators has shown that the maximum variation of the effective mass-loading, effective coupling coefficient and motional inductance as a function on harmonics, is significantly lower for langasite resonators than quartz resonators [11]. The mass-loading influence on AT-cut quartz resonator characteristics has been investigated too by X-ray diffraction topography [12].

A good agreement with electrical measurements was revealed.

This paper addresses the vibration modes by X-ray topography to point out the mass-loading influence on parameters of Y-cut langasite resonators. The results are correlated on the one side with electrical behavior of langasite resonator characteristics and on the other side with X-ray diffraction topography images performed on AT-cut quartz resonators.

II. Experimental

The Sawyer polished Y-cut langasite resonators with 14mm diameter vibrating on 5MHz fundamental frequency with various electrode thicknesses have been used in electrical and X-ray topography experiments. By thermal evaporation in vacuum on langasite plates of Au electrodes with 7 mm and 4.6 mm diameters and 100 nm, 200 nm and 300 nm thicknesses were deposited.

To compare the behavior of the electrical parameters of AT-cut quartz and Y-cut langasite resonators we used the results obtained in the paper [11], where on both type of resonators were deposited in the same conditions, electrodes of 4.6 and 7mm diameter and 75, 125, 200 nm thickness.

The resonance and antiresonance frequencies and series resistance of the fundamental, 3rd, 5th and 7th overtones of the free and electroded langasite plates were measured after every two pairs of electrode deposition.

On the basis of the relations for the transmission-line equivalent electrical circuits of the piezoelectric resonator, which vibrates in the thickness-shear mode, the effective mass-loading, coupling coefficient, motional inductance, motional capacitance and quality factor were computed.

Mass-loading effect could be evidenced by the change of these parameters on harmonic order.

X-ray topography measurements have been performed by conventional transmission Laue setting using white beam synchrotron radiation at LURE/DCI, Orsay, France.

The fundamental, third and fifth overtone modes were imaged.

III. Electrical measurements

The behavior of the motional inductance is the most significant for comparison of mass-loading influence on quartz and langasite resonator characteristics.

To compare the behavior of motional inductance of AT-cut quartz resonators with that of Y-cut langasite resonators [11], in Figure 1 are presented the harmonic dependence of inductance of both types of resonators with the same electrode parameters (Au, 7 mm electrode diameter and 75 nm, 125 nm and 200 nm electrode thickness).

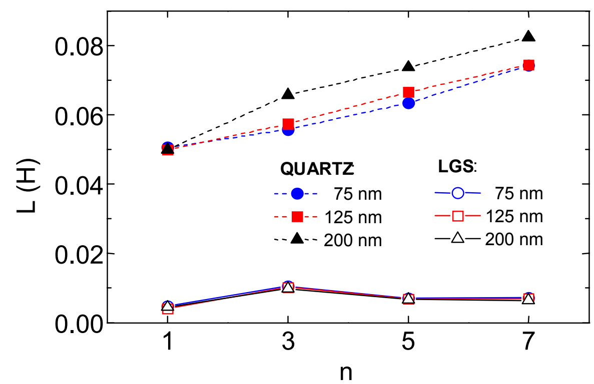

Fig. 1. Inductance variation with harmonic order for quartz and langasite resonators.

Figure 2 shows the harmonic dependence of motional inductance for AT-cut quartz and Y-cut langasite resonators with Au electrodes, 100nm thickness and 4.6mm; 7mm diameters.

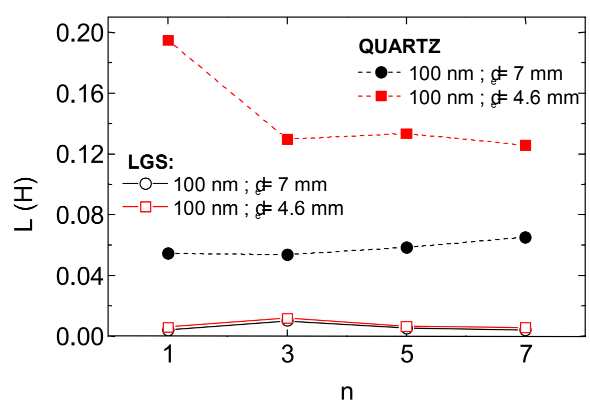

Fig. 2. Harmonic dependence of quartz and langasite resonators inductance on electrode diameter

By analyzing the figures 1 and 2 we observe:

-The inductance of quartz resonators increases with harmonics for all electrode thickness, while the inductance of langasite resonators is almost constant (Fig. 1)

-The change of electrode thickness determines a significant variation of inductance in the case of quartz resonators, but almost no change for langasite resonators (Fig. 1)

-While the inductance of quartz resonators increases almost 2.5 times when the electrode diameter decreases from 7mm to 4.6mm, the inductance of langasite resonators presents a very small change with electrode diameter (Fig. 2).

For low frequencies (n=1 ; 3) and thin electrode (75 nm) the motional inductance of the AT-cut quartz resonators increases with harmonic order due to the coupling of the thickness-shear with thickness-twist modes. This behavior is in a good agreement with the theory based on the analysis of the trapped-energy resonators vibrating in coupled thickness-shear with thickness-twist modes. For high frequencies (n=5 ; 7) and 125 nm, 200 nm electrode thicknesses, the inductance of AT-cut resonators increases due to the stress effects.

Consequently, the mass-loading influence on langasite resonator characteristics is lower than on quartz resonator characteristics.

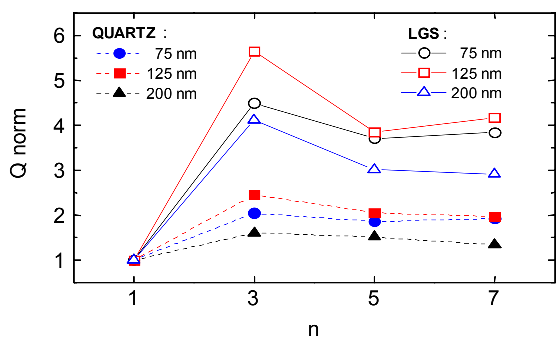

Fig. 3. The quality factor dependence on harmonics for various electrode thicknesses.

In Figure 3 is presented quality factor dependence on harmonics for AT-cut quartz and Y-cut langasite resonators with various electrode thickness and diameters.

Analyzing Figure 3 one observes that the normalized Q values measured for all electrode thickness are higher in the case of langasite than for quartz resonators. The maximum values of the quality factors of both types of resonators are on third harmonic. For both type of resonators the optimum electrode thickness, which determines the maximum quality factor, is 125 nm.

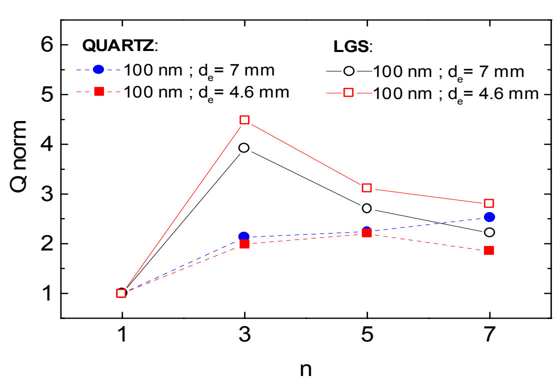

Fig. 4. Quality factor variation with electrode diameter for quartz and langasite resonators.

To analyze the quality factor dependence on electrode diameter for the same electrode thickness, in Figure 4 is presented the normalized Q factor versus harmonics order for quartz and langasite resonators with 100 nm electrode thickness and 4.6 and 7 mm electrode diameters.

The most important differences between the behavior of quartz and langasite resonators are:

- For quartz resonators the quality factor increases with the electrode diameter change from 7 to 4.6 mm, while for langasite resonators Q factor decreases when the diameter increases.
- The increase of electrode diameter determines in the case of quartz resonators a shift of the maximum quality factor towards smaller harmonics, but the maximum Q factor of langasite resonators is situated at 3rd harmonic.

IV. MEASUREMENTS BY X-RAY TOPOGRAPHY

The analysis of the results obtained by X-ray topography measurements of all types of AT-cut quartz and Y-cut langasite resonators shows a very small absorption of incident radiation by the electrodes when the resonators are not excited. We observe only diffraction images of investigated area (under electrodes). The diffraction images obtained are diffused for two reasons: the experiments were made with white X-beam, and in crystal exist the structural defects as dislocations or bad polished surface.

The analysis of the topographs has revealed that the fundamental mode is weakly trapped, while the overtones are much more confined. No coupling with plate modes was observed in the examination of the topographs directly on the films.

The topographs of AT-cut quartz resonators reveal that the active area of the electrodes decreases with harmonic order, which indicates a non-uniform distribution of motion in the electrode region.

The analysis of the diffraction image shows that for AT-cut quartz resonators [12] with large electrode diameter (7mm), thin electrode thickness (100 nm) on fundamental and third harmonic, the coupling of thickness-shear with thickness-twist modes as taken into account in the Tiersten equations, is the main cause of non-uniform distribution of motion. For quartz resonators vibrating at higher frequencies with thicker electrodes (300 nm), the non-uniform distribution seems to be done by the interfacial stresses.

In the case of the Y-cut langasite resonators (Fig. 3), with three values of electrode thickness (100; 200; 300 nm) and with 7mm diameter of electrode, the X-ray topography analysis shows that the active area is constant with harmonic order. For resonators working on third overtone with 200nm thickness of electrode is observed a larger area and image deformation from circular to ellipsoidal.

This behavior could indicate a less non-uniformity of motion distribution. The explanation of the image deformation from circular to ellipsoidal seems to be the decoupling of the two vibration modes (TS and TT).

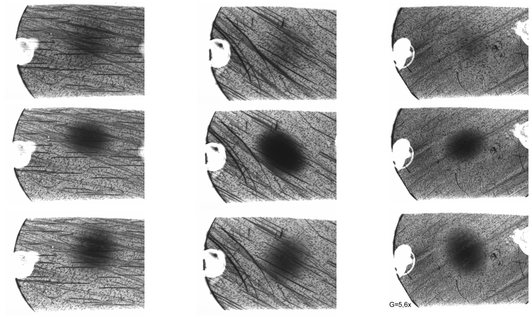

Fig. 5. X-ray topographs of Y-cut langasite resonators on fundamental, third and fifth overtones for three electrode thickness

The results obtained by X-ray topography for both types of resonators are in good agreement with harmonic dependence of motional inductance and quality factor.

The topographic images of langasite resonators present an X-ray diffracted intensity practically unchanged for the three electrode thickness and for high overtones, while the topographs of quartz resonators show an anisotropy dependent of harmonic order and mass-loading.

The analysis of the topographic images for both types of resonators indicates a maximum of the diffracted intensity on third overtone due to the strong energy-trapping at this frequency. Due to the strong coupling of the TS and TT modes, we expect to have the maximum values of the quality factors on third harmonic.

At fifth and seventh harmonics the acoustic energy is absorbed more than at third overtone and the contrast and the area of diffraction images decreases [13,14,15] and, consequently, we can say that the active area of the electrodes decreases with harmonic order.

With increase of the electrode thickness maximum of energy changes position to the left side of the excitation area and the shape of the diffraction image changes from circular to ellipsoidal [15, 16, 17]. The shift of the maximum of energy to the left side of the excitation area can be due to the presence of defects like growth sectors boundaries.

V. CONCLUSIONS

The investigation of the mass-loading effects on characteristics of the thickness-shear vibrating resonators by X-ray topography shows a good agreement between the results previously obtained by electrical measurements and the topographic images.

The analysis of the langasite resonators has revealed that the fundamental mode is weakly trapped, while the overtones are much more confined.

X-ray diffracted intensity is practically unchanged for all electrode thickness and for high overtones. In the case of quartz resonators diffracted intensity has shown an anisotropic dependence on harmonic order and mass-loading. That indicates a less non-uniform distribution of motion over the electrodes in Y-cut langasite resonators than in the case of AT-cut quartz resonators.

The results obtained by X-ray topography are in good agreement with harmonic dependence of motional inductance and quality factor. A strong enhancement of the diffracted intensity is observed on third harmonic on topographs, which corresponds with maximum value of quality factor.

The results of the investigations by X-ray topography of the langasite resonators allow us to conclude that the mass-loading influence on langasite resonator characteristics is smaller than in the case of quartz resonators.

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