Linear and nonlinear interactions in surface acoustic wave driven phononic resonators

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We propose to exploit the interaction between surface acoustic waves (SAW) and locally-resonant phononic resonators to achieve coherent driving of micro- nano-mechanical resonators with SAW and, reciprocally, to control SAW propagation at a deep sub-wavelength scale. We investigate the proposed physical system both in the linear and non-linear regimes and reveal the occurrence of Duffing-like nonlinearities and of non-linear coupled mechanical states in the 100-MHz frequency range.

Elastic waves are powerful information carriers standing at the core of modern telecommunication devices. Surface acoustic waves (SAW), in particular, have been industrially used as radio-frequency filters, or delay lines since the 1970s and remain relevant in all current connectivity standard technologies. More recently, the scope of their potential application fields has expanded covering fields as diverse as life science and quantum information technology [1]: SAWs are mechanical vibrations, and as such, can coherently couple to a number of physical systems. Developing further this rich and expanding landscape calls for advanced strategies to manipulate these elastic vibrations.

We propose in this work to exploit the interaction between surface acoustic waves and locally-resonant, micron-scale phononic resonators to achieve coherent driving of mechanical micro- nano-resonators with SAW and, reciprocally, to control SAW propagation and localisation at a deep sub-wavelength scale. The experimental platform is based on a versatile configuration featuring pillars individually fabricated by focused ion beam induced deposition (FIBID) on a highly-coupled piezoelectric substrate. Optical measurements by laser scanning interferometry allows retrieving both the resonator frequency response and mode shape, hence enabling direct observation of the vectorial nature of the interaction. We demonstrate the possibility to confine and enhance the elastic energy distribution using cylindrical pillars exhibiting dimensions at least ten times smaller than the excitation wavelength. The elastic field behavior can be further controlled through resonator-to-resonator coupling, leading to a variety of linear and non-linear interaction schemes.

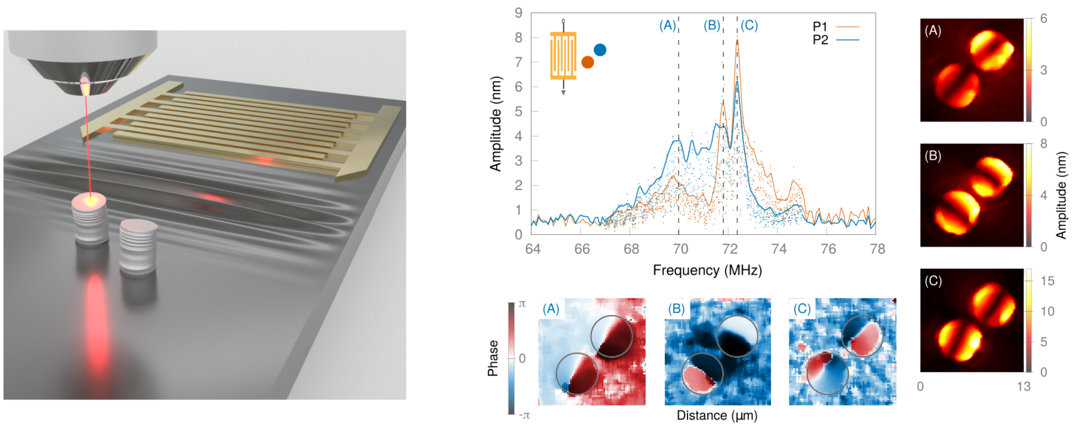

Fig. 1: Left: Schematic of the sample and of the proposed measurement and excitation schemes: mechanical resonators are excited by surface acoustic waves launched using interdigital transducers deposited on a lithium niobate substrate. The elastic displacement field is characterized by laser scanning heterodyne interferometry. Right: Experimental frequency responses and elastic field maps measured in a pair of phononic resonators separated by a 1.5μm-gap distance and excited by a SAW at a 45°-incidence angle. Plasmon-like dipole states are here observed. From [2].

The proposed devices, that operate in the 70-MHz range, are readily scalable to higher frequencies. They illustrate the relevance of SAW-based phononic devices for the implementation of high-frequency phononic-NEMS circuits with complex dynamics.

References

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2. L. Raguin *et al.*, "Dipole states and coherent interaction in surface-acoustic-wave coupled phononic resonators," Nat. Commun. **10,** 4583, (2019).