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Low-frequency sound absorbing metasurface using multiple split resonators

多重分割管共振器による低周波吸音メタ表面

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1. Introduction

Sound absorption/insulation technology has always been required in many places such as houses and public facilities. In particular, low-frequency sounds are not only harmful to objects, but also to mental health, and countermeasures are necessary. In the environment that requires high sound absorption/insulation performance, thick and heavy sound absorbing materials have often been used inspite of their costfullness. It has thus been desired to develop a new class of materials that can absorb/shield the low-frequency sound without the heavy mass and large thickness.

In previous researches, we have been focusing on the Decorated Membrane Resonator (DMR) [1,2], which is one of the acoustic metasurfaces that are sufficiently smaller in size than the wavelength of sound waves. It has been shown that the DMR can achieve nearly 100% sound absorption at the resonance frequency. It is, however, difficult to achieve the efficiency in low-frequency range below 1000Hz by the metasurface unless the size of the resonator is large enough. Other metasurfaces than DMR, such as a three-dimensional single-port labyrinthine structure [3] and split tube resonators [4], have been proposed to overcome this drawback. Those structures are still hampered to be a practical application by their narrow operating range. In the present study, we propose a device that can absorb and block low-frequency sound over a wide range by multiplexing split tube resonators.

2. Acoustic absorber based on split tube resonators

The low-frequency tunable acoustic absorber based on split tube resonators originally proposed in Ref. [4] is a polylactide (PLA) elliptic cylinder with a side cut so that the cross section becomes a split ring. The aluminum plate has the role of reflecting sound waves which resonate with the sound absorber, as well as the role of preventing sound transmission. **Fig. 1** shows the basic structure of a split tube, and **Fig. 2** shows its sound absorption coefficient. The wavelength of the sound wave at 516 Hz, at which the sound absorption peak in Fig. 2 was obtained, was about 66 cm, and the thickness of the sound absorbing structure including the split tube and the aluminum plate was 2.5 cm. The high sound absorption characteristics are thereby exhibited even in low-frequency sounds where sound absorption is difficult due to the long wavelength. The principle of absorbing sound is based on conversion of the sound energy into heat energy by mutual vibration of the split tube and the air layer [5]. Despite that it achieves nearly 100% sound absorption at the resonant frequency, the sharp peak at the resonant frequency hampers to utilize the structure in practical applications that have ambient sound environments with relatively wide frequency spectra.

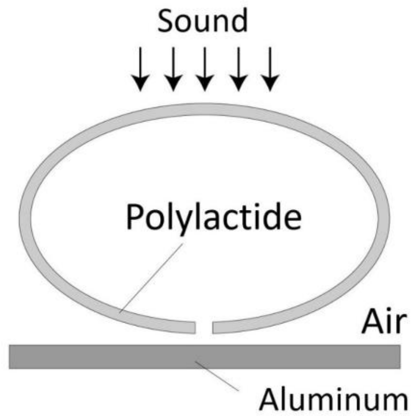

Fig. 1 The basic structure of a split tube.

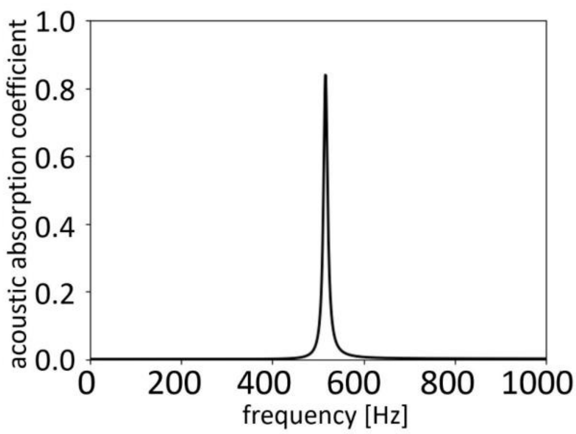

Fig. 2 Sound absorption coefficient of the basic structure of a split tube.

3. Multiple split tube structure

To solve the problem of narrow frequency band, we focus on multiplexing the split tubes with different size to broaden the absorption spectrum. **Fig. 3** shows the structure of a six-fold split pipe, which is one of the multiple split structures proposed in the present study.

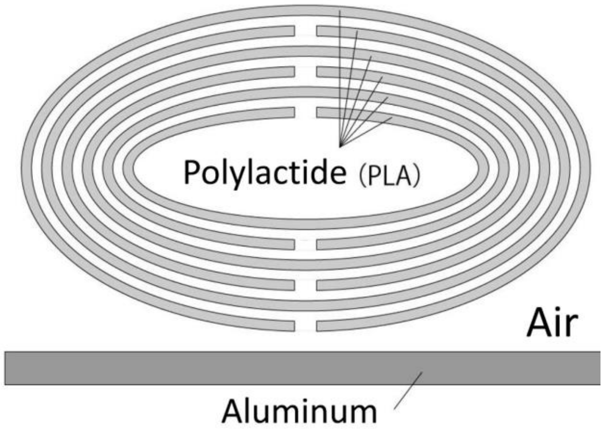

Fig. 3 The structure of a six-fold split pipe.

4. Simulation method

A series of numerical simulations on the metasurface model was performed using COMSOL Multiphysics® [6], a commercial 3D finite-element method (FEM) software developed by COMSOL AB. To evaluate the absorption characteristics, we calculated the absorption coefficient based on the transfer-function method [7]. This method needs to measure the sound pressure at two locations with a microphone, which is simulated by measuring pressure at two different points in the FEM calculations.

5. Result

Fig. 4 shows the sound absorption coefficient for 2- to 6-layered split pipes. It is shown to increase the number of sound absorption peak by increasing the number of layers. The result indicates, however, that the increase of the absorption peak is not simply due to the superposition of the absorption peaks of individual pipe.

We analyzed the modes at each resonant frequency with sound absorption peaks. At frequencies lower than about 500 Hz, sound absorption peaks are obtained by the single mode in which a split tube vibrates at the corresponding frequency. At the higher frequencies than 500 Hz, on the other hand, all the tubes vibrate correctively to form "hybrid modes". Such a hybridization of the mode emerges in the cases more than 4 layers.

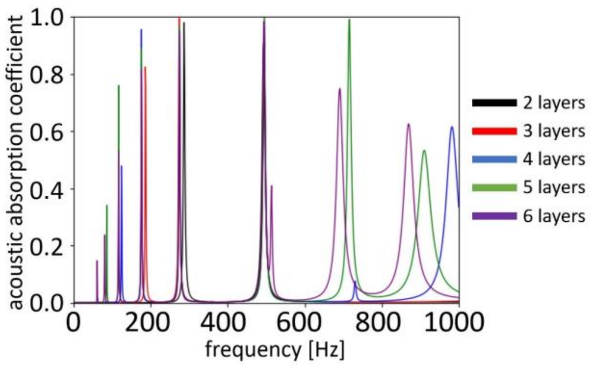

Fig. 4 The sound absorption coefficient for 2- to 6-layered split pipes.

6. Conclusion

We have verified the sound absorption of a split tube in the frequency band below 1000Hz and the multiplexing of sound absorption peaks created by superposing multiple split tubes. We thus succeeded in multiplexing sound absorption peaks in the frequency band below 1000 Hz. We further found the multiplexing is not only by simple superposition of each mode but also by hybridization of mode that exhibits a collective motion of the tubes.

Acknowledgment
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