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Fabrication and characterization of locally resonant acoustic metamaterials made with resonators generated from core-shell drops

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FABRICATION AND CHARACTERIZATION OF LOCALLY RESONANT ACOUSTIC METAMATERIALS MADE WITH RESONATORS GENERATED FROM CORE-SHELL DROPS

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Acoustic metamaterials promise the remarkable ability to control, direct, and manipulate sound waves. Within this infant field, a promising approach to fabricate locally resonant acoustic metamaterials is the use of resonators composed of a heavy core surrounded by a rubber shell dispersed in an epoxy matrix. At the resonant frequency, the resonators vibrate 180° out-of-phase with the matrix and a band gap in transmission is observed making these materials excellent sound absorbers. The resonant frequency of the resonators scales with the core mass; therefore, it can be tailored by increasing the core diameter or the density of the core material. A significant challenge in the study and adoption of these materials is the lack of techniques to easily fabricate resonators with a wide range of sizes, and properties. Here, we present a robust yet simple technique to fabricate resonators with diameters ranging from 50 µm to 5 mm from core-shell drops generated in microfluidic and millifluidic devices. We started by fabricating resonators with core diameters ranging from 50 µm to 1 mm at rates ranging from 2000 to 200 drops/second respectively, from double emulsion drops composed of a concentrated ceramic suspension in the core (inner drop) surrounded by a UV-crosslinkable rubber shell (outer drop) using microcapillary microfluidic devices. The double emulsion drops were collected and exposed to UV to crosslink the shell material forming resonators with resonant frequencies ranging from 100 kHz to 25 kHz depending on their size. Lower resonant frequencies down to 6 kHz were obtained by fabricating resonators with core diameters ranging from 1.2 mm to 2 mm from core-shell drops extruded in air from a coaxial nozzle at rates up to 6 drops/minute. The effects of core density were studied by utilizing suspensions composed of ceramic particles of increasing density including silica, alumina, and lead zirconate titanate (PZT). Resonators were harvested, dried and mixed with epoxy to fabricate acoustic metamaterials. The transmission properties of the acoustic metamaterials made with resonators with different core diameters, core materials, and ordering within the matrix, were measured using a shaker/accelerometer setup in the frequency range from 1 kHz to 12 kHz. For example, acoustic metamaterials composed of randomly dispersed 1.8 mm alumina-core resonators at a 30 vol% concentration showed a well defined band-gap at 8.5 kHz. A finite element model was also developed to capture the acoustic transmission physics of these materials. This technique offers a robust path for the fabrication of acoustic resonators and locally resonant acoustic metamaterials.

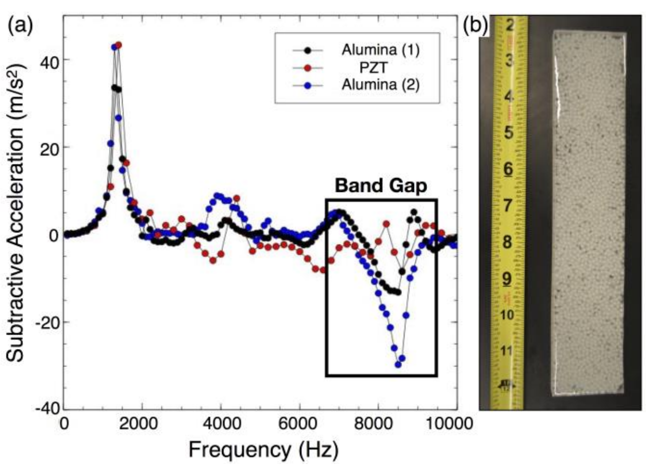

Figure 1 – (a) Subtractive acceleration as a function of frequency for acoustic metamaterials samples with different core-resonator materials. (b) Photograph of an acoustic material sample composed of acoustic resonators randomly dispersed in an epoxy matrix.