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Multilayer Acoustic Metasurfaces for Broadband Sound-Absorbing and Energy-Harvesting Devices

Akira Kojima[1‡], and Kenji Tsuruta[1*] ([1]Okayama Univ.)

1. Introduction

As one of the measures against environmental problems, Sound shielding becomes important technology. In many applications materials with lightweight and thin, yet high sound absorption is required. In recent years, as an alternative to conventional sound absorbing materials, acoustic metasurfaces have been attracting mush attentions. Acoustic metasurfaces[1] are artificial materials that can control acoustic wave propagation, for example, absorption, reflection and transmission. In addition, their dimensions are sub-wavelength order, which is compatible to compact devices. For these reasons, various metasurfaces have been proposed. In the present study, we focused on an acoustic metasurface with membrane resonators. Decorated Membrane Resonator(DMR)[2] has been proposed for sound absorbing device utilizing hybrid resonance between membrane and air layer. **Figure 1** shows a basic structure of DMR. By using impedance-matching to airborne sound, DMR can absorb nearly 100% of incident acoustic wave at resonant frequency.

In addition, DMR has been considered to be a candidate for an energy harvesting device. The strong vibration of membrane at the resonant frequency compresses air layer, thus converting the acoustic energy to electric power via piezoelectric element (e.g., PZT) on the bottom of DMR. Acoustic energy thus harvested is expected to be a power source for sensor network in the IoT era.

We adopted frequency-response analysis by 3D-Finite Element Method. The incident acoustic wave of 1Pa pressure is incident from the direction normal to the surface of the structures to evaluate the absorption as well as the electric power generation within the frequency range from 500Hz to 4000Hz.

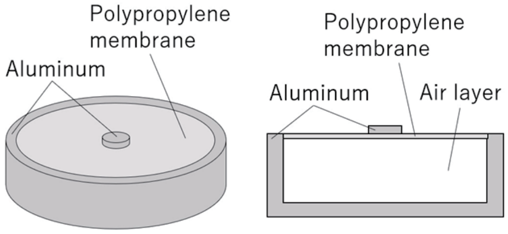

Fig. 1 Decorated Membrane Resonator

2. Sound absorption and voltage generation in DMR

Figure 2 illustrates the 3D model of a DMR with PZT. By frequency domain analysis of the finite-element method (FEM), we simulated sound absorption and voltage generation in a single DMR depicted in Fig.2.

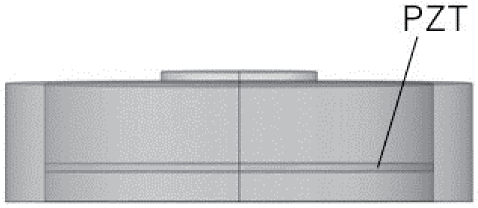

Fig. 2 3D-model of the basic DMR

Figure 3 shows the result of the FEM simulation for both sound absorption and electric voltage generation. The figure clearly reveals that the DMR has a characteristic of high-Q resonance resulting in narrowband for sound absorbing and energy harvesting properties. Since the spectrum expected in an ambient noise has rather broad spectrum, this characteristic of DMR hampers effectiveness in sound shielding application. For this reason, the purpose of our research is designing and optimizing the structure of DMR with broadband responses.

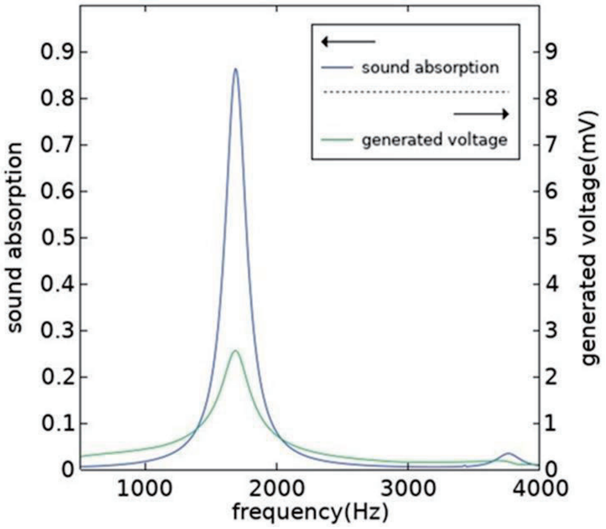

Fig. 3 Sound absorption and voltage generation spectra of the DMR illustrated in Fig.2.

3. Helmholtz-DMR multilayer structure

So far, several attempts have been reported for designing broadband DMR[3] by changing the shape of membrane or the size of air layer. In recent years, on the other hand, high performance metasurfaces have been achieved by coupling with other resonant structures.[4] Here we also examined a new approach

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E-mail: ‡puh15lfs@s.okayama-u.ac.jp,
*tsuruta@okayama-u.ac.jp

with a DMR based structure hybridized with an additional layer that has the same effect as a Helmholtz resonator. Helmholtz resonator is the most classical acoustic resonator for soundproofing. As the resonator is composed of just small neck and cavity, the combination with acoustic metasurfaces is easy to design and fabricate.[5] **Figure 4** shows the structure we propose in the present study. As shown in the figure, the upper layer plays as a Helmholtz resonator and the lower layer corresponds to a DMR.

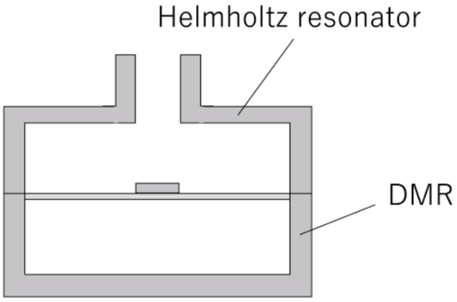

Fig. 4 The schematic of the proposed multilayered structure.

4. Result

Using FEM simulations of sound absorption in the proposed structure, we found two resonant frequencies in the spectrum, which can be attributed to a combined resonance mechanism. We further optimized the structural parameters to obtain higher performance in the spectra. **Figure 5** illustrates the optimized structure of the Helmholtz-DMR multilayer structure. **Figure 6** shows for the absorption/voltage generation spectrum that this structure has two resonant frequencies with over 90% sound absorption and 2~3mV voltage generation.

5. Conclusion

We have proposed a multilayer Helmholtz-DMR structure for a highly efficient sound-absorbing metasurface with power-generation function applicable to the energy harvesting device. The analyses have revealed that the device we designed have two combined resonance frequency with over 90% sound absorption and about 0.1 μW . An experimental verification is also in progress. We plan to extend the present approach to broaden the frequency response by introducing a periodic arrangement of the proposed structure for becoming commonplace in loud environment.

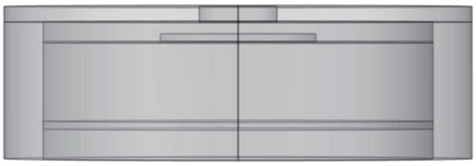

Fig. 5 optimized structure of the Helmholtz-DMR multilayer structure

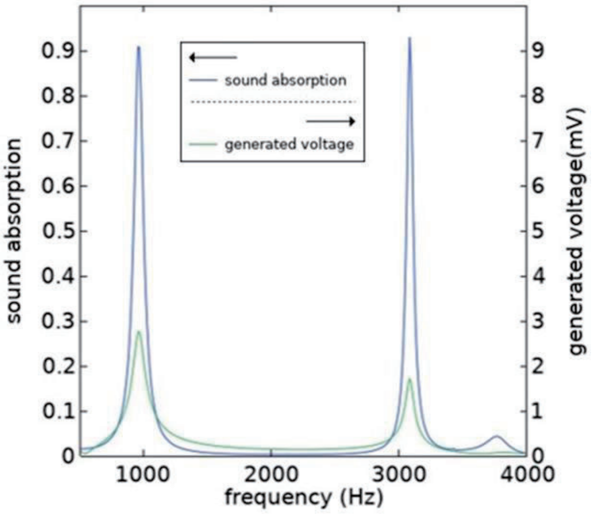

Fig. 6 FEM result for absorption and voltage generation spectrum of the multilayer structure.

Acknowledgment

This work was supported in part by the JSPS KAKENHI Grant Numbers 21H05020.

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