Development of a Quartz-MEMS Resonator

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***Summary*— This paper presents a miniaturized high Q-factor Thickness Shear Mode Resonator (TSMR), manufacture collectively thanks to the Deep Reactive Ion Etching (DRIE) of quartz crystal wafers. The intrinsic qualities of quartz (i.e. high Q factor, low temperature sensitivity and piezoelectricity) and the advantages of DRIE allowed to fabricate resonators of small dimensions and collectively manufactured. Samples vibrating at frequency f of 88 MHz have shown promising results which lead to quality factor and resonance frequency products (Q.f) near the theoretical limit for quartz of 3.2×10^{13} Hz [1].**

Keywords— Time-Frequency, Resonator, quartz-MEMS, DRIE

I. Introduction

Nowadays, the thermostated time basis (OXCO: Oven Controlled Crystal Oscillator) are mainly fabricated with quartz resonator, taking advantage of their high-frequency stability over temperature and of their high-quality factor. However, the fabrication process is still today handcraft, because an individual finishing of the resonators is necessary, which implies a volume constraint and high cost. In recent years, new silicon MEMS (Micro Electro Mechanical System) resonators have been developed to achieve a miniaturization of the time basis at the cost of a degradation of their performance and the power consumption, in order to answer to emerging applications such as 5G base stations, autonomous cars, drones, or nanosatellites [2].

The work aims the development of a miniature resonator in quartz-MEMS technology combining the advantages of MEMS technology in terms of miniaturization, low consumption and low cost, with the advantages of quartz resonators in terms of performance, simplicity and low cost of the electronic oscillator. In order to create a high performance miniaturized OXCO.

II. Methods and Results

A. Conception

The starting point is a standard 100 MHz resonator with two anchors [3]. The resonator is a thickness-shear resonator made from a SC-cut oriented quartz plate.

The objective is to miniaturize this resonator in a tight area of 10 mm^2, which is the thermostatic oven. The diameter of the plate is limited, in order to have enough surfaces to develop a support that meets the thermo-mechanical constraints, due to the oven and acceleration criteria.

During the stage of conception, a major part of the geometrical factors has been optimized. The electrodes have to be circular, with a diameter large enough to minimize the motional resistance of the resonator but also small enough to keep spurious modes away [4]. Moreover, the performances are more robust, when the plate is circular, it implies a better energy trapping and when the resonator has 3 attachment points, it implies a lower damping ratio.

All the finite element simulations were done using a fine mesh in the thickness of the vibrating plate, to correctly simulate the shear modes. The simulation results are fitted with a Butterworth-Van Dyke model, in order to obtain the performance of the resonator.

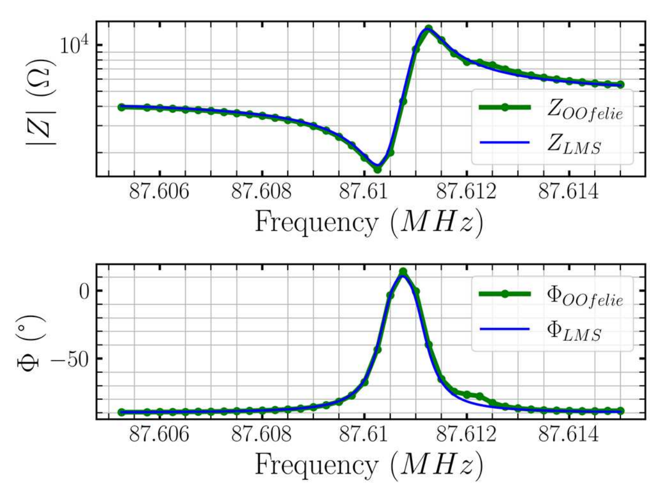

Fig. 1. Frequency response of a simulated resonator.

The simulated resonator showed a quality factor just over 90 000 and a motional resistance of 1.9 kΩ, for a resonance frequency of 86.61 MHz. Figure 1 presents the simulated frequency response of the 5th harmonic to achieve a frequency near 100 MHz with a thickness of 100 µm.

B. *Realization and Characterization*

A 1.5" SC-cut (doubly rotated quartz) wafer of 100 µm thickness is used to manufacture collectively 36 samples. On each side of the plate a gold electrode is deposited by evaporation. Then the manufacturing process using DRIE is done, this is now a proven process within ONERA [5]. Quartz DRIE allows an etching rate of 20 to 30 µm per hour and an excellent sidewall verticality (88° to 92°). The figure 2 shows the condition of the resonator after the DRIE.

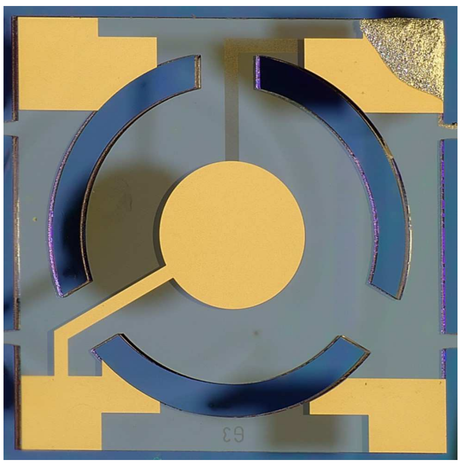

Fig. 2. Tilted image of the resonator after DRIE.

The characterization was done with an impedance meter Agilent 4294A, which allowed to identify the resonance frequency of the resonator. All the characterizations were done under atmosphere, however the vibration is established in the material, so the viscous losses due to the air friction should be limited. Measurements of encapsulated devices under vacuum will be performed in the near future.

Figure 3 shows the frequency response of a measured resonator. On the 5th overtone, the resonance frequency of this resonator reaches 87.609 MHz, and the resonator shows promising performance, with a quality factor of 45 000 and a motional resistance of 2.0 kΩ, so reaching a Q.f product of 3.94×10^{12} Hz near the theoretical limit of quartz of 3.2×10^{13} Hz in the Akhiezer regime for a surface lower than 10 mm^2.

III. DISCUSSION AND OUTLOOK

A discrepancy between measured and theoretical performance appeared. This gap is explainable by different parameters; first, the characterizations were done in air, which slightly reduces the performance of this type of resonator and it would be too time-consuming to simulate this loss by FEM. Secondly, the resonator was glued on a support and this gluing adds a viscous loss at the anchor, according to the simulations, this is one of the highest loss factors for this resonator.

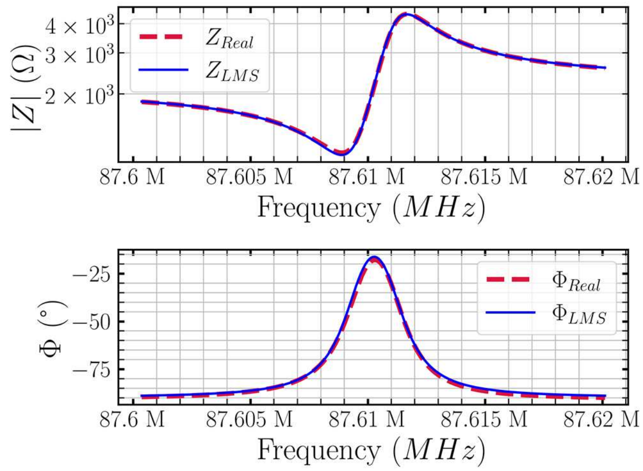

Fig. 3. Frequency response of a measured resonator.

Finally, the electrodes also bring losses by viscosity, normally these losses are negligible. However, during the DRIE process, the electrodes were degraded, due to the diffusion of the metal of the electrodes in the etching mask. We can then assume that their damping and their resistivity have increased and thus deteriorates the performance.

A characterization under vacuum will allow to quickly estimate the losses due to the air. A work on the improvement of the resistance of the electrodes is mandatory, indeed the improvement of the motional resistance of the resonator seems to be an attainable means to enhance the performances of the resonator.

IV. CONCLUSIONS

In this paper, a miniaturized thickness-shear quartz resonator has been presented. First prototypes showed encouraging performance allowing a Q.f product higher than 10^{12}. Future work will be focused on the research of the limiting mechanisms, the improvement of the performance, the encapsulation in micro-OXCO. But also, the development of a new way using Quartz on Quartz wafer, in order to reduce the thickness and to further miniaturize the system.

ACKNOWLEDGMENT

This work was supported by the Centre National d'Etudes Spatiales of France and by the European Space Agency.

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