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Title:Broadband, Reconfigurable and Multifunctional Elastic Wave Control with Smart Metamaterials

Over the past two decades, an extensive research effort has been devoted to elastic metamaterials, structured artificial materials at subwavelength scales, for elastic wave manipulations in solids. Due to the extreme values of material parameters, negative and/or positive, they achieved, the applications can range from wave and/or vibration attenuations, wave guiding and imaging, enhanced sensing, to invisible cloaking. However, conventional passive metamaterials have limitations, i.e. they can only be operated in narrow frequency regions and their functions are usually locked into space or with minor tunabilities once fabricated, lacking real time reconfigurabilities. Those limitations strongly hinder them from practical usages. With the rapid development of smart materials and structures, more and more intelligent elements are being introduced into wave propagation, vibration and sound control systems. The piezoelectric shunting technique is one well known method that receives considerable attention. In this dissertation, by leveraging the circuit control concept, both analog and digital, we propose some circuit controlled active/adaptive/hybrid/programmable metamaterials and metasurfaces for unprecedent elastic wave manipulations. Analytical, numerically and experimentally approaches are combined throughout the dissertation to illustrate design concepts, characterize wave propagation properties, and valid the designs. Specifically, active elastic metamaterials with tunable stiffness in local resonators are first designed for tunable wave and/or vibration mitigations. We then extend this concept to achieve super broadband wave attenuations with frequency-dependent stiffness elements. By introducing the variable stiffness elements to the host medium, a hybrid metamaterial is developed for switched ON/OFF wave propagations and broadband negative refractions. Based on a developed approximate transformation method, an active metamaterial is designed and placed on a plate to achieve spatially varying effective mass densities for broadband elastic trajectory control. Finally, a programmable metasurface with ultrathin-thickness is demonstrated for broadband, real-time and multifunctional wavefront manipulations in a plate. The active, adaptive, hybrid, and programmable elastic metamaterials and/or metasurfaces are still in their infant stages. The examples presented in the dissertation are transformable to different length and time scales and could serve as efficient and powerful tools in exploring some unconventional wave phenomenon in solid structures, i.e. by using concepts in quantum mechanics, where passive approaches are significantly limited. The designs could also immediately open new possibilities in elastic wave control devices including, but not limited to structural health monitoring, stealth technology, active noise control, as well as medical instrumentation and imaging.