NEAR-PERFECT AND NEAR-BROADBAND SOUND ABSORPTION USING ACOUSTIC METASURFACE

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A near-perfect and near-broadband sound absorption at low frequencies is achieved by using hybrid resonance in an acoustic metasurface. The metasurface for perfect absorption at N frequencies consists of two-dimensional periodic array of unit cells, which are composed of 2N meta-atoms. Each meta-atom is designed to acquire hybrid resonance at a target frequency by using two Helmholtz resonators of sub-wavelength scale whose cavities are coiled up. We design a metasurface exhibiting perfect sound-absorption at four different frequencies by using optimization based on a theoretical model. The proposed metasurface is fabricated by using 3D printing. The experimental results show near-perfect and near-broadband sound absorption in that the absorption coefficient is 0.91 on average over a broad frequency range between 360Hz to 540Hz. The normalized bandwidth of 80% absorption to the centre frequency is 0.44 since the experimental results show greater absorption coefficients than 0.8 over the frequency range from 360Hz to 540Hz.

Keywords: acoustic metasurface, perfect absorption, broadband

1. Introduction

Recently, the researches on acoustic metasurfaces for achieving perfect sound absorption at a certain frequency [1-7] have attained considerable interests from scientists and engineers. Among them, the researches on metasurface using subwavelength Helmholtz resonators [3-7] have shown a rapid progress due to their structural solidity and ease of fabrications. Two noteworthy concepts were used to achieve perfect sound absorption using the subwavelength Helmholtz resonators at low frequencies: by coiling up the space in the Helmholtz resonators [3,4] or using hybrid resonances due to the strong interactions between the different Helmholtz resonators of subwavelength scales [5,6]. By combining the both concepts, an acoustic metasurface is proposed by arranging four subwavelength Helmholtz resonators whose cavities are coiled up [7]. The perfect absorption using the metasurface at single or dual frequencies is validated theoretically, numerically and experimentally.

In resonant-type absorber designs, there is always a compromise between high absorption coefficients and broad bandwidths of the absorption bands. Broadening the absorption bands of the metasurface is a challenging but important topic since the bandwidth is a significant factor in the absorber designs. In this work, we propose an acoustic metasurface for perfect absorption at N frequencies by using hybrid resonances among 2N meta-atoms (the subwavelength Helmholtz resonators) and validate their absorption performance theoretically, numerically and experimentally.
2. Geometry and Performance of Acoustic Metasurface

We briefly describe the geometry of proposed metasurface and validate the absorbing performance of the metasurface. To achieve sound absorption at N target frequencies, we propose a geometry of the unit cell by arranging 2N meta-atoms for acquiring hybrid resonances at N frequencies. For example, we can perfectly absorb sound at four different frequencies by using eight different meta-atoms. The whole metasurface panel is a periodic array of the multiple unit cells.

We theoretically obtain an effective impedance of the metasurface \( Z_{MS} \) by using theoretical model proposed in Ref. [6, 7]. The reflection and absorption coefficients could be calculated by using equations of \( R_{MS} = \frac{|Z_{MS} - Z_0|/|Z_{MS} + Z_0|} \) and \( \alpha_{MS} = 1 - R_{MS}^2 \). The model is valid when the size of unit cell is sufficiently small compared to the wavelength of incident wave \( (D \ll \lambda) \). Figure 1(a) shows the absorption coefficients of the metasurface obtained from the theoretical model, the numerical simulation and the experiment.

Figure 1: absorption spectra of the metasurface obtained from theory, simulation, and experiment

As shown in Fig. 1, the results obtained from theoretical model shows good agreement with the numerical simulation and the experiment. The metasurface composed of eight different meta-atoms exhibits over 95% absorption at the peak frequencies. It is shown that the near-perfect and near-broadband absorption is achieved in that the absorption coefficients is 0.91 on average over a broadband frequency range between 360 Hz to 540 Hz. The normalized bandwidth of 80% absorption to the centre frequency \( (\Delta f_0/0.8/f_c) \) is 0.44. The theoretical and numerical results show relatively poorer absorption than the experimental results, which means that the metasurface can have better absorption performance in real applications than the performance expected theoretically or numerically.

3. Conclusion

We proposed an acoustic metasurface for sounds at N frequencies by using 2N meta-atoms, for the purpose of near-perfect and near-broadband absorption. By using the theoretical model considering the visco-thermal effects depending on frequency [6, 7], we obtained the absorption coefficients of the metasurface, and then, verified near-perfect and near-broadband absorption of the proposed metasurface experimentally. On average, 91% of sound energy was absorbed by the metasurface in the frequency range from 360 Hz to 540 Hz.

REFERENCES


