Surface Acoustic Wave Manipulation Using Piezoelectric Metamaterials

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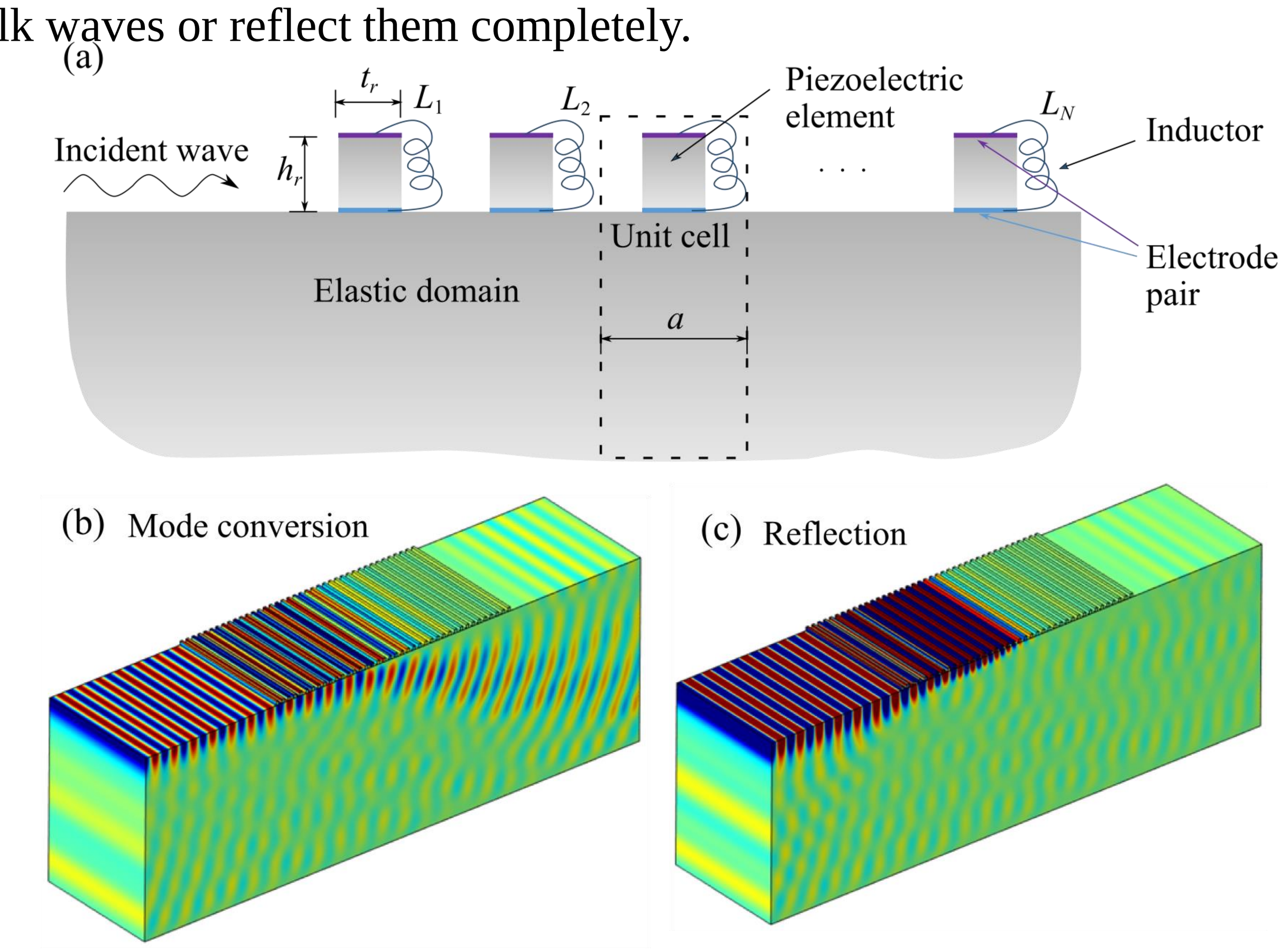
Introduction

- A spatially reversible and programmable metamaterial concept is introduced for the manipulation of surface acoustic waves to achieve on-demand wave mode conversion and reflection.
- The concept uses an array of inductive-shunted piezoelectric elements (with gradually varying inductors in space) bonded on the surface of an elastic propagation domain.
- The value of each inductor directly controls the phase velocity of the Rayleigh wave locally as quantified through unit cell band structure analysis.
- By varying the spatial inductance distribution, the proposed piezoelectric metamaterial domain can be programmed to convert incident surface waves into bulk waves or reflect them completely.



Wave manipulation

- The phase velocity inside the first element in the array is set to match the Rayleigh wave velocity of the substrate so that impedance mismatch is minimized.
- The array could then be programmed to achieve mode conversion by gradually changing the inductance value between each two consecutive elements to increase the wave velocity up to the shear wave velocity
- Position of conversion or reflection in the metamaterial can be controlled by changing the position of gradual change.

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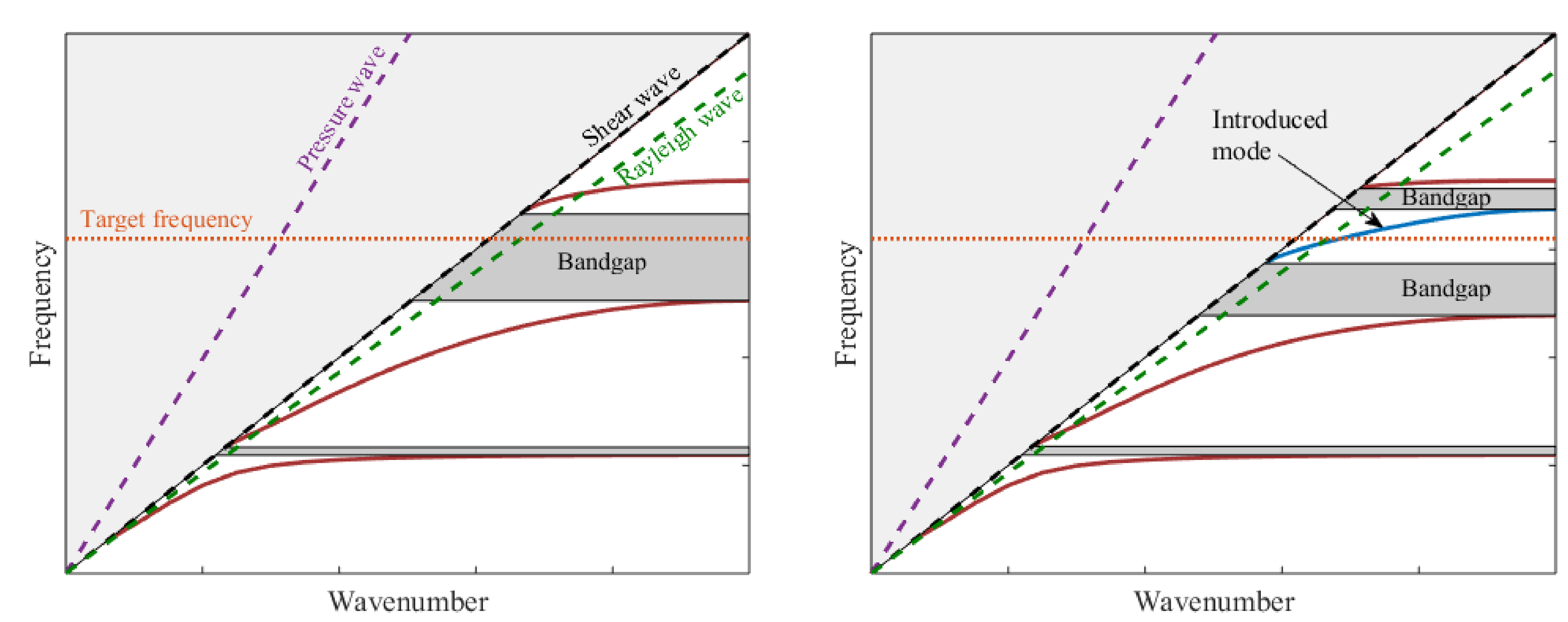
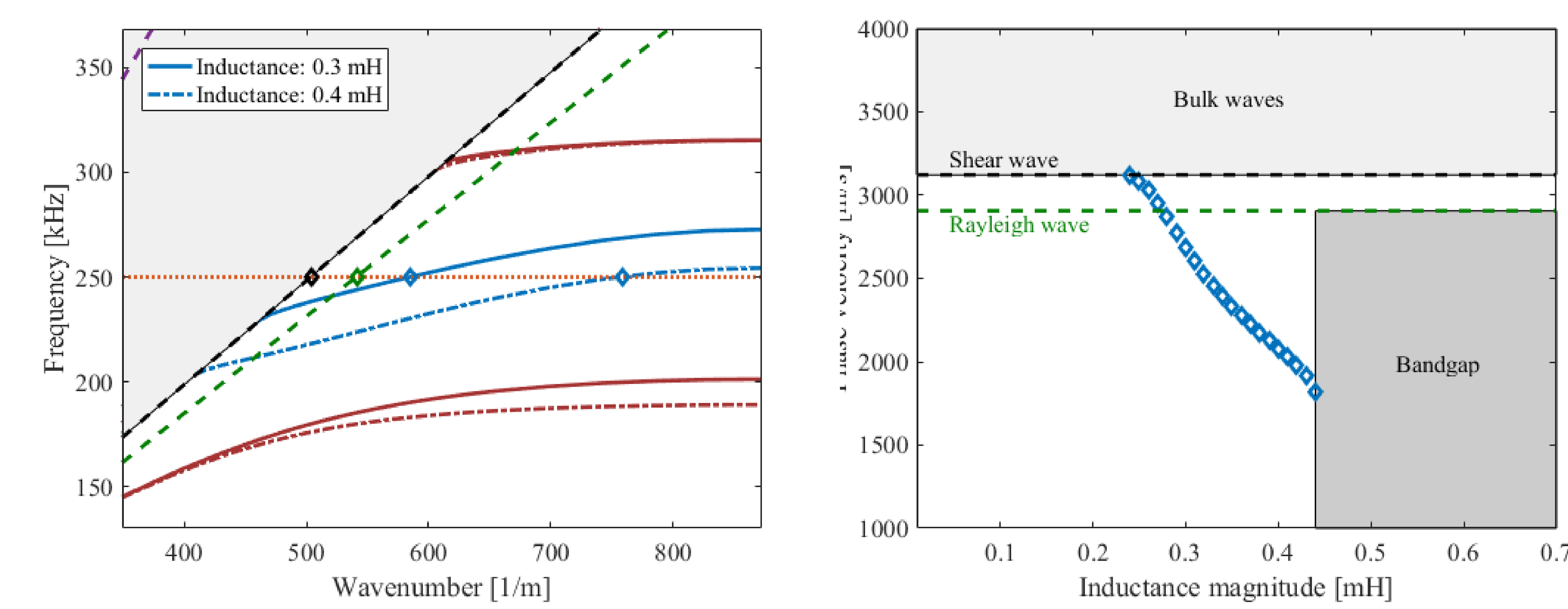
Unit cell analysis

- For the elastic domain far from the piezoelectric metamaterial, three different wave modes are possible: pressure, shear and Rayleigh waves.
- Piezoelectric element geometry is designed so that a Rayleigh wave bandgap is present around target frequency.
- Inductive circuit introduces a mode in this bandgap and this mode divides it into bandgaps and a propagation band.



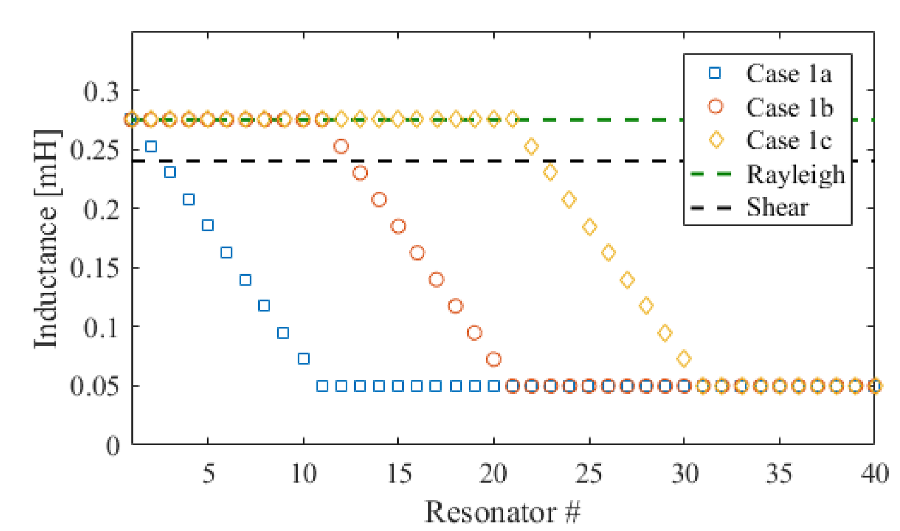
Bandgap formation

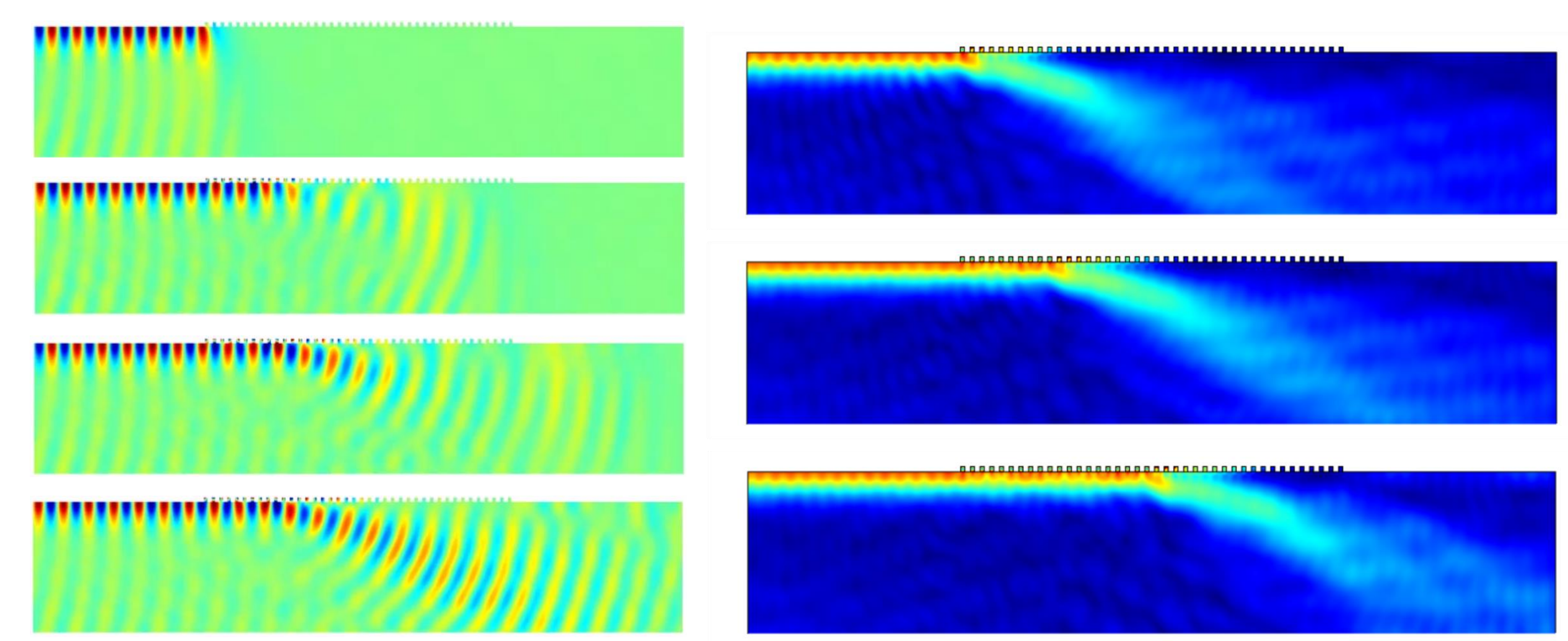
- The effect of inductance value is dominant on the introduced mode.
- A higher value of inductance results in lower electromechanical resonance, which shifts the propagation band accordingly.
- This results in lower surface phase velocities and the propagation band happens at higher wavenumbers and vice versa within a limited range.
- Bandgap is formed outside of this range.



Conversion

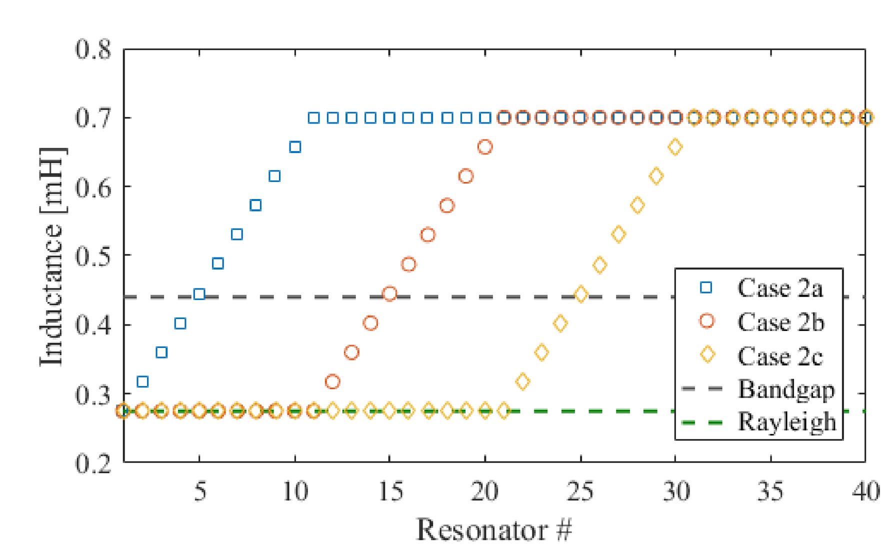
- Gradual decrease of inductance results in conversion to bulk waves.

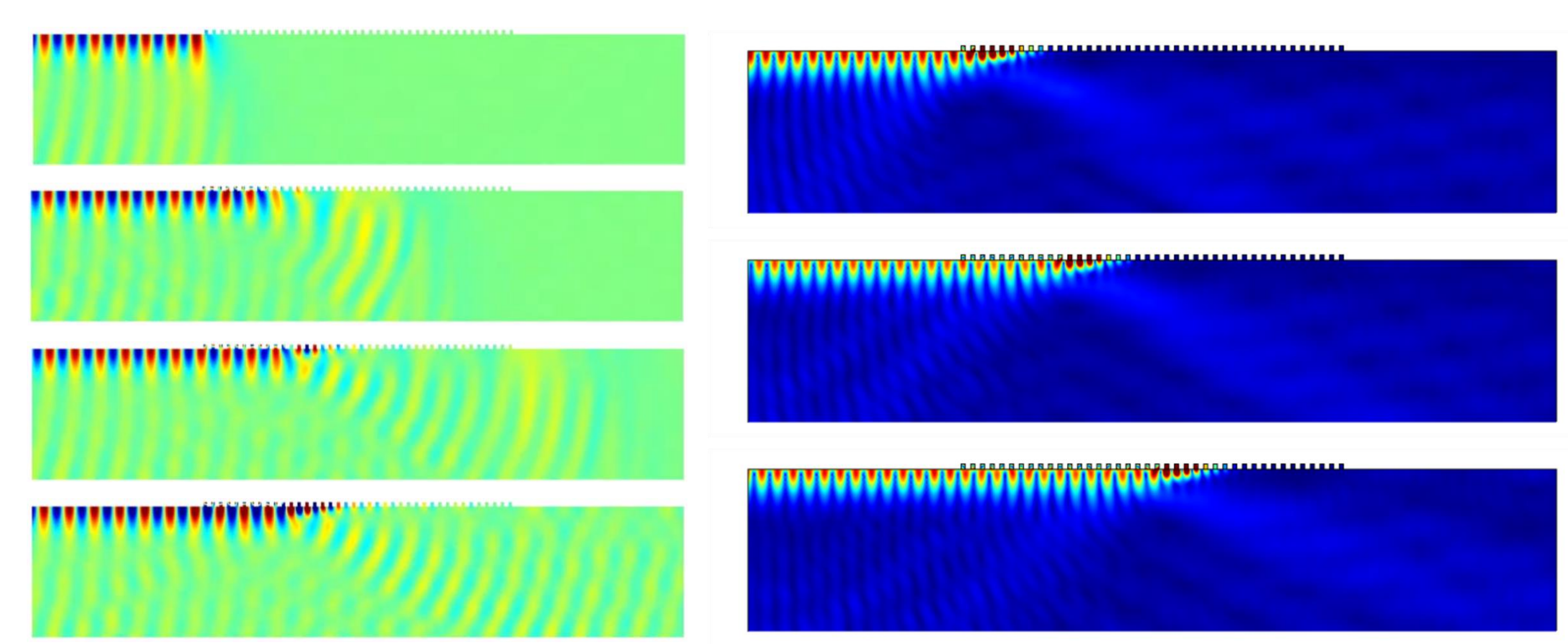




Reflection

- Gradual increase of inductance results in reflection of surface waves.





Conclusion

- To conclude, a programmable piezoelectric metamaterial capable of redirecting incident surface acoustic waves is introduced and demonstrated via case studies. Conversion of surface waves into shear waves and reflection of surface waves are demonstrated in detail.
- The metamaterial domain can be reprogrammed not only to switch between these tasks (which can also be spatially reversed) but also to accurately specify the spatial position (of mode conversion or reflection). This fine control on surface wave propagation through simple circuitry may open new avenues for SAW devices and programmable filters, among others