Synthesis of soft acoustic metamaterials using microfluidics

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Metamaterials are artificial materials which are not available in nature and in which the propagation of waves is non conventional. Building a metamaterial requires to control the physical quantities that drive this propagation. In 1964, Veselago [1] theoretically postulated the possibility to get materials exhibiting negative refractive index. For electromagnetic waves, this imposes simultaneous negative values for both the dielectric permittivity ε and the magnetic permeability μ at the same frequency. This concept was extended to acoustic waves in which wave propagation is here driven by the mass density (ρ) and the compressibility (κ) of the material.

Pioneering works [2] showed that negative values of these quantities may be attained by dispersing small entities (microresonators) in a bulk phase. As the exciting wave frequency matches the one of the dispersed objects, ρ and κ may exhibit very large or negative values, thus leading for example to the expected negative values for the acoustic index. We recently showed [3] that large resonances could be obtained in the presence of micro-sized objects exhibiting a large contrast of sound speed velocity (i.e. a ratio of 3 between the dispersed objects and the matrix) with the surrounding matrix. Moreover, we showed that the acoustic spectrum can be tuned by an external magnetic field when replacing the emulsion oil droplets by ferrofluid droplets [4]. However, possible meta effects (i.e. negative refraction) can only be obtained by reaching larger values for this contrast. Good candidates to reach lower sound speed values are porous materials, which exhibit both a high compressibility and a non zero mass density thus leading to very small $c \sim 1/(\rho.\kappa)^{1/2}$. Thus, we did synthesize porous beads of controlled size and composition using a microfluidic approach. Submitted to an ultrasonic acoustic wave, the obtained composite materials are shown to exhibit very large resonance peaks. These results pave the way to the first realization of soft acoustic metamaterials [4].

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[4] Brunet, Leng, Mondain-Monval, *Science* **342**, 323 (2013)