

Low TCF Lithium Tantalate Contour Mode Resonators

Renyuan Wang and Sunil A. Bhave
OxideMEMS Lab, Cornell University
Ithaca, NY, USA
rw364@cornell.edu

Kushal Bhattacharjee
RF Micro Devices, Inc.
Greensboro, NC, USA

Abstract—This paper presents for the first time thin-film contour mode resonators (CMR) using Lithium Tantalate (LT). Exploiting the inherent low temperature coefficient of frequency (TCF) of certain acoustic modes in LT, we demonstrate low TCF S_0 lamb wave mode CMRs in rotated Y-cut LT thin films. With an electrode configuration using a top interdigitated transducer (IDT) and bottom ground electrode, we fabricated 1-port resonators at 501MHz and 870MHz, and 2-port resonator at 849MHz. These devices exhibit low motional impedance (10-20 Ω), with quality factors as high as 3200. More significantly, a TCF of -20ppm/K is demonstrated from the 1-port devices, while the 2-port device exhibits -16.7ppm/K. These are the lowest TCFs demonstrated to date from an uncompensated thin-film contour mode resonators, making LT thin-film technology a promising candidate for oscillator applications.

Keywords—Lithium Tantalate, contour mode resonator, low temperature coefficient of frequency

I. INTRODUCTION

Lithium Niobate (LN) thin-film contour mode resonators (CMR) have shown great potential for large band-width filters, as they exhibit low motional impedance, high quality factor (Q), and high electro-mechanical coupling factor (k_t^2) [1]. Unfortunately, their high TCF makes them unsuitable for oscillator applications. To alleviate this problem, temperature compensation using silicon dioxide has been successfully demonstrated [2]. However, silicon dioxide compensation layer unavoidably degrades the Q and k_t^2 , and only works over a

limited temperature range. On the other hand, the inherent temperature compensation capability of Lithium Tantalate for low frequency bar type resonators has been demonstrated in the past [3]. To first order, the compensation relies on the fact that the positive temperature coefficient of acoustic velocity in select crystal orientations of LT can compensate for the negative resonant frequency shift caused by thermal expansion. In this paper, we explore the possibility of exploiting this innate property to demonstrate low TCF of the S_0 lamb wave mode in rotated Y-cut Lithium Tantalate (LT) thin films. The resonant mode is excited by interdigitated transducers (IDT) to achieve low TCF CMRs over a wide range of temperature, without compromising the low motional impedance, high Q , and capability of integrating multi-frequency devices on a single chip.

II. DESIGN

We implement both 1-port and 2-port resonators as shown in Fig. 1. The black arrows mark the direction of the displacement of the S_0 mode. To couple to the designed mode, the IDT of the 1-port device has a spacing of λ , where λ is the wavelength of the targeted mode. All the signal fingers are connected to a common bus, and the E-field is setup between the signal finger and the bottom ground electrode. In contrast, the IDT spacing of the 2-port device is $\lambda/2$, and the adjacent fingers are alternately connected to port 1 and port 2 of the device. In this configuration, the mechanical vibration can be excited through either port, while the other port is used to measure the strain induced charge.

III. DEVICE FABRICATION

Similar to [1], we start with a rotated Y-cut LT device wafer and deposit a Cr film for the top electrodes and an SiO_2 sacrificial layer, followed by a buffer layer to protect the bonding agent during the BOE release (Fig. 2a). The device wafer is flip-bonded to a LT carrier wafer and ground down to 1 μm thickness. After defining the IDTs by lift-off, the device geometry is defined using ion-mill with photoresist mask, which also exposes the bottom Cr electrode (Fig. 2d-e). As there is no etch stop layer for the ground via, the Cr metal layer is etched through. Therefore, a conformal gold layer defined by lift-off is used to refill the etched vias and achieve ground contact. To our knowledge, this is the first demonstration of such electrode configuration in LN/LT thin-film CMRs.

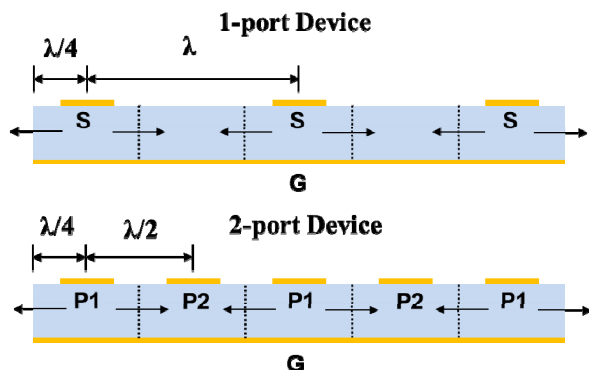


Fig. 1: Conceptual schematic of the cross-section of the CMRs, where black arrows mark the direction of displacement of the targeted vibration mode.

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Finally, the devices are released in buffered HF followed by critical point drying (CPD) (Fig. 2f). Figs. 3a and b show SEMs of fully released 1-port and 2-port devices. The small signal pad size and ion milled trenches around the pad are designed to minimize the pad capacitance. As shown in the inset of Fig. 3a, the ion mill produces clean and vertical sidewall, which is critical for achieving high quality factor in CMR devices. A grid of 10um by 10um square ground vias is used to minimize the ground contact impedance.

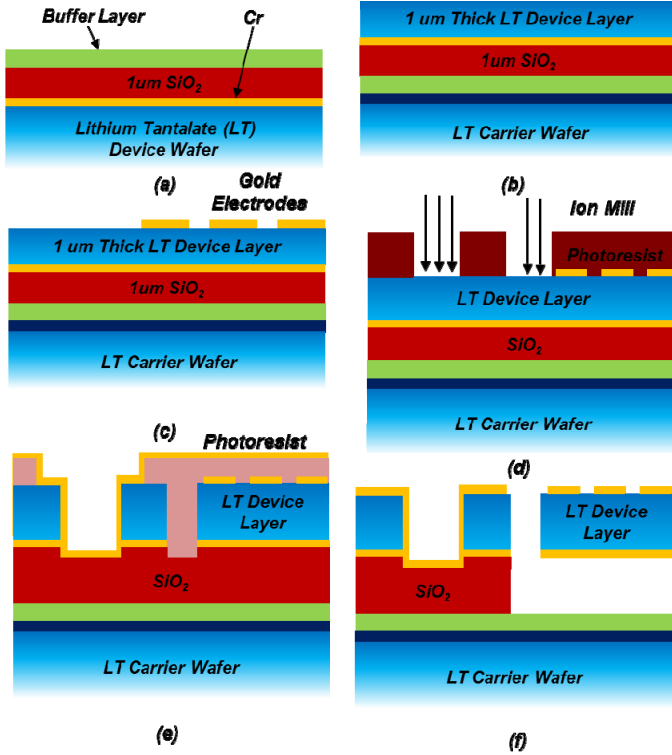


Fig. 2: Fabrication Process: (a) Deposition of Cr, sacrificial layer; (b) Bonding of device wafer to carrier wafer, and grinding down the device layer; (c) Define IDTs; (d) Ion mill defining device geometry and ground vias; (e) Gold ground contact by lift-off; (f) Release device in buffered HF followed by CPD.

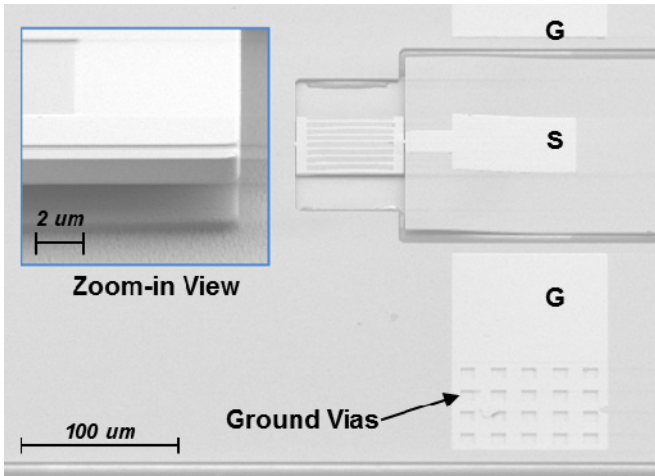


Fig. 3a: SEM of a fully released 870MHz 1-port CMR; inset: zoom-in view of side wall profile showing the ion mill produced vertical and smooth sidewall.

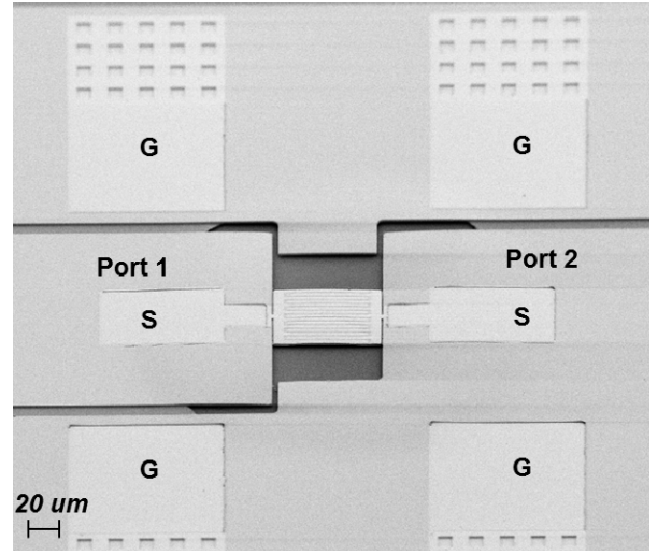


Fig. 3b: SEM of a 2-port 849MHz device.

IV. MEASUREMENTS

We measure the devices using an Agilent E8364A network analyzer with -12dBm stimulus. First, we measure a 1-port resonator designed to operate in the 15th order S₀ lamb wave mode with a wavelength of 6.6um. Fig. 4 shows the broadband impedance spectrum. The 15th order mode is at 870MHz, which is in good agreement with FEM simulation. The spectrum shows suppressed spurious modes similar to what was observed in [1]. The series resonant frequency is 870MHz, with impedance of 38Ω, while the parallel resonance has an impedance of 3.07kΩ at 874MHz. This yields a coupling factor of 0.9% using the definition $k_t^2 = 1 - (f_s/f_p)^2$. In the k_t^2 measurement, we did not de-embed the pad capacitance. Therefore, the k_t^2 is only half of what was predicted by FEM simulation. Extracted using the method from [5] and verified by measuring the 3dB bandwidth, the Q of the series and parallel resonances are 700 and 2600, respectively. The degraded series Q is caused by the electrical

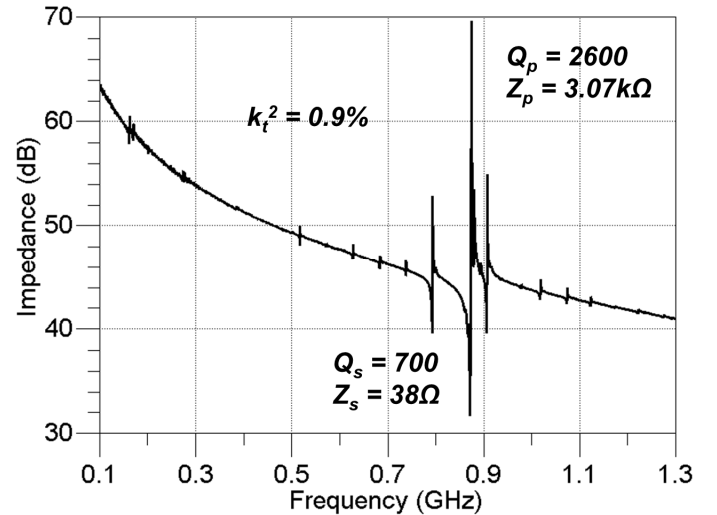


Fig. 4: Measured broad band impedance spectrum of an 870MHz 1-Port LT CMR. (The k_t^2 shown in the figure is measured without de-embedding).

impedance loading from the ground via contacts. By curve fitting the spectrum, we extract the parameters for the equivalent mBVD model (Fig. 5). The fitting shows that the resistance attributed to electrical routing is 28Ω , which matches with the measured electrical routing resistance from on-chip calibration structures. The extracted motional impedance of the resonator is only 10Ω , indicating low acoustic loss. It is worth noting that we achieve a $>10\text{dB}$ series resonance peak height in spite of the large parallel capacitance of 1.08pF .

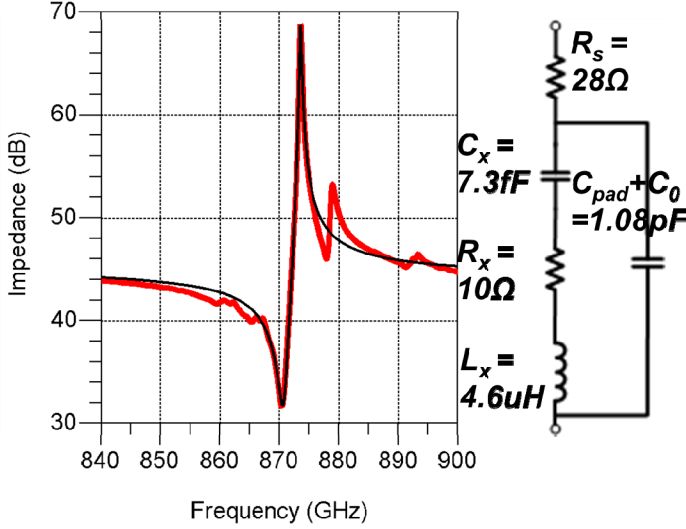


Fig. 5: Curve fitting of the resonant peak, and extracted mBVD model of the 870MHz resonance.

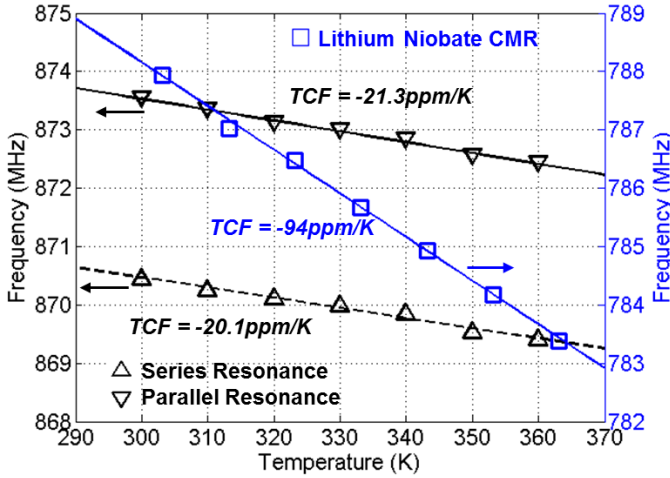


Fig.6: TCF measurements of the LT CMR device. Black lines are the TCF measurements of the parallel peak and series peak; blue line shows the TCF of a lithium niobate resonator presented in [1] for comparison.

The TCF of the device is measured by sweeping the temperature from 300K to 360K on a Cascade vacuum probe station. Fig. 6 shows the frequency shifts of both the series resonance and the parallel resonance. The TCFs of the series resonance and the parallel resonance are -20.1ppm/K and -21.3ppm/K , respectively, which is 4.5 times lower than that of lithium niobate CMRs presented in [1] (LN TCF is shown as the blue line in Fig. 6).

Similarly, we characterize a 1-port resonator designed to operate in the 11th order S_0 lamb wave mode with a wavelength of $11.6\mu\text{m}$ (Fig. 7). The series resonant frequency of the 11th order mode is 501MHz. The series Q is 800, while the parallel resonant frequency is 503MHz with a Q of 3200. The k_t^2 is 0.8% (without de-embedding), and the impedances of the series and parallel resonances are 50Ω and $5.78\text{k}\Omega$, respectively. The mBVD model parameters extracted by curve fitting the spectrum are $R_s = 19.5\Omega$, $C_s = 8.8\text{fF}$, $C_0 + C_{\text{pad}} = 1.1\text{pF}$, $R_p = 30.5\Omega$, and $L_p = 11.5\mu\text{H}$, where the extracted impedance from electrical routing is consistent with that of the 870MHz device. The TCF of the parallel and series resonances are shown in Fig. 8 and are calculated to be -21.5ppm/K and -22.5ppm/K , respectively. In [4], the authors showed that the TCF strongly depends on the film thickness to wavelength ratio for LT thin-film devices when the ratio exceeds 0.2. However, our resonators have a thickness/wavelength ratio of less than 0.15. As a result, the coupling factor and TCF do not exhibit any dependence on thickness to wavelength ratio for both the 870MHz and 501MHz devices.

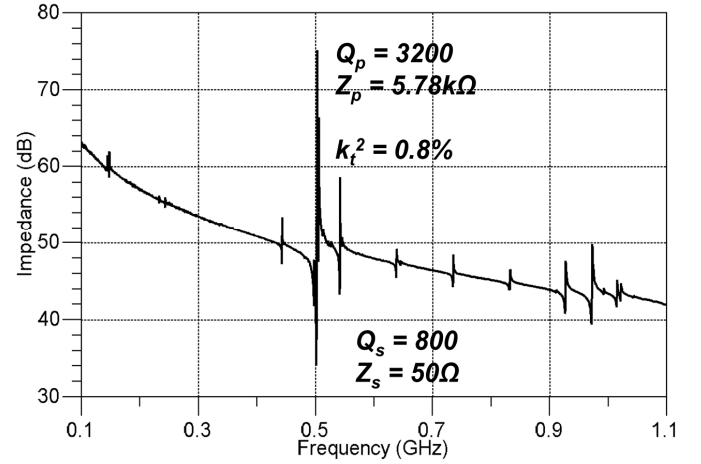


Fig. 7: Measured broad band impedance spectrum of a 501MHz 1-Port LT CMR. (The k_t^2 shown in the figure is measured without de-embedding).

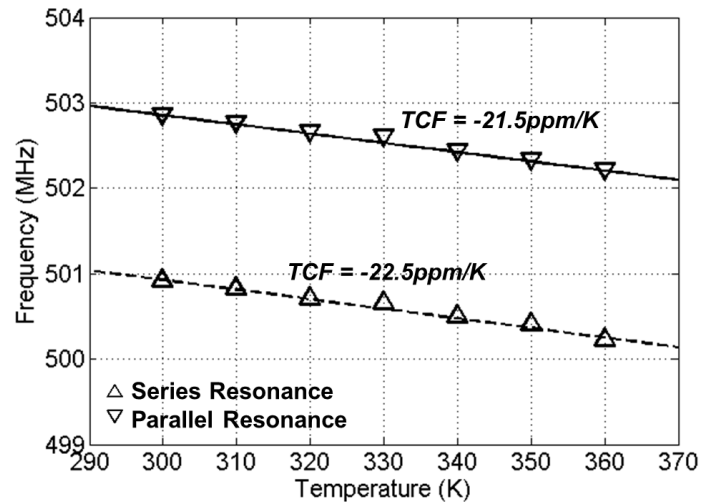


Fig.8: TCF measurements of the 501MHz 1-port LT CMR device.

Finally, we measure a 2-port device designed to resonate in the 15th order mode with a wavelength of 6.6 μ m (Fig. 9). The resonant frequency is 849MHz with an insertion loss of only -3.4dB, which is primarily limited by the electrical via impedance. The measured TCF for this device is -16.7ppm/K. The 2-port IDT configuration reinforces the S_0 modal response leading to a 4.5ppm/K improvement in TCF compared to the 1-port resonators.

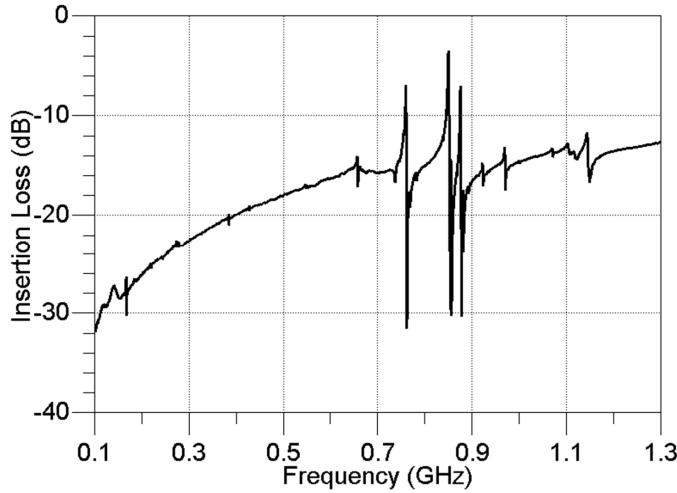


Fig. 9: Measured broad band S_{21} parameter of an 849MHz 2-Port LT CMR.

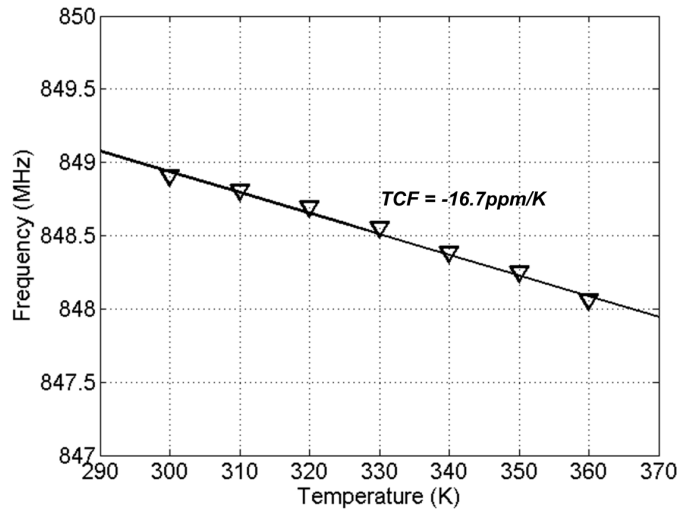


Fig. 10: TCF measurement of the 2-port resonator.

V. CONCLUSION

In conclusion, we have demonstrated thin film Lithium Tantalate high-order contour mode resonators with low TCF. The resonators experimentally verify the innate low TCF of the S_0 wave in LT, eliminating the need for a compensation material and simultaneously demonstrating high Q and low motional impedance. We have measured 1-port CMRs at 501MHz and 870MHz with quality factors as high as 3200 with motional impedances in the range of 10-20 Ω . Both devices exhibit low TCF around -20ppm/K. We also demonstrated a 2-port 849MHz device with -16.7ppm/K TCF. Without compromising the Q and impedance, the TCF is improved by a factor of 4.5 compared to LN CMR, highlighting the potential of LT CMRs for oscillator and sensor applications.

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