Acoustic non-reciprocity in strongly nonlinear locally resonant lattices

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Abstract. Due to the impracticality and the need for external bias in dynamic or activated media, the study of passive systems to break acoustic reciprocity have recently gained many researchers' attention. In this work, we aim to passively break acoustic reciprocity using asymmetric strongly nonlinear locally resonant lattices. The asymmetry in the lattice is induced through modulating the stiffness of local resonators embedded within the cells. This allows modifying existing structures without the need to completely replace the structure or conduct major changes. The achieved non-reciprocity is induced by the fact that these structures can support traveling breathers and the presence of different families of breathers depending on the lattice parameters. The stiffness modulation offers tunable passbands (PBs) in the band structure that can overlap and separate at different energy levels. The numerical results demonstrate that the partial overlap between these PBs can lead to strong passive acoustic non-reciprocity.

Introduction

Due to their unique dynamical properties, mechanical metamaterials have recently drawn the attention of many researchers. Beyond the linear regime limit, metamaterials can exhibit interesting nonlinear behavior that can offer additional dynamical properties with no counterpart in linear metamaterials [1]. For instance, nonlinearity can lead to energy-dependent band structures, ultra-low frequency bandgaps, intermodal hopping, and subharmonic bandgaps. In addition, pure strongly nonlinear lattices (i.e., sonic vacua) can support traveling breathers [2]. Breathers are traveling oscillatory wavepackets with spatially localized envelopes and energy-dependent speeds. Strongly nonlinear (sonic vacua) lattices with an asymmetric stiff/soft interface have shown reciprocity breaking induced by breather propagation [3]. The asymmetric stiff/soft interface lattice can be demonstrated through grounding stiffness modulation in sonic vacua lattices. In this work, we consider a strongly nonlinear asymmetric grounded locally resonant lattice waveguide. The lattice's cells are connected by a purely cubic nonlinear stiffness with no linear component (i.e., sonic vacua). The lattice consists of two sub-lattices (i.e., stiff/soft interface). The stiffness modulation is demonstrated through the linear local resonator stiffness.

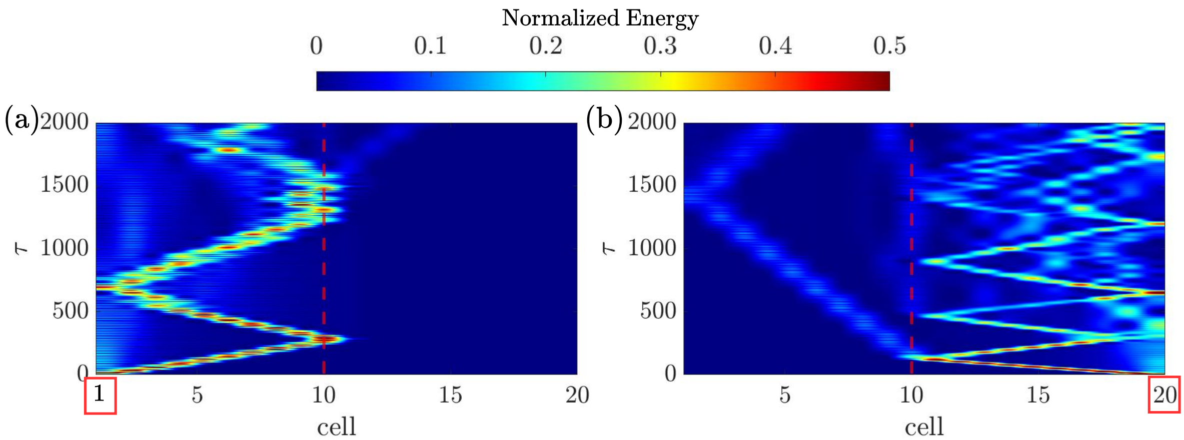

Figure 1: Spatio-temporal plots of the instantaneous total energy in the system excited from the stiff chain (left panels) and from the soft chain (right panels) at different energy levels: (a) Stiff sub-lattice excited, $I_0 = 0.6$. (b) Soft sub-lattice excited, $I_0 = 0.6$.

Results and discussion

Upon exciting the stiff sub-lattice (Fig. 1(a)), breather propagation is also limited to the sub-lattice where breathers are generated and no breathers can penetrate the interface in the stiff/soft direction. However, breathers can penetrate the interface between the sub-lattices and travel through the stiff chain when the soft chain is excited in the soft/stiff direction, as shown in the Fig. 1(b). This indicates that a strong acoustic non-reciprocity at this energy level can be realized passively through the proposed structure. Indeed, the partial overlap between the PBs of both sub-lattices results in breaking the reciprocity at this energy level.

References

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