[Invited] Tunability of electrically controlled piezoelectric phononic crystals

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Tunability of Electrically Controlled Piezoelectric Phononic Crystals

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Abstract: Two devices based on Phononic Crystals (PCs) made of piezoelectric materials are studied: (1) a stack of piezoelectric rods or plates, poled along their thickness, (2) a piezoelectric plate, poled along its thickness, covered by periodic arrays of electrodes on its two faces. These devices exhibit Bragg gaps that may be tuned by changing the electrical boundary conditions on the periodically placed electrodes.

Phononic crystals (PCs) have received a great deal of attention. Of particular interest is the existence under certain conditions of frequency ranges associated with Bragg scattering, where the propagation of elastic waves is forbidden. Due to this effect, one-dimensional PCs (i.e. Bragg mirrors) are extensively used in surface and bulk acoustic wave (SAW and BAW) components to confine acoustic modes in a cavity, or to couple different cavities in specific frequency ranges. These devices usually exploit piezoelectric materials, since the piezoelectric effect is an efficient method to excite acoustic waves with electrical inputs, using for instance interdigital transducers. In this context, tunable piezoelectric one-dimensional PCs would enable the realization of reconfigurable devices, either for multi-band operation, or to compensate for deviations of the operating point (due to fabrication issues, or thermal effects for instance).

Band gap tunability of partly or fully piezoelectric PCs has already been the subject of numerous studies. For example, a one-dimensional piezoelectric structure, made of a stack of piezoelectric rods, poled along their thickness, was shown to exhibit Bragg gaps around 100 kHz that depend on the electrical boundary conditions applied on periodically placed electrodes[1]. The origin of the gap, which is the Electrical Charge Bragg (ECB) band gap, is due to a discontinuity of the electrical displacement from one rod (or plate) to the next. The width of these ECB band gaps is directly related to a specific electromechanical coupling factor of the piezoelectric material (k_{33} for rods, k_t for plates). These ECB band gaps are highly tunable, by connecting the electrodes of the device to variable capacitances[2].

However, in order to avoid parasitic modes in the ECB band gaps (radial mode, flexural modes, etc.), severe constraints must be applied on the piezoelectric elements aspect ratio (rods, layers of infinite lateral extension…). To overcome this limitation while maintaining a good efficiency for the device, piezoelectric composites (or piezocomposites) with 1-3 connectivity[3] are used. They are made of parallel piezoelectric rods of high elastic impedance embedded in a polymer matrix of low elastic impedance. The piezocomposite is assumed to be poled along its thickness.

The ECB band gap is illustrated on Figure 1, where a stack of 20 piezocomposite plates separated by thin electrodes is considered. An electrical potential is applied on the first plate and the displacement is picked up at the opposite extremity. Depending on the electrical boundary conditions applied on the intermediate plates, (Open Circuit : OC or Short Circuit : SC), a shift of the Band gaps is clearly exhibited. Numerical results, using the finite element code ATILA and experiments are in agreement.

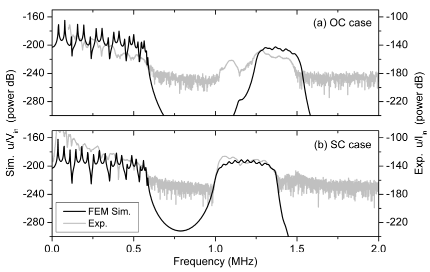

Figure 1: Stack of 20 plates of piezocomposites. Electrical excitation on the first plate. Displacement is picked up on the opposite extremity when the intermediate plates are either open-circuited (OC-top) or short-circuited (SC-bottom).

However, adapting such systems for operation at much higher frequencies (100 MHz-1 GHz range for instance for agile acoustic RF resonators and filters) is quite challenging, since it requires building a stack alternating piezoelectric elements and metallic layers with each metallic layer individually connected to external components. To avoid this issue, it can be interesting to consider Lamb waves in thin plates, instead of thickness modes in stacked rods or plates. Here, we consider a piezoelectric thin plate poled along its thickness covered by a periodic array of electrodes on both of its faces. Then, similarly to the rod or plate stack cases (i.e. the ECB band gap effect), the electrical boundary conditions applied on the metallization influence the propagation mode inside the plate[4].

For this configuration, the phenomenon has a different origin (electric field reversed between successive electrodes). Figure 2 illustrates the Electrical Bragg (EB) band gap considering a piezoelectric plate, 0.5 mm-thick, poled along its thickness, with a grating of 10 electrodes (1 mm-spacing). An electrical potential is applied on the first electrode and the electrical potential is picked up on the last one. Depending on the electrical boundary conditions applied on the intermediate electrodes (OC or SC), a band gap appears or does not appear in the frequency range [0.8-1.2] MHz. Numerical results, using the finite element code ATILA, and experiments are in agreement.

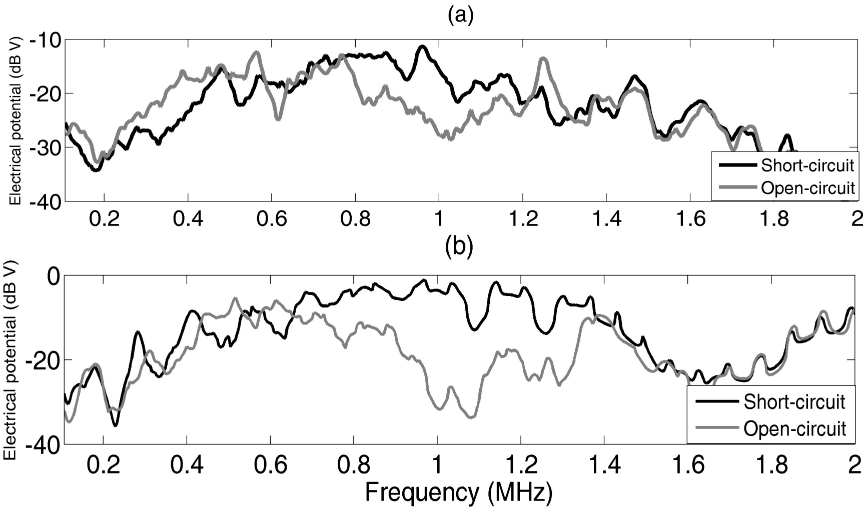

Figure 2 : Piezoelectric plate with a grating of 10 electrodes. (a) Experimental and (b) numerical electrical potential at the output electrode, with a sinusoidal voltage source at the input one, as a function of its frequency, considering SC (black line) or OC (gray line) intermediate electrodes, after the application of the moving average operation.

In this paper, for the two devices under study (stack of rods or plates, plate with a grating of electrodes), depending on the electrical boundary condition, tunability is clearly demonstrated, i.e. an increase or a decrease of the width and the position of the stop bands. For both devices under study, ultrasonic experiments have shown a good agreement with theoretical predictions. Extension of this concept to surface waves in piezoelectric substrates is currently under progress in order to develop tuning strategies compatible with microfabricated RF components.

Finally, these concepts can be extended to space-time modulations of electrical boundary conditions, giving access to tuning/control of nonlinear physical effects such as non reciprocity[5].

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