【Grant-in-Aid for Scientific Research (S)】

Broad Section D

Title of Project : Development and quantitative interpretation of acoustic and phoxonic metamaterial devices from kHz to GHz frequencies

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Keyword : acoustic, metamaterial, phonon, electromagnetic, plasmon, microscope, metasurface

【Purpose and Background of the Research】

Metamaterials, locally-resonant materials not found in nature that contain artificial sub-wavelength structure, offer new opportunities in physics, materials science and technology. Electromagnetic varieties consist of split rings, giving negative permeability, or I-shaped wire elements, giving negative permittivity, for example. Acoustic varieties often show negative bulk modulus and density. Single-negative acoustic metamaterials (one negative parameter) can be used for damping, with applications in vibration isolation. Double-negative versions can focus acoustic waves into tiny areas below the diffraction limit. Enhanced acoustic transmission, either using resonances in small sub-wavelength apertures—a phenomenon known as extraordinary transmission—or using impedance matched miniature meta-atoms placed between highly mismatched media, can also be achieved. We propose the development and quantitative interpretation of acoustic and phoxonic, i.e. simultaneous photonic and phononic, metamaterial devices from kHz to GHz frequencies.

【Research Methods】

We aim to make scanning acoustic microscopes based on metamaterial extraordinary transmission in air, as well as make a metasurface for efficient acoustic transmission between highly mismatched media, in particular from water to air and vice versa. We also aim to create simple lightweight single-component acoustic metamaterials based on pillars or beams engraved with cavities or slits that can stop all modes of vibration over a wide band of frequencies or support plate flexural modes with double-negative behaviour (see Fig. 1). In addition, we aim to make phoxonic metamaterials (see Fig. 2) based on silicon or metallodielectric nanostructures, and to characterize their behaviour through optical and acoustic spectroscopy.

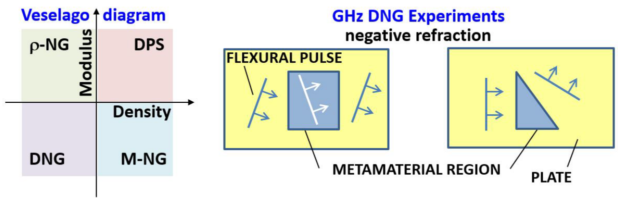

Figure 1 Veselago diagram (elastic modulus M vs density ρ) and our proposed experiments on GHz DNG (double-negative) metamaterials. ρ-NG: negative density, M-NG: negative modulus, DPS: double positive.

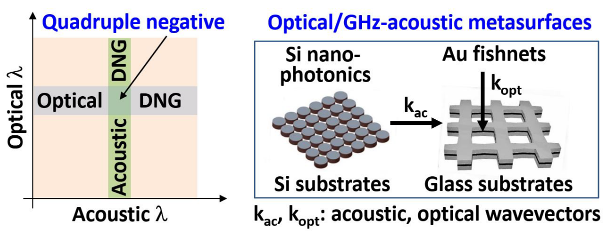

Figure 2 Phoxonic metasurfaces with optical and GHz-acoustic metamaterial bandgaps and "quadruple negative" metamaterials.

【Expected Research Achievements and Scientific Significance】

Metamaterial-scanning acoustic microscopes should lead to deeply-sub-wavelength resolution imaging of textiles or skin texture, with broad application in industry and biomedicine. New metasurfaces should lead to wide-band response and applications in efficient acoustic transduction. We should also be able to develop multiple-resonator-frequency kHz- down to Hz-frequency metapillars and metabeams for total vibration absorption, and acoustic metaplates with double-negative behaviour. In addition, the creation of phoxonic metamaterials should lead to novel "quadruple-negative" metamaterials with application to acoustic-optic modulation and co-focused sub-diffraction-limit acoustic and optic beams.

【Publications Relevant to the Project】

・Q. Xie, S. Mezil, P. H. Otsuka, M. Tomoda, J. Laurent, O. Matsuda, Z. Shen and O. B. Wright, 'Imaging GHz zero-group-velocity Lamb waves', Nat. Comm. **10**, 2228, 2019.

・E. Bok, J. J. Park, H. Choi, C. K. Han, O. B.Wright and S. H. Lee, 'Metasurface for Water-to-Air Sound Transmission', Phys. Rev. Lett. **120**, 044302, 2018.

【Term of Project】 FY2019-2021

【Budget Allocation】 107,700 Thousand Yen

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