Filter Synthesis using Shear-Wave Piezoelectric Layer Resonators.

L. Catherinot[a], T. Baron[b], P. Monfraix[c], L. Rigaudeau[d], S. Ballandras[b], M. Chatras[a], S. Bila[a] and D. Cros[a]

[a] Xlim, CNRS UMR 6172 University of Limoges, France
[b] FEMTO-ST, UMR CNRS-UFC-ENSMM-UTBM 6174, Besançon, France
[c] Thalès Alénia Space, Toulouse, France
[d], CNES, Toulouse, France

matthieu.chatras@xlim.fr

I. CONTEXT

Acoustic waves in elastic solids are used in numerous applications in signal processing, including frequency generation, control and filtering in modern wireless communication systems. With the growing demand for multimedia and mobile applications, the new generations of telecommunication satellites require higher performances, higher functionalities and still stronger cost and size constraints.[1][2][3] In that context, BAW devices have many potentialities for the development of smart RF subsystems. For instance this technology is now used as alternative to Surface Acoustic Waves (SAW) filters in handset duplexers for UMTS and DCS standards around 2 GHz with Aluminum Nitride piezoelectric layers[12]. However, Aluminum Nitride is not suitable for large band applications, due to its electromechanical coupling coefficient. Its relative percentage, which represents the difference between resonant and antiresonant frequencies is 7%. This material is mainly processed for local oscillators or narrowband filtering operations (<5%) [4] [5].

That is why Lithium Niobate layers are studied to reach large band pass specifications for satellites requirements. It is essential to maximize the values of electromechanical coupling coefficient in Lithium Niobate, and to use wisely crystallographic cuts in order to perform the best results for longitudinal or transverse waves coupling larger difference between resonant and antiresonant frequencies. Thanks to Lithium Niobate shear wave propagation behavior, the goal will become synthesizing large bandpass frequency response of simple filters structures.

II. ELECTROMECHANICAL COUPLING COEFFICIENT.

The study of the disorientation in piezoelectric materials allows determining the best propagation axes to optimize electromechanical coupling coefficient in lithium niobate. In order to reach this goal, we first solve the piezoelectric problem.

Mechanical and electric fields are coupled in piezoelectric solids, so we must solve both Maxwell and elastodynamic equations [6]. The velocity of elastic waves in elastic solids is generally five orders of magnitude lower than the electric waves. A quasi static approximation permits to obtain independents propagations for elastic and electric waves.
By solving the generalized Christoffel equation in piezoelectric materials, we can work with tensorial expressions that give phase velocity and polarization. For "z" propagation (fig1.), three plane waves are created, which have orthogonal polarization with different velocities.

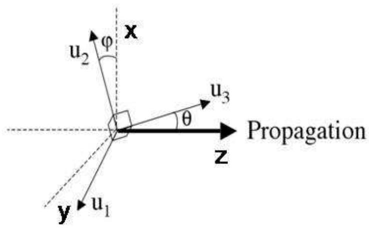

Fig.1: Propagation in anisotropic crystal

It results a thickness wave polarized along the "Z" axis, and two shear waves, polarized in the "XY" waves plane. These velocities permit to define very important parameters for BAW resonators: thickness electromechanical coupling coefficient kt^2 and shear electromechanical coefficient ks^2.

The higher these coefficients are, the best electromechanical coupling the piezoelectric layer gives. If we consider the electrical response of the resonator coefficients correspond to the relative variation between the resonant and anti-resonant frequencies. If the electromechanical coefficient increases, the difference between resonant and antiresonant expands. The following expression describes the dependence of kt^2 according to resonant and antiresonant [7].

$$k_t^{\,2} = \frac{\pi^2}{4}\left(\frac{f_p - f_s}{f_p}\right)$$

Moreover it is necessary to optimize order to fulfill large band pass application specification. It is possible to determine the best electromechanical coupling coefficients according to the crystallographic angle. Indeed, particular crystallographic cuts (according to the acoustics norms: the propagation is along the "Y" axis) have good piezoelectric coupling effects. Before studying capabilities, we must rotate relative to the angle θ (fig. 2) the constraints, the piezoelectric and the permittivity tensors on to obtain these values beside the "Z" axis.

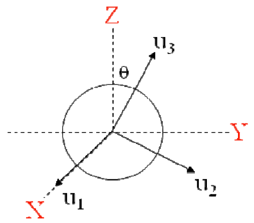

Fig.2: Rotation of the tensor relative to the θangle.

It is not possible for Aluminum Nitride to have a coupling coefficient kt² higher than 7%. There are two different cuts for Lithium Niobate Y+36° (corresponding to Z+126°) and Y+163° (corresponding to Z+253°). For these orientations, we can obtain much higher values, which permit large band pass filtering.

If one of the coupling coefficients is equal to zero, and the other is different of zero, we can apply a scalar approach of the piezoelectric problem. If we consider ks² values, we can obtain the more interesting value (65,5%) when *kt²* is equal to zero. Then a 1D simulation tool that computes thickness waves can be used.

$$k_t^2 = \frac{e_{33}^2}{c_{33}\varepsilon_{33}} \qquad k_s^2 = \frac{e_{34}^2}{c_{44}\varepsilon_{33}}$$

These equations allow the computation of the scalar approach in resonator simulation software.

III. FBAR 1D SIMULATION RESULTS

We have explained it is possible to simulate in one dimension the shear-wave piezoelectric problem. The first step is to size the thicknesses of the several layers of the structure to reach the targeted frequencies.

We have computed a Film Bulk Acoustic Resonator (FBAR) structure [8]: a basic BAW resonator consist of a thin Lithium Niobate piezoelectric layer suspended in the air, sandwiched between two metal electrodes Aluminum and Gold in our 1D simulation software. This software solves the acoustic propagation equations in the several layers of the resonator, and it considers mechanic, piezoelectric and electric constant values for each material. It is also necessary to define wisely layer thicknesses, materials and the frequency range in order to compute the electrical response. In fact it is possible to fit the best values of these parameters for preparing future 3D finite elements method simulations of the resonator. Figures 3 and 4 highlight the impedance of the electrical response for FBAR structures with two different crystallographic cuts for the Lithium Niobate piezoelectric.

In the case of figure 3, we used the cut Y+36°, we obtain a coupling coefficient *kt²* equal to 33%.

In the case of figure 4, we used the cut Y+163°, we obtain a coupling coefficient *ks²* equal to 50%.
Figure 5 shows a resonator with Aluminum Nitride piezoelectric layer and Molybdenum electrodes, with the same targeted resonant frequency.

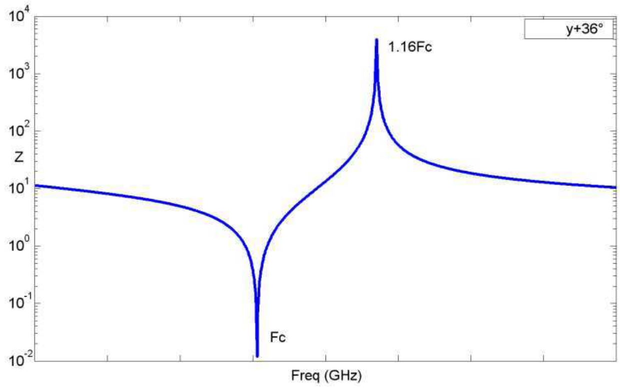

Fig 3: simulation response of a lithium niobate resonator (cut Y+36)

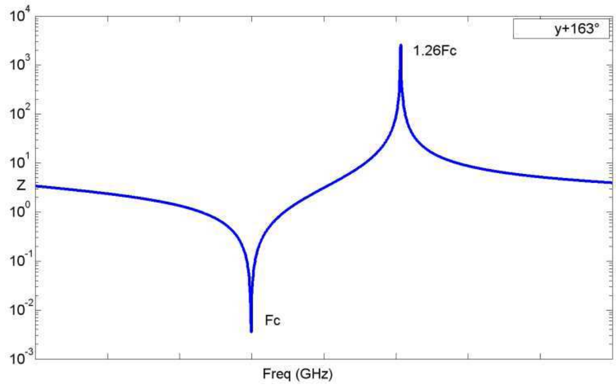

Fig 4: simulation response of a lithium niobate resonator (cut Y+163)

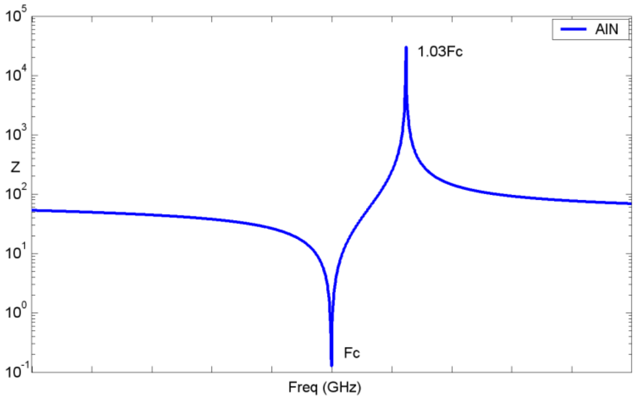

Fig 5: simulation response of an AlN resonator

In the case of figure 5, the obtained coupling coefficient kt^2 is equal to 7,2%. This result will demonstrate that Lithium Niobate is a very good candidate for large band applications. The piezolayers will be fabricated by our partners FEMTO-ST. They have developed a controlled thinning technology by grinding wafers with a liquid abrasive system [9].

IV. CONCLUSION

It has been demonstrated that Lithium Niobate is a good candidate for large band specifications for fractional bandwidth over 10%, due to its properties of electromechanical coupling coefficients, which are higher than other material ones. We have shown the mathematical approach to perform 1D simulation for shear-wave resonators, using the piezoelectric constitutive equations and tensorial calculation. As a result, we can consider a scalar piezoelectric problem, which can be used with our classical simulation software.

ACKNOWLEDGEMENT

This work is supported by the French Space Agency (CNES) (project FOVETTES).

REFERENCES

[1] K.M LAKIN,G.R. KLINE and K.T McCARRON, “Thin Film Bulk Acoustic Filters for GPS”, 1992 IEEE Ultrasonic Symp. Proc., pp 471-476

[2] K.M.LAKIN, G.R. KLINE, K.T. McCARRON, “High-Q Microwave Acoustic Resonators and Filters”, 1993 IEEE Microwave Symp. Digest, vol. 3, pp 1517-1520

[3] W. MUELLER, “A Brief Overview of FBAR Technology”, Agilent Technologies White Paper, 2001, July 20

[4] H.P.LOEBL, M.KLEE, C.METZMACHER, W.BRAND,R.MILSOM, P.LOK, “Piezoelectric Thin AlN Films for Bulk Acoustic Wave (BAW) Resonators”, 2003, Material Chemistry and Physics, pp 143-146

[5] R.LANZ, P.MURALT, "Solidly Mounted BAW Filters for 8 GHz based on AlN Thin Films ",2003 IEEE Ultrasonic Symp,pp 178-181
[6] B .A. AULD "Acoustic Fields in Solids", Vol.1, Wiley Interscience Publication, 1973
[7] R.AIGNER, "Bringing BAW Technology into Volume Production: the Ten Commandments and the Seven Deadly Sins", Third International Symposium on Acoustic Wave Devices for Future Mobile Communication Systems, 2007
[8]T.KAMOHARA, M.AKIYAMA, N.UENO, K.NONAKA, H.TATEYAMA "Growth of Highly c-axis-oriented Aluminum Nitride Thin Films on Molybdenum Electrodes using Aluminum Nitride Interlayers", 2005 Journal of Crystal Growth, 275, pp 383-388
[9] T. Baron, J. Masson, J.P. Romand, S. ALzuaga, L. Catherinot, M. CHATRAS, S. BALLANDRAS." BAW PRESSURE SENSOR ON LINBO3 MEMBRANE LAPPING", EFTF, noordwijk, April 2010
[10] J.D LARSON III, P.D. BRADLEY, S.WARTENBERG, R.C. RUBY, "Modified Butterworth Van-Dyke Circuit fot FBAR Resonators and Automated Measurement System", IEEE Ultrasonic Symp.2000, Vol.1.1, pp 863-868
[11] J.BJURSTROM, L.VESTLING, J.OLSSON, I.KATARDJIEF, "An Accurate Direct Extraction Technique for the MBVD Resonator Model", 2004, 34th European Microwave Conference, pp 1241-1244
[12] S. GIRAUD, S. BILA, M. CHATRAS, D. CROS, M. AUBOURG, « Bulk acoustic Wave Filter Synthesis and Optimization for Multi-Standard communication Terminals**"** *IEEE TUFFC, PP 57, PP 52-58, JAN 2010.*