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Design of Acoustic Metasurface toward a Perfect Absorber
音響メタ表面による高効率遮音機能の設計

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1. Structure design and analysis

Natural materials usually require the thickness comparable to the wavelength in their structures to signifincatly insulate or absorb sound waves. Acoustic metamaterial has defined this common sense, where even a thin structure exhibits perfect sound absorption. The acoustic metamaterial is a new class artificial material made of ascoutic structures smaller than the wavelengths and exhibits a peculiar response to sound wave. More recently, two-dimensional (2D) version of a acoustic metamaerial, *i.e.* metasurface [1][2], has been also proposed as a simple yet powerful concept to realize not only the perfect absorption, but also other functionalities such as energy harvesting. We here designed and numerically investigated acoustic metasurface absorber by Finite Element Method (FEM).

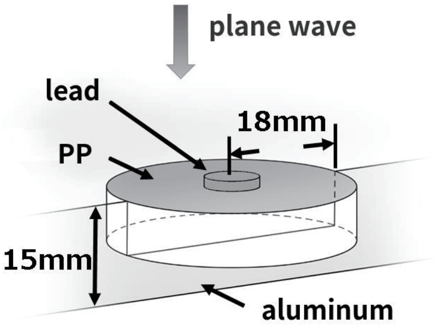

Fig. 1 Schematic of a metasurface composed of aluminum, polypropylene (PP) membrane and lead platelet.

A novel metasurface structure, so-called "Decorated Membrane Resonator (DMR)" has been originally proposed by Ma *et al.* [3][4][5] and shown to exhibit a nearly perfect sound absorption at a certain frequency range. In this study, we numerically investigate the DMR's behavior and propose new DMR's design to improve the absorption performance of the DMR. The unit-cell structure of the DMR is shown in **Fig. 1**. An aluminium plate with a cylinder hole is covered with a polypropylene (PP) membrane and a lead platelet is placed at the center of the membrane. The lead platelet plays an important role to produce resoance modes at the target frequencies. When plane wave is incident to the DMR, the absorptance, which is the ratio of the reflect and incident sound power, shows a clear peak at 1925 Hz as shown in **Fig. 2**. **Figure 3(a)** shows the profile of the eigen mode at the resonance. In **Fig. 3(b)**, the sound pressure field distribution inside DMR and local velocity vector are also shown.

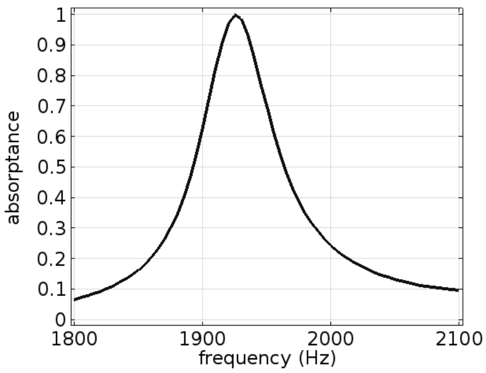

Fig. 2 Absorption spectrum of the metasurface structure, exhibiting the nearly perfect sound absorption at 1925 Hz.

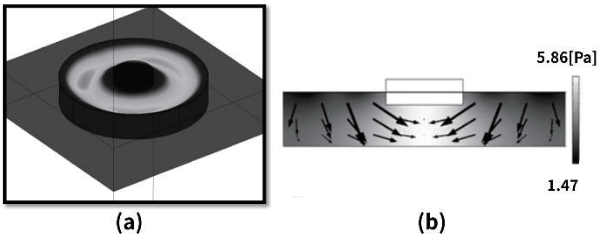

Fig. 3 (a) Mode profile of the metasurface eigen mode at the resonance. (b) Pressure and velocity field distribution inside the resonator at the resonance.

From these results, we found that the sound wave was strongly dissipated inside the DMR by changing its propagation direction from normal to parallel, when the DMR resoance occurred. This physical mechanism makes highly efficient absorptance even in a thin layer possible.

2. Approach for broadband operation

Sound absorbers based on the single resonance works within only narrow bandwidth near the resonance. To improve this drawback, we construct a broadband metasurface by employing three DMRs, which have different resonant frequencies, in the unit cell. The unit cell and its frequency characteristic of the absorptance are shown in **Fig. 4** and **Fig. 5**, respectively. Superposition of each peak's tails makes its bandwidth broad.

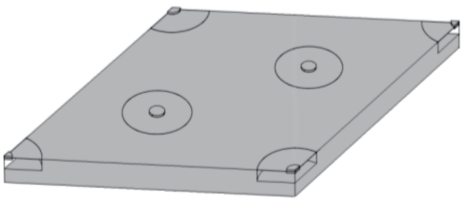

Fig. 4 Unit cell of a broadband metasurface absorber consisting of three DMR structures with different diameters of 36 mm, 34.2 mm, and 32.4 mm.

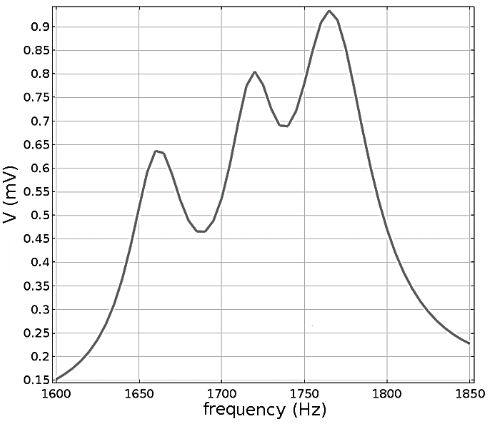

Fig. 5 Absorption spectrum of the broadband metasurface absorber.

3. Application to Energy harvesting

Energy harvesting is the process to efficiently collect the wasted energy generated around our life, such as sound, wind, salinity or thermal energy. In order to convert sound energy to electric one, we here employed a piezoelectric material producing electric charge when mechanical stress is applied to their surface [6].

We placed a Lead Zirconate Titanate (PZT) plate, which is the typical piezoelectric material, on the bottom of the DMR to generate voltage from the sound pressure. In the simulation, the sound with a pressure of 1 Pa and a power of 14.42 μW was introduced to the DMR and the voltage generated at the PZT surface was measured. **Figure 6** shows the frequency dependence of the voltage generated at the PZT surface.

The absolute value of the generated voltage has its maximum at 1960 Hz. It is thus shown that PZT can be regarded as a voltage source of 11 mV. Assuming a load resistance of 50 Ω, the energy of 5.42 μW is consumed at the resistance, corresponding to the conversion efficiency of 37.58 % from the acoustic energy to the electricity.

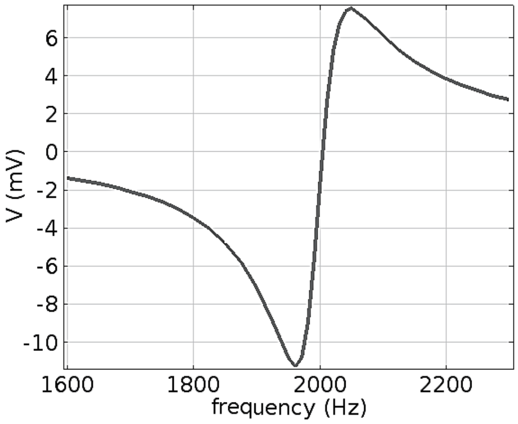

Fig. 6 Frequency dependence of the voltage generated at the PZT's surface placed on the bottom of the DMR.

Acknowledgment

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