Application of optimally-shaped phononic crystals to reduce anchor losses of MEMS resonators

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This work is focused on the application of Phononic Crystals to reduce anchor losses of MEMS contour mode resonators. Anchor losses dominates the losses in these type of released resonators at low frequency and at low temperature. The use of phononic crystals, intended as finite-periodic distribution of holes in the anchor, is fully compatible with fabrication processes and moreover it is easy to implement. The numerical results obtained in this work show how the use of these crystals can significantly reduce the anchor losses: without the use of the crystal the Q-factor related to only anchor losses is 344, with the use of the crystal it can reach up to 105900.

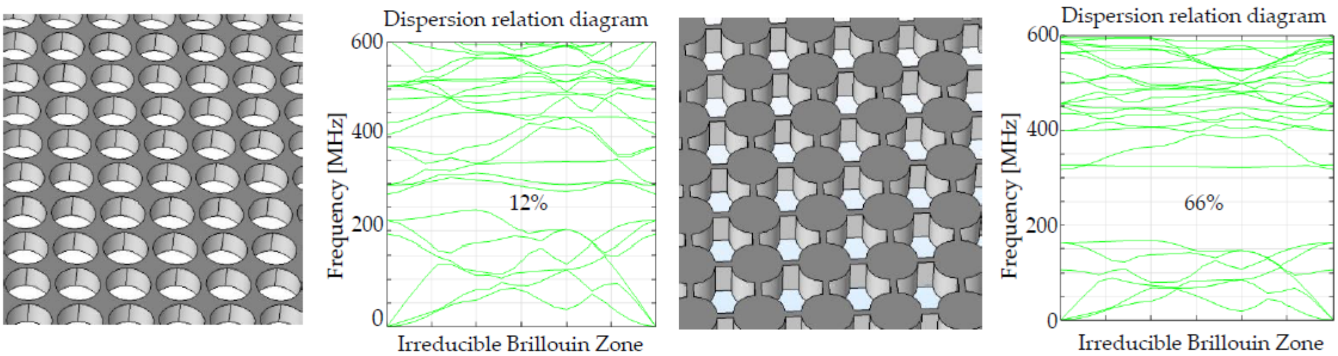
Keywords—MEMS resonators, anchor losses, Phononic crystals

I. INTRODUCTION

In the class of MEMS transducers, AlN contour mode resonators (CMRs) are widely employed for several purposes. A key parameter for assessing the figure of merit of such resonators is the quality factor Q. At low frequency (i.e. 200MHz) and up to room temperature or at low temperature in general, the Q-factor is dominated by is anchor losses [1]. A valid provision to reduce anchor losses is the application of phononic crystals (PnCs), which show complete band gaps in the transmission of elastic waves, therefore they can be considered as highly efficient acoustic reflectors, which can be used in order to confine the elastic energy. The operational features of a PnC are summarized by the central frequency (which should match the resonator's properties) and the relative size of band gaps. The bang gap width is the key parameter in order to scatter the elastic waves: the wider the band gap the highest the scattering. PnCs application is already used in literature to reduce anchor losses: in [2] unreleased resonators in GaN are folded by solid-air PnCs, [3] presents strips built as PnCs that are placed as the anchor itself, in [4] PnCs are used to reduce anchor losses of quartz released resonators. The common feature of the PnCs described in these works is the topology of the solid-air unit cell, carachterized by a circular hole shape: this topology (see Fig. 1a) is endowed with a full bandgap of 13% gap to mid-gap ratio (see Fig. 1b) for thickness-in-plane dimensions' ratio of 0.5 and radius-unit cell carachteristic dimensions' ratio of 0.45; for different ratios the bandgap can be significantly reduced or disappear. This work is focused on the analysis of anchor losses in the presence of PnCs where the hole topology (see Fig. 1c) is found by means of shape optimization process exploiting the Bidirectional Evolutionary Structural Optimization technique [5]. This leads to the widest band gap of 55% gap mid-gap ratio (see Fig. 1d) for thickness-in-plane dimensions' ratio of 0.5, and moreover to a stronger reduction of the anchor losses by locating the PnC around the resonator's anchor. Anchor losses have been calculated simulating the dissipation of the elastic waves scattered in the substrate through the anchor using a robust three-dimensional Finite Element Model including Absorbing Boundary regions (through the Perfectly Matched Layer technique).

II. RESONATOR ANALYSED

The CMR resonator analysed is in AlN, 60 μm wide and 148 μm long, with a thickness equal to 1.2 μm. The natural frequency of interest is around 260 MHz (the mode shape is



(a) (b) (c) (d)

Fig. 1: Comparison between band gaps of phononic crystals with circular hole shape and optimized hole shape, the material employed is AlN. (a) and (c) represent respectively the two geometries for the infinite phononic crystal, (b) and (d) the two related dispersion relation diagrams. Details on the definition of the dispersion relation diagrams can be found in [5].

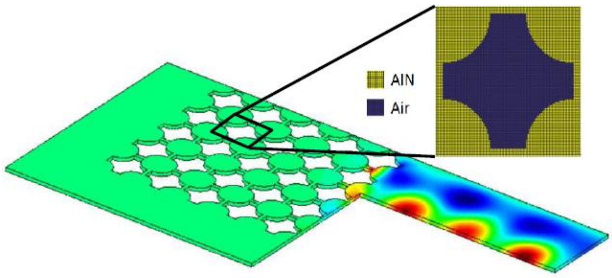


Fig. 2: Analysed CMR resonator (only 1/4 of the resonator is reported): vibrational mode at 260 MHz, finite 5x5 PnC structure is placed in the anchor, the PnC unit cell is highlighted.

depicted in Fig. 2, where 1/4th of the CMR is drawn with the unit cell of the PnC shown in the inset). In order to match the resonant frequency of the CMR the side of the PnC unit cell is 14.2 µm long, leading to a ratio between thickness and in-plane carachteristic dimension of the PnC of 0.085. The radius of the solid circles in the optimized hole topology is about 4.7 µm. This optimized PnC is endowed with a full three-dimensional band gap for in-plane waves with a gap to mid-gap ratio of 11%, centered at 260 MHz. The difference between this 11% band gap ratio and the previously calculated 66% (see Fig. 1d) is due to the different ratio between thickness and in-plane dimensions of the two PnC unit cells analysed (namely 0.085 for the first and 0.500 for the second): the smaller this ratio the narrower the bandgap. It must be noticed that for the aspect ratio of the CMR analysed here the circular hole shape with radius to in-plane carachteristic dimension ratio of 0.45 does not present any full band gap.

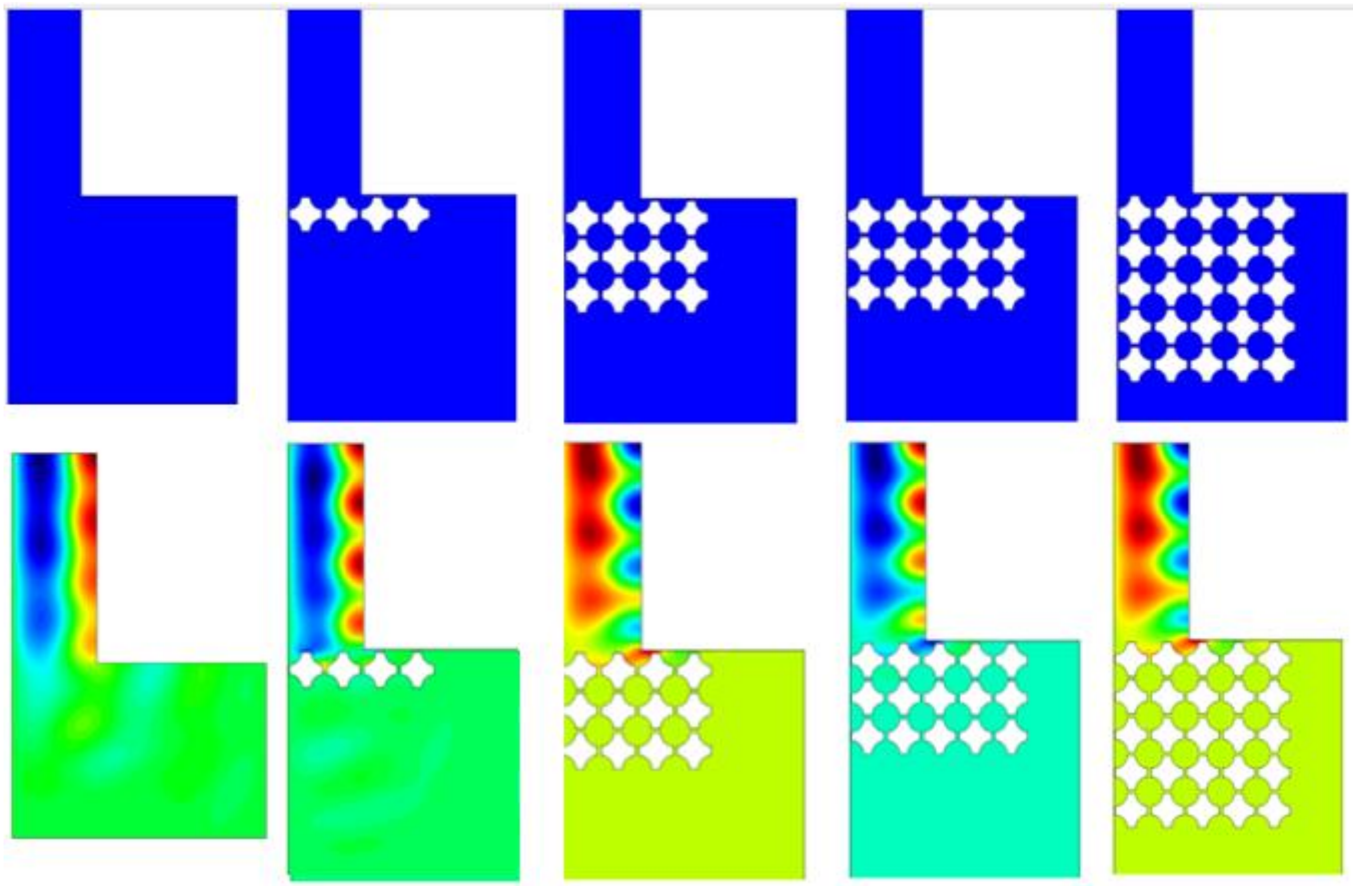
III. Q-FACTOR FOR ANCHOR LOSSES USING PHONONIC CRYSTALS

In this work several configurations of finite PnC are analysed numerically in terms of the resulting Q-factor for anchor losses: namely the ones depicted in Fig. 3. In Tab. 1 the Q-factor values for the configurations of Fig. 3 are reported.

TABLE I. Q-ANCHOR-FACTORS FOR DIFFERENT CONFIGURATIONS

Configuration	*Q anchor*	*Lamb mode frequency [MHz]*
(a) No PnC	344	261.30
(b) 4x1 PnC holes	6517	261.54
(c) 4x3 PnC holes	13470	261.54
(d) 5x3 PnC holes	105964	261.51
(e) 5x5 PnC holes	105900	261.50

The Q-factor for anchor losses only in the absence of PnC is 344, the matching between the numerical result and the experimental testing can be found in [1]. The first comment on the results of Tab. 1 is that the use of PnC in the anchor does not change the resonant frequency of the CMR in all the



(a) (b) (c) (d) (e)

Fig. 3: Representation of a quarter of the released AlN MEMS resonator in the different configurations analysed (a)-(e). The finite phononic crystals are located in the anchor. The carachteristic mode is reported.
The quality factor for anchor losses related to the analysed mode for each of the (a)-(e) configurations are reported in Tab. 1.

configurations considered. By inserting a single line of four PnC's unit cells the anchor losses Q-factor increases approximately by 15-20 times and it reaches the value of 6517 for the considered application. By inserting a second and a third line of four unit cells the anchor losses Q-factor reaches 13470. It must be noticed that the second main losses, namely the thermo-elastic losses, present a Q-factor around 10000-20000 for the CMR analysed. In the configuration of Fig. 3d the Q-factor numerically reaches 100000. In configuration of Fig. 3e the anchor losses Q-factor is comparable to the one of configuration (d), therefore it is possible to conclude that by inserting 5x3 PnCs finite structure the energy dissipation in the analysed CMR is no more dominated by anchor losses but by other type of losses such as thermo-elastic losses, interface losses. Further experimental investigation is required.

IV. CONCLUSIONS

The numerical results reported in this work declare that PnC are good candidate for the reduction of anchor losses in released resonators. Moreover, the optimized shape presented can be easily feasible for microfabrication processes and can cancel the losses produced by the anchor if a proper configuration (e.g. the one of Fig. 3d) is adopted. In order to confirm these numerical predictions a proper experimental campaign must be conducted, nevertheless it must be noticed that the three-dimensional finite element solver used for the anchor losses calculation has been already validated in a previous work [1].

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