10 MHz Length-Extension Mode Quartz MEMS Resonator For Frequency and Time Applications

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Abstract— **In this paper, we present recent advances on a quartz Microelectromechanical system (MEMS) resonator. This resonator is well suited to replace standard macroscopic crystal quartz resonators in crystal oscillators combining high performances, low costs thanks to collective processes and low power consumption in emerging applications such as Internet of Things, embedded systems or the cellular network development (5G).**

Keywords—Quartz; MEMS resonator; Frequency and Time; DRIE

I. INTRODUCTION

This resonator consists of a beam vibrating in length-extension-mode (LEM) at 10 MHz. A specific design of the two lateral beams allows Poisson ratio [1] compensation and thus energy loss at the anchors is minimized, ensuring high mechanical quality (Q) factor. High Q factors are mandatory for most of time-frequency applications as it reduces the phase noise near the carrier and allows for low motional resistance for low floor phase noise. Devices were fabricated from Z cut alpha quartz wafers using collective processes, in particular, resonators were etched over 100 µm using Deep Reactive Ionic Etching (DRIE) as the standard wet chemical etching was not compatible with resonator geometry and required critical dimensions. Resonators prototypes showed promising results as measured Q factors were in the vicinity of 90 000 under vacuum. Future work will focus on increasing Q factor and further characterizations such as thermal sensitivity, Allan deviation and long term ageing.

II. METHODS/RESULTS

Previous work [2] demonstrated the possibility to obtain very high Q factors on LEM quartz resonators up to 200 000 at 2.2 MHz. Unfortunately motional resistances were relatively high, around 5 kΩ, as gold electrodes were only deposited on one quartz surface for process ease. New challenges are on one hand increasing the frequency using shorter central beams and on the other reducing motional resistances using electrodes on both sides of the resonator.

Process fabrication including quartz DRIE has been developed: one face is processed until half of the total quartz thickness (100 µm) is etched, then the wafer is flipped and the other face is processed. Fig.1 shows an example of resonator manufactured this way. One can note that there is no faceting at the edge of the resonator and the critical dimension of the width of the beam is 10 µm making quartz DRIE a promising tool for complex quartz MEMS designs. Resonators were characterized using an impedance analyzer at room temperature.

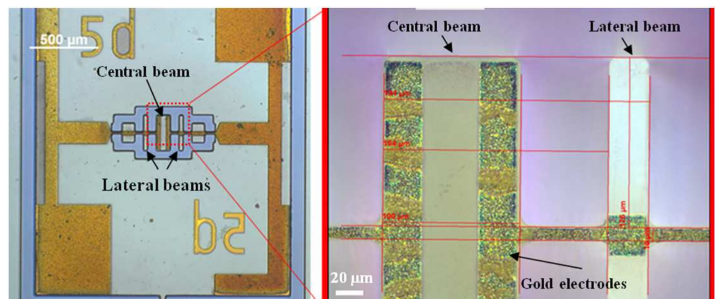

Fig. 1. Left: resonator fabricated using DRIE vibrating at 10 MHz on the fundamental LEM magnification x50, right: zoom-in on the vibrating part at magnification x500.

Phase and module data and fits with the Butterworth Van Dyke model of a 10 MHz LEM resonator are shown in Fig.2. Resonators with highest Q factors were then measured under vacuum (10-3 mbar) and exhibited Q factors as high as 90 000.

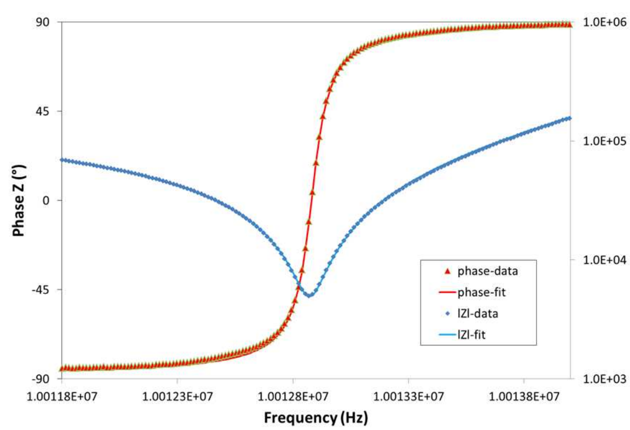

Fig. 2. Impedance frequency characteristics (phase and module impedance) of the 10 MHz LEM quartz resonator.

This is somehow less than previously obtained but one can note the Qxf product is higher and is now close to 10^{12} Hz. It is

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still an order of magnitude less than the theoretical limit meaning that at least one damping mechanisms is not correctly taken into account. As the surface to volume ratio increases with smaller devices, surface contaminants could play a major role in energy damping. It appears that surface contaminants are present, especially on the electrodes as it can be seen in the Figure1. Investigations are still in progress, but it is likely that some compound remain on the surface of the electrodes after removal of DRIE hard mask. Motional resistance has been greatly reduced by using electrodes on both sides: for an equal quality factor, the equivalent motional resistance has been divided by 3 leading to a resistance motional around 4 kΩ for the resonators with the highest quality factors. Further improvements of quality factor will lower the motional resistance.

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