STUDY OF NLC-CUT RESONATORS BY X-RAY TOPOGRAPHY

R.Bourquin[1] ,B.Dulmet [1], R.Velcheva [2], L.Spassov [2]

[1] LCEP/ENSMM, 26 Chemin de l'Epitaphe, 25030 Besançon, France
[2] ISSP-BAS, 72 Tzarigradsko Chaussee Blvd., 1784 Sofia, Bulgaria

ABSTRACT

NLC-Cut [1] has been designed as temperature sensor, specially at very low temperature. The present paper shows the modes shapes of all the resonant modes, and more particuraly anharmonic modes, obtained by X-Ray topography. Comparison is made with the analytical model of Tiersten.

1. INTRODUCTION

The use of quartz resonator as temperature sensor implies that the frequency-temperature curve does not exhibit any activity dip. These perturbations of such curve are due to coupling of the "normal" resonant mode with other resonant modes which are normally not excited by the applied electric field in the resonator[2].
The NLC Cut used to make the quartz resonators is a singly rotated cut. (yxl/-31°.30'). For this orientation, it is the B mode which is excited by classical electrodes. Although resonators operate on first overtone mode, activity dips can occur from coupling with anharmonic mode of C-mode family, in addition of coupling with other modes of lower resonant frequency, such as flexure modes. The prediction of the existence and intensity of activity dip is based on the knowledge of the resonant frequency and shape of modes in resonators. These can be altered by geometrical defects and disturbances coming, by example, from the strips connecting the electrodes to the holder of resonator. This point is critical in the case of very small size, high frequency resonators.
We have used X-Ray topography to investigate the resonant frequencies and mode shapes in 29 MHz resonators. Due to the fact that the resonant frequencies of quartz are, of course, very sensitive to change of temperature, and because we want to observe very leak resonant modes, a real time control of mechanical resonance by X Ray diffraction is needed. It is the reason for which we didn't use the Lang experiment setup. Instead of we have used a large focus X-Ray tube to illuminate the quartz crystal, and an image intensifier to obtain a real time visualization of the diffracted image. Since we don't need a very high resolution the record of the diffracted beam can be. made on high speed photographic film.

2. EXPERIMENTS

The construction parameters of the quartz resonators are:

- diameter of quartz plate :	5 mm
- thickness of quartz plate:	82 µm
- diameter of electrodes:	2.9 mm
- width of electrode tabs:	1 mm

The direction of X cristallographic axis is perpendicular to the flat made on the plate (see figure 1).

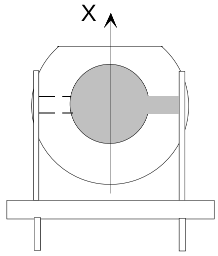


Fig. 1 : Geometry of resonator.

Two groups of quartz having different thickness have been studied.

3.1 Resonator with electrode thickness 58 nm

The figure 1 show the module of admittance of a resonator. Vertical unit is in dB, with a zero level corresponding to 10.5 Ω

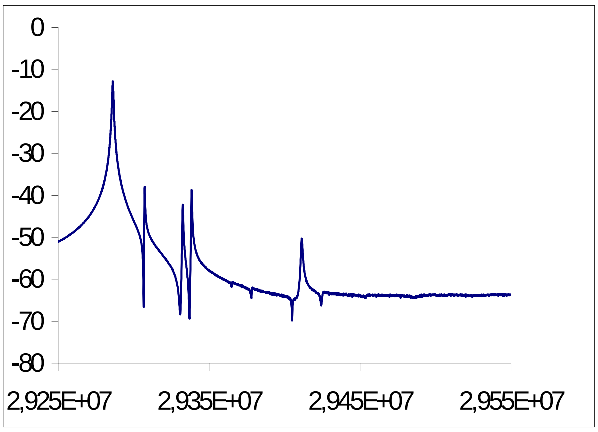
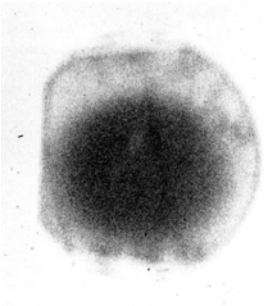


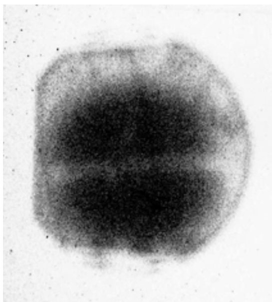
Fig.2 : Admittance of quartz with thin electrode (in log scale)

Aside the four active spurious mode, there exist five other "disturbances" corresponding to modes that are observable by X-Ray imaging. In this resonator the trapping of the vibration is not very strong. As expected from the Tiersten theory of energy trapping in singly rotated resonators [3], the nodal lines are in the X and Z' direction. The X axis is oriented in the horizontal direction. The topographies are made at room temperature.



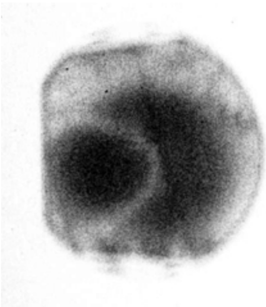
f=29.286 MHz

Fig 3



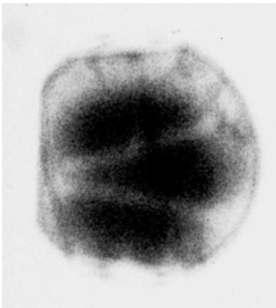
f=29.307 MHz

Fig 4



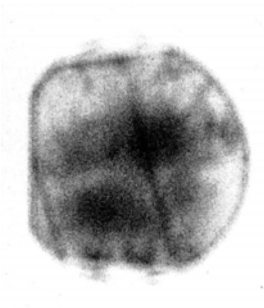
f= 29.332 MHz

Fig 5



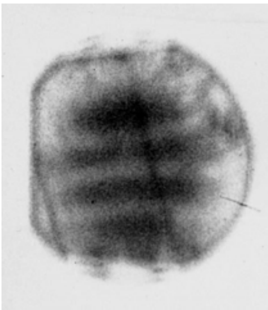
f=29.338 MHz

Fig 6



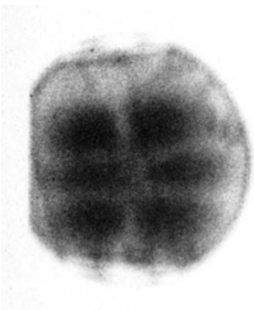
f=29.365 MHz

Fig 7



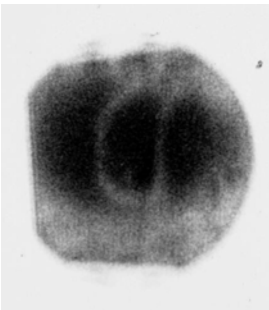
f=29.378 MHz

Fig 8



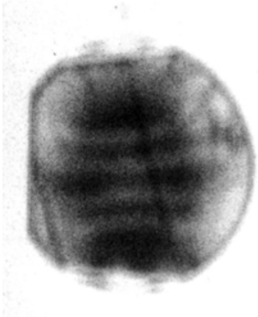
f=29.405 MHZ

Fig 9



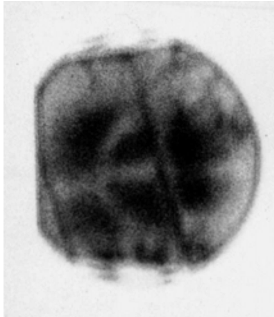
f=29.411 MHz

Fig 10



f=29.424 MHz

Fig 11



f=29.454 MHz

Fig 12

The mode on figure 3 is the main mode on wich the thermal sensor operates. The pictures on figures 4,5,6 and 10 are for the principal spurious resonances. The unusual shape of 1,1,0 mode in figure 5 comes from the superposition of this mode with the 1,0,2 mode (Fig 6) because both modes have very close resonant frequencies.

3.2 Resonator with electrode thickness 180 nm

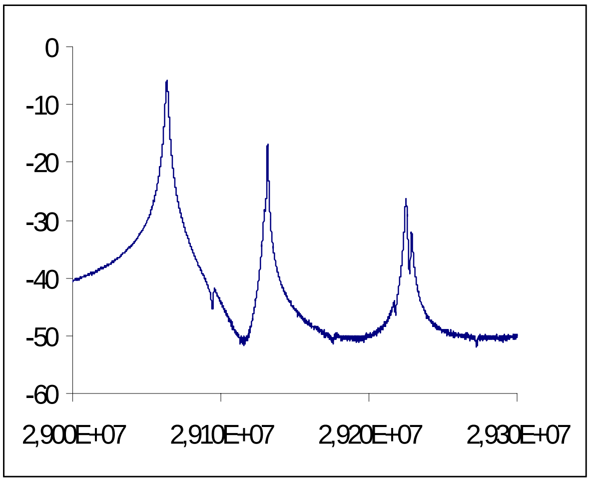
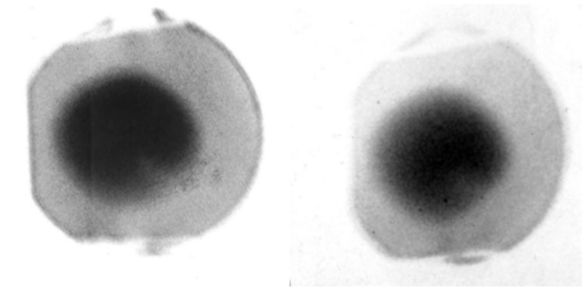


Fig 13 Admittance of quartz with thick electrode (in log scale)

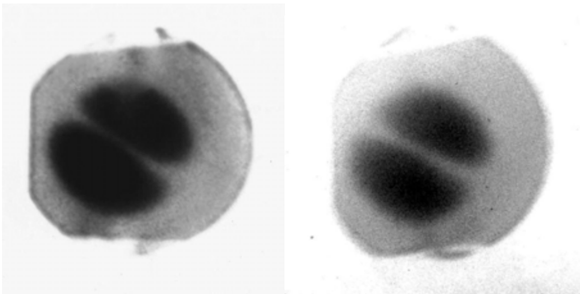
The “frequency spectrum” of a typical resonator is shown on figure 13. On all topographies (Fig.14 to 17), the component of the mechanical displacement the diffraction is sensitive lies in the horizontal direction. Since the trapping of the vibration is strong in this resonator, spurious modes are more spaced and less numerous than in the first group of resonators.

The figures 14 to 15 give the mode shape of the main mode and of the first two anharmonic modes. The u1 component along X axis the mechanical vibration is depicted on the left part of the figures (use 2-1.0 reticular plane), while the u3 component along Z’ axis is on the right (use of 0 0.1 plane). We observe that the nodal lines of the mode shapes are not in the expected direction. The origin of this rotation of mode shape is not well understood for instance. A possible explanation is an effect coming from a lack of parallelism of the plate[4,5]. The similarity of the topographies showing the u1 and the u3 component of the vibration seems to indicate that the mechanical displacement is not exactly along the X direction.



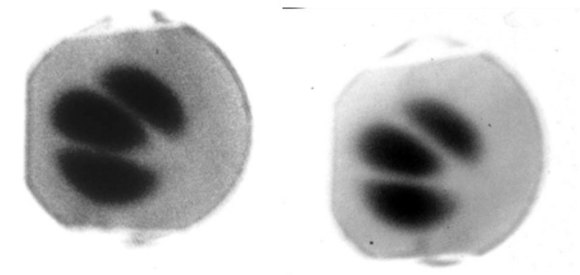
u1 u3

Fig.14 : f=29.071 MHz



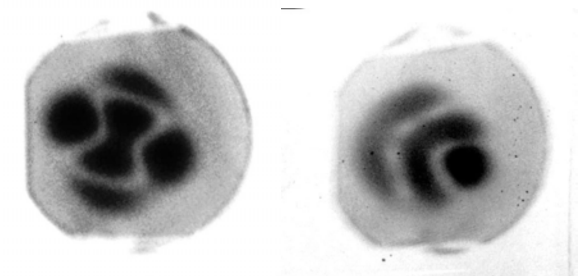
u1 u3

Fig.15 : f=29.110 MHz



u1 u3

Fig.16 : f=29.132 MHz



u1 u3

Fig.17 : f=29.225 MHz

The complex mode shape shown on figure 17 corresponds to the three close spurious resonances on the right side of record on figure 13 and is a mixing of tree "normal" anharmonic modes. In this last case, the u1 and the u3 component of the vibration exhibit different distribution.

All mode shapes shown on the topographies are not exactly centered and the deformation of the mode shapes can be explained by a small defect of parallélism of the faces of the resonator, as it can be verified by fem analysis.[6]

3. COMPARISON WITH THEORY OF TRAPPED ENERGY RESONATOR

The resonant frequencies have been computed by using the result of Tiersten [3] based upon the concept of dispersion constants.

For the first overtone of NLC cut , the computed dispersion constants for the B mode are:

$$M1=118\ 10^9; \qquad P1=32.8.10^9$$

Tiersten theory of trapped energy resonator give the frequencies of resonators having rectangular electrodes. It extension to arbitrary shape of electrode is possible [6]. Nevertheless, for our purpose, it is sufficient to suppose that the electrodes are square with a width equal to the diameter of the real electrodes.

The following table (I) summarize the results:

Electrode thickness : 180 nm		Electrode thickness : 58 nm	
f min = =29.262 MHz f max = 29.718 MHz		F min = 29.050 MHz F max = 29.210 MHz	
mode	f (MHz)	mode	f (MHz)
100	29.071	100	29.286
101	29.115	101	29.328
102	29.205	102	29.409
110	29.215	110	29.411
111	29.260		
103	29.338		
112	29.349		
113	29.482		
120	29.492		
104	29.511		
121	29.537		

Table I : Computed resonant frequencies

Indices of the mode labeling indicates the overtone number and the number of nodal lines in the X and Z' direction. In trapped energy resonators, for a given overtone, the number of well trapped anharmonic modes is finite [7]. f min and f max are the limits of frequency range in which anharmonic modes are observable. By comparing these results with experimental data, care must be taken to the fact that a small change of width of electrode can change significantly the computed values. It is the reason for which the number of retained modes for the thickness of 58 nm° is less than the number of experimental modes. We must also keep in mind the fact that the resonant frequencies of resonators are depends very strongly on the temperature and that accuracy of experimental values are altered by small change of this last parameter.

A comparison of calculated frequencies with experimental data reveal a larger spacing of predicted modes than experimental ones. In counterpart, the order of modes is correctly predicted.

The analytical expression of mode shape in the region under electrodes is:

$$u_1 = \cos(\xi\ x_1)\cos(\upsilon\ x_3)$$

while outside the electrodes the vibration decrease exponentially with damping factors ξ_s in the x1 direction and υ_t in x3 direction (x1,x3 being the coordinates of usual rotated frame of a singly rotated cut). If l 2l labels the width of square electrode, one has [3]:

$$\xi\ \tan(\xi l) = \xi_s; \quad \upsilon \tan(\upsilon l) = \upsilon_t$$

The table II gives the wave number ξ and ν for both kind of resonators calculated with using the value l=1.45 mm.

Electrode thickness :180 nm $\overset{o}{A}$		Electrode thickness :58 nm	
ξ	ν	ξ	ν
967	1019	917	989
2888	3055	2709	2961
4749	5083		4907
	7096		
	9075		
	10894		

Table II : Theoretical wave numbers

Comparison of modes shapes in topographies with what is predicted from the values in table II show that the order of magnitude of wave numbers is in agreement .

4 CONCLUSION

Investigation of resonant modes in NLC cut reveals that the modes shapes and frequency locations are in accordance with what is expected from the classical theory of trapped energy resonator. This confirms the possibility to make resonators with a strong trapping of vibration with the NLC cut. This point is very fruitful to make temperature sensors of very small size.

5 ACKNOWLEDGEMENTS

This work was supported by the CNRS (France) and the Bulgarian Academy of Sciences.

6 REFERENCES

1. L.Spassov, E.Yossiffov, V.Georgiev, L.Vergov, “ A Rotated Y-Cut Quartz Resonator with a Linear Temperaure –Frequency Characteristic, “ Sensors and Actuators, A58 (1997),pp 185-189

2. R.Bourquin, B.Dulmet, G.Genestier, “Mechanical Couplings Involving Discontinuities of the Frequency-Temperature Curves of Contoured Resonators”, Proc.39th Ann.Freq.Cont.Symp. Philadelphie, USA,(1985) pp 404-414

3. H.F.Tiersten, ”Analysis of trapped-energy resonators operating in overtones of coupled shear and thickness twist”, J.Acoust.Soc.Am., Vol 59, N°4, pp 879-888

4. R.Bourquin, “Trapped Energy QUARTZ Crystal Resonator on Wedge-Shaped Plate”, Proc.7th EFTF, Nordwijk, The Netherland (1992), pp 273-277.

5. L.N.Dworsky, “Properties of AT Quartz Resonators on Wedgy Plates” Proc.37th Ann.Freq.Cont.Symp.“, (1983), pp 232-238.

6. B.Dulmet, R.Bourquin, L.Spassov, R.Velcheva, “Finite Element Analysis of Activity-Dips in NLC-Cut Quartz Temperature Sensors”, These Proceedings.

7. By well trapped mode we understand mode for which the decay numbers along the axis in plane of resonator are real in the electroded region and imaginary outside.