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Enhancement of the quality factor of AlN contour mode resonators by acoustic reflection: numerical design and experimental investigation

M. Cremonesi[a,*], A. Frangi[a], C. Cassella[b], G. Piazza[b]

[a] *Department of Civil and Environmental Engineering, Politecnico di Milano, piazza Leonardo da Vinci 32,Milano 20133, ITALY*

[b] *Carnegie Mellon University, USA*

Abstract

Piezoelectrically actuated MEMS resonators can be very effective for building integrated frequency references in the radio frequency range even though experiments show that mode coupling and dissipative phenomena can affect their performance. This contribution addresses the dependence of quality factor on the resonator inactive region. Four configurations with different dimensions of the inactive region have been designed and tested proving that an improvement in the resonator quality factor can be obtained. A refined numerical tools accounting for anchor losses and surface dissipation have been used to reproduce experimental data. The numerical predictions show a good agreement with the experimental tests.

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Keywords: contour mode resonators, numerical design, experimental tests, acoustic reflection

1. Motivation

The adoption of MEMS resonators for timing and frequency control applications as replacements for quartz crystals and surface acoustic wave (SAW) devices is highly dependent on the ability to attain a high quality factor, Q, and electromechanical coupling, kt2, in a small form factor, The AlN resonators operating at frequencies below 500 MHz have their Qs limited by energy leakage into the supporting substrate [1]. Though, there is no

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* Corresponding author. Tel.: 390223994267;
E-mail address: massimiliano.cremonesi@polimi.it

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understanding of how the boundary between active and inactive regions of the piezoelectric resonator impacts its Q (see highlighted region in Fig. 2). This paper elucidates this concept and finds that an almost 40% improvement of Q, without substantial variation of kt2, can be obtained by optimizing the geometry of the resonator inactive region. This improvement was confirmed by both FEM simulation and experimental data.

2. Design and fabrication

The devices of the present study are formed by a thin layer of AlN sandwiched between two metal layers. The top metal layer is arranged in 3 interdigitated electrodes, in which adjacent electrodes are connected to opposite voltage polarities. The bottom metal is a floating plate used to confine the electric field in the AlN body (see Fig 1). As shown in Fig. 1, to produce the devices, we first deposited 100 nm of platinum above 10 nm of titanium (Fig. 1-a). Afterwards we deposited 1 µm of AlN (Fig. 1-b) followed by the deposition of 100 nm of platinum (Fig. 1-c) top electrode. The etching of the AlN (Fig. 1-d), followed by the structural release (Fig. 1-e), completed the device fabrication.

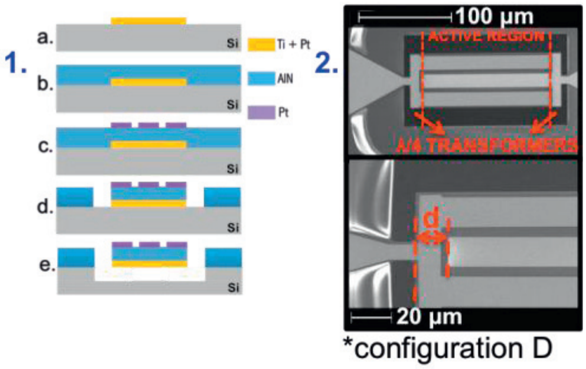

Fig. 1 *Schematic Fabrication process for the AlN resonators built for this work: 2. SEM pictures of a tested device and zoomed in view of the transformer region.*

To study the dependence of the resonator Q on the length of the resonator inactive region, we considered four different configurations of 207 MHz AlN CMRs (conf. A, B, C, D) formed by three active fingers (Fig.2). Each configuration was designed with the same length of the active fingers but different length, d, of the inactive region included between the edge of the fingers and the AlN sidewall beside the anchors. Conf. A, B, C and D were designed with d respectively equal to 8, 9, 10 and 11 µm. These 4 resonators were built with the optimum anchor width, WA =10 µm (Fig. 2), which was found by measuring 36 resonators having WA ranging from 10 to 60 µm. This study showed that an improvement in the resonator Q can be obtained by optimizing d.

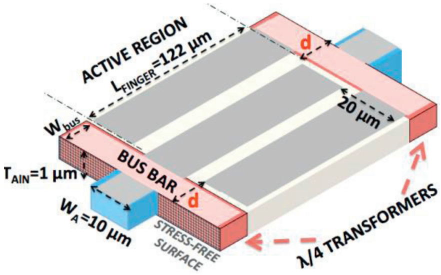

Fig. 2 Schematic representation of the 207 MHz AlN CMRs analyzed in this work.

3. Experimental results

We tested 6 devices for configuration A, 12 devices for configuration B, 6 devices for configuration C, and 6 devices for configuration D. All the devices were extracted from 3 chips belonging to the same wafer. Figure 3 reports the average quality factor measured for each configuration with the error bars representing the standard deviation. The enhancement of the quality factor can be explained by simple acoustic propagation theory. In fact, by modifying d it is possible to transform the equivalent acoustic boundary condition observed by the wave propagating towards the anchors, in a direction orthogonal to the main vibration direction.

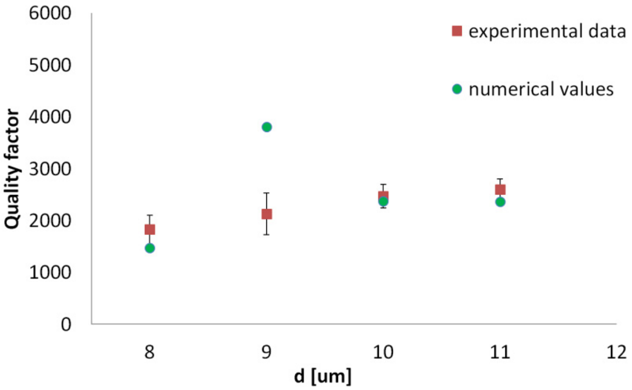

Fig. 3 *Plot of the quality factor varying the dimension of the inactive region d. Red squares represent the average experimental results with error bars, while green circle are the results of the numerical simulations.*

4. Numerical results

In the numerical simulation, to obtain a quantitative prediction of the overall quality factor, we assume the presence of anchor losses and of an additional dissipation mechanism which can be associated with interface losses (see e.g. [3-7]) and is directly proportional to the vibration frequency. Anchor losses have been estimated using a robust Finite Element Method including absorbing boundary regions (PML) and simulating the dissipation of elastic waves scattered in the substrate through the anchors.

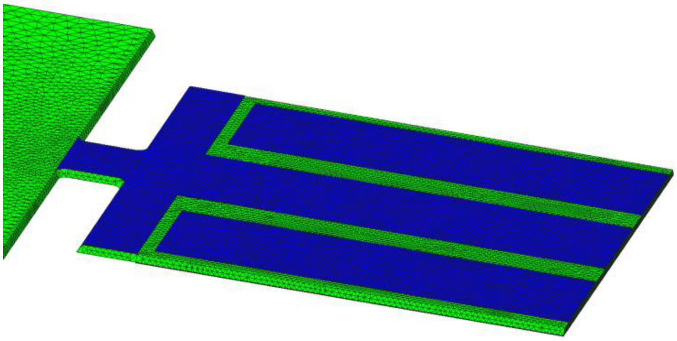

Fig. 4 Finite element mesh used in the numerical simulations.

A simple model for the interface dissipations has been also introduced. Following [5] interface losses have been associated with the Cauchy stress jump across the interfaces between different materials.

Exploiting the symmetry of the devices, only half of the resonator is discretized. Fig. 4 shows the geometrical model and the mesh used in the simulations. To better represent the real geometry two distinct elements are used in the simulations. The body of the resonator has been discretized with 10 nodes tetrahedral elements, while for the electrodes with 15 nodes wedges are used.

Figure 5 depicts the contour plot of the displacement field corresponding to the mechanical mode actuated. The numerical results are finally compared with the experimental data in Figure 3 showing a good agreement.

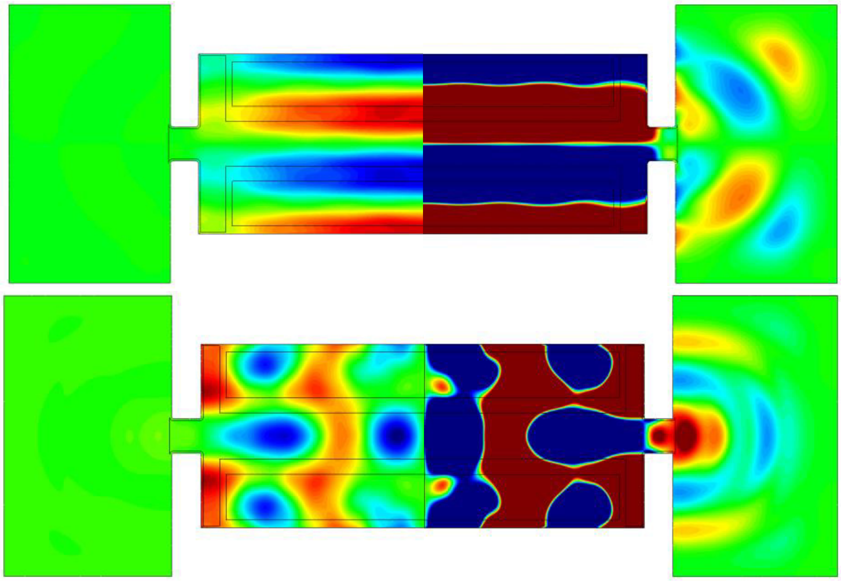

Fig. 5 *Contour plots of the displacement in the direction of vibration (top) and in the orthogonal direction (bottom). In the contour plot on the left the colour scale has been calibrated so as to put in evidence the modal shape in the resonator, while on the right the scale adopted allows to appreciate the pattern of scattered waves in the anchor and in the substrate and their eventual dissipation in the PML regions.*

5. Conclusions

In this work, an experimental and numerical demonstration of the dependence of the quality factor of AlN contour-mode resonators (CMRs) on the size of the resonator inactive region is provided. We found that the optimization of this region permits to limit the amount of acoustic energy that leaks into the substrate through the device anchors and, consequently, maximizes Q.

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