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Wideband acoustic absorber by multicomponent metasurfaces and its application to energy harvesting

構造多重化に基づく広帯域吸音メタ表面と環境発電への応用

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1. Introduction

Sound insulation/absorption is one of the key issues not only for environmental noise problems but also for next-generation motorization. Furthermore, emerging technology of energy harvesting from ambient sound is attracting much attention due to its promise for realization of the low-carbon society where electric devices can operate without electric power supplies. Our aim is to design and fabricate an efficient and wideband acoustic absorber with passive structures in scope of such applications. We here focus on the acoustic metasurface [1], a two-dimensional structure composed of small and thin resonators. Especially, a hybridized metasurface structure, called "Decorated Membrane Resonator (DMR) [2,3] is adopted for our study. This structure has proven to realize a perfect sound absorption at a designed frequency. However, practical application of this structure has been hampered by its narrowness of the absorption band.

In this study, we attempt to design and develop wideband metasurface sound absorbers based on the DMR and its superposition. We have previously proposed a composite type of resonator which exhibits multiple resonance within a certain range of frequency [4]. It has been however rather insufficient to realize wideband operations by a single unit cell structure. We here propose a new model with several DMRs that possess absorption spectra different from each other. A close packing of these DMRs in a flat area leads to a nearly perfect sound insulation as well as efficient sound absorption at several resonant frequencies originated by each individual DMR. An attempts to enhance the piezoelectric conversion using this new model is also proposed in the present study.

2. Simulation method

A set of numerical simulations regarding the metasurface model was performed by using a commercially available 3D Finite Element Method (FEM) software, COMSOL Multiphysics®[5] developed by COMSOL AB. This tool can deal with several physics (constituent equations) at the same time, *e.g.*, fluidic equation for air pressure and solid mechanics along with materials dispersions and/or interfacial losses. This feature was essential for our study where we needed to evaluate sound absorption as well as piezoelectric conversions quantitatively.

3. Metasurface model

Figure 1 shows schematics of two types of the structure of our metasurface models, consisting of aluminum base, aluminum platelet, air cavity, and PolyPropylene (PP) membrane. The previous DMR model depicted in Fig. 1(a) has shown nearly perfect absorption at the resonant frequency with very narrow dispersion [4]. To realize broadband operation, we here propose a new model, illustrated in Fig. 1(b), which includes several DMRs with different absorption peak. The purpose of designing this structure is to pile up multiple absorption peak.

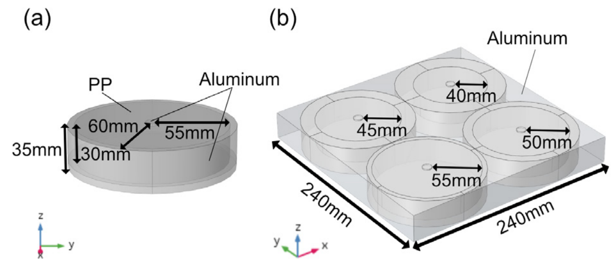

Fig. 1 Two types of DMR models. (a) The previous DMR model in Ref. [4] and (b) a new model with several DMR's composite.

4. Results

To evaluate the absorption characteristics of the DMRs, we calculated the absorption coefficient based on the transfer-function method [6]. Using the FEM calculations for the DMR structure illustrated in Fig 1(b), we found resonant peaks at (a)580, (b)630, (c)690, (d)770, (e)810 and (f)900 Hz in the range of 500-1000 Hz, as shown in **Fig.2**. In the case of the previous DMR structure in Fig. 1(a), the resonant peak is located only at 590 Hz. Through the simulation, we thus confirmed that six resonant modes appear in the new DMR structure, demonstrating an efficient widening of resonant band toward broadband operation.

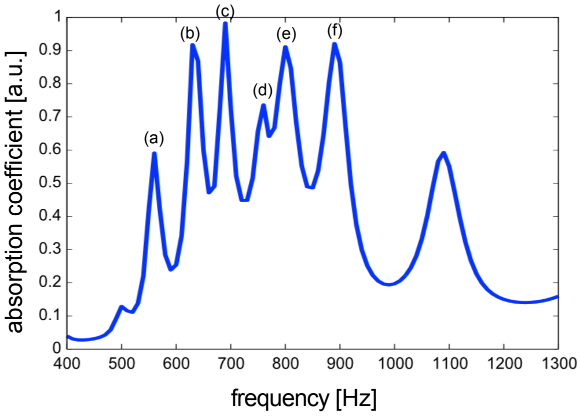

Fig. 2 Frequency spectra of absorption coefficient.

To better understand the underlying mechanism of the multiplication of the resonances, we show the displacement of membrane at each peak in **Fig. 3**. The figure shows that at the absorption peaks in Fig.2, the membrane modes at different DMRs are excited at the same time. This indicates that different DMRs generate some coupled modes that absorb the incident waves efficiently in the broader frequency range.

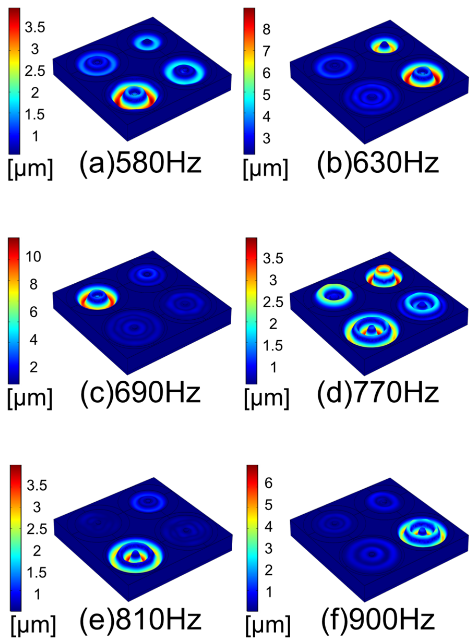

Fig. 3 Displacement of membrane at each resonance frequency.

It was found that a maximum pressure of 5.4 Pa was generated at the bottom of DMR against 1 Pa incident. Therefore, it is most efficient to realize an energy harvesting with the structure in which the piezoelectric material is arranged at the bottom of the DMR.

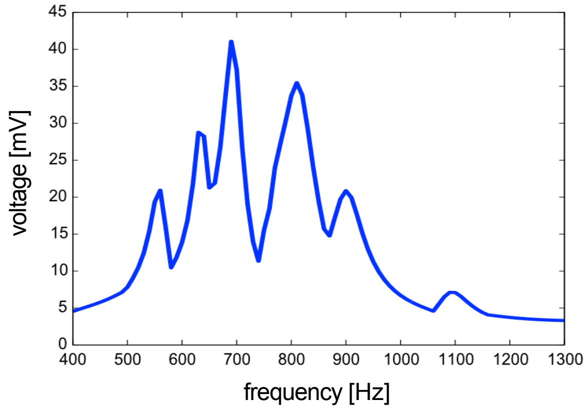

Fig. 4 Frequency spectra of piezoelectric voltage.

Figure 4 shows the (maximum) piezoelectric voltage calculated by the FEM for the present model with a substrate replaced with lead zirconate titanate (PZT) at the bottom of the cavities in the DMR structure. At resonant peak, an enhanced vibration of the membrane mode is converted to high pressure in the air cavity and in turn it leads to an efficient piezoelectric energy conversion at the PZT base. As shown in Fig. 4, it was possible to extract a voltage difference 40 mV along the thickness of the PZT at maximum and approximately 10 mV in average.

5. Conclusion

We have designed the present composite DMR model and demonstrated that it can exhibit a broadband sound absorption as well as an efficient piezoelectric conversion of the audible sound.

References

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