Four different sign combinations of density and modulus exhibited by a single metamaterial

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Possibility of negative values of permittivity and permeability discussed by Veselago [1] became reality by man-made structures consisting of subwavelength-size cells [2, 3]. New phenomena and applications began to come out as the materials properties were extended into the single and double negative quadrants of the ε-μ diagram [4, 5, 6, 7]. Here, we present a dispersive new acoustic metamaterial consisting of Helmholtz resonators and membranes, which exhibited all the four sign combinations of the constitutive parameters; namely density negative (ρNG), modulus negative (BNG), double negative (DNG), and double positive (DPS).

Unlike the conventional media, the density and the modulus of the present metamaterial both change with the frequency. Such change corresponds to the motion of the (ρ,B) point on the $\rho - B$ plane. The trajectories of the motions are shown for the four possible cases in Fig. 1. The present system is the case in Fig. 1c. However, all of the other cases may occur as well, because the frequencies ω_0 and ω_h are determined by size of the the Helmholtz resonator, and the frequency ω_c is determined by the tension of the membrane.

Experimental transmission measurement revealed two stop bands, as shown in Fig. 2a. These stop bands correspond to the frequency ranges $\omega < \omega_0$ and $\omega_c < \omega < \omega_h$ becomes imaginary. For the pass bands, the experimental data were obtained by measuring the phase velocity v_{ph}, using the relation, $k = \omega/v_{ph}$, Fig. 2b. The data agree excellently with the theoretical curve

In conclusion, we presented fabrication of a double negative acoustic metamaterial, which is an acoustic version of the electromagnetic metamaterial consisting of split-ring resonators and continuous wires. This new acoustic metamaterial exhibited sharp transitions in wave characteristics at the three frequencies ω_0, ω_c, and ω_h, transforming from ρNG to DNG, BNG, and DPS states in sequence with increasing frequency. Also, in the DNG band, we observed index of refraction continuously changing two orders of magnetitude, which has potential use for transformation of acoustic waves.

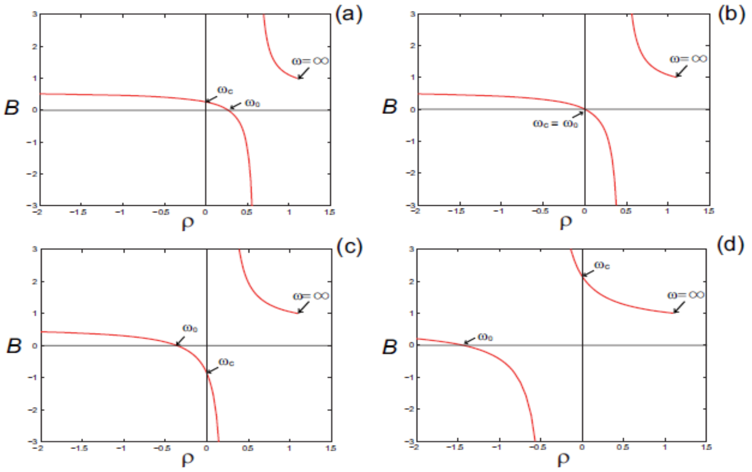

Fig. 1: (a) Graphs of states for the cases $\omega c < \omega 0 < \omega b$ (b)$\omega 0 = \omega c < \omega b$ (c)$\omega 0 < \omega c < \omega b$ (d)$\omega 0 < \omega b < \omega c$

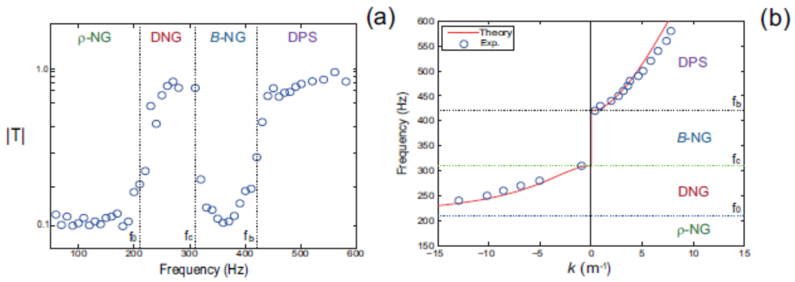

Fig. 2: Experimental results for the composite HR-membrane-structure. (a) Transmission data. (b) Wave-vectors.

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