ELASTIC WAVE PROPAGATION IN MULTILAYERED BRAGG CELL

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Summary Multilayered Bragg Cells are frequently used as resonators or reflectors in diversified bulk acoustic wave (BAW) and surface acoustic wave (SAW) devices. To guarantee the well and stable performance of these Bragg Cells, clear understanding of elastic wave propagation in them is indispensable. Here we devote to accurate analysis and design of multi-layered Bragg Cells by extending the method of reverberation-ray matrix (MRRM). In particular, the formation mechanisms of the frequency bands in Bragg Cells are revealed.

INTRODUCTION

Due to the rigorous demands such as high operational frequency, high sensitivity, high reliability, multiple functionality, broad environment applicability, low attenuation and low cost that arise from the consumer, commercial and military applications, the scheme of innovative acoustic wave devices utilizing multi-layered (stratified) structures was presented to cater for these demands. In addition, multilayered Bragg Cell composed of many thin periodic alternating high- and low-impedance sublayers are usually inserted between the propagation layer and the substrate to reduce the acoustic loss and enhance the quality factor of diversified acoustic wave devices. In the last decade, many efforts have been made on the fabrication of integrated piezoelectric multi-layered materials with Bragg Cell and the realization of superior multi-layered acoustic wave devices with Bragg Cell (Chung et al., 2008), especially aiming at the film bulk acoustic resonators (FBAR).

To ensure the well and stable performance of multi-layered Bragg Cells, clear understanding of the elastic wave propagation in them is indispensable in the design process. Therefore, accurate and reliable modelling method is necessary. By far, two sorts of matrix methods, including the analytical methods based on continuous (distributed-parameter) model, numerical methods based on discrete models and analytical-numerical mixed methods, have been presented for analyzing multi-layered Bragg Cells. Analytical matrix methods, such as the transfer matrix method (TMM) (Adler, 2000) usually give accurate results with low computational cost. However, some of these analytical methods are numerically instable. For example, the conventional TMM ceases to be effective for cases of high frequency-thickness products. Very recently, Guo (2008) have presented a new version of the analytical method of reverberation-ray matrix (MRRM) recently proposed by Pao et al. (2007), which bearing unconditionally numerical stability for accurately modelling the multi-layered media. Numerical methods, including the finite difference method (FDM), the finite element method (FEM), the boundary element method (BEM) and their hybrids, are powerful for modeling multi-layered acoustic wave devices with complex geometries and boundaries. However, they are less accurate and efficient, especially for high frequency analysis. Furthermore, to the authors' knowledge, all existing references aimed at Bragg cell in solidly mounted resonators. Zhang et al. (2006) and Marechal et al. (2008) studied both the resonant transmission and acoustic wave propagation in multilayered Bragg Cell. Likewise, the formation mechanisms of the frequency bands in Bragg Cell are still an untouched topic. It should be pointed out the Bragg Cell, as a kind of reliable wave guiding and isolating structure, is potential for utilization in acoustic wave devices working with various acoustic modes, such as Rayleigh modes, Love modes, Lamb modes, SH modes and bulk longitudinal/transversal modes. For Bragg Cell working with a specific acoustic mode, other spurious modes inevitably exist. Therefore, for appropriately designing the Bragg Cell to improve the performance of diversified acoustic wave devices, the frequency-band features of the Bragg Cells should be studied with considering various wave modes.

Here in this paper, we devote to accurate analysis and design of multilayered Bragg Cells in the framework of three-dimensional elasticity. Firstly, the method of reverberation-ray matrix (MRRM) is extended to the analysis of elastic wave dispersion characteristics of a general Bragg Cell, whose unit cell is consisting of an arbitrary number of isotropic layers. Secondly, the formation mechanisms of the frequency bands are revealed, based on the closed-form dispersion equations obtained for the binary and the ternary Bragg Cells. The influences of unit cell configuration, material parameters and geometrical parameters of the multilayered Bragg Cell on the frequency-band features are attained, with which the Bragg Cell can be designed according to specific wave guide/isolation requirements. Thirdly, numerical examples are given to validate the unified formulation of MRRM, to show the frequency-band features of Bragg Cells and to indicate the effects of essential parameters on the frequency bands. Finally, conclusions are drawn concerning the advantages of the MRRM and the wave propagation characteristics of multi-layered Bragg Cells.

NUMERICAL EXAMPLES

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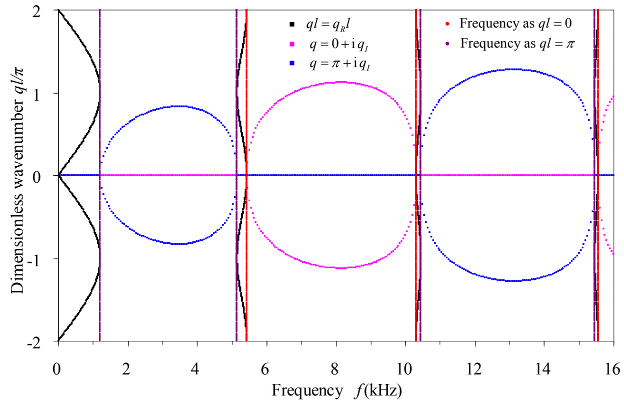
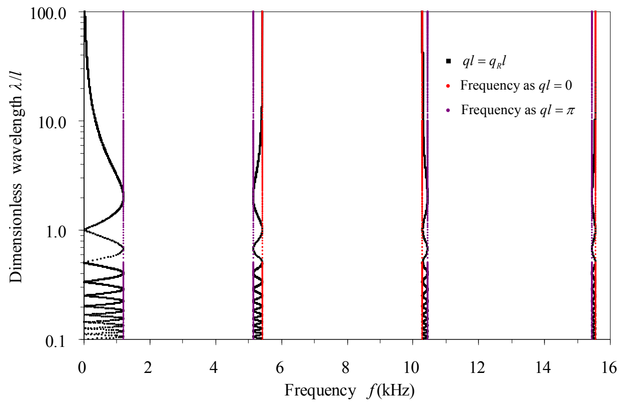
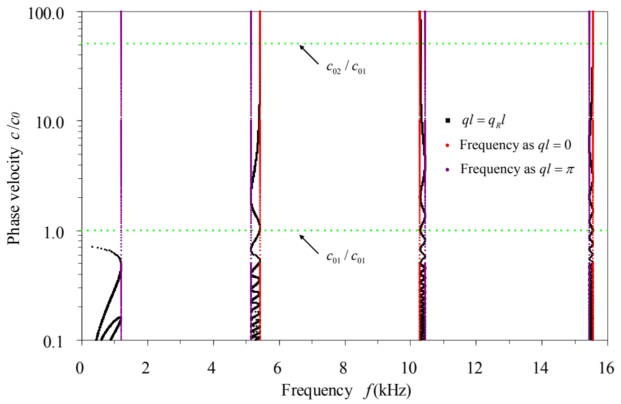
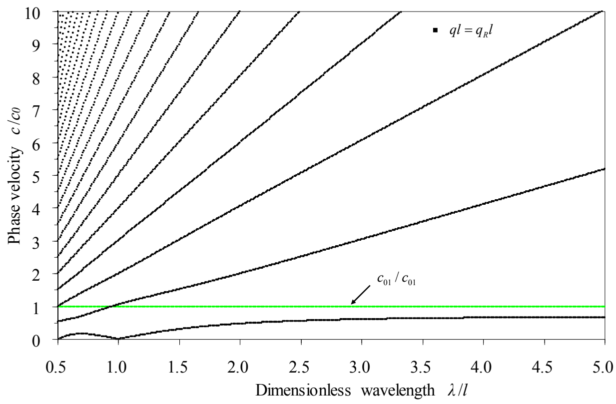
Using the above proposed method of reverberation-ray matrix, we studied the longitudinal wave characteristics in a binary Bragg Cell consisting of alternating steel and rubber layers of identical thickness $l = 0.01$ m. Comprehensive dispersion characteristics of them are calculated and depicted in Fig. 1.





(a) *Wavenumber* versus *frequency* (b) *Wavelength* versus *frequency*





(c) *Phase velocity* versus *frequency* (d) *Phase velocity* versus *wavelength*

Fig. 1 Dispersion spectra of a binary Bragg Cell consisting of steel and rubber layers.

CONCLUSIONS

The method of reverberation-ray matrix (MRRM) is extended for the analysis of dispersion characteristics of elastic waves in general multilayered Bragg Cells. Through analytically studying the closed-form dispersion equations obtained for periodic binary and ternary Bragg Cells, we reveal that the elastic wave band structures in Bragg Cells are formed due to wave zone folding effect and wave interference phenomenon. Numerical examples are given to validate the accuracy of our proposed method of reverberation-ray matrix and to show the comprehensive frequency-band features of Bragg Cells. The influences of unit cell configuration, material parameters and geometrical parameters of the multilayered Bragg Cell on the frequency-band features are attained, with which the Bragg Cell can be designed according to specific wave guide/isolation requirements.

ACKNOWLEDGEMENTS

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