MASS-LOADING EFFECT ON CHARACTERISTICS OF QUARTZ AND LANGASITE DEVICES: COMPARATIVE STUDY

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1. ABSTRACT

This paper presents some of the more relevant results concerning the mass-loading influence on characteristics of quartz and langasite resonators and monolithic filters. Based on the Ballato's transmission-line analogs of the trapped-energy resonators vibrating in thickness-shear mode, the mass-loading effect on electrical resonator characteristics was studied. The effective mass-loading, motional inductance and quality factor of quartz and langasite resonators, as a function of harmonic order for various electrode parameters, were computed. The experimental investigations on frequency-temperature characteristics of plan-parallel Y-cut langasite resonators for various mass-loading conditions were done. In the frame of theTiersten's analysis of monolithic structure, the theoretical calculations of the coupling coefficient of two-pole quartz and langasite monolithic filters as a function of mass-loading were performed. The analysis of these results shows that the mass-loading influence on characteristics of langasite resonators and monolithic filters is lower than on those of the quartz devices.

2. INTRODUCTION

Langasite is one of the promising materials for applications in acoustoelectronic and piezoelectric bulk-wave and surface-wave devices. The main characteristics of the langasite crystals compare favorably with those of quartz: the absence of phase transitions up to the melting point, higher coupling coefficient and low acoustic wave propagation losses [Refs.1-3].

Y-cut langasite plates, which vibrate in thickness-shear mode, exhibit a good thermal stability, low values of the equivalent motional inductance and series resistance, smaller size and high electromechanical coupling coefficient [Refs. 4 -7].

The theoretical and experimental investigations of mass-loading effect on thickness-shear AT-cut and SC-cut quartz resonators using the Ballato's transmission-line analogs [Ref. 8] have shown that the harmonic dependence of electrical parameters is influenced by the electrodes [Refs. 9,10]. The studies are based on the assumption of a 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/or to the stresses at interface electrode-piezoelectric plate. Using the Tiersten's analysis [Ref.11] of the trapped-energy resonator, vibrating in thickness-shear and thickness-twist modes, a correction of the mass-loading and coupling coefficient relations was performed [Ref.12], in order to account for the non-uniform distribution of motion found in practical plate resonators. Experimental results for AT-cut resonators [Ref.13] for 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's and Tiersten's analysis of the trapped-energy SC-cut resonators [Ref.14], Zelenka [Ref.15] 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. The comparative study of the behavior of the AT-cut and SC-cut resonators characteristics for various electrode parameters [Ref.16], 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. In SC-cut resonators the stress effect is very low (stress-compensated cut) and the inertial effect prevails. In AT-cut resonators the stress and inertial effects are present and one of them becomes more important with the change of electrode diameter. 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 with thickness-twist modes and to the effects associated to the electrode deposition. In [Ref.17] are compared the experimentally results of the mass-loading effect on langasite resonators characteristics with that on AT-cut quartz resonators. The analysis of the results revealed that the maximum variation of the effective mass-loading, effective coupling coefficient and inductance as a function on harmonics for various electrode diameters and thickness is significantly lower for langasite resonators than for quartz resonators. Some authors [Refs.18,19] shown that the frequency-temperature characteristics of the resonators are dependent on mass-loading due to the metallic electrodes deposited on piezoelectric substrate. The electrodes define the electrical conditions of the vibration and change a little the effective elastic properties of the plate by means of which is modified the frequency variation with temperature. An experimental and theoretical study of the influence of the mass-loading on the frequency-temperature characteristics of AT-cut quartz resonators was performed [Ref. 20]. The results allow us to conclude that the quartz plate and electrode parameters have a major influence on the frequency-temperature characteristics due to the coupling of the thickness-shear with flexure modes. Recently the measurements of the frequency-temperature characteristics of Y-cut plan-parallel langasite resonators on fundamental, third and fifth overtones were performed and the influence of the mass-loading on this dependence was evaluated [Ref. 21]. Based on Tiersten's analysis an accurate calculation of the coupling coefficient dependence on geometrical dimensions and mass-loading for quartz and langasite monolithic structure was performed [Ref. 22]. We have studied the effect of mass-loading on the coupling coefficient of langasite and quartz monolithic filters.

3. MASS-LOADING INFLUENCE ON ELECTRICAL PARAMETERS OF QUARTZ AND LANGASITE RESONATORS

A comparison between the experimentally results of the mass-loading influence on Y-cut langasite and AT-cut quartz resonators characteristics was performed [Ref.16].
We analyzed the harmonic dependence for various electrode parameters of the most significant resonator characteristics: effective mass-loading, motional inductance and quality factor. Sawyer Y-cut plan-parallel polished langasite and AT-cut quartz plates with 14mm diameter and 5MHz resonant frequency were used in experiments. Ag and Au electrode layers with 75,125,200nm thickness and with 4.6 and 7mm electrode diameters were deposited on quartz and langasite blanks by thermal evaporation. The resonance and antiresonance frequencies and resistances of the fundamental, 3rd, 5th and 7th overtones of the free and electrode plates were measured after every electrode layer. Based on the transmission-line equivalent electrical circuit of the piezoelectric plate resonator vibrating in thickness-shear mode, the effective mass-loading, motional inductance and quality factor were calculated. Mass-loading effect could be evidenced by the change of these parameters on harmonic order on eight AT-cut quartz plates and on the same number of Y-cut langasite blanks with the same geometry and resonant frequency. The values of the effective mass-loading, inductance and quality factor, averaged over eight resonators, were calculated in every case.
The dependence of the inductance on harmonic order for various electrode parameters is the most significant evaluation of mass-loading influence on quartz and langasite resonators.

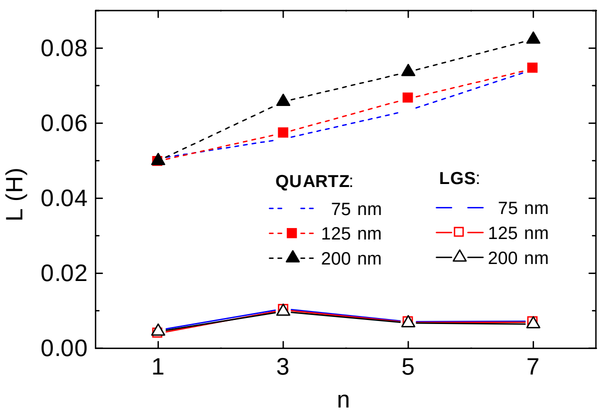

Fig.1. Harmonic variation of inductance with overtone

The inductance L versus harmonic order for quartz and langasite resonators with the same electrode parameters was plotted in figure 1. By analyzing the figure we observe that the inductance of quartz resonators increases with harmonics for all electrode thickness, while the inductance of langasite resonators is almost constant; the change of electrode thickness determines a significant variation of inductance in the case of quartz resonators, but almost no change for langasite resonators.

Taking into account the previous results related to mass-loading effect on quartz resonator characteristics, the change of the inductance with harmonics was ascribed to the internal stresses at electrode-substrate interface. We can conclude that the Y-cut langasite develops a smaller interface stress than AT-cut quartz resonators, having a similar behavior with SC-cut quartz resonators. Consequently, the mass-loading influence on langasite resonators characteristics is lower than on quartz resonators. Figure 2 shows the harmonic dependence of motional inductance for quartz and langasite resonators with 100nm thickness Au electrodes with 4.6 and 7mm diameters.

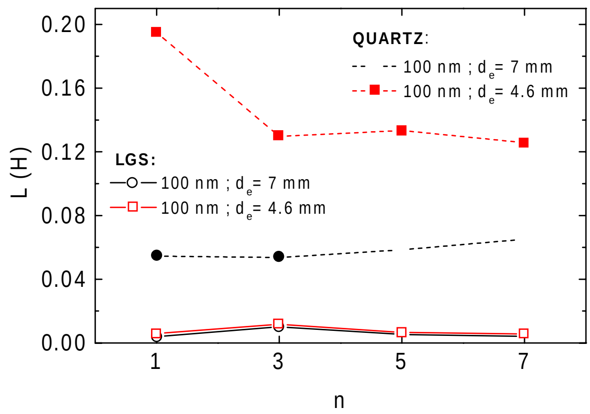

Fig.2. Harmonic dependence of inductance with mass-loading on electrode diameter

By comparing the inductance behavior of quartz and langasite with overtones for different values of electrode diameter we can conclude that the influence of electrode diameter change is smaller for langasite resonators than for quartz resonators. While the inductance of quartz resonators increases almost 2.5 times for the electrode diameter decreasing from 7mm to 4.6mm, the inductance of langasite resonators exhibits a very small change with electrode diameter.

4. MASS-LOADING EFFECT ON FREQUENCY-TEMPERATURE CHARACTERISTICS OF QUARTZ AND LANGASITE RESONATORS

The theoretical and experimental investigations on frequency-temperature characteristics of plan-parallel Y-cut langasite resonators for various mass-loading conditions were performed.
For experiments Sawyer Y-cut plan-parallel, polished langasite plates, with 14mm diameter and 5MHz resonant frequency, were used. On the langasite polished plates have been deposited by thermal evaporation in vacuum Au electrodes with diameter of 7mm and electrode thickness of 100nm, 200nm and 300nm.The frequencies of fundamental, third and fifth overtone were measured in Saunders Temperature Test Systems in the temperature range –35^{0}C and +100^{0}C by changing the temperature in steps of 5 ^{0}C.
For Y-cut langasite resonators the fractional frequency variation with temperature closely approximates a parabolic function. Our measurements show that on fundamental, third and fifth overtones the frequency-temperature characteristics are parabolic functions.
To study the mass-loading effect on frequency-temperature characteristics of Y-cut langasite resonators the analysis of these characteristics on fundamental, third and fifth overtones

frequencies for resonators with different electrode thickness was realized.
The frequency-temperature dependence of resonators 7, 11 with minimum (100nm), respectively maximum electrode thickness (300nm), working on fundamental frequency, is given in figure3. Figure 4 shows the frequency-temperature characteristics of the same resonators on third overtone and figure 5 on fifth overtone.
Analyzing these figures we can conclude that the change of the frequency-temperature characteristics of Y-cut langasite resonators due to the electrode thickness variation is enough small for fundamental and third harmonic (16ppm respectively 12ppm) and higher for fifth overtone (29ppm).

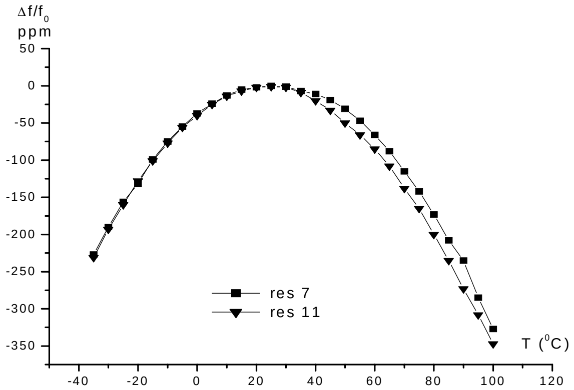

Fig.3. Frequency-temperature characteristics of res.7, 11(n=1); 100nm, respectively 300nm electrode thickness.

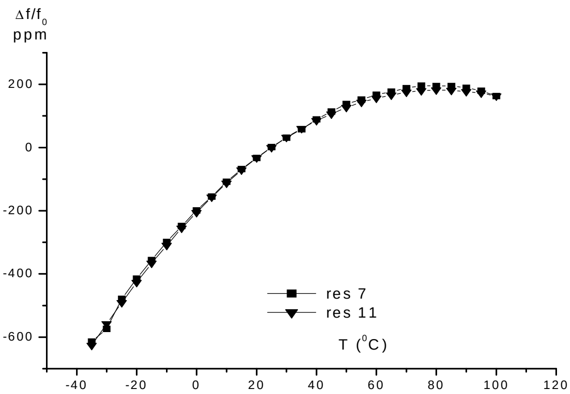

Fig.4. Frequency-temperature characteristics of res.7, 11(n=3); 100nm respectively 300nm electrode thickness.

Comparing these results with the previous ones, obtained for AT-cut quartz resonators [Ref. 8], we expect that the mass-loading effect on frequency-temperature characteristics of Y-cut langasite resonators is smaller than that on AT-cut quartz resonators.

5. MASS-LOADING EFFECT ON MONOLITHIC FILTERS

Using the Tiersten's analysis [11], an accurate calculation of the coupling coefficient as a function of the electrode spacing and the plate thickness ratio for various electrode thicknesses for two-pole quartz and langasite monolithic filters was performed [22]. The effect of mass-loading on coupling coefficient of quartz and langasite monolithic filters, with 10.7MHz central frequency and 15kHz, respectively 50kHz bandwidths, has been evaluated by calculation of the relative change of the coupling coefficient Δk/k and bandwidth Δb/b, due to the relative mass-loading variation with 50%, 100%, 150% and 200%. In figure 6 is presented the dependence of the relative variation of coupling coefficient of quartz monolithic filters on d/t ratio for above-mentioned mass-loading values. Figure 7 shows the same dependence for two-pole langasite monolithic filters. One can see that the change of the coupling coefficient and of the bandwidth on mass-loading is quite different for quartz filter compared to langasite filter. In the case of quartz filter the bandwidth increases with mass-loading (ΔR/R=50%; 100%; 150%; 200%) and this relative variation is strongly amplified for high d/t ratios.

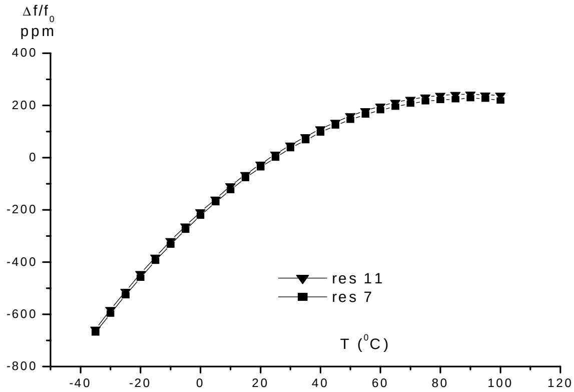

Fig.5. Frequency-temperature characteristics of res.7, 11(n = 5); 100nm, respectively 300nm electrode thickness.

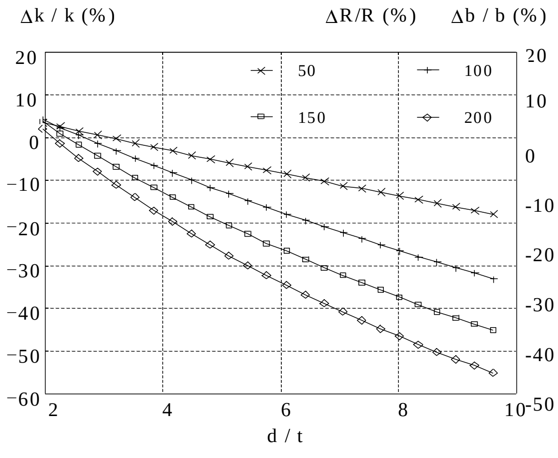

Fig.6. Coupling coefficient versus d/t for quartz filter

For langasite filter the relative variation of bandwidth with mass-loading is zero around d/t=4 and changes in the opposite directions for values below and above d/t=4. Moreover, the mean variation with mass-loading is lower for langasite than for quartz filter. The quasi-independence of the coupling coefficient and of the bandwidth of a band-pass two-pole monolithic filter on mass-loading seems to be one of the most important features of the langasite crystal.

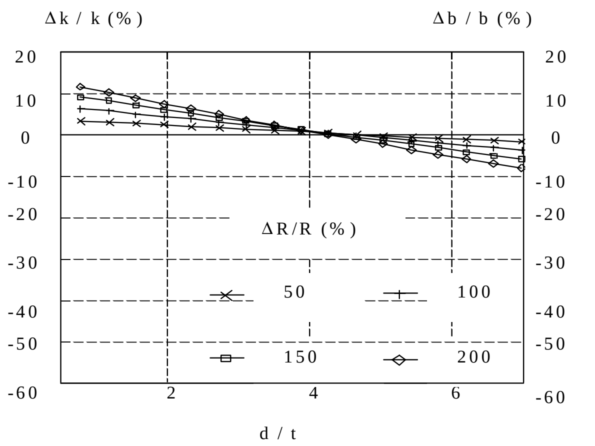

Fig.7. Coupling coefficient versus d/t for langasite filter

6. CONCLUSIONS

The theoretical and experimental results obtained in this study allow us to conclude that the mass-loading influence on characteristics of langasite resonators and monolithic filters is smaller than on the same parameters of quartz devices.

The behavior of the quartz resonator characteristics with mass-loading was ascribed, depending on electrode geometry, to the coupling of thickness-shear with thickness-twist modes or to stresses at interface electrodes-piezoelectric substrate.

The comparison between the experimental results of the mass-loading effect on electrical parameters of the AT-cut quartz resonators and on parameters of Y-cut langasite resonators, have shown that the electrode influence on the langasite resonators is smaller than in the case of quartz resonators. For instance the maximum variation of the inductance harmonic dependence for various materials, electrode thickness and diameters is significantly lower in the case of Y-cut langasite than for AT-cut quartz resonators.

Based on Tiersten's relations, an accurate calculation of the coupling coefficient of the quartz and langasite two-pole monolithic filters, as a function of ratio between the electrode spacing and plate thickness, for various mass-loading was performed. The results revealed that the mass-loading effect on coupling coefficient of langasite filters is smaller than for quartz filters.

The analysis of the measured frequency-temperature characteristics of the Y-cut langasite resonators revealed that the fractional frequency variation with temperature closely approximates a parabolic function on fundamental, third and fifth overtone frequencies. The influence of mass-loading on Y-cut langasite frequency-temperature characteristics seems to be lower than in the case of AT-cut quartz resonators. A comparative study of the two types of resonators in the same conditions will be necessary to do.

7. REFERENCES

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