THE INFLUENCE OF THE MASS-LOADING ON PIEZOELECTRIC DEVICES CHARACTERISTICS

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ABSTRACT

This paper presents some results concerning the mass-loading influence on quartz and langasite resonators and monolithic filter characteristics. The study, using the Ballato's transmission-line analogs of the trapped-energy resonators vibrating in thickness-shear mode, has shown that the harmonic dependence of electrical parameters of resonators is influenced by the electrodes due to the interfacial stresses and to coupling of the thickness-shear with thickness-twist modes. Sawyer plan-parallel polished AT and SC-cut quartz and Y-cut langasite blanks of 14mm diameter, with Ag and Au electrodes with various diameters and thicknesses were used in experiments.

In the frame of the Tiersten's analysis of monolithic structure, the calculations of the coupling coefficient of two-pole quartz and langasite monolithic filters as a function of mass-loading were performed.

The results show that the mass-loading influence on characteristics of langasite resonators and monolithic filters is lower than on those of the quartz devices.

1. MASS-LOADING EFFECT ON QUARTZ AND LANGASITE RESONATORS

The theoretical and experimental investigations of mass-loading effect on thickness-shear AT-cut and SC-cut quartz 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 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 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] for various electrode parameters, mode of electrode deposition and polishing degree of the blanks are 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 [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.

The comparison between theoretical and experimental results for SC-cut resonators [8] with various electrode diameters and thicknesses shows that for 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 resonators 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. 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. In Table1 is presented the effective coupling coefficient k_{eff} and motional inductance L change in function on electrode diameter for AT-cut and SC-cut quartz resonators.

TABLE 1. Variation of k_{eff} and L with electrode diameter for AT-cut and SC-cut resonators

d_e	4.6mm	7mm	4.6mm	7mm
k_{eff}	↗	↘	↗	↗
L	↘	↗	↘	↘
	AT		**SC**	

In experiments have been used the AT-cut and SC-cut quartz resonators with 5MHz resonant frequency, 14mm diameter of the blanks and Ag, Au electrodes of 4.6 and 7mm diameters and 100,300,500nm thickness were used.

A comparison between the experimentally results of the mass-loading influence on Y-cut langasite and AT-cut quartz resonators characteristics was realized [16]. In this paper we analyze the harmonic dependence of the effective mass-loading and motional inductance for various electrode parameters. The blanks used in these experiments are the same with those previously mentioned with exception of electrode thicknesses (75,125,200nm inside of 100,300,500nm). The resonance and antiresonance frequencies, and series resistance of the fundamental, 3rd, 5th and 7th overtones of the free and electroded 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 and motional inductance were calculated. Mass-loading effect was evidenced by the change of these parameters with harmonic order on eight AT-cut quartz plates and on the same number of Y-cut langasite blanks, having the same geometry and resonant frequency. The values of the effective mass-loading and inductance, averaged over eight resonators, have been calculated in every case.

1.1 *Effective mass-loading* μ_{eff}

Figure1 shows the effective mass-loading variation with harmonic order for quartz and langasite resonators deposited with Ag electrodes of 7 mm diameter and 75,125 and 200nm thickness.

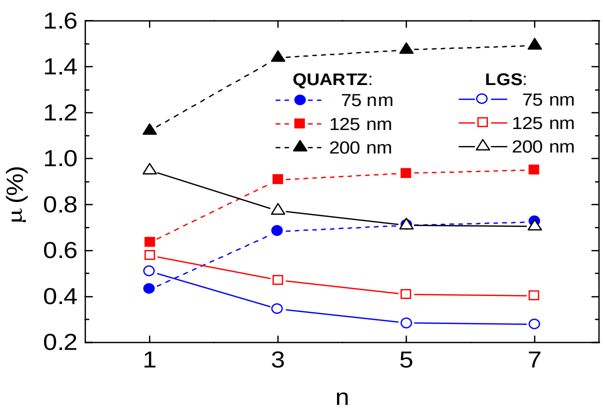

Figure 1. Harmonic dependence of effective mass-loading for quartz and langasite resonators

The effective mass-loading behavior of quartz resonators is different from that of the langasite resonators: the effective mass-loading increases with harmonics for quartz resonators, while it decreases for the langasite resonators. The variation of effective mass-loading for various electrode thickness is smaller for langasite resonators than for quartz resonators.

1.2 Motional inductance L

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.

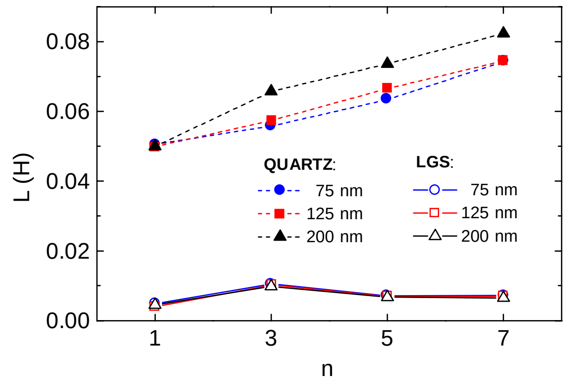

Figure 2. Harmonic variation of inductance for various electrode thicknesses

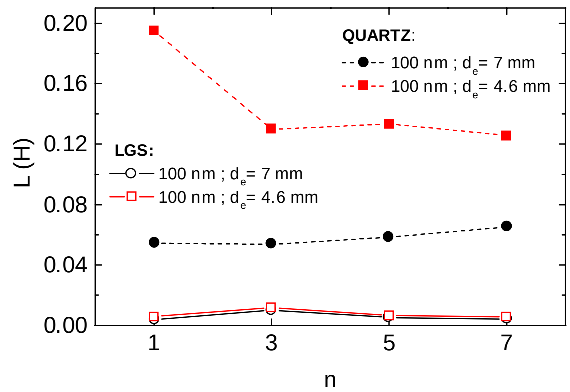

Figure 3. Harmonic dependence of inductance for two electrode diameters

The inductance L versus harmonic order for quartz and langasite resonators with the same electrode parameters was plotted in Figure 2. From this figure we observe that the inductance of quartz resonators increases with harmonics for all electrode thicknesses, 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 the 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.

In Figure 3 is presented the harmonic dependence of motional inductance for quartz and langasite resonators with the same electrode thickness (100nm), and two values of electrode diameters (4.6 and 7mm) Comparison between the behavior with overtones of AT-cut quartz and Y-cut langasite inductance for different values of electrode diameter (Figure3) shows that the influence of electrode diameter change is also smaller for langasite resonators than in the case of quartz resonators. 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 exhibits a very small change with electrode diameter.

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.

2.MASS-LOADING EFFECT ON MONOLITHIC FILTERS

The larger coupling coefficient of langasite in comparison with quartz allows getting filters with larger bandwidth [10,11,12]. Using the Tiersten's analysis [13], 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 [14,15]. 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 4 is presented the dependence of the relative variation of coupling coefficient of quartz monolithic filters on d/t ratio for mentioned mass-loading values. Figure5 presents the same dependence for two-pole langasite monolithic filters. From these figures 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.

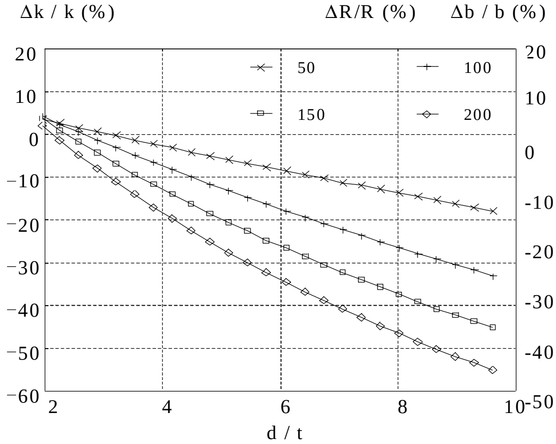

Figure 4. The relative variation of coupling coefficient versus d/t for quartz filter

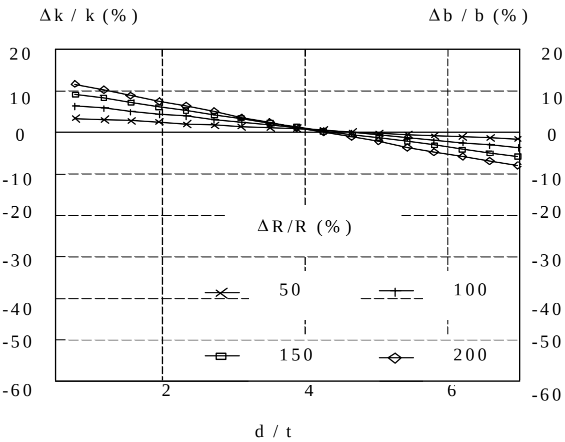

Figure 5. The relative variation of coupling coefficient versus d/t for LGS filter

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.

3. CONCLUSIONS

The theoretical and experimental results obtained in this study allow to conclude that the mass-loading influence on langasite resonators and monolithic filter characteristics is much smaller than those of quartz devices. This 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 and to the stresses at interface electrode-piezoelectric substrate Mass-loading influence on SC-cut quartz resonators is smaller than on AT-cut resonators due to the stress-compensated feature of SC-cut.This means that the interface stresses could be the cause of the non-uniform distribution of motion in thickness shear vibrating resonators. Based on Tiersten's relations, the 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 and for various mass-loading was performed. The results reveal that the mass-loading effect on coupling coefficient of Y-cut langasite filters is smaller than in the case of AT-cut quartz filters. The experimental results of the mass-loading effect on Y-cut langasite resonator characteristics have shown that the electrode influence on these resonators is smaller than in the case of the AT-cut quartz resonators. An interesting conclusion, due to similar behavior of the Y-cut langasite crystal with SC-cut quartz crystal, is that the Y-cut LGS could be a stress-compensated cut. However, further investigations on LGS plates of various orientations are required

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