ANALYSIS BY X-RAY TOPOGRAPHY OF MASS-LOADING EFFECT IN QUARTZ AND LANGASITE RESONATORS

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ABSTRACT

In this paper the results of electrical measurements of the mass-loading influence on AT-cut quartz and 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.

Sawyer plan-parallel polished Y-cut langasite resonators with 14mm diameter, 5MHz resonant frequency, Au electrodes of 7mm diameters and various thicknesses 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 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 AT-cut quartz resonators.

1. INTRODUCTION

Previous investigations on the mass-loading effect in thickness-shear AT-cut quartz and Y-cut langasite resonators have shown that the harmonic dependence of resonators characteristics is influenced by the electrodes due to the non-uniformity of the vibratory motion over the electrodes [1,2,3,4,5].

As suggested in the paper [6], the non-uniform distribution of motion is associated with the coupling of thickness-shear with thickness-twist modes, as well as stresses at the interface between the electrodes and the piezoelectric substrate. Using the Tiersten's analysis [7] 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 [8], in order to account for the non-uniform distribution of motion found in practical plate resonators.

The experimental results regarding mass-loading effects on quartz resonators characteristics [5,6] pointed out that the harmonic dependence of the motional inductance for large thickness of electrodes, small electrode diameters and high frequencies can be ascribed to stress effects, while in the case of small electrode thickness, large electrode diameter and low frequencies the inductance behavior could be explained by the coupling of thickness-shear with thickness-twist modes.

The experimental electrical investigations of the mass-loading effect on plan-parallel Y-cut langasite resonators, with various electrode diameters and thicknesses, were performed [9]. The comparison between the results of measurements on quartz and langasite resonators has shown that the maximum variation of the effective mass-loading, effective coupling coefficient and inductance as a function on harmonics, is significantly lower for Y-cut langasite resonators than for AT-cut quartz resonators.

The mass loading effect on AT-cut resonators characteristics was investigated by X-ray diffraction topography [10] too. A good agreement was obtained between the results of topography investigations and electrical measurements.

This paper addresses the vibration modes by X-ray topography to reveal the mass-loading influence on parameters of Y-cut langasite resonators and to corelate this, on the one side with electrical behavior of langasite characteristics, and on the other side with X-ray diffraction topography images performed on AT-cut quartz resonators.

2. EXPERIMENTAL

The Sawyer plan-parallel, polished AT-cut quartz and Y-cut langasite resonators with 14mm diameter vibrating on 5MHz fundamental frequency, with various electrode diameters and thicknesses, have been used in electrical and X-ray topography experiments. By thermal evaporation in vacuum on quartz plates were deposited Au electrodes with 100nm and 300nm thickness (7mm respectively 4.6mm diameter) and on langasite blanks Au electrodes with 100, 200, 300nm thickness and 7mm diameter. To compare the behaviour of the electrical parameters of AT-cut quartz and Y-cut langasite resonators we used the results obtained in the paper [9], where on both type of resonators were deposited in the same conditions, electrodes with 7mm diameter and 75,125, 200nm thickness.

The resonance and antiresonance frequencies and series resistances of the fundamental, 3rd, 5th and 7th overtones of the free and electroded quartz plates were measured after every two pairs of electrode deposition. Using the relations for the transmission-line equivalent electrical circuits of the piezoelectric plate resonator that vibrates in the thickness-shear mode [1], the motional inductance and quality factor were computed.

X-ray topography measurements were performed by conventional transmission Laue setting using white beam synchrotron radiation at LURE/DCI, Orsay, France [11,12,13]. The fundamental, third and fifth overtone modes were imaged for the excitation at constant current.

3. RESULTS AND DISCUSSION

The analysis of the topographic images 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 diffraction images 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 electroded region. The analysis of the diffraction image (figure 1) shows that for AT-cut quartz resonators with large electrode diameter (7mm), thin electrode thickness (100mm) on fundamental and third harmonic, the coupling of thickness-shear with thickness-twist modes is the main cause of non-uniform distribution of motion [8].

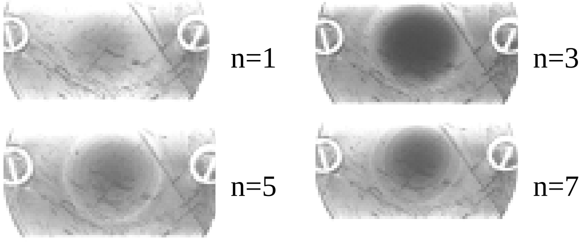

Figure1: X-ray topographic images of AT-cut quartz resonators with 7mm electrode diameter and 100nm electrode thickness.

For quartz resonators vibrating at higher frquencies with thicker electrodes (300nm), the non-uniform distribution seems to be done by the interfacial stresses (figure2)

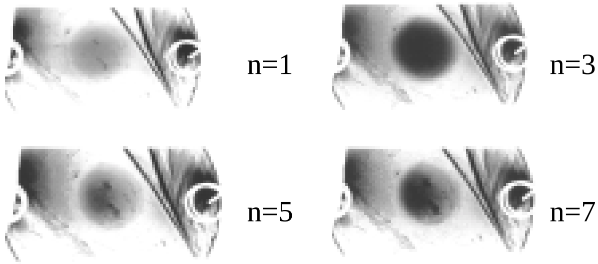

Figure 2: X-ray topographic images of AT-cut resonators with 4.6mm electrode diameter and 300nm electrode thickness

In the case of the Y-cut langasite resonators with three values of electrode thickness (100; 200; 300nm) and 7mm electrode diameter, the X-ray topography analysis shows that the active area is constant with harmonic order, excepted a larger area and image deformation from circular to elipsoidal, for resonators working on third overtone and with 200nm electrode thickness (figure3). This behaviour could indicate a less non-uniformity of motion distribution.

The image deformation from circular to elipsoidal can be explained by two effects: possible deffects of the plates plan-parallelism or the position of the resonator in holder and the change of diffraction conditions due to the high absorbtion of langasite crystals.

These results, obtained by X-ray topography for both types of resonators, are in good agreement with harmonic dependence of motional inductance. The behaviour of motional inductance is the most relevant effect for comparison of mass-loading influence on quartz and langasite resonators.

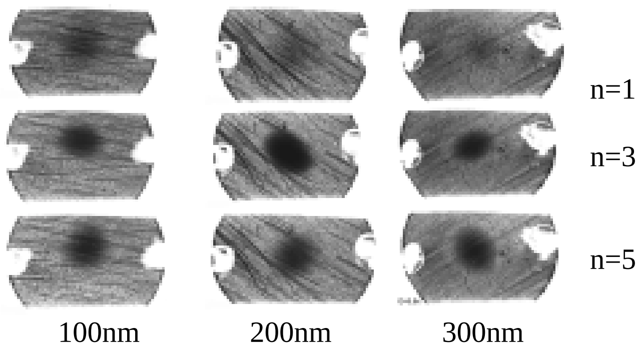

Figure3: X-ray topographic images of Y-cut langasite resonators on fundamental, third and fifth overtones for three electrode thickness

The topographic images of langasite resonators show an X-ray diffracted intensity practically unchanged for the three electrode thicknesses and for high overtones, while in the case of quartz resonators show an anisotropic dependence of harmonic order and mass-loading.

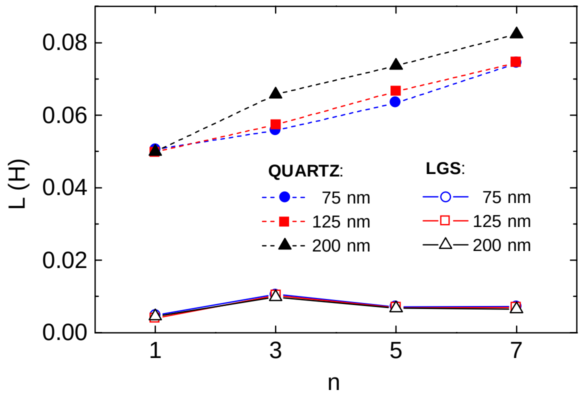

Figure 4: Inductance variation with harmonic order for quartz and langasite resonators.

The analysis of the topographic images for both types of resonators indicates a maximum of the diffracted intensity on third overtone due to strong energy-trapping at this frequency.

Figure 4 presents the inductance variation with harmonic order for AT-cut quartz and Y-cut langasite resonators, previously investigated [9], with various electrode thicknesses (75,125,200nm). The analysis of the graphs shows that:

- inductance of the quartz resonators increases with harmonic order for all electrode thickness, while the inductance of langasite resonators is almost constant;
- change of electrode thickness (mass-loading) determines a significant variation of inductance in the case of quartz resonators and almost no change occurs for langasite resonators.

4. 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. Strong energy absorption on third harmonic is observed 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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